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The Status of Plankton Algocenosis in the North-East Part of the Black Sea (2011–2020)

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Abstract
The paper presents the research results of taxonomic composition and quantitative development of phytoplankton in the Abkhazian sector of the Black Sea in spring-and-autumn periods 2011–2020. Water was sampled onboard the R/V *Deneb* of SSC RAS on several horizons in the upper layer of the sea, up to 50 m. One hundred and nine (109) species of phytoplankton of 10 classes were found, among them 18 potentially toxic and harmful and 2 new for the eastern coast of the Black Sea species of planktonic algae. The average values of abundance and biomass in the water area were 40.26 thousand cells/L (from 8.8 thousand cells/L in autumn to 90 thousand cells/L in spring) and 74 mg/m^3 (from 64 mg/m^3 in autumn to 78 mg/m^3 in summer). The highest values (79 thousand cells/L and 113 mg/m^3) were observed on the sea surface (0–2 m), which was 1.5–18 times higher than on other studied horizons (10–50 m). The maximum abundance of plankton cells (476 thousand cells/L) was observed in the upper sea horizon in May 2013. This was associated with intense development of primnesian algae (*Emiliania huxleyi*), which formed 95 % of the total abundance and 53 % of the biomass during that period. The basis of the phytoplankton abundance and biomass generally was formed by diatomic (30 % and 31 %, respectively) and dinophytic algae (30 % and 60 %, respectively). In spring and autumn, the role of cryptophytic algae increased (up to 20 % of the total abundance).

Keywords: phytoplankton, taxonomic composition, abundance, biomass, Abkhazian sector, Black Sea

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Состояние сообщества фитопланктона в северо-восточной части Черного моря (2011–2020 гг.)

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Аннотация

Представлены результаты исследования таксономического состава и количественного развития фитопланктона в районе Абхазии (Черное море) в весенне-осенний периоды 2011–2020 гг. Пробы воды отбирали с борта НИС «Денеб» ЮНЦ РАН на нескольких горизонтах, расположенных в верхнем слое моря, до 50 м. Обнаружено 109 видов фитопланктона из 10 классов, среди них 18 потенциально токсичных и вредоносных и два новых для восточного побережья Черного моря вида планктонных водорослей. Средние по акватории значения численности и биомассы составили 40.26 тыс. кл./л (от 8.8 тыс. кл./л осенью до 90 тыс. кл./л весной) и 74 мг/м^3 (от 64 мг/м^3 осенью до 78 мг/м^3 летом). Наиболее высокие значения (79 тыс. кл./л и 113 мг/м^3) отмечены в поверхностном слое моря (0–2 м), что в 1.5–18 раз выше, чем в других исследуемых слоях (10–50 м). Максимальное количество планктонных клеток (476 тыс. кл./л) наблюдали в верхнем слое моря в мае 2013 г., что было связано с интенсивным развитием примнезиевых водорослей (*Emiliania huxleyi*), которые в этот период формировали 95 % общей численности и 53 % биомассы. В целом основу численности и биомассы фитопланктона формировали диатомовые (30 и 31 % соответственно) и динофитовые водоросли (30 и 60 % соответственно). Весной и осенью повышалась роль криптофитовых водорослей (до 20 % общей численности).

Ключевые слова: фитопланктон, таксономический состав, численность, биомасса, район Абхазии, Черное море

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Marine scientific research in the waters of the Republic of Abkhazia was carried out until the mid-1980s and were completely stopped in 1991 in connection with the collapse of the USSR and the military conflict between Abkhazia and Georgia. In June 2010, in the territorial waters of the Republic of Abkhazia, the staff of SSC RAS resumed complex ecosystem studies and made a baseline assessment of the current ecological state of the Abkhazian waters. In the composition of phytoplankton, 91 taxa (rank below the genus) of microalgae from 8 divisions were identified. Dinophytic and diatomic algae were the most diversified ones in terms of species – 49 and 17 species, respectively. The largest abundance of species was found in such genera as *Chaetoceros, Protoperidinium, Prorocentrum, Gynmodinium, Dinophysis, Ceratium*. The main contribution to the formation of the abundance of phytoplankton was made by small-celled green and dinophytic algae [1, 2]. The maximum values of abundance and biomass were noted in the near-surface layer of the sea (663.7 thousand cells/L and 1.7 g/m^3). The biomass of phytoplankton was formed mainly due to the development of two groups of phytoplankton: dinophytic and diatomic algae, which is typical for the summer period of development of the Black Sea algocenosis [2]. In March 2011 and for the last part of May 2013, the bloom of coccolithophorids ($2 \cdot 10^6$ – $4.4 \cdot 10^6$ cells/L) was noted in the Abkhazian sector of the Black Sea [3, 4].

For the period from June to September in 2016–2017, 55 following taxa were found in the phytoplankton of the Sukhumi Bay: Bacillariophyta (21), Dinophyta (28), as well as Cyanophyta, Cryptophyta, Euglenophyta, Chrysophyta. The average values of phytoplankton abundance for the period of study made 234.0 ± 67.9 thousand cells/L, biomass – 471.0 ± 141.2 mg/m^3. The maximum abundance (582 thousand cells/L) was observed in July, the maximum biomass (658–1120 mg/m^3) – in August. In summer (June–July), the value of the coccolithophorid *Emiliania huxleyi* increased (80–96 % of the total phytoplankton abundance). Diatomic algae dominated in late summer – early autumn (82–94 % of the total phytoplankton abundance). The abundance of *Dactyliosolen fragilissimu, Pseudosolenia calcar-avis, Pseudonitzschia pseudodelicatissima, Talassiosira* sp., *Skeletonema costatum* was observed in August, and in September – that one of *Cylindrotheca closterium*. The proportion of dinoflagellates in the total phytoplankton biomass in June–July varied from 65 to 48 % (300–130 mg/m^3). *Prorocentrum micans, Scrippsiella trochoidea, Dinophysis rotundata,* the species of genera *Protoperidinium, Gyrodinium, Glenodinium, Gymnodinium* were in the mass. Among the dinophytic algae, such a rare for the Black Sea species as *Peridinium quinquecorne* was registered. During the study, 2–8 % of the total abundance of phytoplankton was formed by euglena algae (genera *Eutreptia, Euglena*) and cyanobacteriae (*Oscillatoria, Lyngbya*). The presence of these species indicates higher levels of nutrients, pollution and desalination of the marine area [5]. As a part of the phytoplankton of the estuarine sections of the rivers of the coast of Abkhazia, 84 taxa were identified with a rank below the genus, among them diatoms – 44, green – 17, euglena – 10, others – 13 [6].

Thus, the phytoplankton studies carried out earlier in the Abkhazian sector were episodic and did not reflect the features of seasonal changes in the abundance of planktonic algae over a long period. Therefore, the purpose of our work is to trace the main changes in the taxonomic structure, abundance and biomass of planktonic algocenoses in the main growing season (spring-autumn) in 2011–2020.

Characteristics of the study area

Hydrophysical conditions in the Abkhazian sector were studied in 2011–2013 [3, 4]. The analysis of long-term data obtained in the study area showed that the average monthly water temperature on the sea surface during the year varies from 8.7 ºC in February to 25.7 ºC in August. The annual range of average monthly salinity values in the coastal areas of the sea is not so large: the average values were recorded in June–July (16.63–16.68 ‰); the highest salinity values were observed from August to January (17.35–17.74 ‰); from February to May, the salinity values decreased (from 17.07 to 16.08 ‰) with an increase in the volume of territorial runoff.

Materials and methods

The studies were carried out in the open part of the Black Sea, in the Abkhazian sector, during the voyages of the R/V *Deneb* of SSC RAS in different seasons of 2011–2020. The study of the vertical structure of phytoplankton was carried out at the horizons of 0, 5, 10, 25, and 50 m or at 3–5 horizons: surface; ½ water layer up to the thermocline; at the beginning, directly in the layer and at the end of the thermocline. Totally, 247 samples were taken and processed. Phytoplankton samples were collected during daylight hours in 1–1.5 L bottles and fixed with Lugol's solution. In order to preserve the coccolithophorids, the duplicate samples were fixed with formalin to a final concentration of 1–2 %. The sedimentation method was used to concentrate the samples [1, 2]. Phytoplankton organisms were counted quantitatively using MICMED-2 and MICMED-5 microscopes in chambers with the volume of 0.05 and 0.1 mL using objectives of 10×/0.30 and 40×/0.65 at least three times. To determine rare and large forms of phytoplankton, a part of the concentrate (1/5–1/10) was examined. The minimum size of considered cells makes 3–5 µm. Guidelines [7, 8] were used for species identification. The raw biomass of algae was estimated by the volumetric method, based on the size and shape of the cells according to the most similar geometric similarity, assuming the specific gravity of algae equal to one, using the original and literature data on cell volume measurements for each species [9].

To assess the similarity of the taxonomic composition [3] of the microalgae communities in the studied water areas of the Black Sea, the Sørensen–Czekanowski (Dice) coefficient (*Cs*) was applied [10]:

$$Cs = (2C / (A+B)) \cdot 100\ \%,$$

where A, B – total abundance of species recorded in compared samples; C – abundance of forms common to two compared samples.

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Results and discussion

Taxonomic composition

In the period from 2011 to 2020, 109 species of algae were found in the phytoplankton of the studied Abkhazian sector, as well as several taxonomic forms, which were not identified to the species level and belonged to the following classes: Bacillariophyceae (diatomic), Dinophyceae (dinophytic), Prymnesiophyceae (primnesian), Cyanophyceae (blue-green), Dictyochophyceae (dictyochales) and Ebriaphyceae (ebridian), Cryptophyceae (cryptophytic), Euglenophyceae (euglena), Prasinophyceae (prasinophytic) and Chlorophyceae (green) (Appendix, Table A.1). Dinophytic (71 species) and diatomic (27 species) algae were distinguished by the greatest species diversity. Other classes numbered from one to three species. Previous studies (spring-autumn periods of 2005–2011) showed that the taxonomic composition of phytoplankton in the open northeastern part of the Black Sea (NEBS) – from the Kerch Strait to Abkhazia – included significant number of dinophytic species (78), while the diversity of diatomic algae (37) was significantly inferior to them [11]. The similarity coefficient (*Cs*) of taxonomic composition in the Abkhazian sector and in the Russian open NEBS made 86 %. The largest abundance of species (62–71) in the Abkhazian sector was found in the spring-and-summer seasons (May–July) 2011–2013, which was due to the high diversity of warm-water species of dinophytic algae forming the part of algocenosis (43–58). At other times, the total number of phytoplankton species was somewhat lower (42–50).

The mesohalobiotic representatives of blue-green (genera *Oscillatoria, Planktolyngbya, Anabaena, Aphanizomenon*) and euglena algae (*Eutreptia lanowii, Euglena viridis* and *Euglena* sp.), typical for desalinated and eutrophic water areas, were not widespread and preferred the upper layers of the sea (0–15 m). Few representatives of dictyochales (*Dictyocha speculum, Octactis octonaria*) and ebridian (*Hermesinum adriaticum*) were usually found in the lower studied layers (30–50 m). In the study area, 14 potentially toxic and harmful species of planktonic dinophytic algae of the genera *Ceratium, Prorocentrum, Dinophysis, Lingulodinium, Polykrikos, Protoceratium, Protoperidinium;* 2 species of the diatomic of the genus *Pseudonitzschia*; 2 species of the blue-green genera *Planktolyngbya, Aphanizomenon* were detected, which, due to their small abundance, could not have any significant negative impact on marine flora and fauna (Appendix, Table A.1).

In September 2014, in the study sector of the sea, a species of dinophytic algae − *Oxyphysis oxytoxoides* Kofoid – new for the eastern part of the Black Sea, was found in a small amount (on average 23 cells/L). In her review article on the dinophyte algae of the Black Sea, L. M. Terenko indicates it as an exotic species, known only in the waters of the Bulgarian coast, where, however, it often results in the bloom of water [12, 13]. In May 2013, another species new to the study sector of the sea was discovered (with an average abundance of 8 cells/L) – *Spatulodinium pseudonoctiluca* (Pouchet) J.Cachon & M.Cachon.

Quantitative values of development and their vertical distribution

The average values of abundance and biomass for the entire study period were 40.26 thousand cells/L and 74 mg/m^3, respectively. The abundance values were close to the long-term averages (54 thousand cells/L) recorded in the open NEBS in the 0–50 m layer in the spring-and-autumn periods of 2007–2011; and biomass values were significantly (four times) inferior to them (280 mg/m^3) [11]. The highest values of abundance and biomass in the Abkhazian sector (79 thousand cells/L and 113 mg/m^3) were noted on the sea surface (0–2 m). In the 10–20 m layer, these values were 1.4–2.3 times lower (35 thousand cells/L and 81 mg/m^3), while in the 25–30 m layer (19 thousand cells/L and 48 mg/m^3) − 2.3–4 times lower (Fig. 1 and 2). In the lower studied layer of the sea (40–50 m), the values of phytoplankton abundance (4.5 thousand cells/L and 28 mg/m^3), respectively, were 4–18 times lower than the surface values.

The maximum abundance of planktonic cells (476 thousand cells/L) was observed in the upper layer of the sea in May 2013. High abundance values (51 and 104 thousand cells/L) on the sea surface were also noted in the summer periods of 2011 and 2012. All abundance peaks were stipulated by the intensive development of primnesian algae (*Emiliania huxleyi*), which during this period formed up to 95 % of the total abundance and 53% of the phytoplankton biomass [4)]. According to the IO RAS researchers, this species was the reason for the bloom of water on the sea surface in the Abkhazian sector in the spring of 2011 and 2013 [3, 4]. In other seasons, the abundance values on the sea surface did not exceed 26 thousand cells/L. Two peaks of cell density were noted in the 10–20 m layer (87 and 112 thousand cells/L) in July 2012 and in May 2013. One abundance peak (68 thousand cells/L) was found in the 25–30 m layer in May 2013.

High biomass values (120–216 mg/m^3) on the sea surface were noted in May, July 2011–2013, October 2011 and September 2014; at other times, these values in the upper layer of the sea varied in the range of 45–92 mg/m^3. The maximum biomass values (140 mg/m^3) in the 10–20 m layer were observed in July 2012; during the rest of the study period, they amounted to 32–93 mg/m^3. In the 25–30 m layer, biomass values varied from 33 mg/m^3 (July 2011) to 72 mg/m^3 (April 2012).

Seasonal dynamics of dominant classes and species of algae

In general, the highest total values of phytoplankton abundance in the studied water column (surface – 50 m) were recorded in the spring time (90 thousand cells/L). In summer, the total number decreased by more than two times (39 thousand cells/L), in autumn it was minimal (8.8 thousand cells/L) and was an order of magnitude inferior to the spring values. At the same time, the biomass values of the entire community of planktonic microalgae in the studied layer of the sea changed little depending on the season: 66 mg/m^3 in spring and 64 mg/m^3 in autumn, while some increase in biomass was observed in summer (78 mg/m^3).

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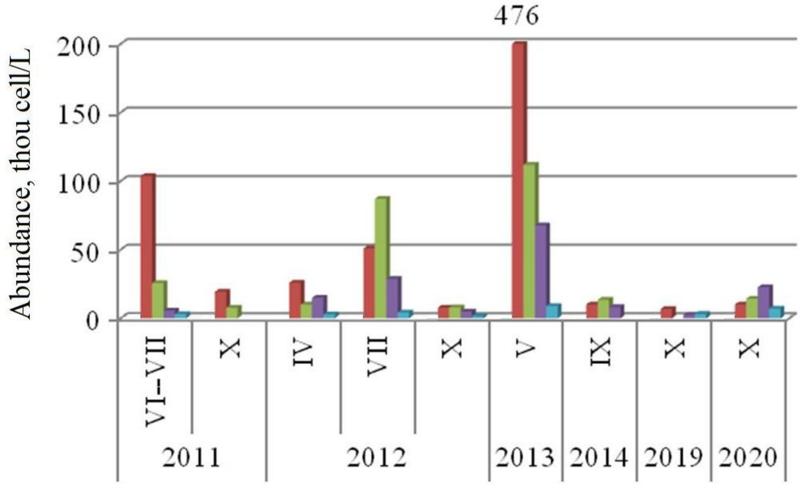

Fig. 1. Vertical distribution of the total phytoplankton abundance in layers 0–2 m (red), 10–20 m (green); 25–30 m (purple), 40–50 m (blue) in the Abkhazian sector of the Black Sea in different seasons of 2011–2020

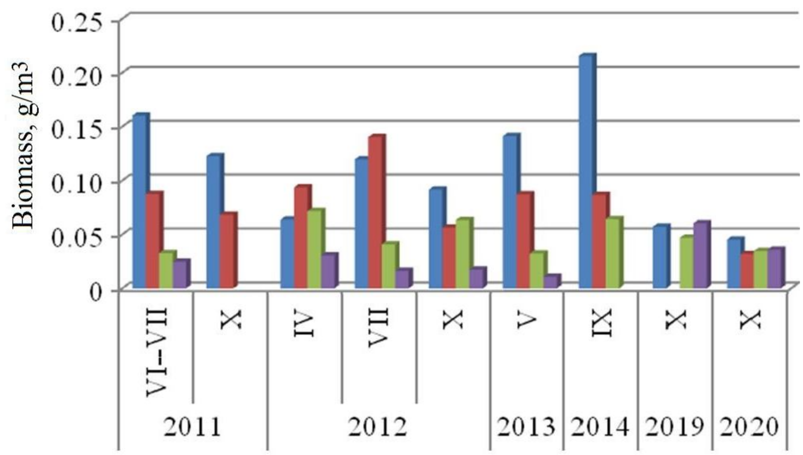

Fig. 2. Vertical distribution of the total phytoplankton biomass in layers 0–2 m (blue), 10–20 m (red), 25–30 m (green), 40–50 m (purple) in the Abkhazian sector of the Black Sea in different seasons of 2011–2020

As detailed above, primnesian algae were one of the dominant components of plankton: they formed from 36–68 % of the abundance in July 2011 and 2012, 35–45 % in October 2019 and 2020, up to 95 % of the abundance in May 2013.

Cryptophytic algae were significantly dominant in abundance (from 4 to 20 %) in 2011, 2012 and 2014, with their maximum proportion (17–20 %) observed in April 2012 and September 2014.

On average, the diatomic algae formed 30 % (from 1 to 55 %) of the total abundance and 31 % (from 5 to 77 %) of the biomass during the study period. Their maximum proportion in abundance values (55 %) was observed in April 2012; in biomass values (58–77 %) – in the autumn period of 2014 and 2019. In a significant number among them there were medium-sized species of algae of the genera *Chaetoceros*, *Pseudonitzschia,* as well as *Dactyliosolen fragilissimus*, *Nitzschia tenuirostris, Thalassionema nitzschioides*, etc. (Appendix, Table A.2). As a rule, the large-celled species *Pseudosolenia calcar-avis* was dominant in diatomic biomass. Occasionally, the role of *Proboscia alata, Chaetoceros affinis*, *Ch. curvisetus* and *Thalassionema nitzschioides* increased.

Dinophytic algae also formed on average 30 % of the total abundance (from 3 to 59 %), while they accounted for the main component of the phytoplankton biomass, namely, 60 % on average (from 22 to 84 %). A high proportion (50–59 %) of dinophytic algae in abundance values was noted in the autumn period of 2012 and 2014. Their role increased in the spring-and-summer periods of 2011 and 2012 and in the autumn periods of 2014 and 2020 in terms of biomass (76–84 %). Small species of algae of the genera *Prorocentrum, Gymnodinium, Gyrodinium,* as well as *Heterocapsa rotundata, Katodinium glaucum, Torodinium robustrum*, were dominant in abundance. The large-celled representatives of the genera *Ceratium, Protoperidinium, Dinophysis,* as well as *Polykrikos cofoidi, Gyrodinium spirale, Protoceratium reticulatum, Diplopsalis lenticula* and some others, were dominant in biomass.

It should be noted that if in the upper layers (0–20 m) high abundance of primnesian algae was observed, then in the deeper layers of the sea (30–50 m) the dinophytic algae dominated, probably due to their possible transition to heterotrophic and mixotrophic types of nutrition.

In the open NEBS, in the spring-and-autumn periods of 2007–2011, the diatomic (40 %), primnesian (34 %) and dinophytic (23 %) algae also were dominant in phytoplankton abundance. The greatest contribution to the phytoplankton biomass was made by diatomic (55 %) and dinophytic (42 %) algae. The leading species in abundance among diatomic algae were *Nitzschia tenuirostris, Thalassionema nitzschioides, Proboscia alata, Pseudosolenia calcar-avis, Skeletonema costatum*, species of the genera *Chaetoceros* and *Pseudo-nitzschia;* among dinophytic ones – *Prorocentrum cordatum, Scrippsiella trochoidea*, representatives of the genera *Gymnodinium* and *Gyrodinium* [11]. The main component of the biomass was formed by numerous medium and large-celled species of diatomic algae, such as *Proboscia alata, Pseudosolenia calcar-avis*, and dinophytic algae of the genera *Ceratium, Protoperidinium, Scrippsiella* and *Prorocentrum.* In the warm period of the year (June–July), in the temperature range from 20 to 24 °C, an increase in the proportion of *Emiliania huxleyi* (up to 67 % of the phytoplankton abundance) was also observed. The species preferred the upper (up to 20 m) layer of the sea.

Conclusions

In the spring-and-autumn periods of 2011–2020, 109 species of phytoplankton from 10 classes were found in the Abkhazian sector, among them 18 potentially toxic and harmful, and 2 species of planktonic algae new for the eastern part of the Black Sea. The species diversity was somewhat inferior to the species diversity noted in the Russian sector of the open NEBS in 2005–2011 (136 species). However, the similarity coefficient of taxonomic composition (the Sørensen–Czekanowski (Dice) coefficient, *Cs*) in the compared sectors was quite high and made 86 %.

The average abundance values concerning the water area made 40.26 thousand cells/L and were close to the long-term average values (54 thousand cells/L) noted in the open NEBS in the 0–50 m layer in the spring-and-autumn periods of 2007–2011. The average values of biomass (74 mg/m^3) were significantly (four times) inferior to the long-term average values (280 mg/m^3).

In the dynamics throughout the season, the peak of phytoplankton abundance (90 thousand cells/L) in the studied layer of the sea (with the surface of 50 m) was recorded in the spring time; in summer and autumn, these values decreased by 2–10 times. Biomass values changed little depending on the season: 66 mg/m^3 in spring, 64 mg/m^3 in autumn, and 78 mg/m^3 in summer.

The highest values (79 thousand cells/L and 113 mg/m^3) were noted in the surface layer of the sea (0–2 m), which is 1.5–18 times higher than in other studied layers (10–50 m). The maximum number of planktonic cells (476 thousand cells/L) was observed in the upper layer of the sea in May 2013, which was associated with the intensive development of primnesian algae (*Emiliania huxleyi*), which were dominant in abundance (95 %) and biomass (53 %) during that period. An increase in the proportion of primnesian algae in the warm season is generally recorded throughout the open NEBS water area.

The maximum value of biomass (216 mg/m^3) on the sea surface was noted in September 2014. 77 % of it was formed by a large-celled species of diatomic algae, *Pseudosolenia calcar-avis,* which is one of the dominant taxa of the Black Sea phytoplankton.

During the study, diatomic and dinophytic algae in the Abkhazian sector, as well as in the Russian open NEBS, constituted a significant part of phytoplankton abundance (totalling to 60 %) and biomass (91 %). In April 2012 and in September 2014, cryptophytic algae made up a significant part of the abundance (17–20 %).

Thus, the results of the study supplement significantly the previously published works covering phytoplankton in the Abkhazian sector of the Black Sea. New data on the seasonal dynamics of species diversity, quantitative development and horizontal distribution of planktonic algae in the studied sector of the sea are presented.

Appendix

Table A.1. Taxonomic composition of phytoplankton in the Abkhazian sector of the Black Sea in 2011–2020

Algae taxa	Year and month of the study								
	2011		2012			2013	2014	2019	2020
	VI–VII	X	IV	VII	X	V	IX	X	X
BACILLARIOPHYCEAE:									
Cerataulina pelagica (Cleve) Hendey	+	–	–	–	–	+	–	+	–
Chaetoceros anastomosans Grun	–	–	+	–	–	–	–	–	–
Chaetoceros affinis Lauder	+	+	+	+	+	–	–	+	+
Chaetoceros compressus Lauder	+	+	+	–	+	–	–	+	+
Chaetoceros curvisetus Cleve	+	–	+	+	–	–	–	–	+
Chaetoceros diversus Cleve	–	–	–	–	–	–	–	–	+
Chaetoceros insignis Proshkina-Lavrenko	–	–	+	–	–	–	–	–	–
Chaetoceros peruvianus Brightwell	–	–	–	–	–	–	–	+	–
Chaetoceros scabrosus Proshkina-Lavrenko	+	–	–	–	–	–	–	+	+
Chaetoceros tortissimus Gran	–	–	–	–	–	–	–	+	–
Chaetoceros spp.	–	–	+	–	–	–	–	+	+
Cocconeis scutellum Ehrenberg	–	–	–	–	–	+	–	–	–
Coscinodiscus granii Gough	–	–	–	–	+	–	–	–	–
Coscinodiscus sp.	+	–	+	+	–	+	–	–	–
Cyclotella sp.	–	–	+	–	–	–	–	–	–
Dactyliosolen fragilissimus (Bergon) Hasle	–	+	–	+	–	–	–	+	+

Continued

Algae taxa	Year and month of the study								
	2011		2012			2013	2014	2019	2020
	VI–VII	X	IV	VII	X	V	IX	X	X
Ditylum brightwellii (T.West) Grunow	–	–	+	–	–	–	–	–	–
Grammatophora marina (Lyngbye) Kützing	–	–	–	–	–	+	–	–	–
Gyrosigma sp.	–	–	–	–	–	–	–	+	–
Hemiaulus hauckii Grunow ex Van Heurck	–	–	–	–	+	–	–	+	–
Nitzschia longissima (Brébisson) Ralfs in Pritchard	–	–	–	–	–	–	–	+	–
Nitzschia tenuirostris Mer.	+	+	+	+	+	+	–	+	+
Odontella mobiliensis (Bailey) Grunow	–	+	–	–	–	–	–		–
Planktoniella sol (Wallich) Schutt	+	–	–	+	–	+	–	+	–
Pleurosigma elongatum Smith	+	+	+	+	+	+	–	+	+
Pseudo-nitzschia pseudodelicatissima (Hasle) Hasle (complex)**	+	+	+	+	+	+	+	+	+
Pseudo-nitzschia seriata (Cleve) H.Peragallo (complex)**	–	–	–	–	–	–	–	+	–
Pseudonitzschia sp.	+	–	+	–	–	+	–		–
Proboscia alata (Brightwell) Sundström	–	–	+	+	–	–	–	+	+
Pseudosolenia calcar-avis (Schultze) Sundstrom	+	+	+	+	+	+	+	+	+
Skeletonema costatum (Greville) Cleve	+	–	–	–	+	–	–	–	–
Thalassionema nitzschioides (Grunow) Mereschkowsky	+	+	+	+	+	+	+	+	+
Thalassiosira sp.	–	–	+	–	–	+	–	+	–
DINOPHYCEAE:									
Akashiwo sanguinea (Hirasaka) Hansen et Moestrup**	+	–	+	+	+	+	+	–	–
Alexandrium sp.**	+	+	–	–	–	+	+	–	–

Continued

Algae taxa	Year and month of the study								
	2011		2012			2013	2014	2019	2020
	VI–VII	X	IV	VII	X	V	IX	X	X
Amphidinium amphidinoides (Geitler) Schiller	–	–	–	–	–	+	–	–	–
Amphidinium crassum Lohmann	–	–	–	–	–	+	–	+	–
Amphidinium longum Lohmann	–	–	–	+	–	–	–	–	–
Amphidinium sphenoides Wulff	–	–	–	–	–	–	–	+	+
Amphidinium sp.	+	+	–	–	–	+	+	–	–
Ceratium furca (Ehrenberg) Claparède & Lachmann	+	+	+	+	+	+	+	+	+
Ceratium fusus (Ehrenberg) Dujardin**	+	+	+	+	+	+	+	+	+
Ceratium tripos (O.F.Müller) Nitzsch**	+	+	+	+	+	+	+	–	+
Cochlodinium archimedes (Pouchet) Lemmermann	–	–	–	–	–	–	–	–	+
Cochlodinium citron Kofoid & Swezy	+	+	+	+	–	+	–	+	+
Cochlodinium sp.	+	–	–	–	–	+	–	–	–
Dinophysis acuminata Clap.et Lachm.**	+	–	+	+	+	+	–	+	–
Dinophysis acuta Ehrenberg**	+	+	–	+	+	+	+	+	+
Dinophysis caudata Saville-Kent**	+	+	+	+	+	+	+	+	+
Dinophysis fortii Pavillard	+	–	–	–	–	+	–	–	–
Dinophysis hastata Stein	–	–	–	–	–	–	+	–	–
Dinophysis odiosa (Pavillard) Tai & Skogsberg	+	–	–	–	–	+	–	–	–
Dinophysis rotundata Claparède & Lachmann	+	+	+	+	+	+	+	+	+
Dinophysis pulchella (Lebour) Balech	–	–	–	+	–	–	–	–	–
Dinophysis sacculus Stein	+	+	–	–	–	+	+	–	–

Continued

Algae taxa	Year and month of the study								
	2011		2012			2013	2014	2019	2020
	VI–VII	X	IV	VII	X	V	IX	X	X
Dinophysis sp.	+	+	–	–	+	+	–	–	–
Diplopsalis lenticula Bergh	+	+	+	+	+	+	+	+	–
Diplopsalis sp.	+	–	–	–	–	–	–	–	–
Dissodinium pseudolunula Swift ex Elbrächter & Drebes	–	–	+	–	–	–	–	–	–
Ensiculifera carinata Matsuoka, Kobayashi & Gains	+	–	+	+	+	+	+	–	–
Glenodinium sp.	+	–	+	+	+	+		–	–
Gymnodinium agile Kofoid et Swezy, 1921	–	+	–	–	–	+	–	–	–
Gymnodinium agiliforme J.Schiller, 1928	–	+	–	+	+	+	+	–	–
Gymnodinium blax Harris.	+	–	–	+	–	+	+	–	+
Gymnodinium nana Schiller	+	+	–	+	+	–	–	–	–
Gymnodinium simplex (Lohm.) Kofoid et Swezy	+	+	+	+	+	+	+	–	–
Gymnodinium wulffii Schill.	+	+	+	+	+	+	+	–	+
Gymnodinium sp.	+	+	+	+	+	+	+	+	+
Gyrodinium flagellare Schiller	–	–	–	–	–	+	–	–	+
*Gyrodinium fusiforme*Kofoid & Swezy	+	+	+	+	+	+	+	–	–
Gyrodinium spirale (Bergh) Kofoid et Swezy	+	+	+	+	+	+	+	+	+
Gyrodinium sp.	+	+	–	+	+	+	–	+	–
Gonyaulax digitalis (Pouchet) Kofoid	+	+	–	+	+	+	–	+	–
Gonyaulax polygramma Stein	–	–	–	–	–	–	–	+	–
Gonyaulax spinifera (Clap.et Lachm.) Diesing	+	–	+	+	+	+	+	+	–

Continued

Algae taxa	Year and month of the study								
	2011		2012			2013	2014	2019	2020
	VI–VII	X	IV	VII	X	V	IX	X	X
Gonyaulax verior Sournia	+	–	–	+	–	+	–	–	–
Gonyaulax sp.	+	–	–	–	–	+	–	+	+
Heterocapsa rotundata (Lohmann) G.Hansen	–	–	–	+	+	+	+	–	+
Heterocapsa sp.	–	–	–	–	–	+	–	–	–
Heterocapsa triquetra (Ehrenberg) Stein	+	–	+	+	–	+	+	–	–
Katodinium glaucum (Lebour) Loeblich	+	+	+	+	–	+	+	–	+
Lessardia elongata Saldarriaga & Taylor	+	–	–	–	–	–	–	–	+
Lingulodinium polyedrum (Stein) Dodge**	+	–	–	+	–	+	–	+	–
Mesoporos perforatus (Gran) Lillick	–	–	–	–	–	+	+	–	–
Oblea rotunda (Lebour) Balech ex Sournia	+	+	+	+	+	+	–	–	–
Oxyphysis oxytoxoides Kofoid*	–	–	–	–	–	–	+	–	–
Oxytoxum variabile Schill.	–	–	–	+	–	+	+	–	–
Pronoctiluca pelagica Fabre-Domergue	–	+	–	+	+	+	+	–	+
Prorocentrum compressum (Bailey) Abé ex Dodge	+	+	+	+	+	+	+	+	+
Prorocentrum cordatum (Ostenfeld) Dodge**	+	+	+	+	+	+	+	+	+
Prorocentrum micans Ehrenberg**	+	+	+	+	+	+	+	+	+
Prorocentrum minimum (Pavillard) Schiller	–	+	–	–	–	+	–	–	+
Prorocentrum sp.	–	–	–	–	–		–	+	+
Protoperidinium bipes (Paulsen) Balech (=*Peridinium minusculum* Pav.)	+	–	–	+	–	+	–	–	+

Continued

Algae taxa	Year and month of the study								
	2011		2012			2013	2014	2019	2020
	VI–VII	X	IV	VII	X	V	IX	X	X
Protoperidinium brevipes (Paulsen) Balech	–	–	–	+	–	+	–	–	+
Protoperidinium conicum (Gran) Balech	+	+	–	–	–	–	–	+	+
Protoperidinium crassipes (Kofoid) Balech**	+	+	+	+	+	+	+	–	–
Protoperidinium depressum (Bailey) Balech	+	–	+	+	–	+	+	–	–
Protoperidinium divergens (Ehrenberg) Balech	+	+	+	+	+	+	+	+	+
Protoperidinium globulus (Stein) Balech	–	–	–	+	–	–	–	–	–
Protoperidinium granii (Ostenfeld) Balech	+	–	+	–	–	+	–	–	–
Protoperidinium knipowitschii (Usachev) Balech	–	+	–	+	+	+	–	–	–
Protoperidinium oblongum (Auriv.) Parke et Dodge	+	–	–	+	+	+	+	+	–
Protoperidinium pallidum (Ostenfeld) Balech	–	+	–	–	–	+	–	+	+
Protoperidinium pellucidum Bergh	+	–	+	+	–	+	+	–	+
Protoperidinium sinaicum (Matzenauer) Balech	–	–	–	–	–	–	–	–	+
Protoperidinium steinii (Jørgensen) Balech	+	+	–	+	+	+	+	+	+
Protoperidinium thorianum (Paulsen) Balech	–	–	–	–	–	+	–	–	–
Protoperidinium spp.	+	+	+	+	+	+	+	+	+
Polykrikos kofoidii Chatton**	+	+	+	+	+	+	–	–	+
Protoceratium reticulatum (Clap.et Lachm.) Butschli**	+	+	–	+	+	+	+	+	+
Protoceratium areolatum Kofoid**	–	–	–	–	+	+	–	–	–
Pyrocystis lunula (Schütt) Schütt (= *Gymnodinium lunula* Schütt)	–	–	–	–	–	+	–	–	–

Continued

Algae taxa	Year and month of the study								
	2011		2012			2013	2014	2019	2020
	VI–VII	X	IV	VII	X	V	IX	X	X
Scrippsiella trochoidea (Stein) Balech ex Loeblich	+	+	+	+	+	+	+	–	+
Spatulodinium pseudonoctiluca (Pouchet) J.Cachon & M.Cachon*	–	–	–	–	–	+	–	–	–
Torodinium robustum Kofoid & Swezy	+	+	+	+	+	+	+	+	+
Spora dinophyta	–	–	–	–	–	+	+	–	+
PRYMNESIOPHYCEAE:									
Emiliania huxleyi (Lohmann) Hay et Mohler	+	–	–	+	–	+	–	+	+
Isochrysis sp.	–	–	–	–	–	–	–	–	+
DICTYOCHOPHYCEAE:									
Dictyocha speculum Ehrenberg	+	+	+	+	+	+	+	+	+
Octactis octonaria (Ehrenberg) Hovasse	–	–	+	–	+	–	–	+	+
EBRIAPHYCEAE:									
Hermesinum adriaticum Zacharias	–	–	–	–	–	–	–	–	+
CYANOPHYCEAE:									
Anabaena sp.	+	–	–	+	–	–	–	–	–
Aphanizomenon elenkinii Kisselev**	+	–	–	–	–	–	–	–	–
Oscillatoria sp.	–	+	–	–	–	–	–	–	–
Planktolyngbya limnetica (Lemmermann) Komárková-Legnerová & Cronberg**	+	+	+	+	+	+	–	–	+

End of table

Algae taxa	Year and month of the study								
	2011		2012			2013	2014	2019	2020
	VI–VII	X	IV	VII	X	V	IX	X	X
CRYPTOPHYCEAE:									
Plagioselmis prolonga Butcher ex Novarino	+	+	+	+	+	+	+	+	–
EUGLENOPHYCEAE:									
Euglena sp.	+	–	–	+	–	+	+	–	+
Euglena viridis (O.F.Müller) Ehrenberg	–	–	–	–	–	–	–	+	–
Eutreptia lanowii Steuer	+	–	–	+	–	–	–	–	–
PRASINOPHYCEAE:									
Pterosperma undulatum Ostenfeld	+	+	–	–	–	–	–	+	–
CHLOROPHYCEAE:									
Scenedesmus sp.	–	–	–	–	–	+	–	–	–

* New for the eastern part of the Black Sea species.

** Potentially toxic or harmful species.

Note: Species names are given according to global classification Algaebase (Available at: https://www.algaebase.org/search/species) and WORMS (Available at: https://www.marinespecies.org/aphia.php?p=search).

Table A.2. Dominant taxa of phytoplankton in the Abkhazian sector of the Black Sea in different seasons of 2011–2020

Year and month of the study		Dominant in abundance	Dominant in biomass
2011	VI–VII	Cryptophytes, 6 %: *Plagioselmis prolonga* Prymnesiales, 36 %: *Emiliania huxleyi* Diatoms, 39 %: *Chaetoceros affinis, Thalassionema nitzschioides* Dinophytes, 17 %: *Gyrodinium fusiforme*, species of genus *Gymnodinium, Prorocentrum cordatum, Scrippsiella trochoidea*	Diatoms, 22 %: *Chaetoceros affinis, Pseudosolenia calcar-avis* Dinophytes, 76 %: *Ceratium tripos, C. furca, Diplopsalis lenticula, Ensiculifera carinata, Protoperidinium divergens, P. crassipes, P. steinii, Scrippsiella trochoidea*
	X	Cryptophytes, 9 %: *Plagioselmis prolonga* Diatoms, 47 %: *Chaetoceros affinis, Ch. compressum, Dactyliosolen fragilissimus, Pseudonitzschia pseudodelicatissima, Thalassionema nitzschioides, Pseudosolenia calcar-avis* Dinophytes, 42 %: species of genus *Gymnodinium, Prorocentrum cordatum, P. micans, Katodinium glaucum, Torodinium robustrum*	Diatoms, 34 %: *Pseudosolenia calcar-avis* Dinophytes, 65 %: species of genus *Ceratium, Dinophysis caudata, D. rotundata, Prorocentrum micans, Protoperidinium divergens, P. crassipes, P. steinii, Protoceratium reticulatum*
2012	IV	Cryptophytes, 17 %: *Plagioselmis prolonga* Diatoms, 55 %: *Chaetoceros affinis, C. insignis, C. curvisetus, Chaetoceros* sp., *Nitzschia tenuirostris, Pseudonitzschia pseudodelicatissima* and *Proboscia alata* Dinophytes, 26 %: *Prorocentrum cordatum, Katodinium glaucum, Scrippsiella trochoidea,* species of genera *Gymnodinium* and *Gyrodinium*	Diatoms, 22 %: *Pseudosolenia calcar-avis* and *Proboscia alata,* species of genera *Chaetoceros* and *Coscinodiscus* Dinophytes, 77 %: *Ceratium tripos, C. fusus, C. furca, Diplopsalis lenticula, Protoperidinium crassipes* and *P. depressum*

Continued

Year and month of the study		Dominant in abundance	Dominant in biomass
2012	VII	Prymnesiales, 68 %: *Emiliania huxleyi* Diatoms, 5 %: *Pseudonitzschia pseudodelicatissima, Pseudosolenia calcar-avis* and *Nitzschia tenuirostris* Dinophytes, 21%: *Gymnodinium simplex, G. nana, G. blax, Gymnodinium* sp., *Gyrodinium fusiforme, Katodinium glaucum, Prorocentrum cordatum, Lessardia elongata, Amphidinium longum*	Diatoms, 12 %: *Pseudosolenia calcar-avis.* Dinophytes, 83 %: *Ceratium furca, C. tripos, Diplopsalis lenticula, Dinophysis caudata, D. rotundata, Lingulodinium polyedrum, Protoperidinium divergens, P. crassipes, Polykrikos kofoidii*
	X	Cryptophytes, 4 %: *Plagioselmis prolonga* Diatoms, 45 %: *Pseudosolenia calcar-avis, Chaetoceros affinis, Thalassionema nitzschioides, Chaetoceros compressum, Skeletonema costatum, Hemiaulax hauckii* Dinophytes, 50 %: *Prorocentrum cordatum*, genus *Gymnodinium, Gyrodinium fusiforme Scrippsiella trochoidea, Torodinium robustum*	Diatoms, 42 %: *Pseudosolenia calcar-avis* Dinophytes, 57 %: *Ceratium furca, C. tripos, Dinophysis rotundata, Akashiwo sanguinea, Protoperidinium divergens, P. crassipes*
2013	V	Prymnesiales, 95 %: *Emiliania huxleyi* Diatoms, 1 %: *Pseudonitzschia pseudodelicatissima* Dinophytes, 3 %: species of genus *Gymnodinium, Gyrodinium, Prorocentrum, Scrippsiella trochoidea, Torodinium robustum*	Prymnesiales, 53 %: *Emiliania huxleyi* Diatoms, 5 %: *Pseudosolenia calcar-avis* Dinophytes, 41 %: *Ceratium furca, C. tripos, P. micans, Protoperidinium crassipes, Dinophysis acuta, D. rotundata, Spatulodinium pseudonoctiluca, Polykrikos kofoidii*

End of table

Year and month of the study		Dominant in abundance	Dominant in biomass
2014	IX	Cryptophytes, 20 %: *Plagioselmis prolonga* Diatoms, 20 %: *Pseudosolenia calcar-avis* and *Thalassionema nitzschioides* Dinophytes, 59 %: *Gyrodinium fusiforme, Katodinium glaucum, Akashiwo sanguinea,* genus *Gymnodinium*	Diatoms, 77 %: *Pseudosolenia calcar-avis* Dinophytes, 22 %: *Ceratium tripos, C. fusus, C. furca, Dinophysis rotundata, Protoperidinium depressum*
2019	X	Prymnesiales, 35 %: *Emiliania huxleyi* Diatoms, 44 %: *Proboscia alata, Chaetoceros affinis, Ch. scabrosus, Ch. tortissimus, Pseudo-nitzschia seriata, Ps. pseudodelicatissima,* and *Pseudosolenia calcar-avis* Dinophytes, 17%: *Prorocentrum cordatum* and *P. micans,* species of genera *Gymnodinium, Gyrodinium*	Diatoms, 58%: *Proboscia alata,* genus *Chaetoceros, Pseudosolenia calcar-avis* Dinophytes, 41 %: *Ceratium furca, C. fusus, Diplopsalis lenticula, Prorocentrum micans, Protoceratium reticulatum,* representatives of genera *Dinophysis, Gyrodinium* and *Protoperidinium*
2020	X	Prymnesiales, 45 %: *Emiliania huxleyi* and *Isochrysis* sp. Diatoms, 17 %: *Thalassionema nitzschioides, Chaetoceros affinis, Nitzschia tenuirostris* Dinophytes, 36 %: *Prorocentrum cordatum, P. micans, Heterocapsa rotundata, Katodinium glaucum, Torodinium robustrum*	Diatoms, 9 %: *Chaetoceros affinis, Ch. curvisetus, Thalassionema nitzschioides* and *Pseudosolenia calcar-avis* Dinophytes, 84 %: *Dinophysis rotundata, Polykrikos cofoidi, Gyrodinium spirale, Protoceratium reticulatum, Protoperidinium divergens, Ceratium tripos, C. fusus, C. furca* and *Prorocentrum micans*

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