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Research Article

Evaluation of Mangrove Water Quality in Pancer Cengkrong, Trenggalek and Sine, Tulungagung, East Java, Indonesia Using Phytoplankton as Bio-indicators

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Abstract

Mangrove ecosystems in Sine and Pancer Cengkrong had degraded due to land-use change and restoration has been carried out over a few year on the damaged location. This study was conducted to evaluate water quality of mangrove ecosystems at both locations based on physical, chemical and phytoplankton parameters as bioindicators. The evaluation of Cengkrong Mangrove was carried out at 4 different locations based on different periode of restoration, namely restoration of 2008-2009, 2013-2014, natural mangroves, and 2005 succession mangroves, whereas there was only one sampling site at Sine mangrove namely 1998-2008 restoration. The physico-chemical parameters measured include water temperature, air temperature, conductivity, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), salinity, nitrate, and orthophosphate. Phytoplankton data was used to measure, trophic diatom index (TDI) as an indicator of water nutrition status, and pollution tolerant value (%PTV) as an indicator of organic pollution. The results showed that the water quality at all the study locations met the Indonesian Ministry of Environment Regulation No 51/2004, except nitrate and phosphate. Based on the TDI index, mangrove in Sine, Cengkrong 2013-2014 restoration, and 2005 succession mangroves were categorized as hyper-eutrophic, natural Cengkrong mangroves were categorized as eutrophic, and 2008-2009 restored Cengkrong mangroves were categorized as meso-eutrophic. Based on the %PTV index, in the Sine mangrove, 2013-2014 Cengkrong restoration, and 2005 succession mangroves were classified as high levels of organic matter pollution, while in the Cengkrong 2008-2009 restoration and natural Cengkrong were classified as a moderate level of organic pollution.

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1. Introduction

Mangroves are natural ecosystems located in tidal areas with several ecological functions (Biswas and Biswas 2019). As they are located at transition areas of inland and seawater, mangroves are affected by tides. Mangroves adapt to survive in this vulnerable environment by having high adaptability to salt (halophytes), low oxygen levels, and unstable soils, and experiencing an inundation cycle due to tides (Hilmi *et al*., 2020). Mangroves have important roles in maintaining and protecting the coast from sea waves, as a storage of carbon stock, and as a habitat for other organisms (Saifullah *et al*., 2016).

There are a lot of mangroves on the island of Java with a typical habitat type. The northern coast of Java with calm hydro-oceanographic state and rich in organic matter is suitable for mangroves to grow. In the northern region of East Java, coastal abrasion often occurs where mangroves are planted and a lot of data have been obtained. Meanwhile, the southern coast of Java is relatively small with steep topographic contours, exposed to Indian Ocean waves and receives minimal supply of coastal sediments. This area receives less attention as compared to the northern counterpart, thus available data is limited (van Oudenhoven *et al*., 2015; Indrajaya *et al.,* 2022). On the southern coast of Java, especially in East Java, mangrove ecosystems can be found in Pancer Cengkrong, Trenggalek Regency and Sine, Tulungagung Regency. Cengkrong and Sine mangroves with the area of about 87 ha (Mughofar *et al*., 2018) and 1 ha (Saputra *et al*., 2020), respectively, are surrounded by anthropogenic activities such as logging, aquaculture, plantations, and agriculture. In the vicinity of Sine mangrove, there are beach activities, tourism, plantations, and agriculture. In 2003-2005, the mangrove ecosystem in Cengkrong was severely damaged due to land conversion and massive deforestation (Susilo *et al*., 2015). This caused changes in land function of the mangrove area and its surroundings and also reduced the quality of mangrove ecosystem services (Rohila *et al*., 2017; Darmawan *et al*., 2020). The decline in the quality of ecosystem services will reduce the usability, yield, productivity, carrying capacity, and capacity of the mangrove ecosystem which in turn reduce the wealth of natural resources (López-Portillo *et al*., 2017). Mitigation was done by replanting or restoring. The restoration activities in the mangrove area of Cengkrong were done from 2008 to 2009 and 2013-2014. There are natural mangroves ecosystem which exist since 1990, and an area which was newly developed as a result of natural successional process since 2005. Meanwhile, there is only one type of mangrove ecosystem we found in Sine, where restoration activity was in 1995 and 2008.

The success of the restoration can be seen from the improvement of water quality by measuring the physical, chemical, and biological parameters. Physicochemical parameters that reflects the water quality conditions important for phytoplankton growth include pH, DO (dissolved oxygen), BOD (biochemical oxygen demand), conductivity, temperature, and turbidity (Singh *et al*., 2017). Phytoplankton community structure and diversity can be measured as bioindicators of aquatic ecosystem health. Phytoplankton is important as primary producers and involve in nutrient cycles that support growth and survival of organisms in the mangrove ecosystem (Hilmi *et al*., 2020; Khumaidi *et al*., 2020). In addition, phytoplankton float passively in the waters, their life cycle is short and they respond to environmental changes quickly which makes them a good bioindicator of water quality (Hilmi *et al*., 2020). One way to use phytoplankton as a bioindicator is to use a biotic index such as Tropic Diatom Index (TDI) and Pollution Tolerance Value (%PTV). TDI was developed to determine the nutritional status of waters, while %PTV was used to determine the level of pollution of aquatic organic matter (Wu *et al*., 2014). Therefore, the purpose of this study was to evaluate water quality in the restored Cengkrong and Sine mangrove ecosystems, East Java based on phytoplankton community structure as a bioindicator.

2. Materials and Methods

2.1 Study Site and Sample Collection

This study was conducted in June - December 2021. Water and phytoplankton samples were collected in the mangrove ecosystem of Pancer Cengkrong, Trenggalek Regency and Sine, Tulungagung Regency, East Java, Indonesia. There were four sampling stations designated at Cengkrong mangrove, which include 2008-2009 restoration site (Cengkrong 1), 2013-2014 restoration site (Cengkrong 2), natural mangroves since 1990 (Cengkrong 3), and 2005 succession mangroves (Cengkrong 4). The 2008-2009 restoration site is located far from anthropogenic activities, the mangrove vegetation grows large and lush. The 2013-2014 restoration site is located close to anthropogenic activities because it is included in the Pancer Cengkrong Mangrove ecotourism area, which has become an attraction for tourist attractions. The natural location since 1990 is the remaining mangrove area due to illegal logging in 2006-2008. The location of the 2005 succession of mangroves is a mangrove area formed from natural succession from 2005 (Mughofar *et al.,* 2017; Paringsih *et al.,* 2018). Meanwhile, there was only one sampling station designated at Sine mangrove area (1995 restoration). The location of the 1995 sine mangrove is a diverse restoration mangrove area from 1995 and there was a renewal of planting in 2008. Besides that, the sine mangrove is close to the sine tourist spot, which makes the surrounding conditions worse (Syafitri, 2021) (Figure 1).

2.2 Research Design

This study used the ex-post facto research design, in which a causal phenomenon that has occurred in the field (natural phenomena) was selected. In this design, researchers do not need to add treatment and only need to see the effect on the dependent variables (Lammers and Badia, 2005). The time of restoration is the independent variable in this study, while the physico-chemical and phytoplankton parameters are the dependent variables. The composition of mangrove vegetation was also determined as a moderator variable that may affect water quality.

2.3 Phytoplankton Samples Collection, Identification, and Enumeration

Phytoplankton sampling was carried out at each specified location with 3 repetitions. Phytoplankton collected is generalized from the surface area (± 30 cm) of the water because each location has a different depth; some are shallow, and some are deep. Phytoplankton samples were collected by filtering 4 L of water through a plankton mesh (10-30 mesh size) (Moncheva and Parr, 2010). The phytoplankton samples obtained were transferred to a flacon bottle and fixed with 5 drops of $CuSO_4$ and 10 drops of 4% formalin. A volume of 1 mL phytoplankton samples were dropped into the Sedgewick-Rafter cell (SRC) counting chamber.

Phytoplankton cells were observed under light microscope at a magnification level of ×200 & x400 (for phytoplankton identification) following the phytoplankton manual (APHA, 2005) and identified using identification keys according to Gell *et al.* (1999); du Buf and Bayer (2002); van Vuuren *et al.* (2006); and Bellinger and Sigee (2010). Observations were made as many

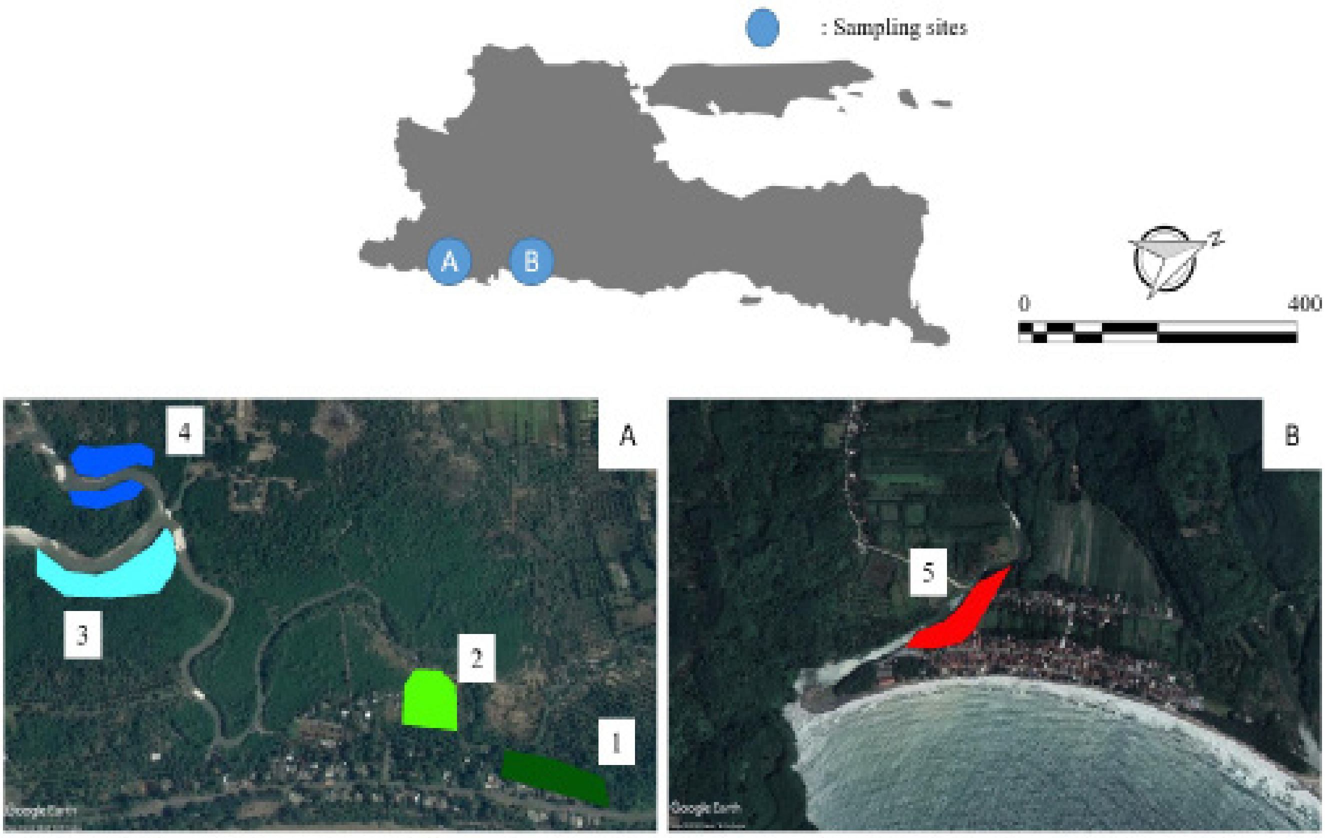

Figure 1. Mangrove ecosystem study site. (Notes: (A) Cengkrong, Trenggalek Regency; (B) Sine, Tulungagung Regency; 1: Cengkrong mangrove restoration in 2008-2009; 2: Cengkrong mangrove restoration in 2013-2014; 3: Cengkrong mangrove succession in 2005; 4: Cengkrong natural mangroves; & 5 : Sine mangrove restoration in 1998 & 2008).

Table 1. Water physicochemical parameters and measurement tools/methods

Parameter	Unit	Tools/Methods
Water temperature	°C	Thermometer
Air temperature	°C	Thermometer
Conductivity	S/m	Conductivity meter
pH	-	pH meter
DO	mg/L	DO meter
BOD	mg/L	Winkler Method
Salinity	‰	Refractometer
Nitrate	mg/L	Colorimetric
Orthophosphate	mg/L	Colorimetric

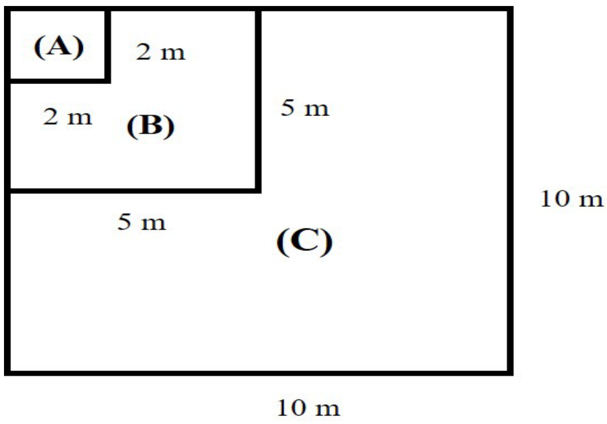

Figure 2. Quadrat size of mangrove vegetation data collection at the research site. (Notes: A = Seedling; B = Sapling; C = Poles)

Table 2. Variations in the biotic index of phytoplankton in the Cengkrong and Sine mangroves

Location	Time Restoration	*E*	*Id*	*H'*
Sine	1998-2008	0.58	0.28	2.32
Cengkrong	2008-2009	0.82	0.1	3.13
	2013-2014	0.69	0.29	2.38
	Natural	0.85	0.13	3.23
	Succession	0.75	0.13	2.84

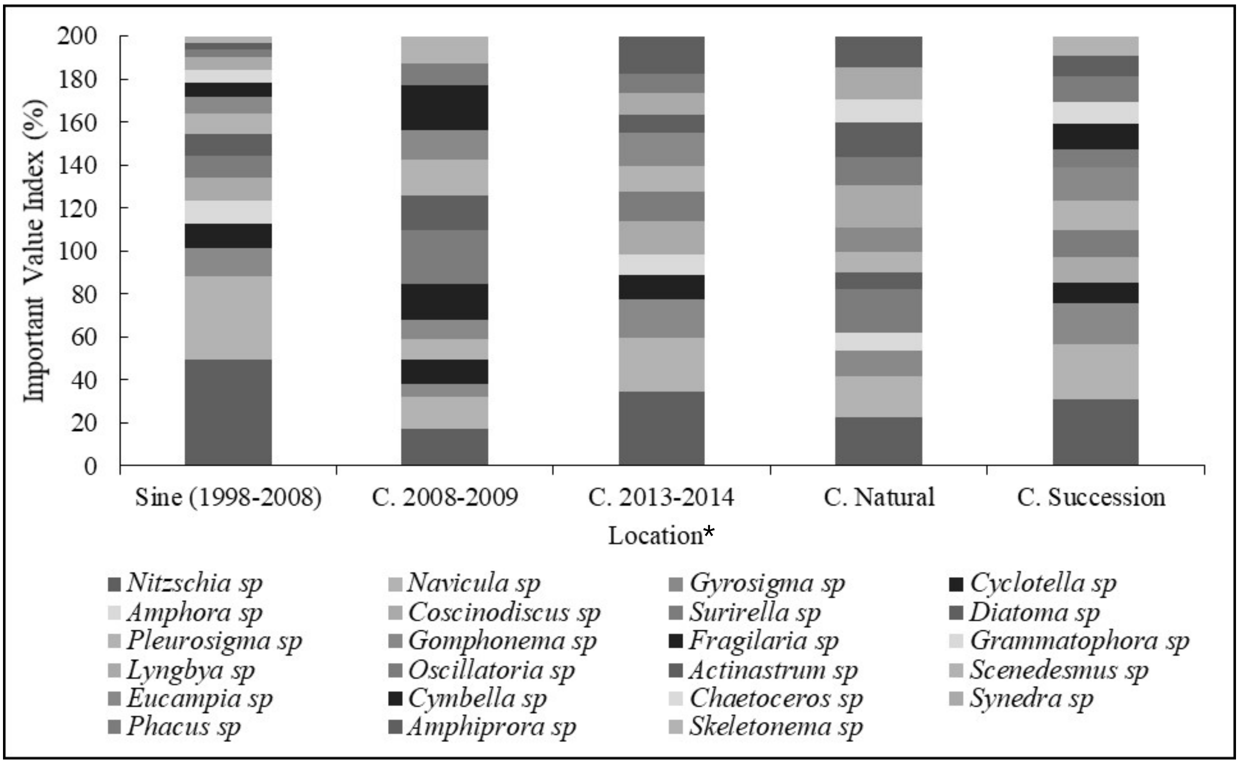

Figure 3. Values of IVI in Cengkrong and Sine Mangroves Ecosystem. (Note: * = The year indicates the time of restoration).

as 500 squares counted at each station. The cell density was calculated according to the equation by APHA (2005) & Effendi *et al.*, (2016):

$$N = n \times \frac{p1}{p2} \times \frac{V1}{V2} \times \frac{1}{W}$$

Where:

N : the abundance of phytoplankton (ind/L)

n : number of observed phytoplankton

p1 : Number of plankton observed

p2 : Number of SRC squares observed

V1 : Volume of water in the sample bottle

V2 : Volume of water in SRC square

W : Volume of filtered water

2.4 Water Samples Collection and Measurement of Physicochemical Parameters

Measurements of physicochemical parameters and water samples collection were carried out at the same location as phytoplankton collection, with 3 repetitions. Water samples were collected at a depth of 30 cm from the water surface. A volume of 1.5 L of water samples were collected using a plastic bottle. Physicochemical parameters measured at the site include water temperature, air temperature, conductivity, pH, salinity, DO. Meanwhile, the physicochemical parameters measured in the laboratory include BOD, nitrate, and orthophosphate (Table 1).

2.5 Mangrove Vegetation Composition Analysis

Mangrove vegetation data was obtained by conducting the sample plot method with several types of mangrove structures. Each station was divided into 3 plots, namely 2 x 2 m for seedling, 5 x 5 m for sapling, and 10 x 10 m for poles. Within each 10 x 10 m plot, smaller plots of 5 x 5 m were made, which contained smaller plots of 2 x 2 m (Yuliana *et al.*, 2019) (Figure 2). Mangrove species identification was carried out according to the keys illustrated in (Djamaluddin *et al.*, 2018). Mangrove data analysis was carried out only to calculate taxa richness and mapping the distribution of mangroves at the research site.

2.6 Data Analysis

Physicochemical parameters data were analysed using descriptive statistical analysis and SPSS software. Phytoplankton species composition and abundance data were further utilised to determine the community structural attributes which include importance value index (IVI), Shannon-Wiener diversity index (*H'*), Simpson's dominance index (*Id*), evenness index (*E*), TDI (trophic diatom index), and % PTV (percentage pollution tolerant values). Mangrove profile was determined based on taxa richness and composition. Correlation between duration of restoration and the physicochemical, and biological properties of water was determined by conducting biplot analysis using PAST 16.0 software. The following equation was used to determine the importance value index (IVI) (Babu *et al.*, 2013):

$$IVI = KR + FR$$

Where KR is relative abundance (%), FR is the relative frequency (%). *H'* was calculated using the following equation:

$$H' = -\sum_{i=1} S\,Pi^2 \log Pi$$

Where *H'* is the Shannon-Wiener diversity index, *S* is the total number of species in the community, P_i is the proportion of the *i* species to the total number (Wu *et al.*, 2014).

The following formula was used to calculate the *Id*:

$$Id = Ni(Ni-1) \times N(N-1)$$

Where *Id* is Simpson's dominance index value, N_i is the number of individuals of the *i* species, *N* is the total number of individuals found (Babu *et al.*, 2013).

Evenness index (*E*) was determined using the following equation:

$$E = \frac{H'}{H'maks}$$

Where E is an evenness index, *H'* max is 2Log *S*, where *S* is the number of species (Wu *et al.*, 2014). The trophic diatom Index (TDI) describes the level of phytoplankton eutrophication in an ecosystem.

The range of TDI values is from 0-100. The formula to determine the TDI values is as follow:

$$TDI = (WMS \times 25) - 25$$

Where, *WMS* is a weighted average sensitivity, which can be obtained from the following formula:

$$WMS = \sum_{i=1}^{n}(ai \times si \times vi) / \sum_{i=1}^{n}(ai \times vi)$$

Where "a_i" is the proportion of all individuals in the sample belonging to the species *i*, *n* is the total number of species in the sample, "s_i" is pollution sensitivity (1-5) of species *i*, "v_i" is the indicator value (1-3) of species *i* (Wu *et al*., 2014).

The formula to calculate % PTV is as follow:

$$\%PTV = \frac{Abundance\ of\ tolerant\ taxa}{total\ taxa\ abundace}$$

The %PTV value was calculated by comparing the abundance of tolerant diatoms (*Gomphonema* sp., *Navicula* spp., *Sellaphora* spp., and *Nitzschia* spp.) with the total number of diatoms obtained (Kelly and Whitton, 1995).

3. Results and Discussion

3.1 Phytoplankton Community Structure in Cengkrong and Sine Mangroves Ecosystem

There were 23 phytoplankton species identified from Cengkrong and Sine mangroves. Phytoplankton species abundance and composition varied spatially in Cengkrong and Sine mangroves. In Sine mangrove, there were 16 species identified, while in Cengkrong, the number of species varied according to locations. The composition and phytoplankton community structure in mangrove ecosystems is shown in the IVI data (Figure 3). In Sine mangroves, there were 2 codominant species, namely *Nitzschia* sp. and *Navicula* sp. with an IVI value of 56.4% and 43.78%, respectively. In Cengkrong mangrove area, 2008-2009 restoration recorded 5 codominant species, namely *Oscillatoria* sp., *Cymbella* sp., *Nitzschia* sp., *Scenedesmus* sp., and *Fragilaria* sp. with IVI values of 24.75%, 20.80%, 17.29%, 17.16%, and 17.12%, respectively. The codominant species found at the Cengkrong mangrove 2013 - 2014 restoration site were *Nitzschia* sp., *Navicula* sp., *Gyrosigma* sp., and *Amphiprora* sp with IVI values of 34.34%, 25.26%, 17.81%, and 17.29%, respectively. The codominant species found in the natural Cengkrong mangrove location were *Nitzschia* sp., *Surirella* sp., *Lyngbya* sp., and *Navicula* sp. with IVI values of 22.75%, 20.25%, 19.4%, and 18.93%, respectively. At the location of 2005 succession mangroves, three codominant species were found, namely *Nitzschia* sp., *Navicula* sp., and *Gyrosigma* sp. with IVI values of 30.96%, 25.86%, and 19.03%, respectively.

Based on the values of IVI, among the dominant species were *Amphora* sp., *Nitzschia* sp., *Gyrosigma* sp., *Surirella* sp., and *Navicula* sp. which were reported to be pollution tolerant species (Bellinger and Sigee, 2010; Kudela Lab, 2016). According to Onyema (2013), *Amphora* sp., *Nitzschia* sp., *Gyrosigma* sp., and *Navicula* sp. are diatoms that have a high level of tolerance and adaptation to the aquatic environment so that they can live in an organically polluted environment. *Amphiprora* sp. has a high tolerance towards organically contaminated waters (van Vuuren *et al*., 2006). According to Taylor *et al*. (2007), *Surirella* sp. lives normally in brackish water. In addition, *Oscillatoria* sp., and *Scenedesmus* sp. are often found in nutrient-rich waters and have a role as a recycler of the nutrient cycle. Both of these species were found in the 2008-2009 restoration, which indicates that the nutrient content can be controlled and recycled so as not to contaminate (Bellinger and Sigee, 2010).

Based on Shannon-Wiener diversity index (*H*'), at Cengkrong mangroves 2008-2009 restoration and natural Cengkrong mangrove, *H*' values recorded were 3.125 and 3.23, respectively, which were categorised as high diversity. At Sine and other sampling stations at Cengkrong, the *H*' values recorded were under the moderate diversity category (Table 2). Wu *et al*. (2014) categorised *H*' of plankton as high diversity when *H*' > 3, moderate for *H*' = 1-3 and low diversity for *H*' < 1. *H*' at Sine mangrove was relatively lower as it is located close to anthropogenic activities such as bathing places, tourism, and residential and settlement areas. These anthropogenic activities contribute to the organic pollutants that is used by phytoplankton as nutrients for metabolism, causing eutrophication (Bellinger and Sigee, 2010). The location of the 2005 succession mangroves is located close to the oil palm plantation area and only one species of mangrove was found. The location of oil palm plantations is located in the stream before the location of natural mangroves since 1990 and 2005 succession mangroves. Land degradation causes water volume to increase due to reduced river equivalence by bringing pollutant content from various rivers and causing high organic matter content in water flow in

Table 3. List of mangrove species recorded at each location

No	Name of species	Sampling site				
		Sine (Mix 1998-2008)	C. 2008-2009	C. 2013-2014	C. Natural	C. Succession
		Seedling				
1	*Acanthus ilicifolius*	+	+	-	-	-
2	*Aegiceras floridum*	-	+	-	-	-
3	*Bruguiera passiflora*	-	-	+	-	-
4	*Camptostemon schultzii*	-	-	+	-	-
5	*Ceriops decandra*	-	-	-	-	+
6	*Ceriops tagal*	-	-	+	-	-
7	*Derris latifolia*	-	+	-	-	-
8	*Derris trifoliata*	+	+	+	-	-
9	*Hibiscus tiliaceus*	-	+	-	-	-
10	*Rhizophora apiculata*	-	-	+	+	-
11	*Rhizophora mucronata*	+	-	+	-	-
12	*Rhizophora stylosa*	-	-	+	-	-
13	*Sonneratia alba*	-	-	+	-	-
14	*Wedelia biflora*	+	+	-	-	-
		Saplings				
1	*Acanthus ebracteatus*	+	+	-	-	-
2	*Acanthus ilicifolius*	+	+	-	-	-
3	*Aegiceras floridum*	-	+	+	-	-
4	*Bruguiera cylindrica*	+	-	-	-	-
5	*Ceriops decandra*	-	-	+	+	+
6	*Ceriops tegal*	-	+	+	-	-
7	*Cocos nucifera*	+	-	-	-	-
8	*Hibiscus tiliaceus*	-	+	-	-	-
9	*Rhizophora apiculata*	-	-	+	+	-
10	*Rhizophora mucronata*	+	+	+	-	-
11	*Rhizophora stylosa*	-	-	+	-	-
12	*Sonneratia alba*	-	+	-	+	-
13	*Sonneratia ovata*	-	+	-	-	-
		Poles				
1	*Acacia* sp.	-	+	-	-	-
2	*Aegiceras floridum*	-	+	-	-	-
3	*Avicennia alba*	+	-	+	+	-
4	*Avicennia marina*	-	+	+	-	-
5	*Bruguiera cylindrica*	+	-	-	-	-
6	*Ceriops decandra*	-	-	-	+	+
7	*Ceriops tagal*	-	-	+	-	-
8	*Cocos nucifera*	+	+	-	-	-
9	*Pandanus tectorius*	-	+	-	-	-
10	*Rhizophora apiculata*	-	-	-	+	-
11	*Rhizophora mucronata*	+	+	-	-	-
12	*Rhizophora stylosa*	-	-	-	+	-
13	*Sonneratia alba*	-	+	+	+	-
14	*Sonneratia ovata*	-	+	-	+	-
15	*Xylocarpus granatum*	-	-	-	+	-
	Total number of species	**8**	**15**	**12**	**7**	**1**

Notes: + present, -absent, one species counts one.

Table 4. Total density at Cengkrong and Sine Mangroves

Location	Total Density		
	Seedlings	Saplings	Poles
Sine	96	36	90
C. 2008-2009	100	45	110
C. 2013-2014	78	150	33
C. Alami	18	33	64
C. Suksesi	5	81	17

both locations. However, according to Fleishman *et al.* (2006); Wall and Nielsen (2012), at the location of 2005 succession, mangroves have low ecosystem services because they only have one type of mangrove. This has the potential to eliminate various ecological functions of mangroves and cause an imbalance (Rahmania *et al.*, 2020). In the Cengkrong 2013 - 2014 restoration, the mangroves found were classified as newly planted (saplings). The sapling phase is the growing phase of a plant. With small growth, the physiology of mangroves in the mangrove restoration of Cengkrong 2013-2014 is still limited, so this affects the accumulation of mangroves on organic matter (Djamaluddin *et al.*, 2018). The increase in organic matter as a nutrient will increase the growth of phytoplankton (Duwig *et al.*, 2014).

Simpson dominance index at 5 mangrove locations ranged from 0.10 - 0.29, which means that no single species has domination (Table 2). According to Effendi *et al.* (2016); Inyang and Wang (2020), Id values close to 0 (zero) describes the absence of dominance in an ecosystem. In addition, the evenness index (*E*) values obtained at 5 mangrove locations ranged from 0.58 to 0.85 (Table 2). Based on the evenness index value obtained, it showed that the level of evenness in 5 mangrove ecosystems locations is classified as uniform except for the Sine mangrove with an *E* value of 0.58. The *E* values > 0.6 has an even distribution of species (Wu *et al.*, 2014). This is positively correlated with the results of the Importance Value Index where it is assumed that each location does not have a dominant species but is a codominant.

The data obtained from the TDI index showed differences in the level of eutrophication in each location (Figure 4A). Diatom is one of the phytoplankton that can be used as biological indicators because they have limited mobility and a long life cycle so that changes in water quality can accumulate in their bodies (Suther and Rissik, 2009). Sine, Cengkrong 2013-2014 restoration,

Table 5. Water quality parameters at Cengkrong and Sine Mangroves

Time Restoration	Physico-chemical Parameters (Min-Max)								
	Water Temperature (ºC)	Air Temperature (ºC)	pH	Conductivity (S/m)	DO (mg/L)	BOD (mg/L)	Salinity (‰)	Nitrate (mg/L)	Orthophosphate (mg/L)
Sine (1998-2008)	24.5-26	25.5-27	7.08-7.23	0.29-1.92	2.47-3.02	2-5.92	5.0-15	0.15-0.55	0.23-0.71
Cengkrong (2008-2009)	28-29.5	29-31.5	7-7.45	1.04-2.14	3.01-5.21	2.64-4.08	4.0-15	0.12-0.28	0.14-0.33
Cengkrong (2013-2014)	28-29	29-29.5	7.25-7.26	0.69-1.19	4.3-4.75	2.8-3.48	0-5	0.37-0.69	0.55-0.58
Cengkrong Natural	27-28	28-29	7.21-7.25	0.58-0.72	4.47-4.63	3.24-4.92	5	0.31-0.36	0.4-0.53
Succession	27-30	29-32	7.74-7.86	0.18-0.63	4.6-4.83	5.92-5.96	3.5-8	0.53-1.6	0.2-0.28
Water Quality Standard (Indonesia Ministry of Environment Regulation No 51/2004)	28-32		7-8.5	-	>5	20	33-34	0.008	0.015

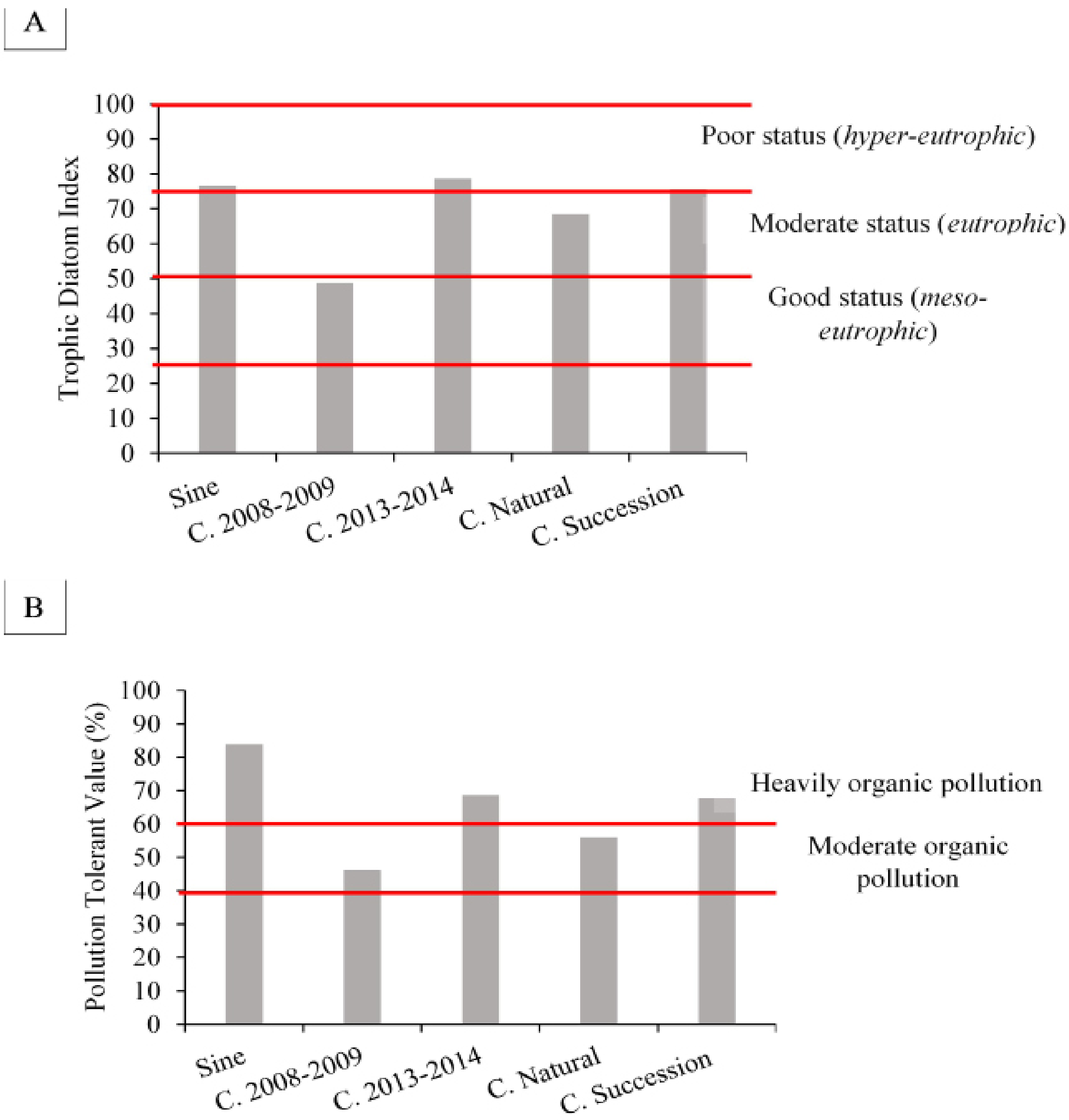

Figure 4. Variations in the value of the biotic index in 5 locations at Cengkrong and Sine mangroves ecosystem (Notes: A = Trophic diatom index; B = % Pollution tolerant value)

and 2005 succession mangroves were classified as poor (hyper-eutrophic) with TDI values of 76.6, 78.7, and 75.7, respectively. The natural Cengkrong mangrove was classified as moderate (eutrophic) with a TDI value of 68.5, and the 2008-2009 Cengkrong restoration was classified as good (meso-eutrophic) with a TDI value of 48.7. The results of the TDI index are positively correlated with disturbances in surrounding activities that occur at each location. The locations of Sine, Cengkrong 2013-2014 restoration and 2005 succession mangroves have a high intensity of disturbance which causes the carrying capacity of the environment to be less than optimal (Rahmania *et al*., 2020).

% Pollution Tolerant Value showed that there were differences in the level of organic matter pollution at each location (Figure 4B). %PTV describes the level of organic matter pollution in an aquatic ecosystem (Taylor, 2007). At the location of mangrove Sine, Cengkrong 2013-2014 restoration, and 2005 succession mangroves, the %PTV values were 83.9%, 68.6%, and 67.8, respectively, which were classified as heavily polluted with organic matter that could indicate high level of eutrophication. This could be contributed by coconut plantations and other agricultural activities; and evidenced by the occurrence of phytoplankton which are indicators of organic matter pollution such as *Nitzschia* sp., *Navicula* sp., *Gyrosigma* sp., and *Amphiprora* sp. (van Vuuren *et al*., 2006). The 2008-2009 Cengkrong restoration and the natural Cengkrong mangrove obtained the %PTV values of 46.3% and 55.9%, respectively, which were classified as moderate organic pollution which can significantly contribute to eutrophication. The organic matter pollution is caused by anthropogenic activities that produce waste carried from rivers and groundwater such as industrial waste, agricultural waste, domestic waste, and other activities along the watershed (Zanardi-Lamardo *et al*., 2019).

3.2 Composition of the Mangrove Community at Cengkrong and Sine

Mangrove composition varied among locations (Table 3). The highest species richness of 15 mangrove species was found at Cengkrong 2008-2009 restoration. The lowest species richness was found at the Cengkrong succession location with 1 mangrove species. Meanwhile, at the Sine mangrove location, 8 species of mangrove were found, in the Cengkrong 2013-2014 restoration, 12 species of mangrove were found, and 7 species of mangrove were found in natural Cengkrong mangroves. The total density obtained at each location is different. The total density at the Sine location included 96 individual seedlings, 36 individual saplings, and 90 individual polishes. The total density at the Cengkrong 2008-2009 restoration site included 100 individual seedlings, 45 individual saplings, and 110 individual polishes. The total density at the Cengkrong 2013-2014 restoration included 78 individual seedlings, 150 individual saplings, and 33 individual polishes. The total density at the natural Cengkrong location included 18 individual seedlings, 33 individual saplings, and 64 individual polishes. The total density at the 2005 succession mangroves included 5 individual (seedlings), 81 individual (saplings), and 17 individual (poles) (Table 4). According to Kusmana (2014), there are 33 taxa species of mangroves found in Indonesia. This showed that the ecosystem quality of the mangrove Cengkrong restoration 2008-2009 is classified

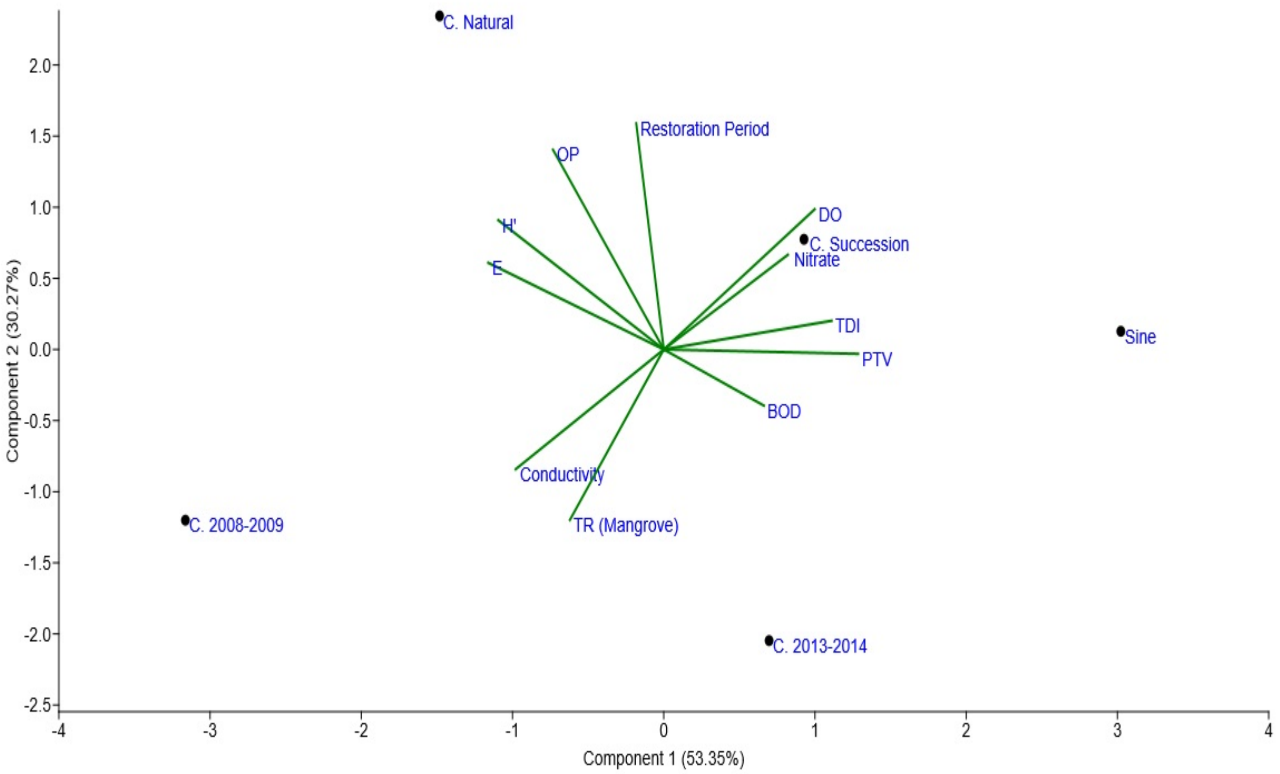

Figure 5. Correlation between water quality and phytoplankton community structure in Sine and Cengkrong mangroves ecosystem using Biplot analysis. (Notes: H' = Shannon-Wiener diversity index (Phytoplankton); E = Evenness index (Phytoplankton); TDI = Trophic diatom index (Phytoplankton); PTV = % Pollution tolerant value (Phytoplankton); TR = Taxa Richness (Mangrove))

as high diversity because almost half of the total species in Indonesia are found in that location (110 individuals in polishing phase). The high diversity also results in the improvement of the quality of an ecosystem (Wall and Nielsen, 2012; Wiryanto *et al*., 2017). This happens because of the ecological role of mangroves as a buffer, filter, and deposition of material originating from the marine, river, and land ecosystems (Carugati *et al*., 2018; Toledo-Bruno *et al*., 2016).

3.3 Water Quality Characteristics Based on Physicochemical Parameters in Cengkrong and Sine Mangroves

Phytoplankton growth can be influenced by physicochemical parameters of an aquatic ecosystem. There were variations in the physicochemical parameters of water in the Cengkrong and Sine mangroves (Table 4). Water temperature and air temperature at 5 locations were not significantly different which still meet the water quality standards for marine biota in mangroves as regulated by the Indonesian Ministry of Environment Regulation No 51/2004 (28 -32°C) (MENLH, 2004). In addition, temperature affects the growth of plankton, where the optimal temperature ranges from 25-30°C (Pourafrasyabi and Ramezanpour, 2012).

The pH values obtained showed no significant difference (Table 5). The pH values obtained in Sine and Cengkrong mangroves ranged from 7-7.86. Based on water quality standards for marine biota in mangroves by Indonesian Ministry of Environment Regulation No 51/2004 (MENLH, 2004), the optimal pH value ranges from 7-8.5. The pH value obtained is good for supporting the sustainability of aquatic life with values ranging from 6.5-8 (Wassie and Melese, 2017).

The conductivity values obtained ranging from 0.18-2.14 S/m were not significantly different among the sampling locations (Table 5). The highest conductivity value recorded was in the Cengkrong 2008-2009 restoration which ranged from 2.14 S/m, while the lowest was in the 2005 succession mangroves at 0.18 S/m. The conductivity of marine waters has a high value because it contains dissolved salts that can be ionized. High electrical conductivity also indicates the many types of organic and mineral materials that enter as waste into the waters (Alshawafi *et al*., 2016).

DO values obtained ranging from 2.47-5.21 mg/L showed no significant difference (Table 5). The location of Cengkrong 2013-2014 had a DO value of 4.2-4.74 mg/L, natural Cengkrong had a DO value of 4.47-4.63 mg/L, and 2005 succession mangroves had a DO value of 4.6-4.83 mg/L. The highest DO value recorded was in the Cengkrong 2008-2009 restoration (5.21 mg/L), while the lowest was in the Sine mangrove (2.47 mg/L). The DO value standard of > 5 mg/L by Indonesian Ministry of Environment Regulation No 51/2004 (MENLH, 2004) was only met by Cengkrong mangrove 2008-2009 restoration site. DO has a role in the reduction and oxidation of organic and inorganic materials (Pour *et al*., 2014). According to Onyema (2013), the range of DO values between 4-6.5 mg/L is good for the sustainability of plankton. The low value of DO in Sine is due to the influence of anthropogenic activities such as tourist attractions, and settlements that produce a lot of organic and inorganic waste from the disposal of the surrounding population. Meanwhile, the high DO value at Cengkrong 2008-2009 was due to the location being far from anthropogenic activities and land degradation so that mangrove growth was optimal and capable of maximal remediation of organic matter (Hilmi *et al*., 2020; Samara *et al*., 2020). Dissolved oxygen in water is used by aquatic organisms for cell metabolism through the respiration process so that energy is formed (Singh *et al*., 2017)

The BOD values obtained showed significant differences ranging from 2.64-5.96 mg/L (Table 5). The highest BOD value was found in the natural Cengkrong mangrove at 5.96 mg/L, while the lowest was in the Cengkrong 2008-2009 restoration at 2.64 mg/L. The BOD values recorded at all sampling locations of Sine and Cengkrong mangroves followed the water quality standard for marine biota by Indonesian Ministry of Environment Regulation No 51/2004 (MENLH, 2004), which was 20 mg/L. According to Singh *et al.* (2017), dissolved oxygen in waters is utilized by aerobic bacteria to oxidize organic matter content in water. The higher the BOD, the higher the decrease in dissolved oxygen in an aquatic system. Changes in BOD were negatively correlated with DO and were consistent with DO results. Where a high BOD value will reduce DO levels in the waters. Remediation by mangroves can reduce the organic matter content at the Cengkrong location 2008-2009. Meanwhile, at the 2005 succession mangroves was due to the accumulation of pollutants and the condition of the mangrove sapling with only 1 type of mangrove (Wall and Nielsen, 2012).

The salinity values obtained showed a significant difference (Table 5). The salinity values obtained in Sine and Cengkrong mangroves ranged from 0-15 ‰. The highest salinity value was found in the Sine and Cengkrong 2008-2009 restoration of 15 ‰, while the lowest salinity value was found in the Cengkrong 2013-

2014 restoration of 0 ‰. The salinity value at 5 locations of Sine and Cengkrong mangroves is following water quality standards for marine biota in mangrove Indonesia Ministry of Environment Regulation No 51/2004 (MENLH, 2004), which is >34 ‰. According to Nybakken (1992), the optimal salinity value for brackish and marine plankton ranges from 0-30 ‰.

The value of the nitrate content obtained showed a significant difference (Table 5). The value of nitrate levels obtained in Sine and Cengkrong mangroves ranged from 0.12-1.6 mg/L. The highest value of nitrate was in the 2005 succession mangroves of 1.6 mg/L, while the lowest values of nitrate were in Cengkrong 2008-2009 restoration of 0.12 mg/L. Based on the water quality standard for marine biota by Indonesian Ministry of Environment Regulation No 51/2004 (MENLH, 2004), where the optimal value of nitrate is 0.008 mg/L, it showed that the nitrate levels at 5 locations did not meet the quality standards. The organic matter carried by surface runoff and deposited in waters normally originated from the residual of the plantation, agricultural, and livestock activities, then accumulates in rivers which eventually carried into the sea (Rohila *et al*., 2017). The difference in nitrate at the study site is due to the influence of the surrounding environment and river water that has accumulated from various areas that carry excess organic matter. In addition, it does not reach its quality standard because the ecosystem has reached the limit of its environmental carrying capacity (Brauman and Daily, 2008; Malik *et al*., 2015). In addition, the high content of nitrate and orthophosphate can also be caused by leaf litter, twigs, and rotting trees where the value of nitrate does not match the quality standard (Brauman and Daily, 2008).

The orthophosphate values obtained in the range of 0.14-0.71 mg/L showed no significant difference (Table 5). The highest value of orthophosphate was found in the Sine mangrove of 0.71 mg/L, while the lowest was in the 2008-2009 restoration of Cengkrong mangrove (0.14 mg/L). Based on the water quality standard for marine biota by Indonesian Ministry of Environment Regulation No 51/2004 (MENLH, 2004), the optimal value of orthophosphate levels is 0.015 mg/L, showing that only mangrove area of Cengkrong 2008-2009 restoration met the standard (0.14 mg/L). Nitrate and phosphate are important factors affecting the productivity of waters and the abundance of phytoplankton (Nybakken, 1992). The high value of orthophosphate in Sine as well as in nitrate is due to community activities that contribute to pollutants from household waste (Malik *et al*., 2015; Sari *et al*., 2017).

3.4 Correlation between Mangrove Diversity and Restoration Period with Water Quality, Phytoplankton Community Structure and Diversity in the Cengkrong and Sine

Based on the biplot correlation test, mangrove composition and restoration time have a relationship with water quality, phytoplankton community structure, and diversity (Figure 5). Cengkrong mangrove restoration in 2008-2009 and 2013-2014 are characterized by high mangrove taxa richness due to planting, which resulted in improved water quality characterized by moderate *H*' and *E*, and low levels of eutrophication and organic pollutants characterized by TDI values and low %PTV. Mangroves react as phytoremediators that reduce the organic matter and nutrients levels in the ecosystem, thus reduce nitrate and phosphate concentrations (Saputra *et al*., 2020). Sine and 2005 succession mangroves have low mangrove taxa richness and high nitrate levels, contributing to eutrophication and contamination of organic matter characterized by high TDI and %PTV. However, the 2005 succession mangroves is characterized by high DO, orthophosphate levels, and moderate phytoplankton community structure which is almost the same as the natural Cengkrong mangrove profile. Meanwhile, the natural Cengkrong mangrove ecosystem has the highest nutrient content, namely orthophosphate and diverse composition of phytoplankton which is characterized by high H' and E. Orthophosphate is useful as a source of nutrients used for living aquatic organisms (Duwig *et al*., 2014). Sources of organic matter and nutrients in each location are from human activities. In Sine Beach, there are tourism and residential activities, while the natural Cengkrong mangroves and 2005 succession mangroves are natural successional processes after illegal logging. So it can be concluded that the restoration carried out in the Pancer Cengkrong mangrove is better than the Sine mangrove, which is indicated by the water quality is almost close to the natural Cengkrong mangrove. In addition, the Sine mangroves also found massive anthropogenic activity around them.

4. Conclusion

Water quality at five sampling locations of Sine and Cengkrong mangroves varied greatly, and met the standard for marine biota (Indonesian Ministry of Environment Regulation No 51/2004), except for nitrate and phosphate. Shannon-Wiener diversity index (H') showed that the study sites had high species diversity. However, based on the TDI index, the mangroves at Sine, Cengkrong 2013-2014 restoration, and 2005 succession mangroves are in the hyper-eutrophic category, natural Cengkrong mangroves are in the eutrophic category, and the restored Cengkrong mangroves 2008-2009 are in the meso-eutrophic category. The level of organic pollution based on the %PTV index, the mangrove ecosystem of Sine, Cengkrong restoration 2013-2014, and 2005 succession mangroves are classified as high levels of organic matter pollution, is due to a large number of anthropogenic activities carried out. Meanwhile, the restoration of the 2008-2009 Cengkrong mangroves and the natural Cengkrong mangroves are classified as moderate levels of organic matter pollution and can cause eutrophication. The conclusion is based on the physicochemical parameters and the biotic index of phytoplankton, the research location that is said to be successful in ecosystem restoration is the 2008-2009 restoration mangrove location.

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Authors' Contributions

All authors have contributed to the final manuscript. The contribution of each author is as follows, Satria; collected the data, drafted the manuscript, and designed the figures dan table. Catur and Luchman; devised the main conceptual ideas and critical revision of the article. All authors discussed the results and contributed to the final manuscript.

Conflict of Interest

The authors declare that they have no competing interests.

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