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COMPARATIVE ANALYSIS OF THE TAXONOMIC STRUCTURE OF MICROALGAE IN BAYS AND ESTUARIES OF THE BLACK SEA–AZOV REGION

Abstract. Bays and estuaries of the Black Sea–Azov region are characterized by pronounced hydrological variability, which creates a wide range of environmental conditions and influences the taxonomic structure of microalgae. Despite the substantial number of studies, available data are mostly reported for separate water bodies, which complicates their comparison. In this study, published data on the taxonomic structure of microalgae were compiled and comparatively analysed at the level of phyla and classes using multivariate statistical approaches, including ordination (NMDS) based on the Bray–Curtis index, permutational multivariate analysis of variance (PERMANOVA), and analysis of the contribution of individual taxa to differences between water body types (SIMPER). In bays, *Bacillariophyta* and *Dinoflagellata* had generally comparable species proportions, whereas in estuaries *Bacillariophyta* comprised substantially more species, while *Dinoflagellata* were represented by few species or were absent in several water bodies. These differences indicate patterns in the taxonomic structure of microalgae between bays and estuaries of the Black Sea–Azov region and could be considered in ecological monitoring.

Keywords: *Bacillariophyta*, *Dinoflagellata*, bays, estuaries, phyla, classes, regional patterns, Black Sea–Azov region

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Introduction

Bays and estuaries are characterized by fluctuations in hydrological and physicochemical parameters, which also affect aquatic biota. Microalgae represent an important and integral component of coastal aquatic ecosystems and respond rapidly to environmental changes. Their species composition and taxonomic structure reflect the ecological state of a water body and allow the detection of changes that are not always clearly captured by other indicators (Barinova et al., 2019; Barsanti, Birindelli, 2021; Shevchenko et al., 2023).

Despite the availability of numerous studies on microalgae in the Black Sea-Azov region, the results are typically reported for individual water bodies (Dolinska, 2016; Terenko, Terenko, 2000; Gerasimyuk, Ennan et al., 2023) or limited to a single type of water body, particularly estuaries (Gerasimyuk, 2018). This approach complicates comparative analysis of microalgal taxonomic composition across different types of water bodies and limits generalization at the regional scale.

As a result, it remains unclear whether the taxonomic structure of microalgae differs between different types of water bodies, particularly between bays and estuaries, and which taxa contribute to these differences, if present. The Black Sea–Azov region, characterized by a high number of bays and estuaries, their spatial proximity, and the availability of accumulated phycological data, provides a suitable setting for such a comparative analysis.

The aim of this study is to perform a comparative analysis of the taxonomic structure of microalgae in bays and estuaries of the Black Sea–Azov region.

We hypothesize that the taxonomic structure of microalgae at the level of phyla and classes differs between bays and estuaries in this region.

Materials and Methods

The study is based on a synthesis of published data on the taxonomic structure of microalgae in bays and estuaries (estuarine water bodies) of the northern part of the Black Sea–Azov region (Fig. 1). Data were compiled for estuaries of the northwestern Black Sea region (Gerasimyuk, 2018), water bodies of the eastern Azov region (Kovaleva, 2008), bays of Crimea (Tokareva et al., 2008; Nevrova, 2015), and the Odesa Bay (Terenko, Terenko, 2000). In total, 22 water bodies were analysed, including 6 bays and 16 estuaries.

Taxonomic assignment of microalgal taxa followed the classification adopted in AlgaeBase (Guiry, Guiry, 2025).

Similarity among water bodies was assessed using the Bray–Curtis index calculated based on the relative proportions of phyla. Ordination was performed using non-metric multidimensional scaling (NMDS). Differences in taxonomic

structure between water body types (bays and estuaries) were tested using permutational multivariate analysis of variance (PERMANOVA) with 9,999 permutations. Homogeneity of multivariate dispersion was assessed using PERMDISP. To evaluate the contribution of individual taxonomic groups to differences between bays and estuaries, similarity percentage analysis (SIMPER) based on the Bray–Curtis index was applied. Differences in the distribution of relative proportions of microalgal phyla between (bays and estuaries were tested using the non-parametric Mann–Whitney test. Effect size was estimated using the Vargha–Delaney A statistic. All calculations were performed in PAST 5.3 (Hammer et al., 2001).

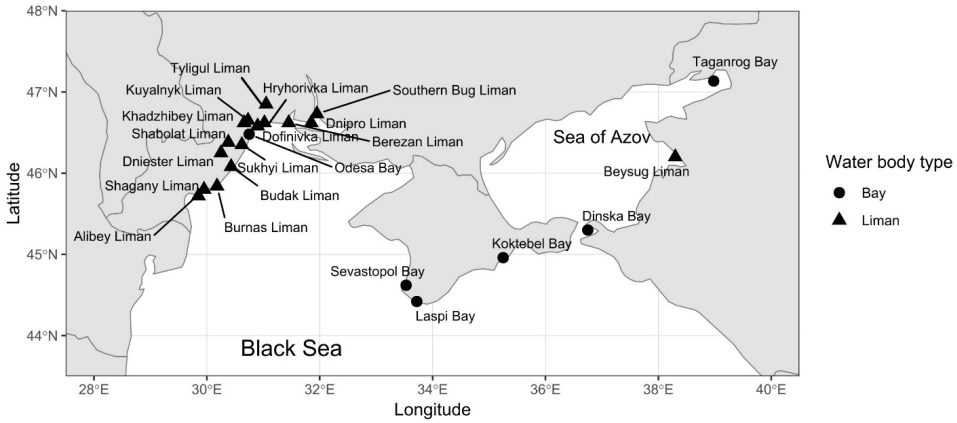

Fig. 1. Map of bays and estuaries in the northern part of the Black Sea-Azov region included in the analysis

Results

Based on published data, a compiled dataset of relative proportions (%) of the main phyla and classes of microalgae was obtained (Fig. 2). In each analysed water body, regardless of type, *Bacillariophyta* prevailed in the taxonomic structure in terms of the species proportion (31.2–97.5%). Representatives of *Cyanobacteriophyta* also contributed substantially, with proportions ranging from 0.9 to 23.1%.

At the same time, differences between water body types were observed. In particular, *Dinoflagellata* and *Haptophyta* showed relatively high proportions in bays (up to 43.5% and 10.2% respectively). In estuaries they generally had lower proportions of the total number of recorded species or were absent: *Dinoflagellata* — up to 5.4% (with exception in the Budak Liman — 26.9%) and *Haptophyta* 3.8%. A similar pattern was observed for *Chrysophyceae*, *Cryptophyceae*, and *Dictyochophyta*, which were mainly recorded in bays and

were nearly absent in estuaries, although their proportions were low in all studied water bodies.

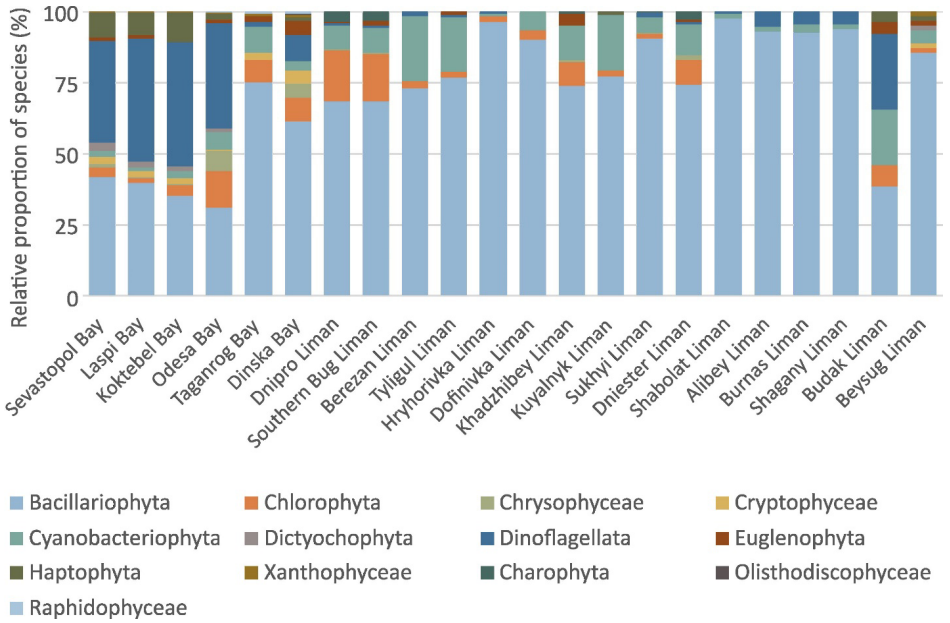

Fig. 2. Representation of microalgal taxa (phyla and classes) in the studied bays and estuaries of the Black and Azov Seas (%)

Non-metric multidimensional scaling (NMDS; stress = 0.09) revealed a clear separation of the studied water bodies according to their type (Fig. 3). The first NMDS axis represents the main gradient in the data and distinctly separates marine bays from estuaries. All bays are located in the negative part of axis 1, whereas estuaries consistently cluster in its positive part, indicating differences in the taxonomic structure of microalgae between these water bodies. The second axis explains a smaller portion of the variation and does not play a substantial role in separating bays and estuaries.

The distribution of taxonomic groups in the ordination space showed that some taxa (*Dinoflagellata*, *Haptophyta* and *Dictyochophyta*) were positioned in the negative part of axis 1 with bays, whereas others occupied its positive part and were characteristic of estuaries. The separation of water bodies along axis 1 is primarily driven by taxa located at its extreme positions.

It should be noted that the Taganrog Bay and Dinska Bay do not group with the other bays, instead occupying positions among the estuaries.

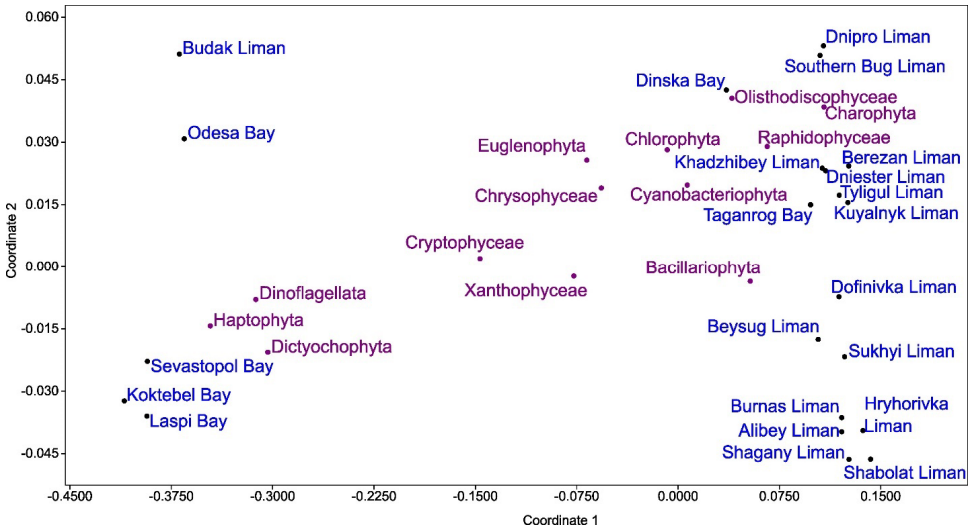

Fig. 3. NMDS ordination of coastal water bodies based on the Bray–Curtis index calculated from the relative proportions of microalgal taxa. Black points represent water bodies, and purple points represent microalgal taxonomic groups

PERMANOVA results indicated statistically significant differences in the taxonomic structure of microalgae between bays and estuaries (F = 16.16, p = 0.0002), with water body type explaining approximately 45% of the total variation. The test for homogeneity of multivariate dispersion (PERMDISP) showed no statistically significant differences between bays and estuaries (p = 0.06), allowing reliable interpretation of the PERMANOVA results.

SIMPER analysis (Table) showed that differences in the proportions of *Bacillariophyta* and *Dinoflagellata* accounted for approximately 70% of the overall dissimilarity between bays and estuaries. *Bacillariophyta* had substantially higher mean relative proportions in estuaries (80.6%) compared to bays (49.1%), whereas *Dinoflagellata* were characteristic of bays (26.9%) and were much less represented in estuaries (3.1%). Additional differences were contributed by *Cyanobacteriophyta*, which were more frequently recorded in estuaries than in bays (9.2% and 4.1%, respectively).

To assess differences between bays and estuaries in the distribution of major microalgal taxa, the non-parametric Mann–Whitney test was applied. The analysis showed that the distribution of *Bacillariophyta* proportions was shifted towards higher values in estuaries compared to bays ($p < 0.01$; A = 0.10). In contrast, *Dinoflagellata* exhibited the opposite pattern, with higher proportions in bays ($p < 0.01$; A = 0.94). Similarly, *Haptophyta* were also characterized by higher values in bays ($p < 0.01$; A = 0.86), although their overall representation was lower than that of *Dinoflagellata*.

Table. **Microalgal taxa contributing to differences between bays and estuaries (SIMPER analysis)**

Taxon	Contributing, %	Mean proportion in bays, %	Mean proportion in estuaries, %
Bacillariophyta	39.7	47.4	80.6
Dinoflagellata	30.1	28.4	3.1
Cyanobacteriophyta	7.9	4.1	9.2
Chlorophyta	6.3	6.3	4.7
Haptophyta	5.5	5.0	0.4
Cryptophyceae	2.6	24	0.2
Euglenophyta	2.5	2.3	0.1
Chrysophyceae	2.0	1.9	0.8
Dictyochophyta	1.4	1.2	0.1
Charophyta	0.8	0.0	0.7
Xanthophyceae	0.7	0.6	0.1
Raphidophyceae	0.4	0.3	0.0
Olisthodiscophyceae	0.1	0.1	0.0

For other taxonomic groups, including *Chlorophyta* and *Cyanobacteriophyta*, despite their occurrence in nearly all analysed water bodies, no statistically significant differences in the distribution of proportions between bays and estuaries were detected ($p > 0.05$).

Thus, the results of the comparative analysis indicate differences in the taxonomic structure of microalgae between bays and estuaries of the Black Sea–Azov region, primarily reflected in the relative proportions of *Bacillariophyta* and *Dinoflagellata*.

Discussion

The results obtained in this study support the proposed hypothesis that the taxonomic structure of microalgae at the level of phyla and classes differs between bays and estuaries of the Black Sea–Azov coast.

The high representation of *Bacillariophyta* and *Dinoflagellata* in coastal water bodies worldwide, as well as their sensitivity to environmental changes, has been reported by other studies (Carstensen et al., 2015; Garrido et al., 2016; Miao et al., 2024). At the same time, the dominance of these groups in terms of species proportions varies among studies. Some reports are consistent with our findings (Cardoso, Torgan, 2007; Saifullah et al., 2014; Telesh et al., 2025), whereas others indicate a prevalence of diatoms in bays (Chan, Hamilton, 2001;

Souza et al., 2013; Stanca et al., 2013) or dinoflagellates in estuaries (Sellner et al., 2001; Prabhudessai, Rivonker, 2020).

This variability likely reflects the primary role of local environmental conditions, particularly salinity, water exchange intensity, and turbulence (Elferink et al., 2020; Bi et al., 2021; Xu et al., 2024), while the water body type represents a generalized expression of these factors. In this context, the results obtained in this study should be interpreted primarily as reflecting regional features of the taxonomic structure of microalgae in coastal water bodies of the Black Sea-Azov region.

Along with the observed general patterns in the distribution of taxonomic groups, some deviations were identified. In particular, in Taganrog Bay and Dinska Bay, the proportion of *Bacillariophyta* substantially exceeds that of *Dinoflagellata*, which may be related to specific salinity conditions as well as trophic and hydrochemical regimes of these water bodies (Belova et al., 2026; Sukhinov, Belova, 2026).

Another example is Budak Liman, which, in contrast, shows a taxonomic structure closer to that of bays, particularly Odesa Bay, with comparable proportions of these two major groups. Limited hydrological and hydrochemical data for this water body do not allow a clear explanation of these differences.

It should be noted that the dataset for coastal water bodies of the Azov Sea in this study is smaller and includes fewer sites compared to those from the Black Sea coast. For some water bodies, available phycological data are limited, particularly for Zapadensky and Shahaivsky estuaries (Kovaleva, 2008). In addition, some strongly transformed water bodies (e.g., Molochny and Utliuk estuaries) (Bren et al., 2022), characterized by unstable and significantly altered hydrological conditions, were not included in the analysis.

Among other limitations, the dataset includes both planktonic and benthic microalgal communities, and for some water bodies, information is available for only one of these components, which may affect the completeness of the taxonomic representation. Despite these limitations, the analysis allowed generalization of the main features of microalgal taxonomic structure in coastal water bodies and revealed differences between their types at the level of higher taxa.

The results of this study may be useful for monitoring the ecological status of coastal water bodies. Future research could focus on expanding spatial coverage and testing the observed patterns in other regions, as well as applying molecular, non-culture-based approaches to improve data comparability and reduce the time required for data acquisition.

Conclusions

This study synthesizes published data on the proportions of microalgal taxonomic groups in bays and estuaries of the Black Sea-Azov coast and provides their comparative analysis at the level of phyla and classes. In bays, *Bacillariophyta* and *Dinoflagellata* generally showed comparable proportions, whereas in estuaries *Bacillariophyta* substantially prevailed. These differences reflect patterns in the taxonomic structure of microalgae between the studied water body types and reflect features of the Black Sea–Azov region.

ETHICS DECLARATION

The authors declare no conflict of interst.

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Порівняльний аналіз таксономічної структури мікроводоростей заток та лиманів Чорноморсько-Азовського регіону

Затоки та лимани Чорноморсько-Азовського регіону характеризуються вираженою гідрологічною мінливістю, що формує широкий спектр умов середовища та впливає на таксономічну структуру мікроводоростей. Попри значну кількість досліджень, наявні дані переважно наводяться для окремих водойм, що ускладнює їхнє порівняння. У роботі узагальнено літературні дані про таксономічну структуру мікроводоростей та проведено їхній порівняльний аналіз на рівні відділів і класів із застосуванням багатовимірних статистичних підходів, включаючи ординацію (NMDS) на основі індексу Брея–Куртіса, пермутаційний аналіз варіації (PERMANOVA) та SIMPER-аналіз. У затоках *Bacillariophyta* та *Dinoflagellata* характеризувалися загалом співставними пропорціями видів, тоді як у лиманах *Bacillariophyta* включали значно більшу кількість видів, а *Dinoflagellata* були представлені незначною кількістю видів або були відсутні в окремих водоймах. Виявлені відмінності свідчать про наявність закономірностей у таксономічній структурі мікроводоростей між затоками та лиманами Чорноморсько-Азовського регіону та можуть бути перспективними для використання в екологічному моніторингу.

Ключові слова: *Bacillariophyta*, *Dinoflagellata*, затоки, лимани, відділи, класи, регіональні закономірності, Чорноморсько-Азовський регіон

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