Phytoplankton community structure in Kemanyungan-Linduk estuaries and adjacent water of Banten Bay, West Java, Indonesia

[1]Sulastri, [2]Sulistiono

[1] Research Center for Limnology and Water Resources, National Research and Innovation Agency (BRIN), Raya Bogor-Jakarta Street, Km 46, Cibinong, 16911, West Java Indonesia; [2] Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, Bogor, West Java, Indonesia.
Corresponding author: Sulastri, sula001@brin.go.id

Abstract. The estuary in Banten Bay has a lot of pressures from the surrounding area due to industries and settlements. This condition could trigger pollution and sedimentation to the estuary and coastal waters. This study aims to reveal ecological status based on phytoplankton community structure in Kemayungan-Linduk waters of Banten Bay. Samples were collected at 6 stations from February to April 2021. The data included environmental factors, phytoplankton composition and abundance, species richness index, diversity index, and evenness index. Water quality parameters showed a high variability during the observation. Higher turbidity was recorded in Kemanyngan estuary. Phytoplankton consisted of Bacillariophyceae, Chlorophyceae, Cyanophyceae, Dictyochophyceae, Dinophyceae, Euglenophyceae, and Zygnematophyceae, with Bacillariophyceae as a dominant group contributing 54.1% out of 100% of total abundance. Higher percentage of Bacillariophyceae in coastal waters was related to salinity, potential of hydrogen (pH), and transparency. Higher percentage of Chlorophyceae and Euglenophyceae in Kemanyungan estuary was related to total suspended solid (TSS), turbidity, and nitrate (N-NO_3). Higher percentage of Cyanophyceae and Dinophyceae in Linduk estuary was related to total phosphorus (TP) and dissolved oxygen (DO) respectively. Phytoplankton abundance (1330 to 13831 individual L^{-1}), number of species (14 to 27), diversity index (0.82 to 3.12), species richness index (1.52 to 4.39), and evenness index (0.30 to 0.91), showed a large heterogeneity across the sampling sites and sampling time. The lowest index diversity, species richness index and evenness were recorded in coastal water around Kemanyungan estuary. Based on the phytoplankton diversity index, it is shown that ecological status in the study area was moderate stress

Key Words: diversity, estuary, ecological status, phytoplankton.

Introduction. Estuaries form a transition zone, which is the most productive of water bodies, and a valuable aquatic ecosystem between freshwater and marine environment (Oliviera et al 2022). Nutrients are supplied to estuaries from flowing river, sea, and atmospheric deposition (Niu et al 2020). They are dynamic environment and have a high variability of physical, chemical, and biological parameters (Baliarsingh et al 2021). Various habitats for a variety of communities of fish and crustacean are found in this ecosystem, such as mud flats, deeper water, salt marshes, or mangrove swamp (Pessanha et al 2021). An estuary is also known as a site of spawning and feeding ground of marine and other organisms. Therefore, an estuary has an important role to support the sustainability of marine fisheries production (Martinho et al 2012).

Globally, estuarine ecosystems are some of the most heavily used and threatened natural systems (Barbier et al 2011). Estuarine ecosystems are facing the impact of anthropogenic activities because they receive all of the contaminants and nutrients from upper rivers and runoffs in watersheds (Garnier et al 2021). High level of population activity in urban areas provides more pollutants carried by rivers to estuaries and coastal waters, which then affects these ecosystems (Freeman et al 2019). A study reported that the nutrients, heavy metals, and organic pollutants in most estuaries in Indonesia exceed standard limit value which indicates poor water quality (Adyasari et al 2021).

Banten Bay is located in the north of West Java, as a part of coast of Java Island. The development of various industries and settlements in Banten city could lead to horrendous pollution and sedimentation to the estuaries. Runoffs carrying nutrients, sediments, and pollutants flow downstream and into the estuarine systems. Land reclamations, nutrients, sewage, sediment input, and chemical contaminants are anthropogenic drivers which could change estuarine environment (Kennish 2021). The increase of pollutant load from terrestrial ecosystems would have adverse impacts on the estuaries and coastal waters, and it subsequently affects water quality and phytoplankton in the ecosystem (Tas et al 2009).

Phytoplankton has a high sensitivity to changes in the aquatic environment (Monem et al 2017). Therefore, phytoplankton diversity and abundance are commonly used as biological indicators of water quality (Ronauli et al 2022). A previous study also showed that some estuaries flowing into Banten Bay are slightly polluted (Sugiarti et al 2021). Kemanyungan and Linduk rivers cross the urban areas and flow into Banten Bay. Basic information as well as phytoplankton used to analyze the ecological integrity of Kemanyungan and Linduk waters were limited. This study aims to reveal the ecological status based on phytoplankton community structure in Kemayungan-Linduk estuaries and the adjacent waters of Banten Bay.

Material and Method

Research location. The study was conducted in Kemanyungan-Linduk estuaries and adjacent waters of Banten Bay, Banten Province, West Java, Indonesia (Figure 1). Kemanyungan and Linduk rivers cross the urban areas of Banten city and flow into Banten Bay.

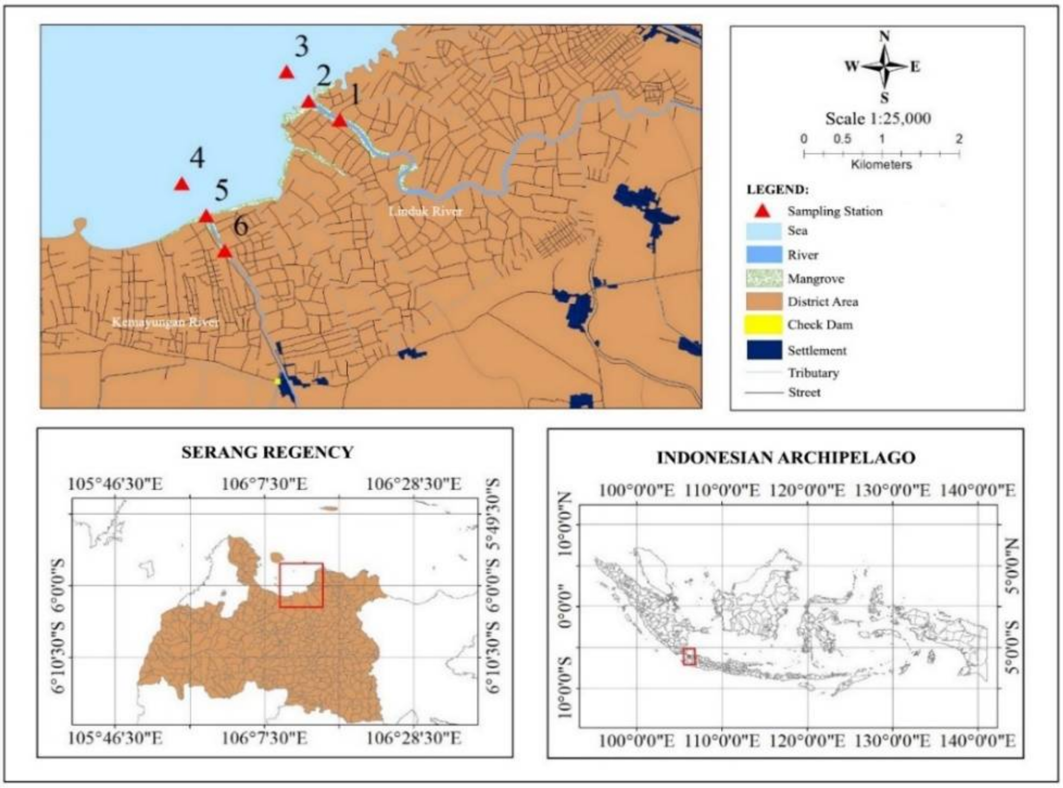

Figure 1. Study area located in West Java, Indonesia; sampling sites shown by red triangles.

Sample collection. Samples were collected at six stations. Station (St) 1 and station (St) 2 are located in Linduk estuary, station (St) 3 is located in the coastal waters around Linduk estuary, station (St) 4 is located in the coastal waters around Kemanyungan estuary, station (St) 5 and station (ST) 6 are located in Kemanyungan estuary (Figure 1). Phytoplankton sampling and environmental parameters measuring were conducted from

February to April 2022. Water samples were taken from each station by using polyethylene bottle sampler then kept in a cooler box for preservation. Water physical and chemical parameters include nitrate (N-NO_3), total phosphorus (TP), water temperature, potential of hydrogen (pH), dissolved oxygen (DO), transparency, turbidity, total suspended solid (TSS), and salinity. Temperature, pH, DO, TSS, salinity, and turbidity measurements were conducted in *situ* using water quality checker (YSI), while water transparency data were collected by measurement of Secchi depth. N-NO_3, TP, and TSS were measured in the laboratory. TSS concentration was analyzed using gravimetric method, while N-NO_3 and TP contents were determined by Brucine method and Ascorbic acid method respectively (Rice et al 2012).

Phytoplankton samples were obtained by filtering 50 L of water from the surface water through plankton net (mesh size 30 μm) then preserved with 1% lugol solution. Phytoplankton species were identified according to a number of references (Scott & Prescott 1961; Prescott et al 1962; Yamaji 1966; Tomas 1997; Gell et al 1999) using an inverted microscope with a magnification of 400x. Phytoplankton abundance was calculated using Sedgwick-Rafter Cell (SRC) with 50 x 20 x 1 mm^3 size.

***Data analysis**.* Species composition of phytoplankton was analyzed to estimate the diversity indices such as Shannon diversity index with formula: $H' = -\sum Pi \ln Pi$, where, $Pi = Ni/N$ is the proportion of species in the community, Ni is number individual of species *i* and N is total number of individuals (Shannon 2001). Pielou evenness index was calculated using formula: $J' = H'/\ln S$, where H' is species diversity, S is number of species (Pielou 1966), and Margalef's richness index was calculated using formula: $d' = (S-1)/\ln N$, where S is total number of species, N is total number of individuals (Türkmen & Kazanci 2010). Lastly, principal component analysis (PCA) was performed to determine the relationship between phytoplankton composition and environmental factors.

Results

***Physico-chemical characteristics**.* The water physico-chemical properties of site observed are presented in Table 1 and Figure 2. Physico-chemical parameters values show different environmental characteristics between Kemanyungan estuary and Linduk estuary. Kemanyungan estuary (St 5 and St 6) was characterized by high turbidity, TSS, and nitrate concentration, with the average values of 90.4 and 89.7 NTU; 361.1 and 293.7 mg L^{-1}; 0.781 and 0.646 mg L^{-1}respectively (Table 1). Linduk estuary (St 1 and St 2) was characterized by low salinity with the average values of 1.4 and 4.7 ppt respectively. Coastal waters (St 3 and St 4) were characterized by high salinity, pH, and transparency with the average values of 29.7 and 29.7 ppt; 8 and 7.9; 118.4 and 105.7 cm respectively (Table 1). Temperature value ranged from 29 to 33°C, which is commonly found in tropical areas. The pH values ranged from 7.2 to 8.0, which indicate alkaline conditions. Spatially, DO and TP concentrations varied during the observation (Table 1).

Physico-chemical parameters temporally showed variability during the observation (Figure 2). Higher transparency was recorded in March and lower transparency was recorded in February especially in coastal waters (St3 and St4). In estuary (St 1, St 2, St 5 and St 6), lower turbidity was recorded in April. Higher turbidity and TSS were recorded in February and April especially in St 5 and St 6. Temporally, salinity in the estuaries was found more varied compared to that in the coastal waters. DO showed a high variation especially in the coastal waters. Lower DO concentration was recorded in coastal waters (St 3 and St 4).

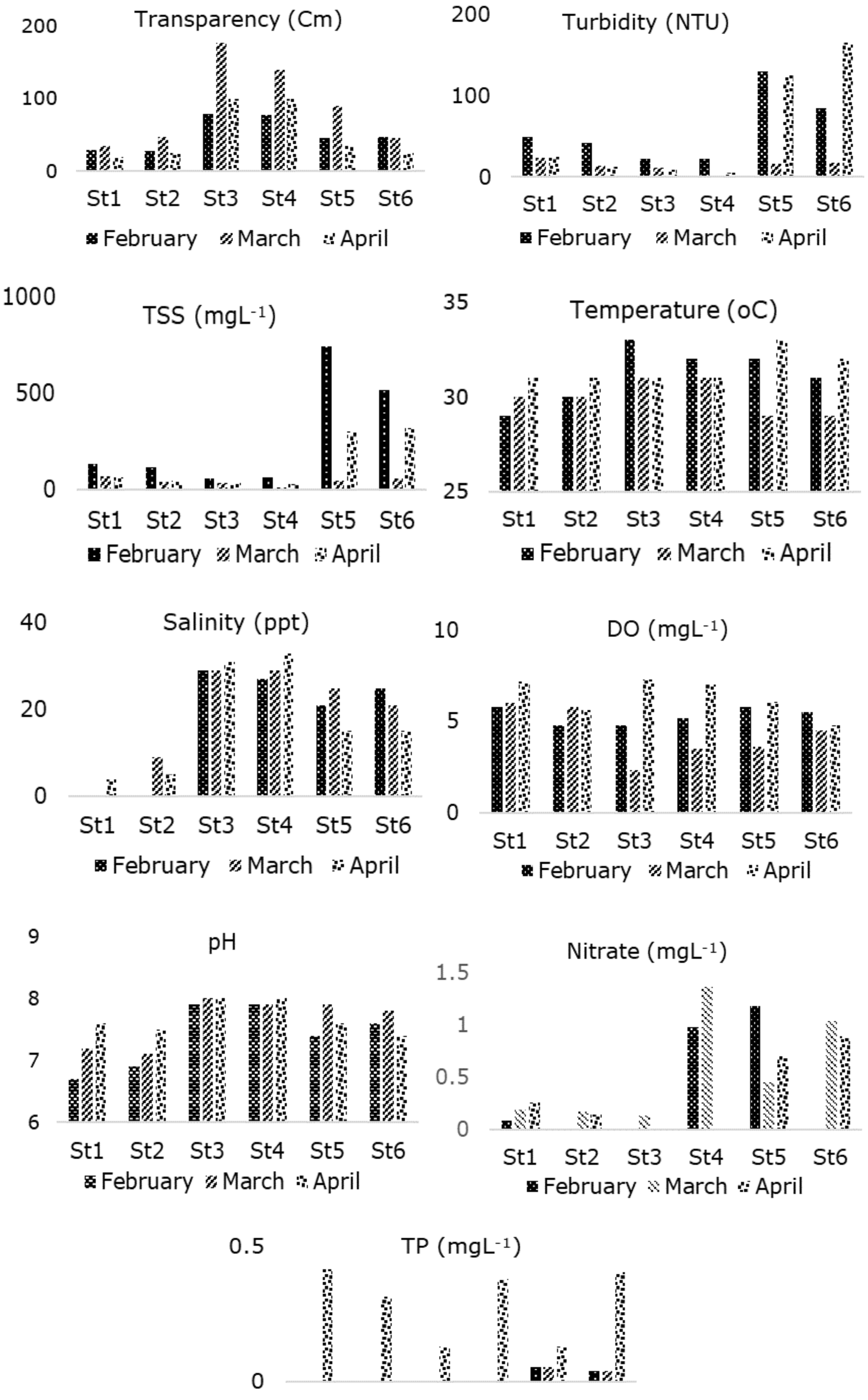

Figure 2. Physico-chemical parameters of water quality.

Table 1
Physico-chemical properties of water in Estuary of Kemanyungan and Linduk River and adjacent waters

Parameter	*Range / average*	*Station*					
		St1	*St2*	*St3*	*St4*	*St5*	*St6*
Turbidity (NTU)	Range	24-49	13-42	8.7-23	1.29-22	16.2-130	18-166
	Average	32.7	23.03	14.5	9.67	90.4	89.7
Transparency (cm)	Range	20-34	25-47	78.5-178.5	77.5-139.5	35-90	25-47.5
	Average	27.7	33	118.4	105.7	57	39.5
TSS (mg L^{-1})	Range	64-134	42-115	32-58	6.9-59	44.2-741	53-513
	Average	89	65.5	40.8	30.3	361.1	293.7
Temperature (^oC)	Range	29-31	30-31	31-33	31-32	29-33	29-32
	Average	30	30.4	31.7	31.4	31.4	30.7
Salinity (ppt)	Range	0-4	0-9	29-31	27-33	15-26	15-25
	Average	1.4	4.7	29.7	29.7	20.4	20.4
DO (mg L^{-1})	Range	5.8-7.2	4.8-5.8	2.3-7.3	3.7-7.0	3.6-6.1	4.5-5.5
	Average	6.4	5.4	4.8	5.2	5.27	4.9
pH	Range	6.7-7.6	6.9-7.5	7.9-8.0	7.9-8.0	7.4-7.9	7.4-7.8
	Average	7.2	7.2	8	7.9	7.6	7.6
Nitrate (mg L^{-1})	Range	0.087-0.258	0.001-0.178	0.001-0.139	0.001-1.363	0.455-1.180	0.001-1.044
	Average	0.179	0.107	0.047	0.78	0.781	0.646
TP (mg L^{-1})	Range	0.001-0.413	0.001-0.314	0.001-0.131	0.001-0.380	0.052-0.131	0.041-0.405
	Average	0.138	0.105	0.044	0.127	0.078	0.162

Phytoplankton diversity and abundance. There are seven classes of phytoplankton, namely Bacillariophyceae, Chlorophyceae, Cyanophyceae, Dictyochophyceae, Dinophyceae, Euglenophyceae, and Zygnematophyceae. Fifty-four and one percent (54.1%) to one hundred percent (100%) of total abundance of phytoplankton was dominated by Bacillariophyceae (Figure 3). High percentage of Bacillariophyceae was recorded in the coastal waters (Figure 3). There was also a different percentage of abundance of phytoplankton in Kemanyungan estuary and Linduk estuary. Higher percentage of Zygnematophyceae (0.76 to 7.26%) and Euglenophyceae (0.66 to 27.4%) was recorded in Kemanyungan estuary, while higher percentage of Cyanophyceae (1.4 to 14.6%) and Dinophyceae (1.12 to 14.62%) was recorded in Linduk estuary.

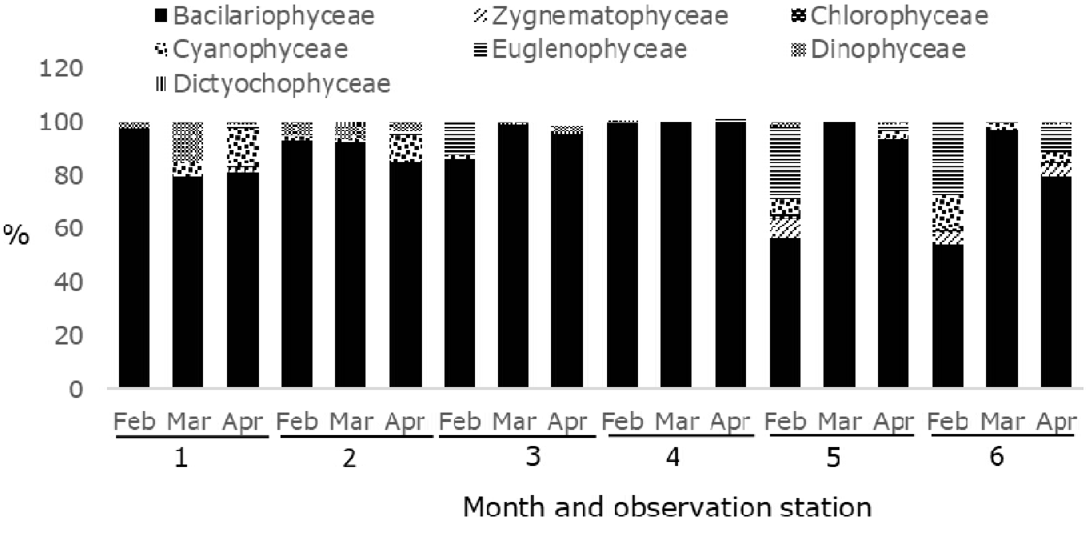

Figure 3. Phytoplankton composition (%).

Phytoplankton was found in varied abundance, spatially and temporally. Lower abundance of phytoplankton was found in Kemanyungan estuary, and temporally, the highest abundance of phytoplankton was recorded in the coastal waters (St 4), especially in February (Figure 4). Number of species ranged from 12 to 33. The lowest number of species was recorded in the coastal waters (St 3 and St 4), and higher number of species was recorded in the estuaries (St 1, St 2, St 5, and St 6) (Figure 4).

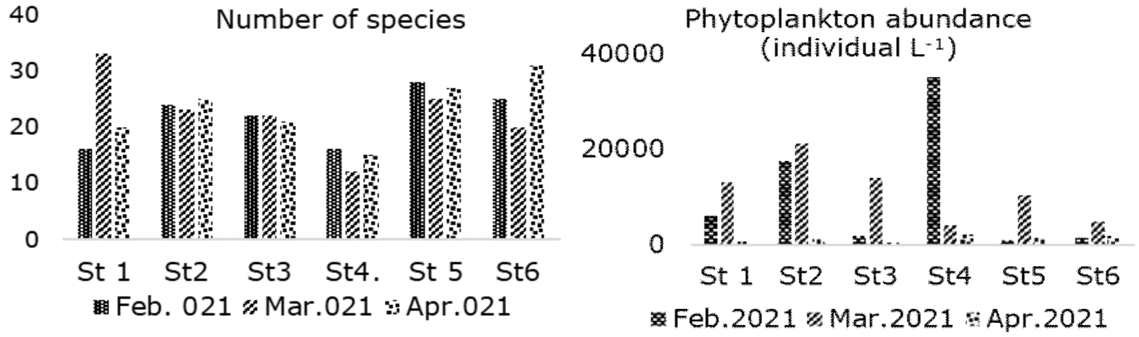

Figure 4. Number of species and phytoplankton abundance.

Bacillariophyceae had a high diversity of species, while Dictyochophyceae were only present in small number of species during observation (Table 2). Most phytoplankton composition was dominated by marine species, either in the coastal waters or in the estuarine waters. *Rhizosolenia* genus belonging to Bacillariophyceae has many species recorded in this observation (Table 2). Some species such as *Rhizosolenia alata*, *Nitzschia sigma*, *Bacteriastrum varians*, *Thalassiothrix frauenfeldii* and *Thalassiothrix nitzschioides* had a wide distribution and were found in all stations. Based on the species distribution, species of *Coscinodiscus* sp. 1*,* *Thalassiosira* sp. and *Dinophysis arctica* was only found in coastal waters (St 3 and St 4), while species of *Diatoma* sp., *Frustulia* sp., *Closterium tumidum*, *Closterium gracile*, *Closterium braunii*, *Closterium dianae, Sphaerocystis* sp*.* and *Ceratium hirundinella* were only found in upper estuary of Kemanyungan River (St 6) (Table 2). Large number of freshwater species belonging to Zygnematophyceae such as *Closterium* spp. and Euglenophyceae such as *Euglena* spp. and *Phacus* spp., then *Nitzschia* spp. belonging to Bacillariophyceae were recorded in Kemanyungan estuary (St 5 and St 6) (Table 2).

Table 2

The occurrence of phytoplankton species during the observation

Species	*Station*						*Species*	*Station*					
	1	*2*	*3*	*4*	*5*	*6*		*1*	*2*	*3*	*4*	*5*	*6*
Bacillariophyceae							**Bacillariophyceae**						
Amphora sp.		*					*Rhizosolenia* sp. 2			*			
Asterionellopsis sp.	*	*	*		*	*	*Sundstroemia setigera*		*	*			
Bacteriastrum delicatulum			*		*	*	*Surirella robusta*	*	*			*	*
Bacteriastrum furcatum	*	*	*	*	*	*	*Synedra* sp.	*				*	*
Bacteriastrum hyalinum		*	*				*Tabellaria* sp.				*		*
Bacteriastrum sp.		*		*	*		*Thalassionema frauenfeldii*	*	*	*	*	*	*
Biddulphia sinensis	*				*		*Thalassionema nitzschioides*	*	*	*	*	*	*
Biddulphia sp.		*	*				*Thalassionema* sp. 1				*	*	*
Chaetoceros didymus			*		*		*Thalassionema* sp. 2	*					
Chaetoceros neogracile		*					*Thalassiosira* sp.			*	*		
Chaetoceros pendulus		*			*		**Zygnematophyceae**						
Chaetoceros teres			*		*		*Closterium braunii*						*
Chaetoceros sp. 1	*		*	*	*		*Closterium dianae*						*
Chaetoceros sp. 2	*	*	*	*	*	*	*Closterium gracile*						*
Chaetoceros sp. 3	*	*	*	*	*	*	*Closterium lineatum*	*	*				
Chaetoceros sp. 4			*	*	*		*Closterium tumidum*						*
Coscinodiscus sp. 1			*	*			*Closterium* sp. 1					*	*
Coscinodiscus sp. 2	*	*	*		*	*	*Closterium* sp. 2					*	
Coscinodiscus sp. 3	*	*	*				*Closterium* sp. 3					*	
Coscinodiscus sp. 4	*	*			*		**Chlorophyceae**						
Coscinodiscus sp. 5	*		*				*Eudorina* sp.					*	

Cyclotella sp.					*	*	*Pediastrum duplex*		*				*
Diatoma sp.						*	*Scenedesmus* sp.		*				
Ditylum sp. 1	*	*	*	*			*Sphaerocystis* sp.						*
Ditylum sp. 2		*	*				**Cyanophyceae**						
Eucampia sp.		*	*				*Anabaena* sp.		*			*	
Fragilaria sp.	*			*		*	*Arthrospira* sp.						*
Frustulia sp.						*	*Oscillatoria* sp. 1	*	*	*	*	*	*
Guinardia sp.	*					*	*Oscillatoria* sp. 2	*	*				*
Gyrosigma sp.					*		*Planktothrix* sp.		*				
Hemiaulus sp. 1		*		*		*	*Trichodesmium* sp.		*				
Hemiaulus sp. 2			*	*			**Euglenophyceae**						
Hemiaulus sp. 3		*		*	*		*Euglena acus*	*	*	*		*	*
Hyalodiscus sp.	*		*	*	*	*	*Euglena granulata*		*				
Lauderia sp.			*				*Euglena proxima*					*	*
Leptocylindrus sp.		*	*	*		*	*Euglena* sp.					*	
Navicula sp. 1	*	*	*		*	*	*Lepocinclis oxyuris*					*	*
Navicula sp. 2	*				*		*Phacus longicauda*					*	*
Nitzschia clausii f. *clausii*	*	*	*	*	*	*	*Phacus orbicularis*					*	*
Nitzscia lanceolata							*Phacus* sp.	*				*	*
Nitzschia longissima	*	*	*	*		*	*Strombomonas* sp.		*			*	
Nitzschia sp. 1					*	*	**Dinophyceae**						
Nitzschia sp. 2					*	*	*Ceratium hirundinella*						*
Nitzschia sp. 3		*			*		*Ceratium* sp. 1					*	
Odontella sp.			*			*	*Ceratium* sp. 2	*	*				
Pinnularia distans		*					*Ceratium* sp. 3		*	*			
Pinnularia sp.		*	*			*	*Dinophysis arctica*			*	*		
Pleurosigma sp.	*		*	*	*	*	*Peridinium* sp. 1	*		*	*	*	*
Pseudoguinardia sp.	*	*					*Peridinium* sp. 2	*	*				
Pseudonitzschia sp.	*	*	*		*	*	*Peridinium* sp. 3	*		*			
Rhizosolenia alata	*	*	*	*	*	*	*Protoperidinium depressum*	*	*				
Rhizosolenia fragilissima	*	*	*		*	*	*Protoperidinium inflatum*			*			
Rhizosolenia hebetata		*		*	*	*	*Tripos lineatus*	*	*	*	*		
Rhizosolenia imbricata	*	*		*		*	**Dictyochophyceae**						
Rhizosolenia styliformis	*	*			*	*	*Dictyocha fibula*		*				
Rhizosolenia sp. 1	*	*	*	*	*	*	*Dyctiocha* sp.				*		

Note: * = present during observation.

Most species belonging to Cyanophyceae such as *Oscillatoria* spp. were commonly found in Linduk Estuary, and several species, such as *Ceratium* spp. and *Peridinium* spp. which represented Dinophyceae, were commonly found in the coastal waters and the estuary of Linduk River (Table 2).

The diversity index (H'), Margalef's richness index (d'), and evenness index (J') of phytoplankton ranged from 0.82 to 3.12, 1.52 to 4.39 and 0.30 to 0.91 respectively (Figure 5). Spatially and temporally, distribution of diversity index, Margalef's richness index, and evenness index showed a large heterogeneity across the sampling sites and sampling time (Figure 5). Low average diversity index, Margalef's richness index, and evenness index were recorded in St 4 (coastal waters). Mostly, higher average value of Margalef's richness index (d') was recorded in the estuaries (St 1, St 5, and St 6) (Figure 5). Higher value of index evenness was recorded in the coastal waters around Linduk Estuary (St 3) and in Kemanyungan Estuary (St 5 and St 6).

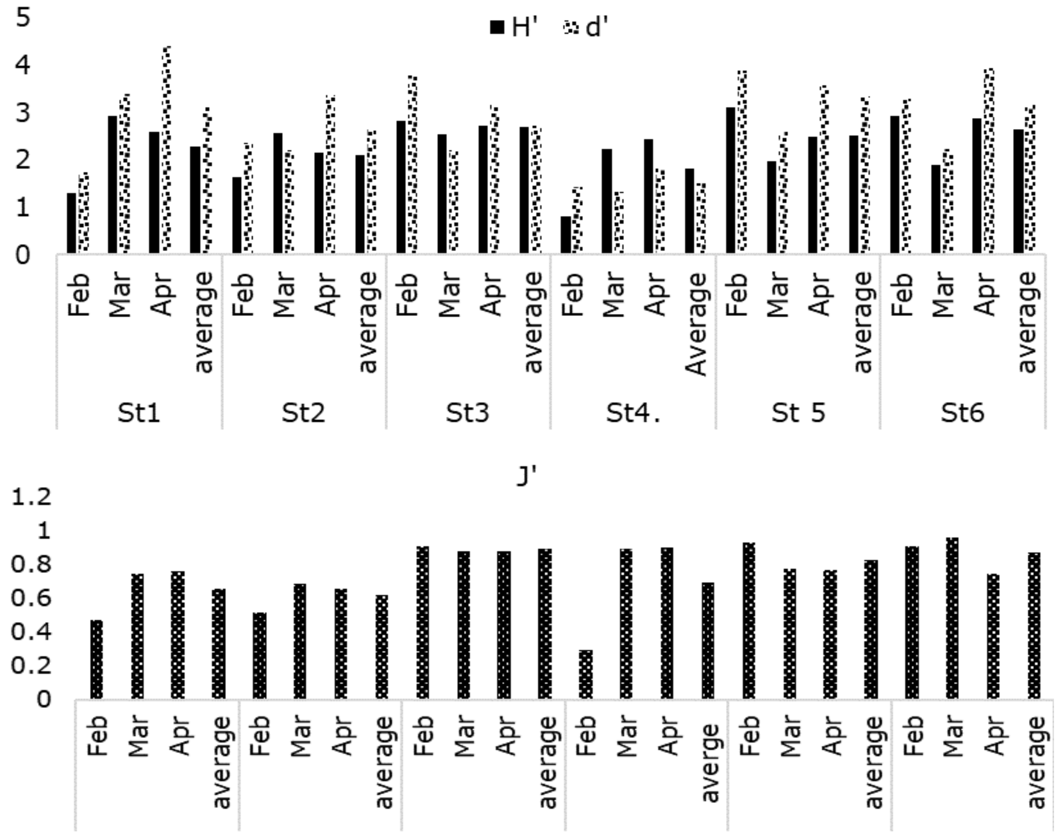

Figure 5. Diversity index (H’), Margalef’s richness index (d’), evenness index (J’) of phytoplankton.

Relationship between environmental factors and phytoplankton. The relationship between phytoplankton and aquatic environmental factors is presented in Figure 6. PCA analysis showed that water quality affected the distribution and relative phytoplankton abundance. PCA analysis also showed that high percentage of Bacillariophyceae recorded in St 3 and St 4 was related to high value of transparency, water temperature, salinity, and pH, while high percentage of Cyanophyceae in St 2 and St 3 was related to high concentration of TP. High percentage of Euglenophyceae and Chlorophyceae found in St 5 and St 6 was related to high value of turbidity, TSS, and nitrate concentration, while high percentage of Dinophyceae and Dicthiochophyceae found in St 2 and St 3 was related to high DO concentration.

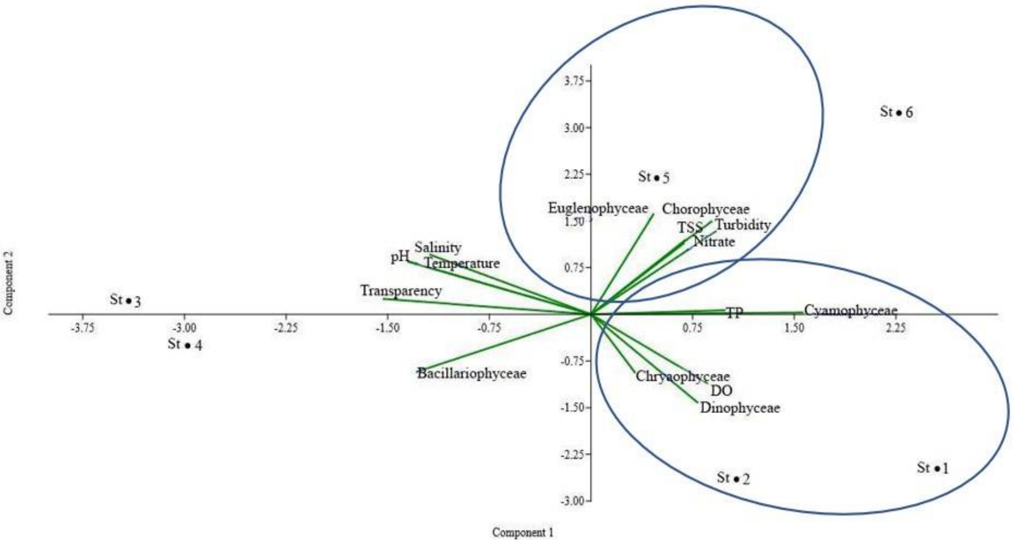

Figure 6. Principal component analysis (PCA) ordination of 6 sites based on phytoplankton and environmental parameters (temperature, salinity, transparency, turbidity, TSS, DO, pH, nitrate, and TP).

Discussion. The variability of transparency and turbidity appears to be connected with the distribution of TSS. In general, more turbid waters are found in estuaries than in coastal waters due to continual re-suspension of fine sediments from the substrate (Lestari et al 2021). Higher turbidity in Kemanyungan Estuary (St 5 and St 6) was also supported by high concentration of TSS. Many factors influence high concentration of TSS in the estuary. As reported, suspended sediment in an estuary is a result of freshwater inflows, tidal currents, winds, waves, and dredging operations (Reisinger et al 2017). A study suggests that relatively higher river discharge in the estuaries is associated with higher suspended particulate matter (Bharathi et al 2022). In Kemanyungan estuary, high concentration of TSS in February was probably caused by higher water discharge containing suspended material input from surrounding areas, since the rainy season falls in February in West Java. On the other hand, morphologically, Kemanyungan estuary is smaller and shallower than Linduk estuary. This condition could also contribute to higher concentration of TSS in Kemanyungan estuary in April due to particulate matter in sediment suspended in the upper column, which caused tidal currents and very strong river flow. A study about the relationship between land use in watershed and water quality in Kemanyungan-Linduk estuaries is essential to control the sediment load in this area. The variability of temperature value, ranging from 29 to 33^{o}C, in the observation site was commonly found in tropical areas. The variability of salinity in an estuary could be induced by freshwater river flow and input of seawater through a tidal cycle (Baliarsingh et al 2021). Higher salinity and pH in Kemanyungan estuary indicated that high seawater entered through the mouth of Kemanyungan estuary. Inversely, the lower salinity in Linduk estuary indicated that freshwater flow was higher in this estuary than that in Kemanyungan Estuary.

Spatially and temporally, variability of DO is related to physical and biochemical processes (Liu et al 2020). River discharge, alongshore wind speed, water temperature, salinity, and nutrients also influence the variability of DO (Liu et al 2020). Spatially, environmental parameters in an estuary change over time due to events such as intrusion of upwelling of marine waters and seasonal river flow (Cloern et al 2017). High nitrate in the estuary (St 5 and St 6) could come from both point source and non-point source in surrounding area input, such as industrial facilities, and agricultural activities (Wurtsbaugh et al 2019; Lestari et al 2021). Nitrate (N-NO_3) is easily carried by runoffs and discharged into rivers and to estuary (Lestari et al 2021; Tao et al 2021). Therefore, runoffs from farmlands that are under fertilization and industrial facilities may also elevate in Kemanyungan estuary. Spatially and temporally, phosphorus concentration showed variability during the observation (Figure 2). Riverine input and physical and biological processes are the dominant factors responsible for variations of phosphorus in estuaries and coastal waters (Yang et al 2018). Low phosphorus concentration in February and March was probably due to the dilution effect of precipitation, since February and March are still in the rainy season in West Java.

Bacillariophyceae dominance in all sites indicated that Bacillariophyceae has adaptability and high tolerance to the environment condition. Class of Bacillariophyceae is the most common found in estuarine and coastal waters (Oliviera at al 2022; Rozirwan et al 2022). This phenomenon was also supported by a wide distribution of some marine species, such as *Rhizosolenia* spp., *Bacteriastrum varians*, *Thalassiothrix frauenfeldii*, *Thalassionema*, *Nitzschioides*, and some species from genus *Chaetoceros.* Those species were also found in estuarine ecosystems of Kemanyungan and Linduk rivers. It seems that some marine and freshwater species were tolerant to salinity fluctuations. Based on species distribution, some attached algae, such as *Pleurosigma* sp., *Pinnularia* sp., *Nitzschia* spp., *Surirella robusta*, and *Closterium* spp. were recorded in the estuaries. The changes of tidal and current pattern could influence the distribution of phytoplankton species in the estuaries. When the tide receded and river flowed very strongly, there were many particulates suspended in water column including attached algae. Chlorophyceae, Cyanophyceae, and Euglenophyceae were present in a small number of species and commonly occurred in the estuaries during this observation. This was probably because the species are of freshwater origin. The occurrence of some species, such as *Closterium* spp., *Euglena* spp., *Phacus* spp. and *Pediastrum duplex* in

Kemanyungan estuary indicated that this estuary was rich in organic matter (Table 2). As reported, those species are commonly found in waters which are rich in organic matter (Bhat et al 2015). Low phytoplankton abundance in Kemanyungan estuary could be related to high TSS and turbidity. High turbidity could reduce light intensity and limit phytoplankton growth. As reported, phytoplankton productivity in estuaries is regulated by turbidity (Gameiro et al 2011).

Several previous studies also discussed the relationship between phytoplankton composition and water quality. In an estuary, phytoplankton production is regulated by salinity, light, turbidity, temperature, nutrients, grazers, and the dynamics of the water basin, while variations of nutrient concentrations and salinity give more influence on phytoplankton community structure (Bharathi & Sarma 2019). Similar to our finding, the dominance of Bacillariophyceae is related to temperature and pH, while the dominance of Euglenophyceae is related to turbidity (Pourafrasyabi & Ramezanpour 2014). Relatively high abundance of Euglenophyceae and Chlorophyceae was related to high nitrate concentration (Figure 6). This fact was supported by the occurrence of some species, such as *Euglena* spp., *Phacus* spp., *Closterium* spp., and *Pediastrum duplex* which showed tolerance to organic pollution in waters.

Based on the diversity index, Kemanyungan-Linduk estuaries and coastal waters were classified as moderate ecological stress with values of 0.82 to 3.12. The values of diversity index above 3.0 indicate that the habitat is stable, while the values under 1.0 indicate that there is a degradation of the habitat (Türkmen & Kazanci 2010). The average of Margalef's richness index (d') ranged from 1.52 to 4.39 during the observation. Generally, for healthy environment, richness index ranges from 2.5 to 3.5 (Magurran 1988). Low diversity index, Margalef's richness index, and evenness index were found in the coastal waters (St 4) because of the dominance of *Peseudonitzschia* and *Hyalodiscus* sp. This condition signified that coastal waters (St 4) were an unstable habitat in this month (February), indicated by the highest abundance of phytoplankton with *Pseudonitzschia* sp. as dominant species. High abundance of *Pseudonitzschia* sp. in coastal waters is associated with high concentration of nitrate in waters (Macintyre et al 2011; Arapov et al 2020). This finding supported our result that coastal water around Kemanyungan Estuary (St 4) (Figure2) has high nitrate concentration characterized by high abundance of *Pesudonitzschia*.

In temperate areas, a *Pseudonitzschia* spp. bloom in summer is associated with higher temperature and salinity, while high population of *Pseudonitzschia* spp. in winter is associated with high concentration of nitrate (Arapov et al 2020). It is important to monitor the abundance of *Pseudonitzschia* spp. and the water quality in this area, since *Pseudonitzschia* spp. is a species that has the potential to produce toxic materials. This toxic material is likely to accumulate in aquatic animals (Tas & Lundholm 2017). Higher Margalef's richness index (d') (> 3) was recorded in the estuarine waters (St 1, St 5, and St 6) with a higher value (> 3), which indicated healthy condition, while lower richness index was recorded in the coastal waters. Higher Margalef's richness index (d') in the estuarine waters was due to the diversity of Chlorophyceae, Cyanopyceae, Euglenophyceae along with Bacillariophyceae. However, in Kemanyungan estuary more diversity of Euglenophyceae and Chlorophyceae was represented by species adapted to organic pollution. Pielou's evenness index (J') described the equal distribution of the number of individuals at the community level. The values of evenness index (J') are between 0 and 1. Values that are closer to 1 indicate that these individuals are evenly distributed (Kennish 2021). Spatially, the evenness index (J') showed a variability in this observation (Figure 5). Higher average evenness index (J') with the value of 0.83 to 0.89 recorded in Kemanyungan estuary (St 5 and St 6) and the coastal waters around Linduk estuary (St 3) indicated that the distribution of each phytoplankton taxon tended to be equal in those sites. The variability of diversity index, richness index, and evenness index was probably related to a number of factors, such as physical, chemical, morphological, and hydrological characteristics. A number of physical factors, such as water movement and sediment resuspension influence phytoplankton (Oliviera et al 2022). As reported, depth, tide, and monsoon related to variables of water quality (TSS, salinity, light availability and dissolved nitrates) significantly affect the changes of phytoplankton community structure (Canini et al 2013; Calvacanti et al 2022).

Conclusions. Kemanyungan estuary, Linduk estuary, and coastal waters have different water quality characteristics. Phytoplankton consists of Bacillariophyceae, Chlorophyceae, Cyanophyceae, Dictyochophyceae, Dinophyceae, Euglenophyceae and Zygnematophyceae. Bacillariophyceae is the dominant group of phytoplankton contributing 54.1 to 100% of total abundance. The dominance of Bacillariophyceae is related to salinity, transparency, pH, and temperature. Phytoplankton composition has different responses to the water quality parameters. Phytoplankton abundance, number of species, diversity index, species richness index, and evenness index show a large heterogeneity across the sampling sites and sampling time. The lowest diversity index and Margalef's index were recorded in coastal water around Kemanyungan estuary which indicated unstable condition of habitat in this station. Based on the phytoplankton diversity index, the study area is classified as moderate ecological stress. Seasonally, it is important to monitor phytoplankton diversity and water quality to determine the key factors that influence unstable environmental conditions as basic management of this research area.

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Authors:
Sulastri, Research Center for Limnology and Water Resources, National Research and Innovation Agency (BRIN), Raya Bogor-Jakarta Street, Km 46, Cibinong, 16911, West Java, Indonesia, e-mail: sula001@brin.go.id
Sulistiono, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, Bogor 16680, West Java, Indonesia, e-mail: onosulistiono@gmail.com

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