4-Year Algal Blooms Monitoring of the Western Black Sea Coast Using Sentinel-3 Data

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ABSTRACT

Data on chlorophyll-a contents in algae (open waters) obtained using Sentinel-3 satellite images, for days close to the equinoxes and solstices in the 2022 – 2025 years, highlighted that the coastal area in the western Black Sea is slightly affected by eutrophication. In the studied area – Musura Gulf and the coastal zone from the shore to approximately 5 km offshore of the Black Sea, between the southern breakwater of the Sulina Channel and the mouth of the Saint George Branch – overall, chlorophyll-a concentrations values ranging from 0.02 – 2.00 μg/L were recorded. The highest values of the mean chlorophyll-a contents were identified in the day close to the summer solstice of 2024 (1.78 μg/L) in the coastal area, as well as in the day close to the spring equinox of 2025 (1.63 μg/L) in the Musura Gulf. The lowest value of the mean chlorophyll-a contents recorded in the Musura Gulf was 0.92 μg/L, in the day close to the winter solstice of 2025, and in the coastal area, 0.69 μg/L, in the days close to the winter solstice of 2024 and 2025. Therefore, the Black Sea waters in the mentioned days are classified as ultra- and oligotrophic.

KEYWORDS: *chlorophyll-a, algal blooms, phytoplankton, eutrophication, Sentinel-3 data, Western Black Sea coast*

1 INTRODUCTION

The Black Sea, an elliptical basin located between two folded Alpine belts (Degens and Ross, 1974) is the largest inland sea in the world (Murray, 1991). The Romanian Continental Platform represents, from a structural point of view, the extension of the Dobrogenian units (Mutihac and Mutihac, 2010). The Black Sea is a stratified system, the presence between 50 – 150 m and up to 200 m of a halocline, determining the reduction of vertical circulation and ventilation processes, the upper layer being oxygenated seasonally due to the cooling and mixing of cold waters during winter (BSC, 2008; Grégoire, 2023).

The waters of the Danube and its branches, being polluted with nutrients like nitrogen and phosphorus, due to the anthropogenic impact in its watershed (Bodík, 2006; Frîncu,

2021; Halder et al., 2022), affect through discharge the water quality, as well as the sediments of the Black Sea, especially in the Danube Delta zone (Lancelot et al., 2002; Reschke et al., 2002). These contribute to the eutrophication of the coastal waters of the Black Sea (Ajeagah et al., 2013).

The presence of eutrophication is noted by the modification of water biochemistry and has negative consequences on the environment, affecting the life of aquatic organisms (Diaz and Rosenberg, 2008; Turner and Chislock, 2010).

This study aims to monitor, near the most important astronomical moments (equinoxes and solstices) in the 2022 – 2025 years, an important index of eutrophication: the chlorophyll-a content present in algae in the Musura Gulf (an area of 46.27 km^2) and in the coastal zone of the Black Sea in front of the Danube Delta, over a distance of approximately 5 km from the shore to the sea (between the southern breakwater of the Sulina Channel and the mouth of the Saint George Branch) – an area of 159.74 km^2, based on Sentinel-3 data (Fig. 1).

Determining water quality using satellite techniques has the advantage of a rapid and very low-cost study, chlorophyll-a being the most important water quality parameter (Uyar et al., 2023). It is found in all phytoplankton species and represents a substitute for biomass in all aquatic systems (Vollenweider et al., 1998; Gitelson et al., 2011). The vertical distribution of phytoplankton is controlled by several factors, such as temperature, vertical light distribution, and water chemistry (Nikitine, 1925).

Algal blooms are another indicator of water quality. Some species of algae, such as cyanobacteria, can produce toxins that affect the aquatic ecosystem, posing a threat (Joshi et al., 2024). The difficulty lies in determining whether the algae species are toxic or non-toxic (Acheampong, 2018).

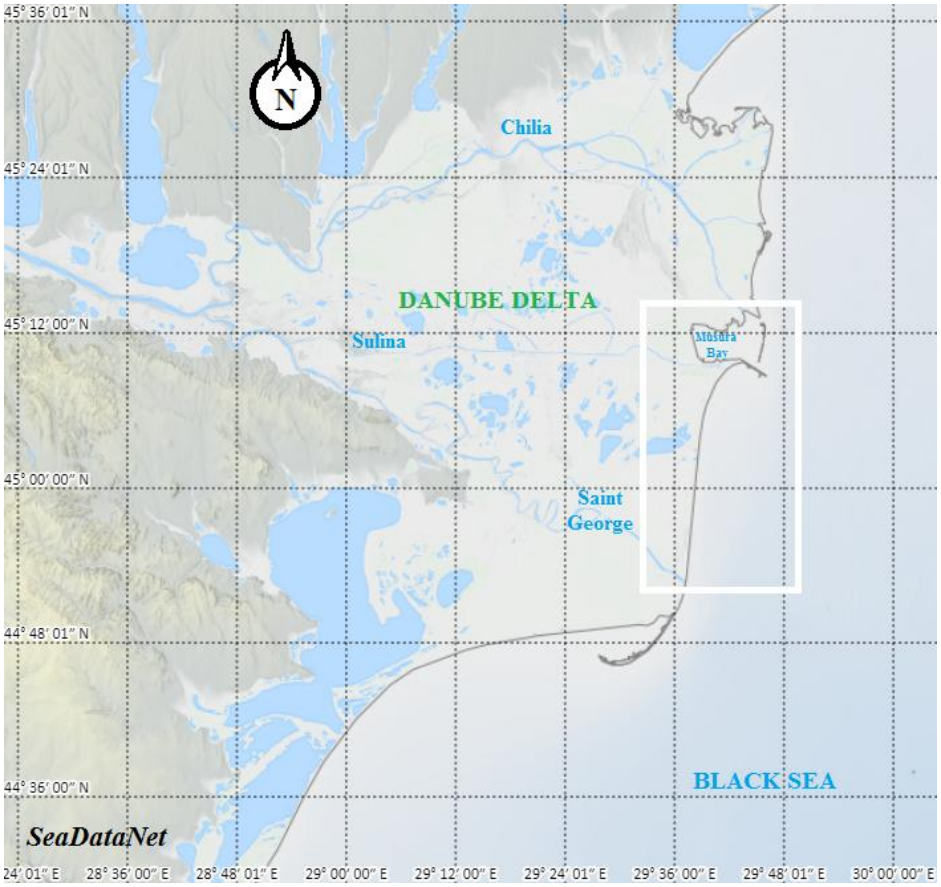

Figure 1. Location of the study area

2 MATERIALS AND METHODS

Chlorophyll-a data (open waters) were obtained by downloading satellite images from the Copernicus Browser for the 2022 – 2025 years, during the days close to the equinoxes and solstices (Fig. 2, Fig. 3, Table 1). The choice of these days was justified by the absence of clouds, verified by the RGB images (Level 1), by the multitude of values expressed in pixels as well as by the absence of atmospherical errors.

The satellite used was Sentinel-3 (OLCI – Ocean and Land Colour Instrument), with a resolution of 300 meters. The spectral band CHL_OC4ME (Level 2) was used, and the degree of cloud cover was 0%.

The statistical parameters of chlorophyll-a, as well as the values of the areas of the studied zones (Musura Gulf and the coastal area between the mouths of the Sulina and Saint George branches). were also obtained from the Copernicus Browser.

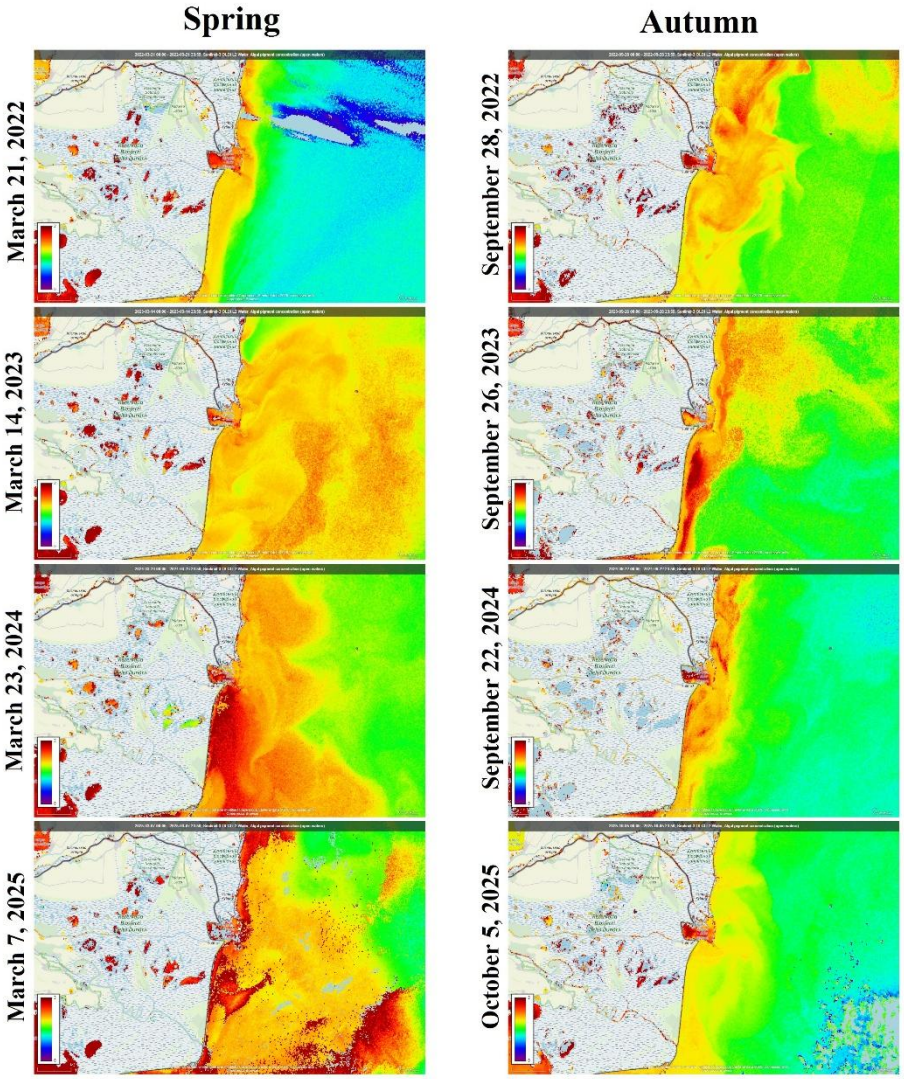

Figure 2. Algal pigment concentration (open waters) on the Western Black Sea coast near equinoxes of 2022 – 2025 years

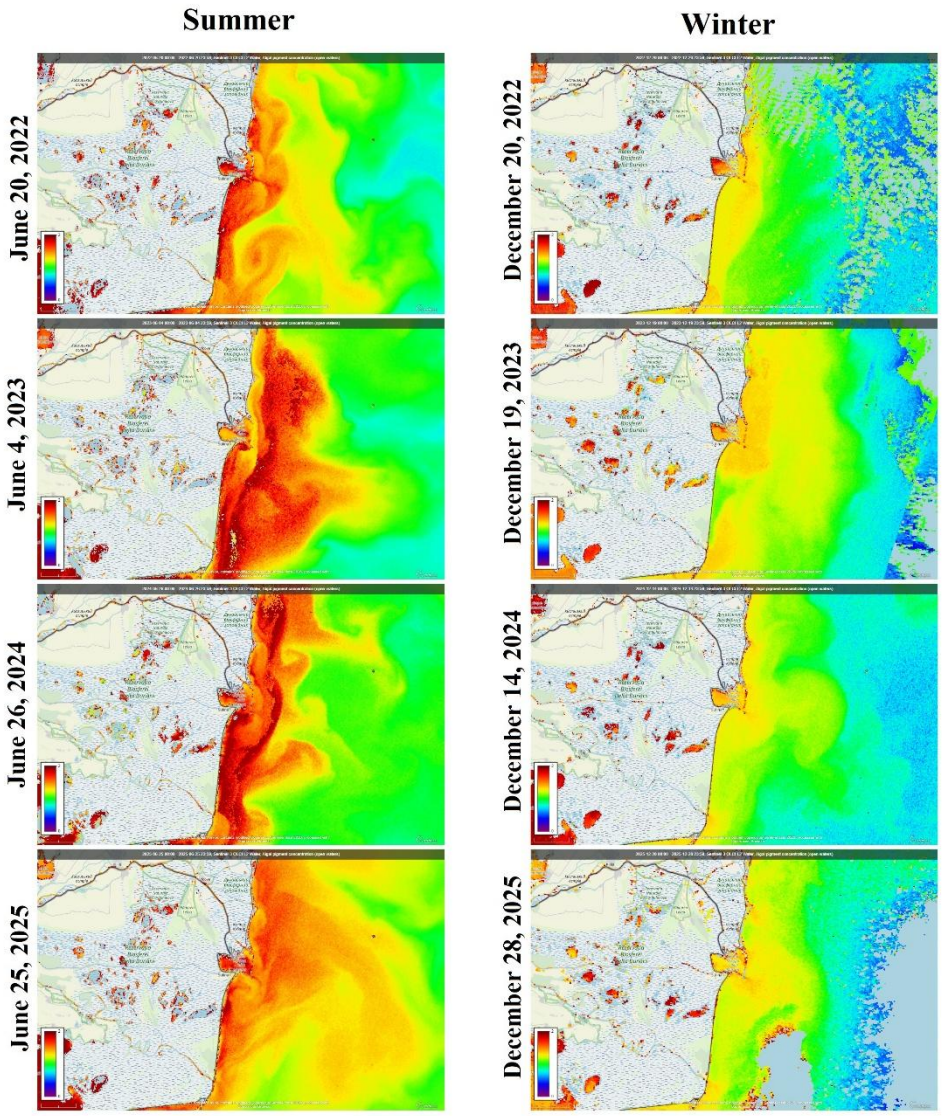

Figure 3. Algal pigment concentration (open waters) on the Western Black Sea coast near solstices of 2022 – 2025 years

The trophic classification of waters was carried out according to the system proposed by OECD (1982).

Table 1. Algal pigment concentration (open waters) parameters on the Western Black Sea coast near equinoxes and solstices of 2022 – 2025 years

Location	Year	Month and day	Median (µg/L)	Mean (µg/L)	Standard deviation	Min./Max. range (µg/L)	P_{10} - P_{90} (µg/L)
Musura Gulf (46.27 km^2)	2022	March 21	1.46	1.47	0.25	0.99 – 2.00	1.15 – 1.83
		June 20	1.59	1.57	0.32	0.85 – 2.00	1.09 – 2.00
		September 28	1.59	1.58	0.34	0.57 – 2.00	1.01 – 2.00
		December 20	0.94	1.09	0.32	0.65 – 2.00	0.82 – 1.61
	2023	March 14	1.13	1.24	0.30	0.85 – 2.00	0.96 – 1.73
		June 4	1.09	1.21	0.32	0.82 – 2.00	0.93 – 1.76

		September 26	1.10	1.19	0.30	0.28 – 2.00	0.91 – 1.59
		December 19	0.94	1.02	0.25	0.09 – 2.00	0.87 – 1.34
	2024	March 23	1.31	1.40	0.38	0.85 – 2.00	0.94 – 2.00
		June 26	1.40	1.44	0.31	0.80 – 2.00	1.04 – 2.00
		September 22	1.53	1.51	0.45	0.28 – 2.00	0.91 – 2.00
		December 14	0.93	0.99	0.22	0.54 – 2.00	0.82 – 1.21
	2025	March 7	1.64	1.63	0.31	0.19 – 2.00	1.21 – 2.00
		June 25	1.53	1.50	0.31	0.82 – 2.00	1.09 – 2.00
		October 5	1.40	1.44	0.37	0.24 – 2.00	0.94 – 2.00
		December 28	0.83	0.92	0.23	0.71 – 2.00	0.77 – 1.12
Coastal zone (159.74 km^2)	2022	March 21	0.85	0.86	0.12	0.30 – 2.00	0.79 – 0.91
		June 20	1.45	1.49	0.29	0.69 – 2.00	1.13 – 1.98
		September 28	0.87	0.87	0.13	0.60 – 2.00	0.72 – 1.02
		December 20	0.74	0.76	0.13	0.55 – 2.00	0.68 – 0.82
	2023	March 14	0.93	0.94	0.12	0.68 – 2.00	0.83 – 1.07
		June 4	1.59	1.58	0.34	0.76 – 2.00	1.12 – 2.00
		September 26	1.24	1.36	0.40	0.30 – 2.00	0.93 – 2.00
		December 19	0.77	0.71	0.20	0.33 – 2.00	0.44 – 0.90
	2024	March 23	1.81	1.67	0.35	0.09 – 2.00	1.10 – 2.00
		June 26	1.87	1.78	0.28	0.80 – 2.00	1.39 – 2.00
		September 22	0.99	1.02	0.19	0.66 – 2.00	0.80 – 1.26
		December 14	0.68	0.69	0.14	0.02 – 2.00	0.57 – 0.79
	2025	March 7	1.37	1.46	0.44	0.71 – 2.00	0.91 – 2.00
		June 25	1.24	1.30	0.27	0.77 – 2.00	0.99 – 1.70
		October 5	0.79	0.79	0.09	0.30 – 2.00	0.71 – 0.85
		December 28	0.65	0.69	0.18	0.50 – 2.00	0.58 – 0.83

3 RESULTS AND DISCUSSION

3.1 Musura Gulf

During the day close to the spring equinox, chlorophyll-a contents ranging from 0.99 to 2.00 µg/L were identified in the investigated area in 2022, with the mean of 1.47 µg/L, with higher values in the northwestern part and lower values in the northeastern and southern parts. In 2023, chlorophyll-a contents ranging from 0.85 to 2.00 µg/L were observed, with the mean of 1.24 µg/L, with higher values in the central and western parts and lower values in the northern and southern parts. The 2024 year also shows, in the same period, chlorophyll-a contents ranging between 0.85 – 2.00 µg/L, but with a higher mean of 1.40 µg/L, with higher values in the southern and western parts and lower in the northeastern part. In 2025, chlorophyll-a contents range between 0.19 – 2.00 µg/L, with the mean of 1.63 µg/L, with higher values in the southern and western parts and lower in the northeastern part, but many values were missing, especially in the western, central and southeastern parts. Therefore, a decrease in chlorophyll-a concentrations is noted in 2023, but an increase in 2025, the waters falling, however, in all four years, in the oligotrophic class. The variation in concentrations within the bay is also observed.

The day close to the summer solstice showed, in 2022, chlorophyll-a contents with values ranging between 0.85 – 2.00 µg/L, with the mean of 1.57 µg/L, with higher values in the west and center and lower elsewhere, but many values that were missing more in the north. In 2023, chlorophyll-a contents ranging between 0.82 – 2.00 µg/L are observed, with

the mean of 1.21 μg/L, with higher values in the east than in the west. In the same period, the 2024 year presents chlorophyll-a contents ranging between 0.80 – 2.00 μg/L, but with a slightly higher average of 1.44 μg/L, with higher values in the northwest and lower in the rest of the area. In 2025, chlorophyll-a contents ranged from 0.82 to 2.00 μg/L, with the mean of 1.50 μg/L, with lower values in the northeast and higher in the rest of the area. A decrease in chlorophyll-a concentrations was also observed in 2023, but an increase from 2024, the waters being oligotrophic. A variation in concentrations within the gulf is also noted.

During the day close to the autumn equinox, chlorophyll-a contents were identified in 2022 with values ranging from 0.57 to 2.00 μg/L, with the mean of 1.58 μg/L, with higher values in the western part and lower values in the eastern part. In 2023, chlorophyll-a contents ranging from 0.28 – 2.00 μg/L are distinguished, with the mean of 1.19 μg/L, with higher values in the northwestern part and lower in the rest of the studied area. In 2024, chlorophyll-a contents also ranging from 0.28 – 2.00 μg/L, but with a higher average of 1.51 μg/L, with higher values in the central and western part and lower in the rest of the bay. In 2025, chlorophyll-a contents are between 0.24 – 2.00 μg/L, with the mean of 1.44 μg/L, with higher values in the western and southern parts and lower in the northeastern part. Therefore, a decrease in chlorophyll-a concentrations is observed in 2023, but an increase in 2024, the waters falling, however, in all four years, in the oligotrophic class. The variation in concentrations within the gulf is also observed.

The day close to the winter solstice highlighted, in 2022, chlorophyll-a contents with values between 0.65 – 2.00 μg/L, with the mean of 1.09 μg/L, with higher values in the west than in the east. In 2023, chlorophyll-a contents are observed between 0.09 – 2.00 μg/L, with the mean of 1.02 μg/L, with higher values in the northwest than in the rest of the area. In the same period, the 2024 year presents chlorophyll-a contents ranging between 0.54 – 2.00 μg/L, with the mean of 0.99 μg/L, with lower values in the northeastern part and higher in the rest of the area. In the 2025 year, chlorophyll-a contents are between 0.71 – 2.00 μg/L, with the mean of 0.92 μg/L, with higher values in the northeastern part and lower in the rest of the area. Therefore, a decrease in chlorophyll-a concentrations is observed from one year to another, the waters being oligotrophic in the first two years, reaching, from 2024, ultraoligotrophic. A variation in concentrations is also noted within the gulf.

3.2 Coastal zone between the mouths of the Sulina and Saint George branches

During the day close to the spring equinox, chlorophyll-a contents ranging from 0.30 to 2.00 μg/L were reported in the investigated area in 2022, with the mean of 0.86 μg/L, with higher values in the north than in the south. In 2023, chlorophyll-a contents ranging from 0.68 to 2.00 μg/L were observed, with the mean of 0.94 μg/L, with higher values in the north than in the south. In 2024, chlorophyll-a contents ranging from 0.09 to 2.00 μg/L, with the mean of 1.67 μg/L, with higher values in the north and central parts and lower values in the south, were reported. In 2025, chlorophyll-a contents ranged between 0.71 – 2.00 μg/L, with the mean of 1.46 μg/L, with higher values in the central part and lower in the southeastern and northeastern parts. Therefore, an increase in chlorophyll-a concentrations is noted in 2024, but a decrease in 2025, the waters falling, however, in the last two years, into the oligotrophic class. Also, the variation in concentrations within the study area is observed.

The day close to the summer solstice showed, in 2022, chlorophyll-a contents with values between 0.69 – 2.00 μg/L, with the mean of 1.49 μg/L, with higher values in the west and lower in the east. In 2023, chlorophyll-a contents between 0.76 – 2.00 μg/L are observed, with the mean of 1.58 μg/L, with higher values in the south than in the north. In the same period, the 2024 year shows chlorophyll-a contents between 0.80 – 2.00 μg/L, with the mean of 1.78 μg/L, with higher values in the central part and lower values in the west and east. In

2025, chlorophyll-a contents ranged from 0.77 – 2.00 μg/L, with the mean of 1.30 μg/L, with higher values in the north than in the south. A progressive increase in chlorophyll-a concentrations is also observed in the first three years and a decrease in 2025, the waters being oligotrophic. A variation in concentrations within the area is also noted.

During the day close to the autumn equinox, chlorophyll-a contents were identified in 2022 with values ranging from 0.60 to 2.00 μg/L, with the mean of 0.87 μg/L, with higher values in the north, central and eastern parts and lower values in the south and western parts. In 2023, chlorophyll-a contents ranged between 0.30 – 2.00 μg/L, with the mean of 1.36 μg/L, with higher values in the eastern part and lower in the western part. In 2024, chlorophyll-a contents ranged between 0.66 – 2.00 μg/L, with the mean of 1.02 μg/L, with higher values in the western, northern and central parts and lower in the southern and eastern parts. In 2025, chlorophyll-a contents ranged between 0.30 – 2.00 μg/L, with the mean of 0.79 μg/L, with higher values in the northern and southern parts and lower in the central part. Therefore, an increase in chlorophyll-a concentrations is observed in 2023, then a decrease in 2024, the waters falling into the ultraoligotrophic class in 2025. Also, the variation in concentrations within the studied area is observed.

The day close to the winter solstice highlighted, in 2022, chlorophyll-a contents with values between 0.55 – 2.00 μg/L, with the mean of 0.76 μg/L, with higher values in the south, in the area of the mouth of the Saint George Branch. In 2023, chlorophyll-a contents are observed between 0.33 – 2.00 μg/L, with the mean of 0.71 μg/L, with higher values in the northern and southeastern parts, than in the rest of the zone. In the same period, the 2024 year presents chlorophyll-a contents ranging between 0.02 – 2.00 μg/L, with the mean of 0.69 μg/L, with higher values in the northern part and in the area of the mouth of the Saint George Branch. In the 2025 year, chlorophyll-a contents range between 0.50 – 2.00 μg/L, with the mean of 0.69 μg/L, with higher values in the northern and southern extremities. Therefore, a slight decrease in chlorophyll-a concentrations is observed in the first three years, the waters being ultraoligotrophic. A variation of contents within the investigated area is also noted.

The main causes of waters eutrophication in the western part of the Black Sea consist of the nutrient input brought by the Danube and its branches, through agriculture and urban sewage (Vuță and Dumitran, 2013).

4 CONCLUSIONS

Chlorophyll-a data recorded with the Sentinel-3 satellite during the day close to the most important astronomical moments – the equinoxes and solstices – during the 2022 – 2025 years, on the western coast of the Black Sea, indicate that the waters are slightly affected by eutrophication.

Although the mean values of chlorophyll-a contents differ from one year to another, from one season to another and from one zone to another, values <1 μg/L were recorded in Musura Gulf only in the days close to the winter solstice in 2024 and 2025, and in the coastal area, in all winter days, in the days close to the spring equinox in 2022 and 2023, as well as in the days close to the autumn equinox in 2022 and 2025.

It is worth noting that in 2022 and 2025, the mean values of chlorophyll-a contents are higher in Musura Gulf than in the coastal area.

In conclusion, the Black Sea waters in the investigated zone, in the mentioned days, are classified as ultra- and oligotrophic.

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