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Bacillariophyceae Distribution and Water Quality in Estuarine-Mangrove Environments: The Commonest Phytoplankton in Musi Estuary, Indonesia

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Abstract: This study reveals the distribution of Bacillariophyceae in estuarine-mangrove which is mainly influenced by the quality of the waters. The main component analysis approach between variables is critical in this study because it determines the environmental characteristics in each estuarine zone. Estuarine-mangrove environments have different physical-chemical dynamics compared to other types of waters, one of which is Musi Estuary, located on the coast of South Sumatra. The aquatic environment of the Musi Estuary is influenced by tidal fluctuations that bring nutrients from inland waters and mangrove litter. This condition is perfect for the phytoplankton habitat, which plays an essential role in the ecological processes of waters as primary producers. This study aims to examine the diversity of Bacillariophyceae phytoplankton in the mangrove estuary environment and its possible role in estuarine ecology. Data were collected at ten observation stations in July, including samples of phytoplankton and water physical-chemical data such as pH, dissolved oxygen, temperature, salinity, water brightness, current speed, nitrates, and phosphates. Quantitative measurement of phytoplankton was performed using an Olympus CX23 light microscope at 100X magnification, while data were analyzed using PCA and Bray-Curtis similarity analysis. Water environment conditions were measured in a stable range in each zone except for salinity and brightness. Furthermore, only Bacillariophyceae were observed in all observation zones dominated by the *Skeletonema* genus. It is a dominant presence, and its abundance determined its role as a significant primary producer in the estuary outer zone near the sea. This study implicitly revealed the existence of *Skeletonema* in influencing ecological processes in estuary mangrove waters.

Keywords: biodiversity, species, Musi Estuary, principal components analysis, phytoplankton.

河口红树林环境中的芽孢杆菌属分布和水质：印度尼西亚穆西河口最常见的浮游植物

摘要：本研究揭示了河口-红树林中硅藻类的分布主要受水质影响。变量之间的主成分分析方法在本研究中至关重要，因为它决定了每个河口区域的环境特征。与其他类型的水域相比，河口-红树林环境具有不同的物理化学动力学，其中之一是位于南苏门答腊海岸的穆西河口。穆西河口的水生环境受到潮汐波动的影响，潮汐波动从内陆水域和红树林枯枝落叶中带

来养分。这种条件非常适合浮游植物栖息地，浮游植物在作为初级生产者的水域生态过程中起着至关重要的作用。本研究旨在考察红树林河口环境中硅藻纲浮游植物的多样性及其在河口生态学中的可能作用。7月份在10个观测站采集了数据，包括浮游植物样本和酸碱度值、溶解氧、温度、盐度、水体亮度、流速、硝酸盐和磷酸盐等水体物理化学数据。使用放大100倍的奥林巴斯客户体验23光学显微镜对浮游植物进行定量测量，同时使用主成分分析和布雷柯蒂斯相似性分析对数据进行分析。除盐度和亮度外，各区的水环境条件均在稳定范围内测量。此外，在以骨条藻属为主的所有观察区中仅观察到硅藻纲。它是一个主要的存在，它的丰富性决定了它作为靠近大海的河口外围区域重要初级生产者的作用。这项研究隐含地揭示了骨条藻在影响河口红树林水域生态过程中的存在。

关键词：生物多样性、物种、穆斯河口、主成分分析、浮游植物。

1. Introduction

Tropical estuaries and mangrove forests are among the world's most productive, valuable, and important coastal ecosystems. It has essential natural resources for nutrient recycling, carbon sequestration, and the well-being of humans and other organisms, including the coastal social, economic, and cultural aspects [1]-[2]. This ecosystem, located between the waters of the strait and the longest river, is influenced by the dynamics of tidal fluctuations from two types of waters, namely, fresh and saline waters. This ecosystem facilitates the movement of organic material from land and mangrove litter to the sea from fluvial discharge [3]-[4]. The estuary environment has dynamic and complex rules, influenced by physical-chemical fluctuations of water, which in turn impact the biological community [5]. The existence and task of the structure of biological communities need to be understood in their ecological interactions, especially the phytoplankton community, which plays an essential role in providing the primary food source in the food web in estuary waters. Phytoplankton live in short cycles and respond to environmental changes in estuaries well so that they can act as bioindicators of brackish water ecosystems [6]. However, some species are also found not to have good adaptability. As a result, the population declines significantly and may become extinct in local habitats [7]. These conditions foster the understanding that phytoplankton plays an essential ecological role in estuarine mangrove forests, thus providing an essential value in assessing sustainable aquatic ecosystems.

The Musi Estuary is located on the east coast of South Sumatra. It is a dynamic and complex area influenced by tidal physical-chemical interactions, variations in freshwater entering from upstream Musi, and saline water entering the Bangka Strait [8]-[9]. The entire coast is affected by sedimentation of organic

material, so it is rich in nutrient aspects and increases its fishery resources. Estuaries are places where the marine and land environments physical, chemical, and biological systems are exchanged in a short fluctuating time [6], [8], [10]. Based on this, it is expected that the implications of phytoplankton communities are more complex in ecological processes than in aquatic environments.

The general species of phytoplankton in the mangrove waters of the Musi Estuary have not been clearly disclosed, especially at the regional zone level. Previous phytoplankton studies in the Musi estuary area have discussed spatial variability at specific points and daily temporals [9], [11]. A general species study at a site is needed to assess the adaptive environmental characteristics of some common phytoplankton species.

The general species of phytoplankton in the mangrove estuary waters of the Musi estuary have not been studied further, so there needs to be a study of community structure to assess the most common phytoplankton species. This study will be closely related to its function as the primary producer of mangrove estuary waters. Based on this, we studied the structure and ways in which the phytoplankton community interacted with the mangrove-estuarine environment. Is there a dominance caused by the adaptability of each species to changes in the physical and chemical environment and the ability to compete better than other species in using nutrient sources in the estuary.

2. Materials and Methods

2.1. Study Site

The Musi Estuary is located on the east coast of South Sumatra and has the number one largest mangrove vegetation zone in western Indonesia. This area was dominated by the mangrove plants *Avicennia*

marina, *Avicennia alba*, *Sonneratia caseolaris*, *Sonneratia alba*, *Rhizophora mucronata*, and *Nypa fruticans* [8]-[9], [12]. Due to high sedimentation, this estuary area has the characteristics of deep mud. Moreover, environmental conditions were strongly influenced by tides. This area was a transportation route for residents and domestic and industrial ship transportation. Additionally, organic material from domestic, agricultural, and industrial anthropogenic

activities accumulated in the estuary area.

This research was conducted in July 2020. Phytoplankton sampling and water quality measurements were carried out at ten observation stations on mid tide, determination of five stations based on the assumption that it was influenced by freshwater. Stations 6 and 7 were based on the central area of the estuary, while stations 8, 9, and 10 were affected by seawater (Figure 1).

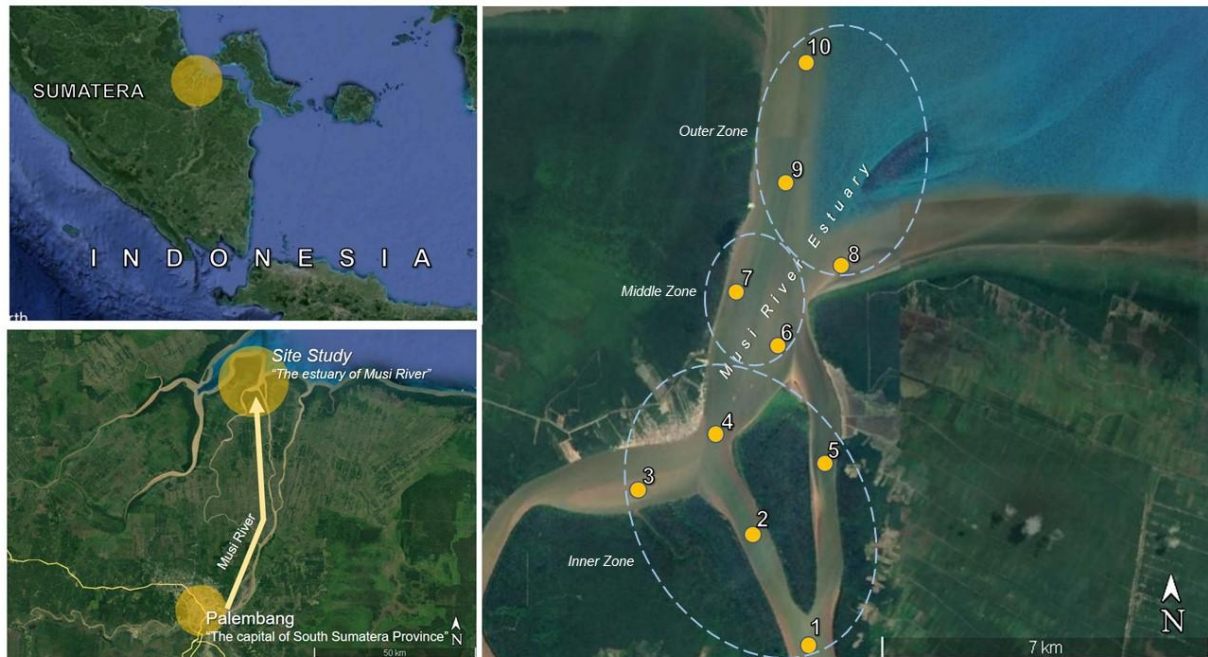


Fig. 1 Location of the study area

2.2. Data Collection

The water quality data were collected simultaneously with phytoplankton retrieval at each station. Each physical and chemical parameter was measured in situ, pH, dissolved oxygen, and temperature, using Multiparameter Hanna Hi 98194, salinity using a hand refractometer, water brightness using a Secchi disk, current speed using current meter FP111 Global Flow Probe. The 100-L water sample for phytoplankton was filtered using a 25 μm plankton net. The water volume filtered was 250 mL with 4% formalin solution. Furthermore, water sampling for nitrate and phosphate measurements was done using a 250 mL dark bottle. Samples were carried in cooler box during the trip to the laboratory [13].

Nitrate analysis used the cadmium reduction method measured at a wavelength of 543 nm spectrophotometer UV-vis while phosphate analysis used the ascorbic acid reduction method with absorbance measurement of 880 nm spectrophotometer UV-vis [14].

2.3. Quantitative Phytoplankton Analysis

Quantitative analysis of phytoplankton used an Olympus CX23 light microscope at 100X magnification equipped with a Sedgwick Rafter

Counter Cell (SRCC) [11], [15]. Identification was based on morphology and the number of cells counted to analyze abundance and biodiversity. Species identification referred to the reference [16].

2.4. Data Analysis

The abundance of phytoplankton was expressed in cell/L, the volume of filtered water was 100 L and the volume of water was taken to be 250 mL [11], [13]. Phytoplankton diversity (H') and dominance (D) were calculated using the Shannon-Wiener diversity index and Simpson dominance index [17].

The interactions correlation between the physical-chemical parameters (salinity, dissolved oxygen, temperature, pH, water brightness, current, nitrates, and phosphates) with the biodiversity and abundance were analyzed using Principal Component Analysis with XLSTAT 2021 and cluster dissimilarity analysis using the Bray-Curtis dissimilarity with PAST3 software [9], [14].

3. Results

3.1. Physical-Chemical Parameters in Estuarine-Mangrove

A spatial description of the environmental

conditions at 10 stations is presented in Figure 2. Temperature, salinity, dissolved oxygen, pH, water brightness, current velocity, nitrates, and phosphates differed in the study sites. Each parameter at each station had a measurement pattern based on the spatial size. The spatial similarity of each parameter is shown in the dendrogram of Figure 3. Spatial multivariable similarities with the highest correlation value were salinity and pH (0.986), temperature, and brightness (0.921).

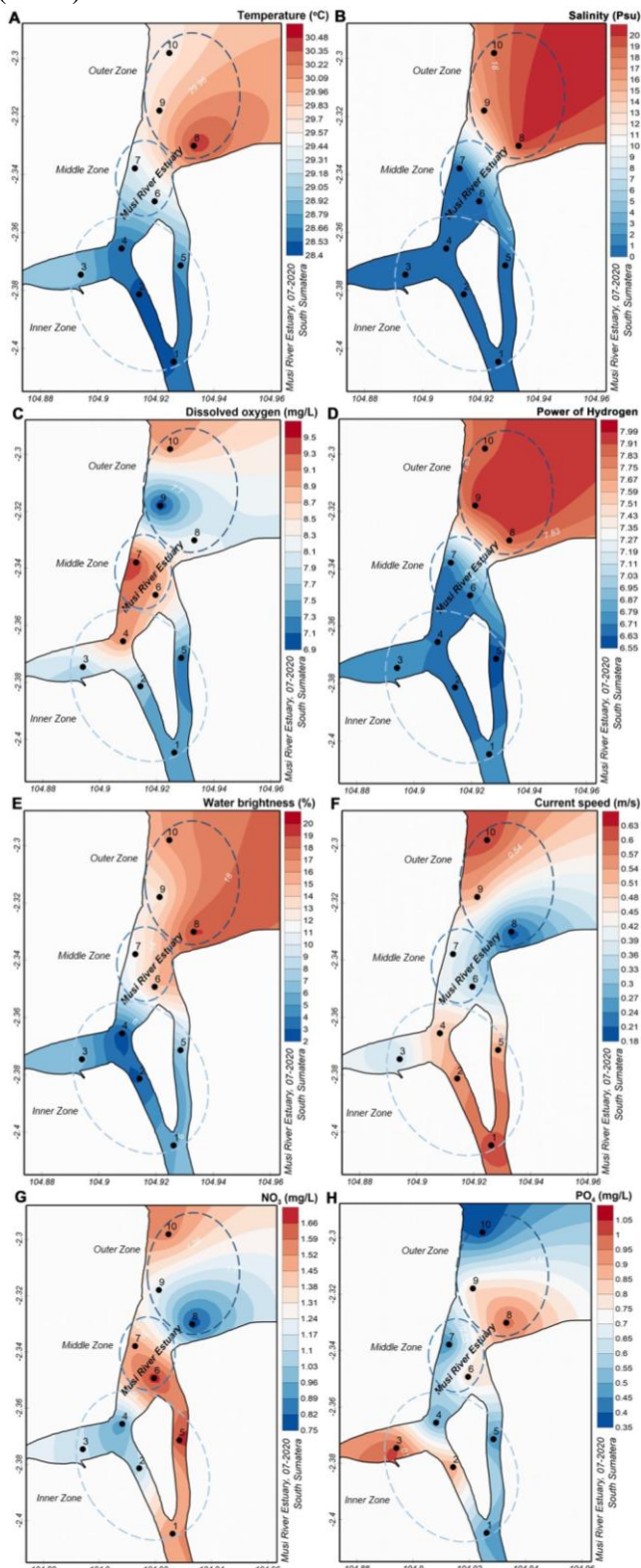


Fig. 2 Water quality parameters in Musi Estuary

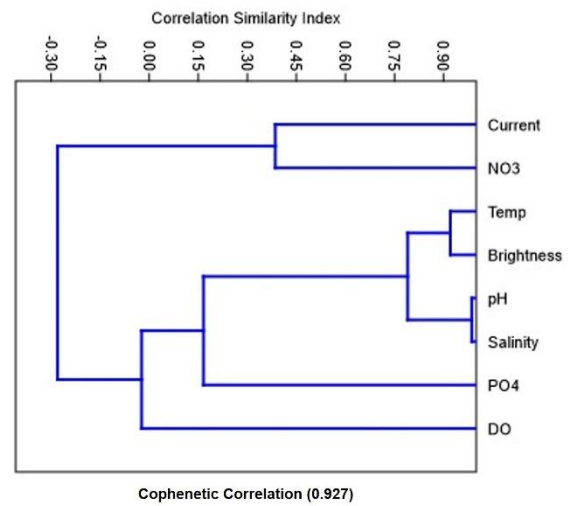


Fig. 3 Cluster of the water quality using a correlation similarity index

Measurements of physical-chemical parameters obtained consecutively resulted ranging from 28.24 °C-30.46 °C (temperature), 0 Psu – 20 Psu (salinity), 6.87 mg/L-9.46 mg/L (DO), 6.56-7.96 (pH), 2.3 %-19.2 % (brightness water), 0.19 m/s-0.63 m/s (current speed), 0.755 mg/L-1.716 mg/L (NO₃), 0.354 mg/L-1.015 mg/L (PO₄). The water temperature range was quite close due to tropical weather factors, which tended to be stable throughout the day. The salinity values described the geographical differences in the study locations. Among the ten locations, there were only three locations where the influence of seawater was quite strong. The dissolved oxygen tended to be higher at heavier locations in the interior of the river. More high alkaline level in estuary (more than 7 as neutral) also tended to be higher near the sea.

3.2. Community Structure of Bacillariophyceae

Nineteen were genera identified from the class Bacillariophyceae (Figure 4). The major genera that were found in frequency at all stations in these waters were *Amphora*, *Leptocylindrus*, *Skeletonema*, and *Thalassiosira*. However, the genus which is considered minor, is found in frequency less than three stations, namely, *Cymbella*, *Coscinodiscus*, *Cylindrotheca*, *Eucampia*, *Hemiaulus*, *Planktoniella*, and *Rhizosolenia*. Several genera were found in large and small numbers. The percentage of the genus *Skeletonema* (72.16%) was the highest, while *Coscinodiscus* (0.06%) was the lowest (Figure 5). The existence of all genera can be seen in Table 1.

The *Skeletonema* genus was found at all the study sites. It also contributed a lot to the density of the phytoplankton community in the Musi estuary waters. It was believed to have a better adaptability to the physical-chemical dynamics of the estuary.

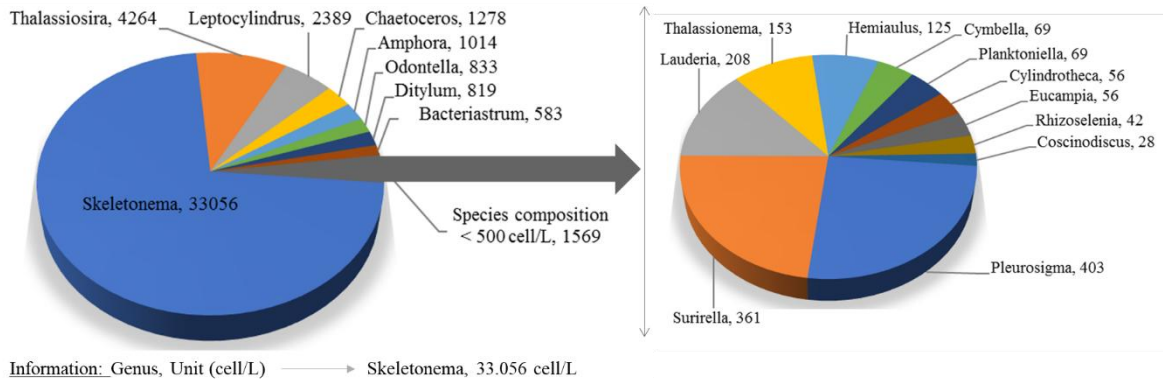


Fig. 4 Composition and density of Bacillariophyceae in total

Table 1 Occurrence and cell density of Bacillariophyceae at observation stations

Genus	Station Location in Estuary									
	Inner Zone					Middle Zone		Outer Zone		
	1	2	3	4	5	6	7	8	9	10
<i>Amphora</i>	+	+	+	+	+	+	+	+	+	+
<i>Bacteriastrium</i>	-	-	-	-	-	+	+	+	+	+
<i>Cymbella</i>	-	-	-	-	-	-	-	+	+	-
<i>Chaetoceros</i>	+	-	-	-	-	+	+	+	+	+
<i>Coscinodiscus</i>	-	-	-	-	-	-	+	+	-	-
<i>Cylindrotheca</i>	+	+	-	-	-	-	-	-	-	-
<i>Ditylum</i>	-	-	+	+	-	-	+	+	+	+
<i>Escambia</i>	-	-	-	-	-	-	-	-	+	-
<i>Hemiaulus</i>	-	-	-	-	-	-	-	-	+	+
<i>Lauder</i>	-	-	-	-	-	+	+	+	+	+
<i>Leptocylindrus</i>	+	+	+	+	+	+	+	+	+	+
<i>Odontella</i>	+	-	-	-	-	+	-	+	+	+
<i>Planktoniella</i>	-	-	-	-	-	-	-	+	-	-
<i>Pleurosigma</i>	+	+	+	+	+	+	+	-	-	-
<i>Rhizoselenia</i>	-	-	-	-	-	+	-	-	-	-
<i>Skeletonema</i>	+	+	++	+	+++	++++	++++	++++	*	++++
<i>Surirella</i>	-	-	-	-	-	+	+	+	+	+
<i>Thalassionema</i>	-	-	-	-	-	+	+	+	+	+
<i>Thalassiosira</i>	+	+	+	+	+	+	+	++	+	+
Total density (cell/L)	105	73	163	97	265	437	441	547	620	550

Note: (-) Not found, (+) 1 to 100 cell/L, (++) 101 to 200 cell/L, (+++) 201 to 300 cell/L, (++++) 301 to 400 cell/L, (*) > 400 cell/L

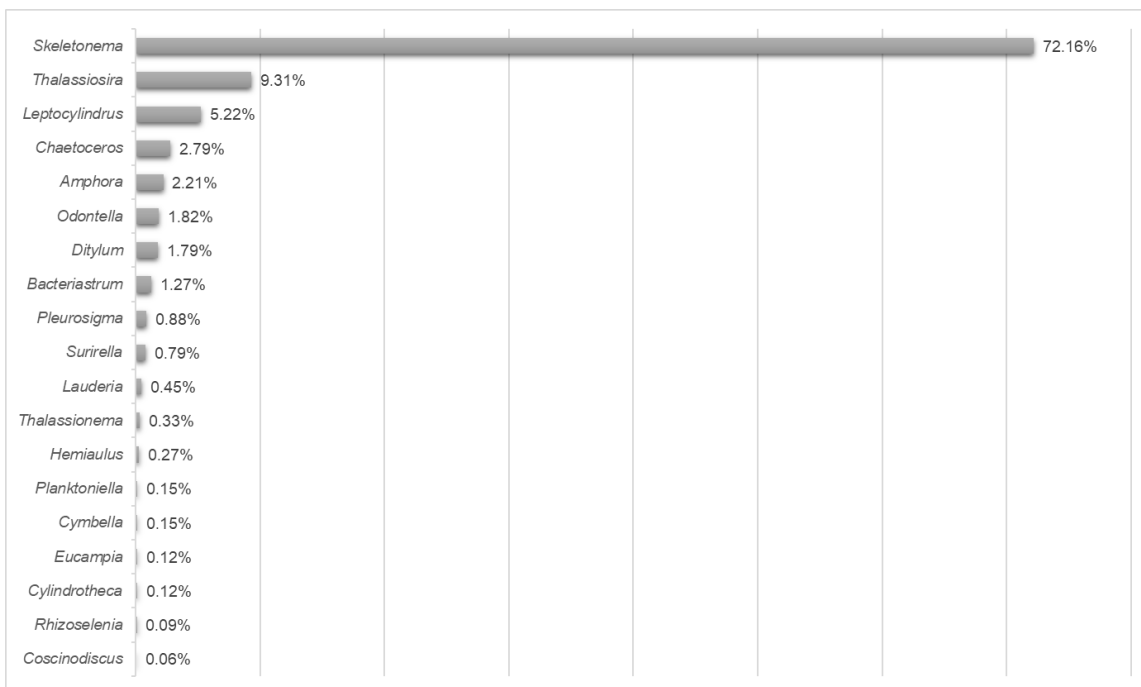


Fig. 5 Genus percentage of Bacillariophyceae

3.3. Abundance and Biodiversity of Bacillariophyceae

The distribution of phytoplankton was higher in the outer estuary near the sea than in the interior. As previously determined, stations 8, 9, 10 were more influenced by salinity water and became the area with the highest abundance of Bacillariophyceae. Stations located in rivers tended to be influenced by freshwater to be areas of lower abundance. Based on this, the stations used as objects of observation had linear characteristics with their location in the estuary.

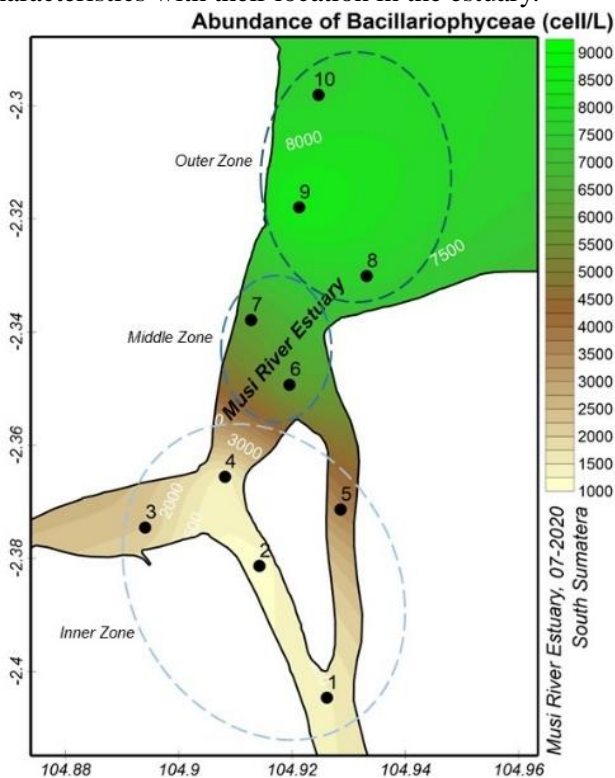


Fig. 6 Spatial distribution of Bacillariophyceae

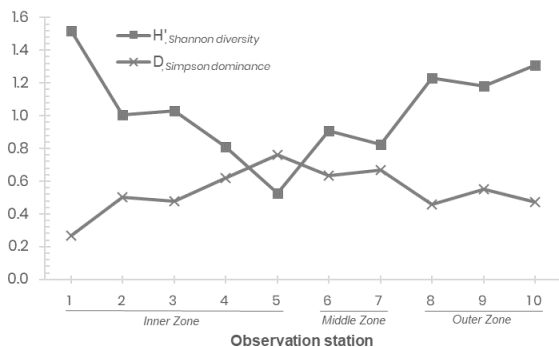


Fig. 7 Biodiversity index of Bacillariophyceae

The Shannon H' (0.526 – 1.519) and Simpson D (0.267 – 0.762) were analyzed to explain the level of biodiversity. The lowest H' index level was station 5, and the highest was station 1. The lowest Simpson D level was at station 1, and the highest was at station 5. The two formulas, Shannon H' and Simpson D curves, intersected each other, as shown in Figure 7.

3.4. Correlation of the Bacillariophyceae Abundance and Biodiversity with the Estuarine-Mangrove Environments

Based on principal component analysis, cumulative eigenvalues were 65.60%, and only two clusters were found. Both were formed by the linkage between the F1 and F2 axes.

As shown in Figure 8A, the first cluster was formed on the positive F1 axis with active variables including brightness, temperature, salinity, and pH, which characterize observations at stations 9 and 8. Furthermore, the second cluster was spread on the positive F2 axis, including the active variables uniformity and species diversity observations at stations 1 and 2. The negative axis F2 included the active variable of species dominance observations at stations 6 and 7.

The Bray-Curtis similarity index was calculated to analyze the similarity of locations based on the physical-chemical conditions of the environment and the structure of the phytoplankton community of Bacillariophyceae. The ten study sites were grouped into three clusters based on the dendrogram (Figure 8B). The mean percentage of the Cophenetic correlation was 92.8%. The first cluster included stations 1, 2, 3, 4, and 5, the second cluster included stations 6 and 7, the third cluster included stations 8, 9, and 10. The three clusters showed the closeness between areas spread out in estuarine-mangrove environments in the Musi Estuary.

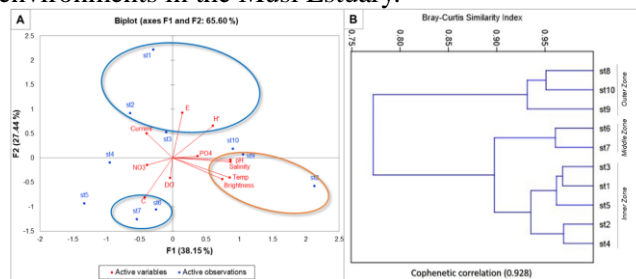


Fig. 8 Correlations of the interaction of water quality and biodiversity index at each station: A) Principal component analysis (PCA); B) Bray-Curtis similarity index

4. Discussion

Estuarine-mangrove environments in the estuary tended to change according to tidal conditions. However, the variables of salinity and water clarity had significant differences when measured spatially in all parts of the estuary at mid-tide. Both variables depend on geographic location. Stations in deep estuaries had lower salinity because they were heavily influenced by fresh water. In contrast, stations near the sea tended to have higher salinity [18]-[19]. Additionally, the brightness obtained was based on the current conditions concerning lifting and stirring the suspended material [19]. Significantly different values of these environmental variables were also observed in other

water areas, such as the San Francisco Bay [20], Chesapeake Bay, and the Baltic Sea [21]. Variables of depth and type of water substrate impact the brightness level of other currents. However, both measurements were not a priority for assessing environmental aspects in this study because they were outside the study. Meanwhile, the assessment of the aquatic environment for phytoplankton was at the optimum level for life except in areas known to have been polluted due to various local human activities [22].

The phytoplankton found in this study only came from the class Bacillariophyceae. The existence of the Bacillariophyceae group raised the suspicion that the environmental conditions in the Musi estuary were not suitable for developing groups from other classes. However, research on finding the level of dominance of Bacillariophyceae in waters is not the first to be reported, previously at the Mediterranean Coast [23], Osaka, and Tokyo Bays [24]. The latest in Vancouver Island waters, Canada [25], got the same dominance species as research in Musi Estuary. A cause for developing Bacillariophyceae was the stable and warm temperature conditions so that they were often found in tropical waters [26] and only seen during one summer period in higher latitude regions [27]. In addition, the *Skeletonema* genus of the same class had an extremely great adaptability to brackish waters [28]. All of these abilities were supported by the excellent level of nutrient fertility in each area. Here, the concentration of net primary production was accumulated in the water [29]. The semi-enclosed geography of estuaries supports the creation of a fertile aquatic environment, deposits organic material from river flows consisting of various kinds of organic waste disposal. Organic material from litter in mangrove ecosystems and dead organisms create excess nutrient abundance in tropical estuaries [30].

Eutrophication in the estuary benefited the *Skeletonema* of the Bacillariophyceae class. Studies of its behavior indicated that *Skeletonema* could become a species that could bloom in waters. Several areas have been reported to have bloomed algae from the genus *Skeletonema* in the waters of Masan-Chinhae Bay, South Korea [31], East China Sea [32], Ariake Sea, Japan [33], and Yangtze Estuary, China [34]. The ability to bloom due to eutrophication of waters also often occurred in other genera of the Bacillariophyceae class, including *Pseudo-nitzschia cuspidata* in the waters of Marina Bay, Malaysia Borneo [35], *Asterionellopsis glacialis* in the waters of Bengal Bay [36], and *Thalassiosira angulata* in the waters of White Sea [37].

Skeletonema has a complex involvement in ecological processes in estuaries. As happened in this study, high abundance in the waters indicated its essential role in the food web as a primary producer of water. The trophic level one level above depended

strongly on the existence of *Skeletonema* as a food source [38]. This phytoplankton has good biochemical content and is not a toxic genus to other organisms [39]. The existence of *Skeletonema* in the Musi estuary food web greatly regulates the life cycle of other organisms in the waters. *Skeletonema* abundance increased at observation locations near the sea. Based on the instincts of an organism, it was suspected that many trophic predators approached that location to look for food sources, one of which was fish [40]. The implications of phytoplankton in the environmental ecosystem of the Musi estuary are very complex. Through an assessment of its community structure, it was essential ecologically for the sustainable use of the potential of brackish waters on the coast of South Sumatra.

5. Conclusion

We found that the dominance of Bacillariophyceae was due to the contribution of *Skeletonema sp.* This contribution was due to water quality factors in the Musi Estuary, which influenced the distribution of phytoplankton in each estuary zone. The outer zone, middle zone, and inner zone were the zones that had the highest to lowest abundance of phytoplankton. Several locations showed a high presence of Bacillariophyceae causing blooming events such as those that occurred in Masan-Chinhae Bay, East China Sea, Ariake Sea, and Yangtze Estuary. The *Skeletonema* genus was the main contributor to the blooming event. Phytoplankton blooming in semi-enclosed aquatic ecosystems would cause a longer-term lack of dissolved oxygen and threaten the lives of other aquatic organisms. However, the zoning system of this study can represent estuaries in other parts of the world by showing that the outer zone of the estuary is more prone to experiencing blooming events. Based on this study, the *Skeletonema* species were the main species in the Musi Estuary waters with the support of their aquatic characteristics. It is hoped that the next study will be able to analyze the impact of a species that is blooming on aquatic organisms, because there is an assumption that each species has different implications.

Acknowledgments

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