Assessment of phytoplankton community structure in Musi Estuary, South Sumatra, Indonesia

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Abstract. Phytoplankton is the most important primary producer in the estuary ecosystem, but its distribution and community structure is strongly affected by the water quality parameters. This study aimed to assess the distribution of phytoplankton abundance in the Musi Estuary waters and its relationship with the environmental parameters. The study was carried out by collecting water quality data (i.e. temperature, pH, dissolved oxygen, transparency and current) at eight observation stations. The samples were collected by a plankton net of 20 µm. The results showed that the water quality parameters were found in good condition for phytoplankton growth. The temperature was ranging from 29 to 30.5ºC, the salinity was 0-25 ppt, the pH was 7.6 to 8.1, the transparency was 4.71 to 31.67%, the nitrate was about 0.75 to 1.71 mg L^{-1}, the phosphate was about 0.35 to 1.05 mg L^{-1} and the dissolved oxygen (DO) was 3.2 to 12.5 mg L^{-1}. The phytoplankton was grouped into four classes: Bacillariophyceae (99.66%), Dinophyceae (0.28%), Conjugatophyceae (0.04%) and Cyanophyceae (0.02%), and 29 species of phytoplankton were identified. In addition, the analysis indicated that the phytoplankton abundance was ranging from 2.5 to 22,142.5 cells L^{-1}, with *Skeletonema costatum* having the highest percentage (92.18%) in the species' composition. The diversity index (H') showed that phytoplankton is generally in the low category (0.19<H<0.8), and it is dominated by *S. costatum* species (C>0.5). Based on the PCA analysis, the correlation between the water quality parameters with the phytoplankton abundance and diversity in Musi Estuary was characterised by DO, pH, transparency and currents, with a high similarity between the observation stations, especially in the high mixing area around the rivers' mouth.

Key Words: diversity, estuary, phytoplankton, diatoms, water quality.

Introduction. Phytoplankton is a planktonic organism with a very weak movement ability. It is greatly influenced by the physical dynamics of waters, especially currents and waves. The role of phytoplankton as a primary producer in waters, at the first level of the trophic chain, is very important for the aquatic ecosystems, being both a nutrition source and an oxygen producer (El-Naggar et al 2019; Shalloof et al 2020). Also, the abundance of phytoplankton can be used as a fertility bio-indicator in the waters (Purina et al 2018). According to Amengual-Morro et al (2012) and Guo et al (2019), phytoplankton's role as a bioindicator is to provide information on the water quality: a high abundance and diversity will indicate a good water n condition, otherwise waters might be polluted or of an insufficient quality. Estuary waters' quality depend on the supply of anthropogenic waste and nutrient content.

The presence of phytoplankton in the estuaries is reported to vary widely, depending on the area and on the influence of environmental parameters. The estuary is usually a phytoplankton region due to the nutrients' supply from the river runoff. However, certain species will dominate, so that red tides or algae blooms often occur (Kumar et al 2018; Li et al 2014; Tian et al 2020). Generally, phytoplankton species reported to dominate the estuary area are the diatom groups from the Bacillariophyceae class (Karthik et al 2020; Li et al 2021). This class has a very high tolerance to the environment (Manickam et al 2020). In addition, the fertility of estuary waters impacts the abundance of high aquatic biota, which is conditioned by the feeding, spawning and nursery grounds (Miró et al 2020). Local fishers also utilize this estuary as a fishing area.

The Musi Estuary is a very high activity area. It is a transportation route for ships from the open sea (i.e. Java Sea, Karimata Strait, Sunda Strait and Bangka Strait) to the river port of Bom Baru, in Palembang City. In addition, this estuary where both domestic and agricultural waste are discharged, is an area of continuously mixing freshwater masses from the Sumatra mainland and the seawater masses from the Bangka Strait (Rozirwan et al 2020). The tides' movement impacts the distribution of changes in temperature, salinity, pH, dissolved oxygen, transparency, currents and nutrients. This condition will impact the growth and distribution of aquatic biota, especially of the phytoplankton (Rozirwan et al 2019). In addition, residents use this area as a fishing ground and residential area. Phytoplankton distribution information describes the initial conditions in these waters, being used as a basis for further research, related to the determination and suitability of the fishing areas.

Material and Method

Study area. The Musi Estuary area has a mud substrate, with a vegetation dominated by mangroves such as: *Avicennia marina*, *Sonneratia alba*, *Rhizophora mucronata*, *Bruguiera gymnorrhiza* and *Nypa fruticans*. The Musi Estuary is very dynamic because it is greatly influenced by the tides. When the tidal currents arrived, they significantly influence all parameters of the aquatic environment. The study area covers a length of about 15 km and a width of about 2 km. Geographically, Payung Island is in the middle of the estuary, covered by mangroves, and is not inhabited by humans. In the western part of the estuary, the local population of Sungsang Village, Banyuasin Regency, is quite dense, with more than 5,000 citizens. In contrast, the eastern part is the transportation route for large ships from the sea to the Bom Baru Port of Palembang.

This research was carried out by a survey method in July 2019, where environmental parameters and phytoplankton samples were measured at eight observation stations. Stations 1, 2, and 3 are determined based on the assumption that there is a dominant freshwater influence. Stations 4 and 8 are determined based on the mixing area of seawater and freshwater masses, then stations 5, 6, and 7 are determined based on stronger seawater dominance (Figure 1).

Figure 1. The sampling area of Musi Estuary, South Sumatra, Indonesia.

Data and sample processing. Water quality parameters, measured directly in the field, include: temperature, dissolved oxygen (DO), pH, salinity, transparency, and current velocity. Water temperature was measured using a digital thermometer, DO was measured using a DO meter, water pH was measured using a pH meter, water salinity was measured using a hand refractometer, water transparency was measured with a Secchi disk. Current meters were used to measure current velocity.

Phytoplankton samples were taken from the surface water: a volume of 100 L was filtered using a 25 μm plankton-net. A volume of about 250 mL filtered water sample was obtained and a 4% formalin solution was added. Samples were labeled and stored in a coolbox for analysis in the laboratory.

Sample identification. The identification of phytoplankton samples was performed under a light microscope using the Sedgwick Rafter Counter Cell (SRCC), where cell morphological observations were made on the shape and color of cells. Also, cell counts were carried out for abundance and biodiversity data. The phytoplankton species identification referred to (Tomas 1997; Verlecar & Desai 2004).

Data analysis. The abundance of phytoplankton is calculated as the number of cells per liter, with reference to the following formula (APHA 1998):

$$N = \frac{1}{Vd} \times \frac{Vt}{Vs} \times P$$

Where:
N - the abundance of phytoplankton (cells L^{-1});
Vd - the initial volume of filtered water (L);
Vt - the resulting volume of filtered water (mL);
Vs - the water volume in the Sedgwick rafter counting cell (mL);
P - the number of observed phytoplankton individuals (cell).

The phytoplankton diversity and dominance of species were calculated using the Shannon-Wiener (H') and the Simpson (C) index, with the following formulas (Odum 1971):

$$H' = -\sum_{i=1}^{s} \left(\frac{ni}{N}\right) ln \left(\frac{ni}{N}\right)$$

$$C = -\sum_{i=1}^{s} \left[\frac{ni}{N}\right]^2$$

Where:
ni - the abundance of species i;
N - the number of phytoplankton (cells L^{-1}).

The Bray-Curtis dissimilarity was calculated for the phytoplankton abundance and diversity at the observation stations, with the following formula (Legendre & Legendre 2012):

$$BCij = 1 - \frac{2Cij}{Si + Sj}$$

Where:
Cij - the sum of only the lesser counts for each species found in both sites;
Sj - the total number of specimens counted on site j;
Si - the total number of specimens counted on site i;
i & j - the two sites.

The correlation between environmental parameters data (such as; temperature, dissolved oxygen, pH, salinity, transparency and current velocity) with the abundance and diversity of phytoplankton in Musi Estuary was performed by PCA and similarity clustering, using the XLstat 2021 software.

Results. Water quality parameters are measured in situ or directly in the field. Data on DO, salinity and transparency fluctuated, but showed only slight variations in temperature, pH, nitrate, phosphate and current.

At the observation stations, salinity ranged from 0 to 25 ppt and DO from 3.2 to 12.5 mg L^{-1}, increasing towards the sea and decreasing towards the river. Meanwhile, transparency fluctuated between 4.71 and 31.67%, being more balanced at the observation locations, which increased significantly towards the sea. This condition may be due to the high sedimentation distribution at the observation stations towards the sea. Simultaneously, the temperature was low, variating between 29-30.8°C, the pH was 7.6 to 8.1, nitrate was about 0.75 to 1.71 mg L^{-1}, phosphate was about 0.35 to 1.05 mg L^{-1} and the current speed was about 0.02 to 0.08 m s^{-1}. These distributions influenced strongly by the seawater and freshwater masses (Figure 2).

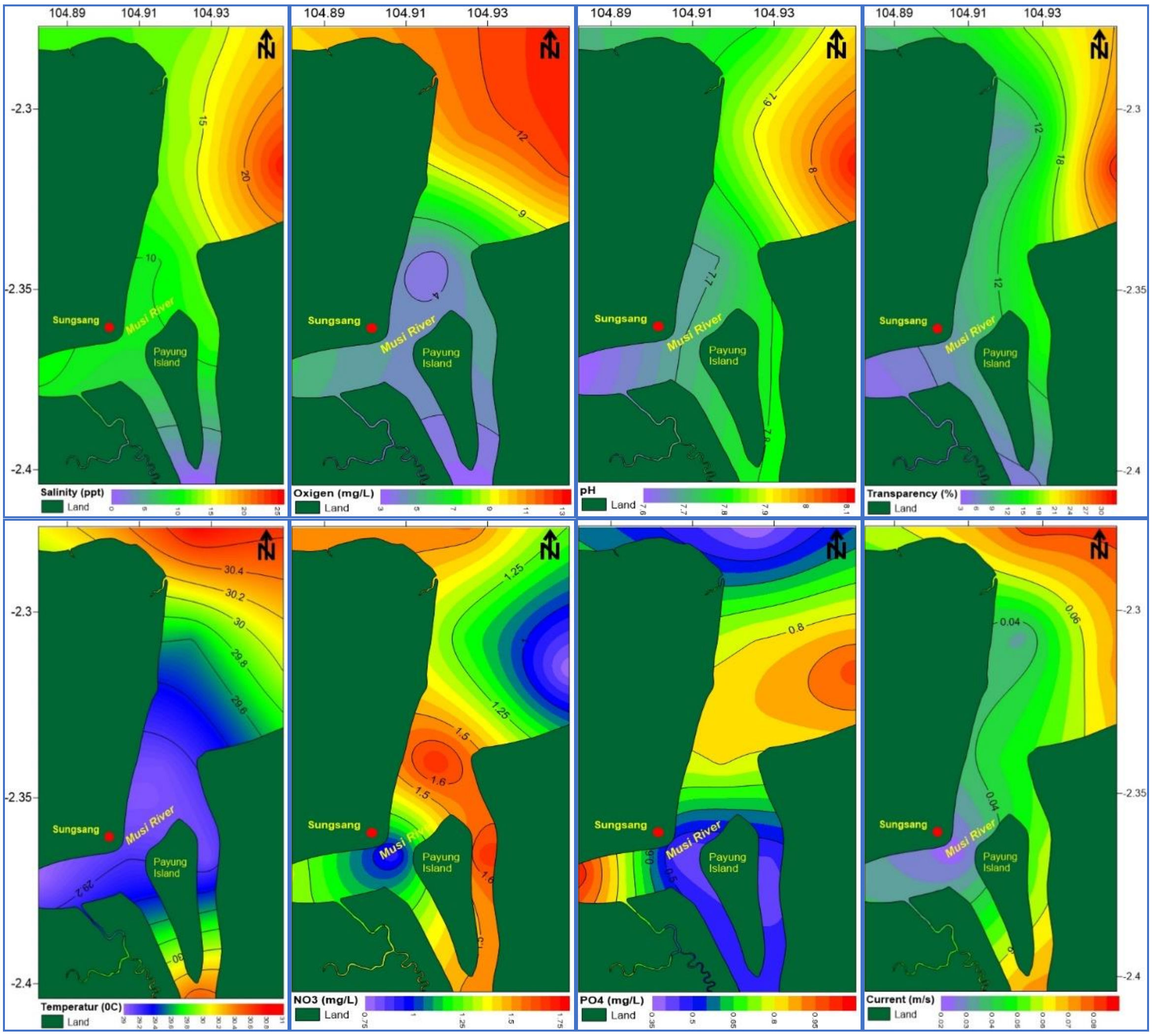

Figure 2. Water quality parameters of Musi Estuary.

Community structure of phytoplankton species. The 29 species of phytoplankton in Musi Estuary were classified in four phylogenetic groups: 24 species of Bacillariophyceae (99.66%), three species of Dinophyceae (0.28%) and only one species of Conjugatophyceae and Cyanophyceae (0.02-0.04% each), respectively (Figure 3). At the species level, *Skeletonema costatum* was shown to be dominant at all observation stations, and *Coscinodiscus centralis* was rarely found.

In the Bacillariophyceae class the following species were identified: *Amphipleura rutilans*, *Aulacoseira granulate*, *Bacteriastrum furcatum*, *Chaetoceros affinis*, *Corethron pennatum*, *Coscinodiscus centralis*, *Cylindrotheca closterium*, *Cymatopleura elliptica*, *Cymbella naviculiformis*, *Ditylum affinis abbreviations*, *Fragilaria pinnata*, *Odontella* *sinensis*, *Pinnularia viridis*, *Pleurosigma normanii*, *S. costatum*, *Surirella ovalis*, *Thalassionema nitzschioides* and *Thalassiosira nordenskioeldi*. In the Dinophyceae class, there were identified *Dinophysis hastata*, *Protoperidinium steinii* and *Pyrophacus horologium*. In the Conjugatophyceae class, *Closterium gracile* was identified and in the Cyanophyceae class, *Nodularia spumigena* was identified (Table 1). The diatom group of phytoplankton dominated the species composition.

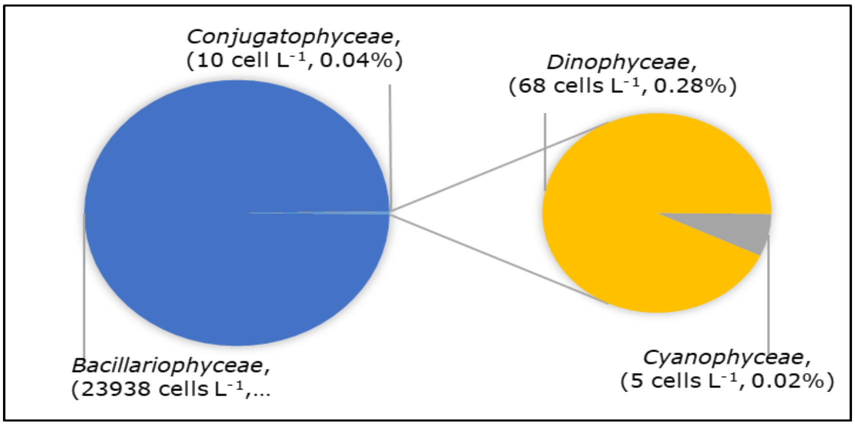

Figure 3. Phytoplankton composition structure of Musi Estuary.

Table 1

Phytoplankton species in Musi Estuary

Class/Species	*Station*							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
				Bacillariophyceae				
Amphipleura rutilans	-	-	-	-	-	-	+	-
Aulacoseira granulata	-	-	-	-	-	-	-	+
Bacteriastrum furcatum	+	+	-	+	+	-	-	-
Chaetoceros affinis	-	-	+	+	+	+	+	+
Corethron pennatum	-	-	-	-	-	+	-	-
Coscinodiscus centralis	+	+	+	+	+	+	+	+
Cylindrotheca closterium	-	+	-	-	-	+	-	+
Cymatopleura elliptica	+	+	-	-	-	-	-	-
Cymbella naviculiformis	-	-	-	-	-	-	+	-
Ditylum brightwellii	-	+	-	+	+	+	+	+
Fragilaria pinnata	+	-	-	-	-	-	-	-
Guinardia delicatula	-	-	-	-	-	+	-	-
Helicotheca tamesis	+	-	-	-	-	-	-	-
Hemiaulus sinensis	-	+	-	-	-	-	-	-
Lauderia annulata	-	-	+	-	-	-	-	-
Leptocylindrus danicus	+	+	-	-	-	-	-	-
Licmophora abbreviata	+	-	+	+	+	+	-	+
Odontella sinensis	-	-	+	-	+	-	+	-
Pinnularia viridis	-	-	-	-	-	-	+	-
Pleurosigma normanii	-	-	-	-	-	-	+	-
Skeletonema costatum	+	+	++	+++	+++	++	+	+++
Surirella ovalis	-	-	-	+	+	-	-	-
Thalassionema nitzschioides	-	+	+	+	+	+	+	+
Thalassiosira nordenskioeldi	-	+	+	+	+	-	-	+
				Conjugatophyceae				
Closterium gracile	+	-	-	-	+	-	-	-
				Cyanophyceae				
Nodularia spumigena	-	-	-	-	-	-	-	+
				Dinophyceae				
Dinophysis hastata	-	-	-	-	-	-	+	-
Protoperidinium steinii	-	+	-	+	+	+	+	+
Pyrophacus horologium	-	-	-	-	+	-	-	-

(-): not found; (+): 1-2,000 cells L^{-1}; (++): 2,001–4,000 cells L^{-1}; (+++): >4,000 cells L^{-1}.

The percentage composition of phytoplankton species (Figure 4) was dominated by the *S. costatum* species (92.18%), while other species had a low abundance (<2.5%). This means that the water conditions are very suitable for the growth of the *S. costatum* species.

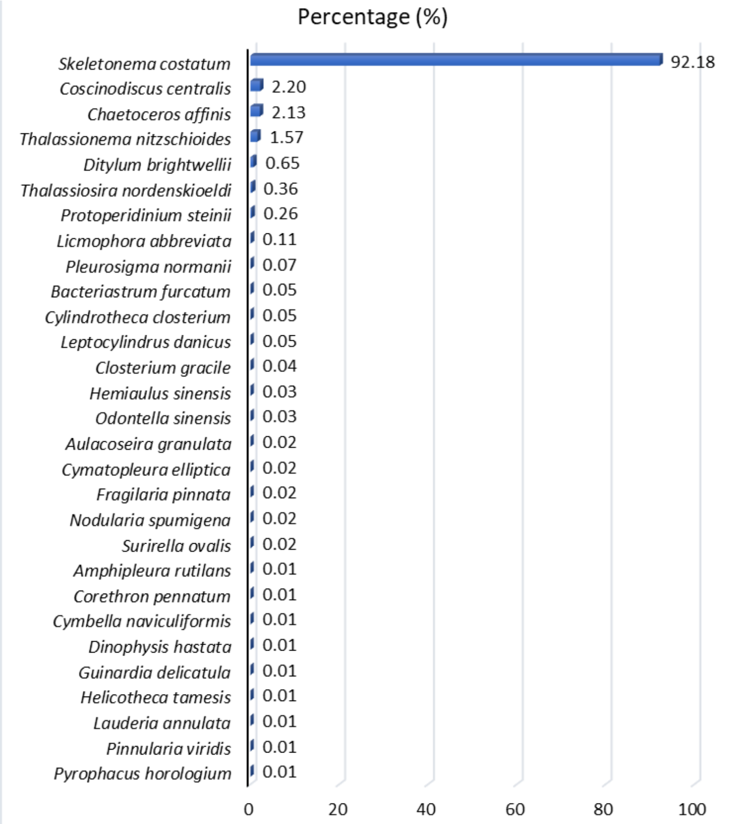

Figure 4. Percentage of phytoplankton species in Musi Estuary.

Distribution of phytoplankton abundance and diversity. The distribution of the phytoplankton abundance is depicted as increasing in the river's mouth area, by more than 4,000 cells L^{-1}, in the middle of the mixing area between freshwater and seawater masses. The mixing process impacts the phytoplankton's intake of nutrients from the water and, consequently, their growth, higher around the river mouth area, compared to the river and sea areas, as suggested by their abundance distribution (Figure 5).

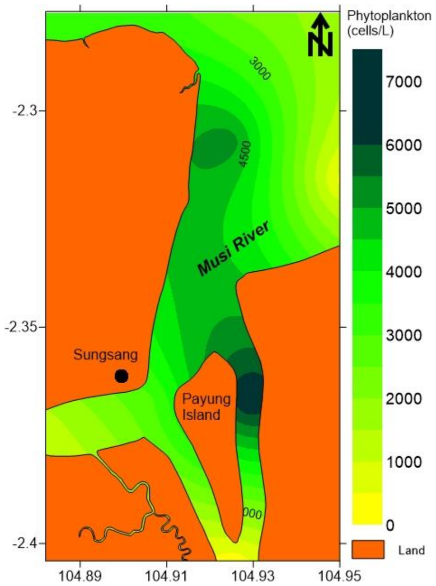

Figure 5. Distribution of phytoplankton abundance in Musi Estuary.

The results of the diversity index (H') showed that phytoplankton were in the low category (H'<1), except for the station 7, with moderate categories (12 species). This is supported by the dominance index (C) showing that there are species which dominate at all observation stations with a value of C>0.5, except for the Station 7, with a more balanced species composition (Figure 6).

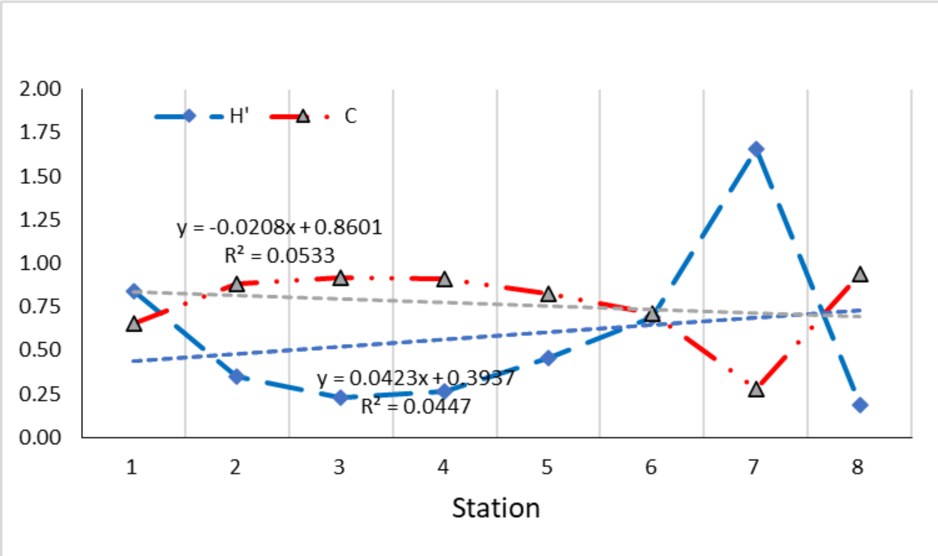

Figure 6. Phytoplankton biodiversity index of Musi Estuary.

Correlation between the water quality parameter and the phytoplankton abundance and diversity in Musi Estuary. Based on the principal component analysis (PCA), cumulative eigenvalues were 80.85% and a minimum cosine squared variable value of 0.5, only two groups were found. Both groups were formed by the relationship between the F1 and F2 axes, which is based on the eigenvalues that the total information displayed from these two axes (>80%) is represented from all analyzed data (Figure 7A).

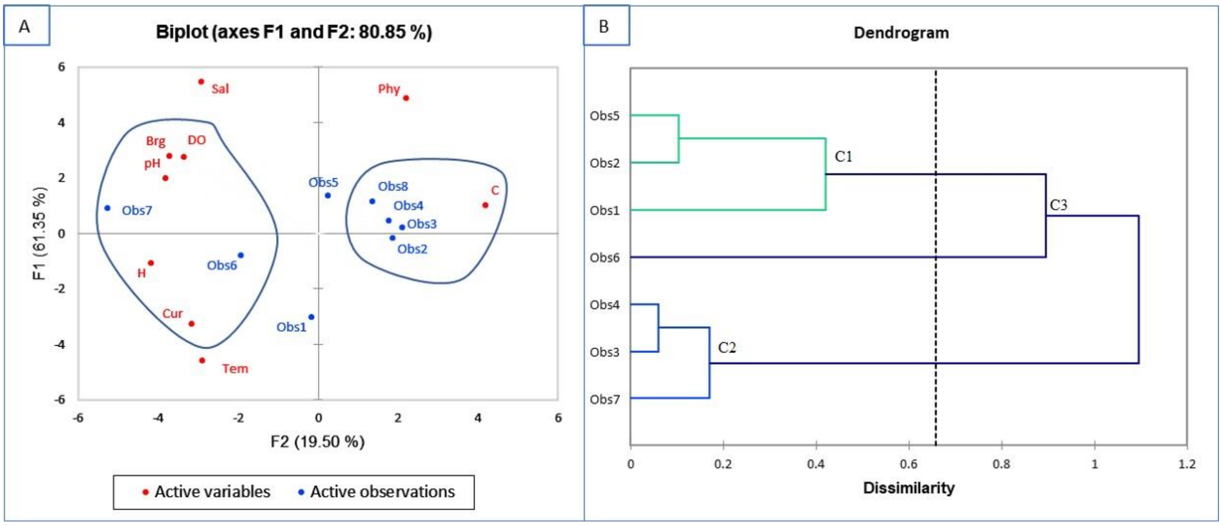

Figure 7. Correlation between water quality parameters with phytoplankton abundance and diversity (A), and similarity index (B). (Phy-phytoplankton abundance, Cur-current speed, Brg-transparancy, Tem-temperature, H'-diversity index, DO-dissolved oxygen, C-domination index, Obs 1...8-station observation).

As shown in Figure 7A, the first cluster was formed on the positive F1 axis, based on the criterium of a high species dominance, grouping stations 2, 3, 4, and 8, characterized by the domination of *S. costatum* species (92.18%) at almost all observation stations. The second cluster, formed on the negative F1 axis, groups stations 6 and 7, based on the criterium of higher DO, pH, transparency and current speeds, which are characterized by an increase in phytoplankton diversity. Both observation stations were found towards the sea. This means that the seawater masses' impact increase on the phytoplankton diversity is more substantial compared to water masses from the Musi River.

The Bray-Curtis dissimilarity was calculated for the phytoplankton abundance and diversity at the observation stations in Musi Estuary. As shown in the dendrogram (Figure 7B), the eight observation stations were grouped the three classes (C1, C2, and C3) showing an average similarity level of about 93.7%. In addition, the highest similarity, 95.8%, is shown in the class C1, i.e. stations 1, 2, and 5, followed by the class C2, i.e. stations 3, 4 and 7, with a similarity of 98.4%, and eventually the class C3 of station 6, which demonstrated the closest similarity to the phytoplankton abundance and diversity at 87%. These results showed a high level of similarity in almost all observation stations, which indicated that the environmental conditions in the Musi Estuary are favorable to the phytoplankton abundance and diversity.

Discussion. Water quality in the Musi River Estuary is suitable for the phytoplankton growth. Dissolved oxygen (DO) fluctuated significantly among the observation stations, which is thought to be due to the tidal effects. DO was decreasing at the stations towards the river, and conversely, it was increasing towards the sea. Dissolved oxygen in the water is influenced by bathymetry, currents, water masses mixing, and phytoplankton's photosynthetic process (Baxa et al 2020; Eisenstadt et al 2010; Wang & Zhang 2020).

Salinity in brackish waters decreases towards the rivers and increases towards the sea. The salinity difference is influenced by the volume of freshwater discharge from the Musi River into the sea. It impacts the salinity concentration in the area (Nche-Fambo et al 2015; Rozirwan et al 2021). The transparency in the Musi Estuary was found in the low category, due to the very high suspended material coming from the river, decreasing the transparency value towards the river. This condition will impact the phytoplankton photosynthesis rate: an increase in transparency will be directly proportional to the intensity of the photosynthetic process in phytoplankton (Jendyk et al 2014; Schofield et al 2013).

Water temperature is found in a narrow range for the estuary category and it was not significantly different between the observation stations, although it was measured at different times. This condition is due to the influence of the relatively more stable seawater temperature at the measurement time (Saputra et al 2021; Zhao et al 2020). The pH value of the waters was found to be in an excellent range for the phytoplankton growth. The fluctuation of the pH value in the waters is influenced by carbon dioxide and oxygen. Besides that, it has an impact on the metabolic rate of aquatic biota. Musi Estuary currents' velocity is found in the low category, but it can still affect the distribution of phytoplankton, due to their limited or weak movements. These currents are greatly influenced by tides (Seo et al 2019). At high tides, the current will move towards the river, and at low tides it will move to the opposite way. Nitrate and phosphate in Musi estuary were found still good for the phytoplankton growth, with only slight differences between observation stations. Nitrates and phosphates can produce higher amounts of phytoplankton, as reported by (Ferreira et al 2020; Karthik et al 2020; Miró et al 2020; Tao et al 2020; Zaghloul et al 2020).

Phytoplankton composition in the Musi Estuary was classified into: Bacillariophyceae 99.66%, Dinophyceae 0.28%, Conjugatophyceae 0.04% and Cyanophyceae 0.02%, and it was dominated by *S. costatum* species from the class Bacillariophyceae, due to its high tolerance for environmental changes. In addition, it is also grouped in diatoms, which are mostly reported in shallow waters (Klamt et al 2020; Riato & Leira 2020; Rochelle-Newall et al 2011; Rozirwan et al 2019; Saifullah et al 2019; Tao et al 2020).

The Dinophyceae class comprised three species, i.e., *Dinophysis hastata*, *Protoperidinium steinii*, and *Pyrophacus horologium*, reported to frequently cause algae blooms (Dai et al 2020; Shi et al 2018). Eventually there were also identified two single-species classes Cyanophyceae, with *Nodularia spumigena*, and Conjugatophyceae, with

Closterium gracile. These two species are also grouped in diatoms reported in various waters (Carlsson & Rita 2019; Konkel et al 2020; Saber et al 2018).

Phytoplankton diversity in Musi Estuary increased towards the seawater and decreased towards the river, but still remained in the low category, as shown by the dominance index, with *S. costatum* as dominant species (Huang et al 2020; Wang et al 2020; Zhang et al 2020; Zhang et al 2019).

The relationship between water quality parameters with phytoplankton abundance and diversity is indicated by dissolved oxygen, pH, transparency and currents. The parameters are very high at the observation station towards the sea, while the species dominance is found in almost all observation stations, especially towards the river. Dissolved oxygen is found high towards the sea due to the influence of the physical dynamics of seawater such as waves, currents and tides on the continuous mixing of oxygen from the air into the water (Cravo et al 2020; Cui et al 2019). Likewise, pH was found to be increasing towards the sea and decreasing towards the river. The water transparency is found to be still in a low category, even lower into the river. This will have an impact on the abundance and diversity of phytoplankton by limiting the photosynthesis (Cravo et al 2020; Stoyneva-Gärtner et al 2020; Saputra et al 2021; Villafañe et al 2018).

The similarity index indicated a substantial value, signifying that the phytoplankton abundance and diversity values are elevated at almost all of the observation stations on the Musi Estuary water, which was also reported in various estuaries and coastal waters (Li et al 2017; Ren et al 2020; Roshith et al 2018; Rozirwan et al 2019; Vajravelu et al 2018).

Conclusions. Phytoplankton composition in Musi Estuary waters counted 29 species grouped into four classes dominated by diatoms, namely: Bacillariophyceae (99.66%), Dinophyceae (0.28%), Conjugatophyceae (0.04%), and Cyanophyceae (0.02). The phytoplankton abundance distribution is found high around the river mouth, decreasing towards the sea and river. The species diversity is found in the low category, with dominant species. Water quality parameters, consisting of dissolved oxygen, pH, transparency and currents, were not significantly different between the observation stations, especially for the high mixing area around in the river mouth.

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Conflict of interest. The authors declare no conflict of interest.

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