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Evaluation of the quality of mangrove ecosystems using macrozoobenthos as bioindicators in the Southern Coast of East Java, Indonesia

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Abstract. *Retnaningdyah C, Febriansyah SC, Hakim L. 2022. Evaluation of the quality of mangrove ecosystems using macrozoobenthos as bioindicators in the Southern Coast of East Java, Indonesia. Biodiversitas 23*: 6480-6491. The mangrove ecosystem in East Java has been degraded due to land use change. Some of these mangrove ecosystems have been restored. However, the success of these restoration activities has never been evaluated. This study aimed to evaluate the quality of some mangrove ecosystems on the Southern Coast of East Java by observing the physical and chemical quality of water and macrozoobenthos that live in mangroves, especially crustaceans and gastropods, as bioindicators. Samplings were carried out on seven mangrove ecosystems, namely restored ecosystems (Cengkrong, Sine, Getem, Kondang Merak, Clungup Mangrove Conservation/CMC) and natural ecosystems as reference sites (Alas Purwo National Park/TNAP and Sempu island). The water quality parameters observed were pH, conductivity, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), nitrate, orthophosphate, Total Suspended Solid (TSS), salinity, sulfide content (H_2S), oil and fat content, and dissolved lead (Pb) content. The macrozoobenthos communities observed were gastropods and crabs, while the mangrove communities monitored were only trees, using plots, each measuring 10x10 m. The results showed that some water quality parameters did not meet the sea water quality standards for marine life, namely DO and nitrate levels for all locations, H_2S, and oil/fat in some locations. The quality of the restored mangrove ecosystem in the Cengkrong and CMC areas was better than that of other sites, with a Shannon-Wiener species diversity index (H') for mangrove trees of 2.796 and 2.235 and was close to the quality at the reference sites, namely Alas Purwo and Sempu island (H' 2.953 and 2.356). The H' value of macrozoobenthos in the Cengkrong and CMC mangrove ecosystem was also high (4.37 and 3.47) and almost the same as the H' value of Sempu Island and Alas Purwo (3.45 and 3.88), while in other mangrove ecosystems it ranged from 1.33 to 2.60. The species diversity of mangrove vegetation had a significant (α 0.05-0.1) to very significant (α <0.05) positive correlation with the diversity of crabs and gastropods, so the diversity of macrozoobenthos (crabs and gastropods) can be used as a bioindicator of the quality of the mangrove ecosystem.

Keywords: Crabs, gastropods, mangrove restoration, water quality

INTRODUCTION

Mangrove is an ecosystem that grows in land and sea transition areas and is often influenced by tides (Noor et al. 2006). Mangrove ecosystems have halophytic characteristics, areas exposed to tides, muddy environmental conditions, and accumulation of organic matter (Yuvaraj et al. 2017). Mangroves play ecological roles as a place for breeding various aquatic and terrestrial species (fish, crustaceans, mollusks, etc.), as a protector from sea wave abrasion, as a habitat for flora and fauna, as a place for organic detritus to coastal areas to support water productivity, and as a carbon sink (Saifullah et al. 2016; Asuk et al. 2018).

Indonesia has rich mangrove ecosystems, which spread from Sumatra to Papua. One of them is on the coast of the island of Java. There are a lot of mangrove ecosystems with different habitat types. The difference in environmental conditions between the northern and southern regions causes the formation of a distinctive habitat (van Oudenhoven et al. 2015; Arif et al. 2017). The ideal area for mangroves to grow is the northern coast of Java, where the area is a large river estuary area and is rich in organic matter. On the other hand, the southern coast of Java has a small estuary area and is exposed to the waves of the Indian Ocean, causing a lack of supply of coastal sediments and steep topography. Therefore, the mangroves in the southern region receive less attention, so data on these mangroves are lacking (van Oudenhoven et al. 2015; Mughofar et al. 2018; Saputra et al. 2020).

Anthropogenic activities significantly influence the mangroves on the southern coast of Java. Mangrove ecosystems on the south coast of Java, especially in East Java, have been severely degraded by human activities, such as land conversion into ponds, agriculture, and plantations (Cambell and Brown 2015; Biswas and Biswas 2019). Some beaches that have experienced degradation are Cengkrong Beach (Mughofar et al. 2018), Sine Beach (Saputra et al. 2020), Getem Beach, Kondang Merak Beach, and Clungup Mangrove Conservation (Hakim et al. 2017; Retnaningdyah et al. 2021). Continuing human activities without any countermeasures can reduce the carrying capacity (Malik et al. 2015), which decreases the quality of mangrove ecosystem services (Rohila et al. 2017; Darmawan et al. 2020). Ideally, degraded ecosystem should be restored to its natural condition (Nichols et al. 2019).

The success of the restoration is reflected in the increase in the diversity of the mangrove vegetation, the improved physical and chemical quality of the environment, and the diversity of macrozoobenthos that live in the mangroves, such as crustaceans and gastropods, as bioindicators. Physical and chemical parameters that can be used as indicators of water quality are pH, conductivity, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Total Suspended Solid (TSS), salinity, orthophosphate, nitrate, Sulfide content (H_2S), oil and fat content, and dissolved lead (Pb) content. Macrozoobenthos is a community of invertebrate fauna that lives in sediments and surfaces such as attached to leaves, roots, and tree branches, which can be used as a bioindicator (Dorić and Učukovic 2017). Macrozoobenthos consists of several groups: Insects, Molluscs, Oligochaeta, and Crustaceans (Sihombing et al. 2017; Shaiek et al. 2018). Crabs, including crustaceans, are the dominant marine fauna found in mangrove ecosystems besides Molluscs and Gastropods. This research focused on macrobenthos, i.e., gastropods and crabs, as bioindicators.

Gastropods and crabs are macrofauna often found in mangrove ecosystems because mangroves are ideal habitats that support their survival (Sihombing et al. 2017). Gastropods and crabs play a role in food webs in aquatic ecosystems (Batvari et al. 2016). Gastropods and crabs are often used as ecosystem bioindicators because they live attached to the substrate and at the bottom of the water (mud and sand), which causes direct contact with pollutants that enter their habitat (Sharma et al. 2018; Nur et al. 2021; Sueb et al. 2021). Gastropods and crabs also have relatively long and sedentary life cycles, so they can be used to detect ecosystem temporal and spatial changes (Shaiek et al. 2018; Afwanudin et al. 2019). Crabs make permanent and semi-permanent holes in the soil or substrate in the mangrove ecosystem as their habitat. Different types of mangrove vegetation are inhabited by different crabs (Katili et al. 2017). Thus changes in environmental factors will significantly affect the community structure and diversity of crabs (Lapolo et al. 2018). This study aimed to evaluate the quality of the mangrove ecosystem on the southern coast of East Java by monitoring the water's physical and chemical quality, the community structure and diversity of macrozoobenthos, especially crabs and gastropods, and the diversity of mangrove vegetation. The results can be used as a basis for recommendations for using macrozoobenthos as a bioindicator of mangrove ecosystem quality.

MATERIALS AND METHODS

Study area

The research was carried out from June to November 2021. Samplings were carried out on seven mangrove ecosystems on the southern coast of East Java, Indonesia, consisting of two types: the restored mangrove ecosystem and the natural mangrove ecosystem as a reference site (Figure 1). The restored mangrove ecosystems were located at Cengkrong Beach in Trenggalek District, Sine Beach in Tulungagung District, Getem Beach in Jember District, Kondang Merak Beach, and Clungup Mangrove Conservation (CMC) in Malang District. The natural mangrove ecosystems were located at Bedul Beach (Alas Purwo National Park/TNAP) in Banyuwangi District and Sempu Island in Malang District. Data analysis and identification of gastropods and crabs were carried out at the Laboratory of Ecology and Tropical Ecosystem Restoration, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya, Malang.

The research is Ex Post Facto, a method to select a causal effect phenomenon that has occurred in the field, so researchers just need to see the effect on the dependent variables. The dependent variables in this study were the physical-chemical parameters of water quality, the diversity and abundance of mangrove trees, and macrozoobenthos, while the independent variable was the type of mangrove ecosystem, i.e., restoration or natural ecosystem. The design for determining the sampling location used purposive random sampling based on time restoration. In each ecosystem, samplings were carried out on 3-11 plots as replication.

Samplings in the Cengkrong Trenggalek area were carried out on the mangrove ecosystem restored in 2008 (3 plots), and in 2013 (4 plots), natural mangroves which were left over from logging in 2005 (2 plots), and mangrove ecosystems resulting from natural succession after the logging (2 plots). Samplings in CMC were carried out on mangrove ecosystems restored in 2015 (3 plots), natural ecosystems with the addition of periodic plantings (3 plots), and natural mangroves (at Kondang Buntung) (3 plots). Meanwhile, samplings at Sine Beach, Getem Beach, and Kondang Merak Beach were carried out on one mangrove ecosystem type, each using 3 plots. The mangrove ecosystem at Sine Beach was the result of restoration starting in 1975, at Getem beach was the result of restoration in 1980, while at Kondang Merak Beach was the result of rehabilitation in 2019. Samplings of the mangrove ecosystem at the Sempu Island reference site were carried out in Teluk Semut (3 plots), Raas Bay (2 plots), and Sumber Air Tawar (2 plots). Meanwhile, at the reference site in Alas Purwo/TNAP, 8 plots were taken in the Bedul Beach area.

Mangrove trees vegetation sampling

Trees vegetation analysis was carried out by making plots, each measuring 10x10 m. Characteristics of trees mangrove vegetation are the mangrove plant with a height was >1 m and diameter at breast height (DBH) >4 cm. In each plot, we monitored the species and density of each species found in the plot. The result of vegetation analysis then be used to determine the profile of community structure including taxa richness, total density, evenness, dominance index and Shannon Wiener diversity index.

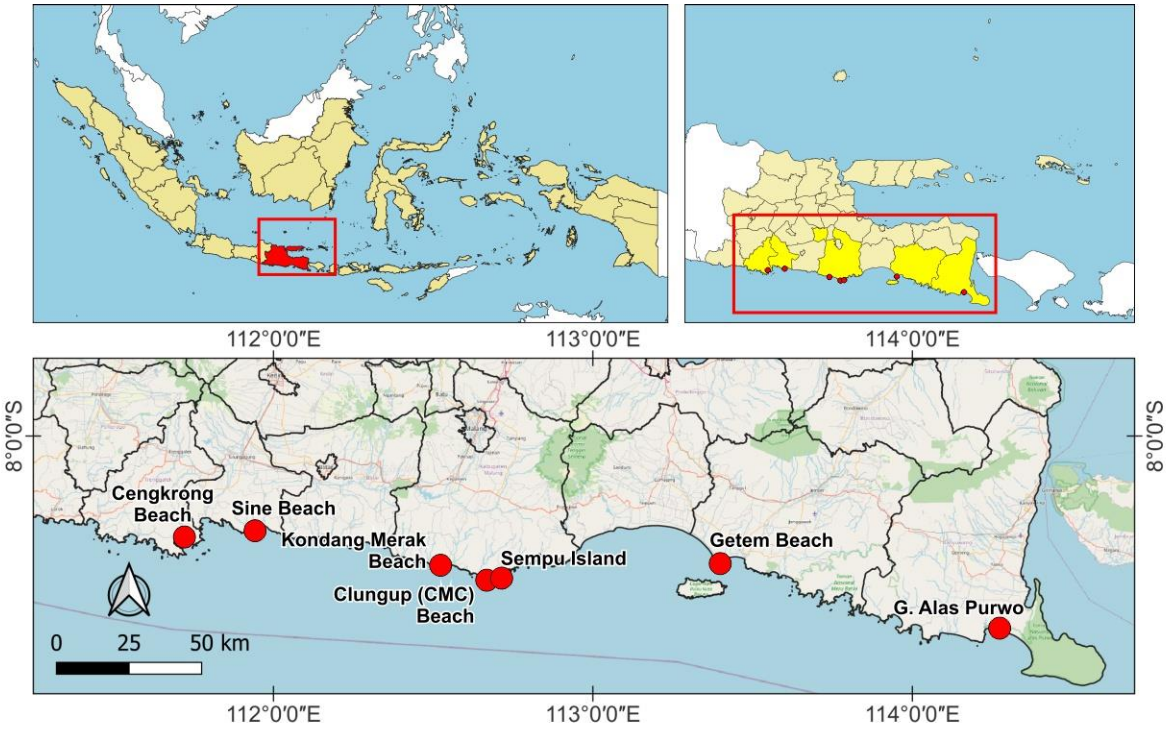

Figure 1. Sampling location in this research

Sampling, identification and counting of macrozoobenthos

In this study, sampling of macrozoobenthos was only carried out on mangrove crabs and gastropods. Benthos sampling in each mangrove ecosystem was carried out by making a plot of 1x1 m, consisting of two methods, namely the digging method and the visual encounter method. The digging method was carried out by digging the substrate approximately 10 cm depth and then filtering using a sieve (0.5 mm mesh) (Marini et al. 2013). The visual encounter method was carried out by directly counting the crabs and gastropods contained in the plot. Some of the crabs and gastropods were taken for identification. The obtained benthic samples (gastropods and crabs) were preserved with 70% alcohol solution in labeled plastic containers for further analysis (Hastuti et al. 2018; Rahman et al. 2021). Samples were observed using a stereo microscope with a magnification of 40-100x and identified using a guide from books (Dharma 2005; Murniati and Pratiwi 2015; Bowling 2019). The identified samples were counted as the total number of individuals/m^2.

Water sampling and measurement of water physicochemical parameters

Water sampling was carried out on the same plot as the macrozoobenthos sampling location. One-liter water sample was taken using a plastic bottle. The measured water physicochemical parameters were pH, conductivity, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), nitrate, orthophosphate, Total Suspended Solid (TSS), salinity, sulfide content (H_2S), oil and fat content, and dissolved lead (Pb) content (Table 1). The physicochemical parameters measured at the site were pH, DO, conductivity, TSS, and salinity. The other parameters were measured in the laboratory.

Mangrove biota data analysis

The diversity and abundance of macrozoobenthos (crabs and gastropods), and mangrove trees were determined by calculating total density/abundance, species richness, Shannon-Wiener Diversity Index (H'), Dominance Index (D), and Evenness Index (E). Difference test analysis of water physicochemical parameter data at each location was conducted using ANOVA test followed by Tukey HSD. The correlation between physicochemical properties of water and the biotic index (macrozoobenthos and trees) was carried out by biplot analysis from principal component analyzes (PCA) using PAST 16.0 software. The results of this PCA analysis can also determine whether macrozoobenthos can be used as a bioindicator of mangrove ecosystem quality.

Table 1. Physicochemical parameters measured along with units and methods (Clesceri et al. 1998)

Parameter	Unit	Method
pH	-	pH meter
Conductivity	S/m	Conductivity meter
Dissolved Oxygen (DO)	mg/L	Digital oxygen meter
Biochemical Oxygen Demand (BOD)	mg/L	Digital oxygen meter
Total Suspended Solid (TSS)	mg/L	Gravimetry
Salinity	%	Refraktometer
Nitrate	mg/L	Brucine methods
Orthophosphate (dissolved phosphate)	mg/L	Stannous chloride
Dihydrogen Sulfide (H_2S)	mg/L	Spectrophotometry
Oil and fat	mg/L	Gravimetry
Dissolved Pb	mg/L	Spectrophotometry

The followings are the measured biotic index equations:

Shannon-Wiener Diversity Index (H')

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

Where:
H' : The value of the Shannon-Wiener diversity index
s : Total number of species in the community
Pi : The proportion of the number of individuals of the each species to the total number

Dominance Index (D)

$$D = Ni(Ni - 1)/N(N - 1)$$

Where:
D : Simpson's dominance index
Ni : Number of individuals of the i species
N : Total number of individuals found

Evenness Index (E)

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

Where:
E : Evenness Index
H max : ^{2}Log S
H' : The value of the Shannon-Wiener diversity index

RESULTS AND DISCUSSION

The physical and chemical quality of water

The physical and chemical quality of water in seven mangrove ecosystems are presented in Table 2. The pH of the water ranged from 7.21 to 7.98, meeting the standard of seawater quality for marine life based on the Decree of the State Minister of the Environment No. 22 of 2021 concerning Seawater Quality Standards for Marine Biota, which determines the pH ranging from 7 to 8.5. The water pH is influenced by the intensity of sunlight needed by producers to carry out the photosynthesis process and subsequently also has an impact on the acidity of the water (Yildiz et al. 2013; Charan et al. 2017; Mohamed et al. 2019). According to Wassie and Melese (2017), the ideal pH value for supporting the survival of aquatic ecosystems is between 6.5 and 8.

Dissolved oxygen (DO) levels in the mangrove ecosystem of the south coast of East Java ranged from 3.55 to 5.42 mg/L. DO levels based on the Decree of the State Minister of the Environment No. 22 of 2021 concerning Seawater Quality Standards for Marine Biota require a minimum of 5 mg/L. Thus, the DO levels in the mangrove ecosystem of the south coast of East Java did not meet the quality standards, except in Alas Purwo. Only the mangrove ecosystem in the Alas Purwo area had met the quality standards. The government protects the location by establishing it as a National Park called TNAP, categorized as a conservation forest, which was used as a reference site in this study. DO levels in waters affect the respiratory activity of aquatic organisms (Singh et al. 2017). Each organism has a certain tolerance range for oxygen levels in the waters (Haas et al. 2014). The optimum DO levels for the growth of macrozoobenthos, especially mangrove crabs, ranged from 5.11 to 5.77 mg/L (Faturrohman et al. 2017).

The low DO levels in some mangrove ecosystems may be influenced by the water's organic matter content (Singh et al. 2017). The levels of organic matter in the waters can be shown by the BOD value. The BOD levels in the study area ranged from 2.35 to 7.87 mg/L. This BOD level met the quality standard value set for marine biota, which is 20 mg/L. High levels of BOD were found in the mangroves of the TNAP area, possibly due to a large amount of mangrove litter and animal waste found in the area (Kroeger et al. 2017; Eddy et al. 2021). These results showed that human activities around the waters can still be supported by this mangrove ecosystem, so the organic pollutants can be immediately purified naturally by microbes in the waters (Sannigrahi et al. 2020). The levels of organic matter can affect the community structure of aquatic organisms. Each organism has a wide or narrow tolerance range to organic matter (Mizwar and Surapati 2020). If the organism has a wide tolerance range for organic matter, it is included in the group of organisms that are tolerant of organic matter contamination and vice versa. High BOD levels in waters indicate high organic pollution (Singh et al. 2017). Only the types of organisms that are tolerant of this organic matter contamination will live (Mizwar and Surapati 2020).

The turbidity level is indicated by the water's total suspended solids (TSS) (Wisha and Ondara 2017). The total suspended solids content in the study sites ranged from 0.62 to 3.13 mg/L. In general, this TSS value has met the water quality standard for marine biota in mangrove PP NO. 22/MENLH/2021, which set a maximum value of 80 mg/L. High suspended solids in the waters can inhibit the penetration of the sunlight and subsequently also decrease the primary productivity of macroalgae in the waters (Buana et al. 2021). In addition, a high TSS will also reduce the crabs' mobility, resulting in a decrease in predation speed (Lunt and Smee 2015).

The salinity of the waters in the study sites ranged from 0.67 to 35.43%. A maximum salinity threshold based on water quality standards for marine biota in the mangrove ecosystem, according to the Decree of the State Minister of the Environment No. 22 of 2021, is 34%. Several locations, such as CMC and Sempu Island, had high salinity because they are located very close to seawater, so at high tide, the sea water enters the mangrove ecosystem. At the Kondang Merak mangrove, the salinity was low because it is located adjacent to the river. This salinity is directly proportional to the conductivity of the water. The conductivity values at the study site ranged from 0.22 to 5.05 S/m.

Nitrate levels ranged from 0.08 to 1.13 mg/L and orthophosphate levels from 0.01 to 0.14 mg/L. The maximum threshold of nitrate for marine life is 0.008 mg/L. Thus, all the observed waters have exceeded the specified quality standard value. These results support the high organic matter content. Human activities around the waters strongly influence nitrate and orthophosphate levels. These high levels of nitrate and orthophosphate will trigger eutrophication, leading to algae blooms (Inyang and Wang 2020).

Dihydrogen sulfide (H_2S) levels in some mangrove ecosystems in the study sites ranged from 0.0001 to 0.0963 mg/L. The maximum level of sulfide required for biota life (Decree of the State Minister of the Environment No. 22 of 2021) is 0.01 mg/L. High levels of sulfide in some locations are caused by high levels of organic matter with low DO, so high decomposition of organic matter can occur anaerobically, which increases levels of H_2S (Sherief and Hassan 2022).

Oil and fat levels in the study area ranged from 0.90 to 2.56 mg/L. The maximum threshold level of oil and fat content for marine biota based on the Decree of the State Minister of the Environment No. 22 of 2021 is 1 mg/L. All research locations had oil and fat content exceeding the specified quality standard values, except in the Getem and Kondang Merak areas. Meanwhile, the dissolved lead content in the study area ranged from 0.0014 to 0.0042 mg/L, which, in all locations, met the water quality standards for marine biota based on the Decree of the State Minister of the Environment No. 22 of 2021, with the maximum threshold value of 0.008 mg/L. According to Kadarsah et al. 2020, the ideal content for dissolved Pb in water ranges from 10^{-5} to 10^{-2} ppm. The presence of excess dissolved heavy metals will have a negative impact on aquatic biota because metals are toxic and can damage organs in the body.

The species diversity and abundance of mangrove trees

Each mangrove ecosystem observed has different characteristics (Table 3). In all of the research locations, we found 22 species of trees. The restored mangrove ecosystem in the Cengkrong area had the highest species richness, i.e., 14, almost the same as the location of the TNAP reference site (12 species). The mangrove ecosystems of Cengkrong and Getem also had a high tree density ranging from 41 to 54 individuals/100m^2. Kondang Merak had the lowest density of trees (5 Individuals/100m^2), while other locations have medium densities ranging from 18-30 Individuals/100m^2.

The Cengkrong mangrove ecosystem had Shannon-Wiener tree species diversity (2.796), almost the same as that in the TNAP location (2.953). The restored mangrove ecosystem in the Cengkrong area had better quality than other ecosystems. Meanwhile, the tree species diversity index in Sine and Kondang Merak was very low (0.353-0.359), indicating that these two mangrove ecosystems were still degraded. This is also supported by low evenness index (0.353-0.718) and high dominance index (0.774-0.867). Restoration efforts that have been carried out in several locations have not increased the mangrove diversity index significantly. Mangrove degradation in East Java is due to land conversion for aquaculture and other land uses, and illegal logging for firewood (Thomas et al. 2017; Rudianto et al. 2020).

The species diversity and abundance of macrozoobenthos in mangrove ecosystems

The number of species and the abundance of macrozoobenthos varied among mangrove ecosystems. The total number of mangrove crab species in all study sites was 29 (Table 4), while for gastropods was 56 (Table 5). The mangrove crab species at the reference site was 14, with a total abundance of 23 individuals/m^2 (Sempu island), while in TNAP 9 species were found, with a total abundance of 750 individuals/m^2. The restored mangrove ecosystem of the Cengkrong area (restoration in 2008, 2014, and natural remains) has the same and even higher species richness than the mangrove ecosystem at the reference site, which had 15 species with a total abundance of 142 individuals/m^2.

The species richness and abundance affect the diversity index (H'), Evenness (E), and dominance index (D). The Shannon-Wiener mangrove crab species diversity index value in the mangrove ecosystems of CMC, Cengkrong, Sempu island, and Alas Purwo was high (2.20-3.12), while in other ecosystems was low (0.34-1.87). Low evenness values and high dominance index were found in the Getem and Kondang Merak mangrove ecosystems (Table 4).

The highest gastropod species richness was found in the Cengkrong Mangrove ecosystem (27 species), exceeding the reference site area of Sempu Island (17 species) and Alas Purwo (18 species). Gastropod species richness in other mangrove ecosystems ranged from 3 to 8 species. The highest total abundance was found in Alas Purwo (4525 individuals/m^2), while the lowest was found in the Malang area (CMC, Kondang Merak, and Sempu island ranging from 22-75 individuals/m^2). Other mangrove ecosystems had a total abundance between 416-500 individuals/m^2 (Table 5). The Shannon Wiener diversity index (H') and evenness (E) of mangrove gastropods at all locations were in the low to moderate category (H': 0.07-1.96 and E: 0.03-0.57), while the dominance index value was low (0.04-0.37) except in Kondang Merak ecosystem (0.88).

Table 2. Physicochemical water quality profile in seven mangrove ecosystems on the South Coast of East Java, Indonesia

Parameter	Cengkrong	Sine	Getem	CMC	Kondang Merak	Sempu Island	Alas Purwo	Standard
pH	7.21±0.16 a	7.82±0.07 bc	7.62±0.04 abc	7.49±0.21 ab	7.82±0.09 bc	7.62±0.39 bc	7.98±0.08 c	7-8.5
Conductivity (S/m)	1.07±0.57 a	0.34±0.25 a	1.60±0.06 a	4.43±1.29 bc	0.22±0.03 a	5.05±0.28 c	3.42±0.48 b	-
DO (mg/L)	3.90±0.93 a	4.71±0.12 ab	3.55±0.24 a	4.06±0.54 ab	4.80±0.04 ab	4.70±0.95 ab	5.42±0.23 b	>5
BOD (mg/L)	4.38±2.01 ab	4.09±0.84 ab	2.35±0.67 a	5.13±1.76 ab	3.87±0.82 ab	4.86±1.43 ab	7.87±3.83 b	20
Salinity (%)	7.55±4.70 ab	5.00±2.60 a	10.00±0.0 ab	30.22±11.31 cd	0.67±0.58 a	35.43±1.72 d	20.13±5.82 bc	34
TSS (mg/L)	3.13±1.42 a	1.57±0.22 a	0.62±0.47 a	2.78±2.23 a	0.99±0.22 a	0.83±0.30 a	2.42±0.89 a	80
Nitrate (mg/L)	0.29±0.20 ab	1.13±0.55 c	0.62±0.18 b	0.10±0.05 a	0.65±0.18 b	0.08±0.06 a	0.10±0.05 a	0.008
Orthophosphate (mg/L)	0.04±0.02 a	0.03±0.00 a	0.08±0.02 b	0.01±0.01 a	0.02±0.01 a	0.01±0.00 a	0.14±0.02 c	-
H_2S (mg/L)	0.0057±0.0097 a	0.0001±0.0000 a	0.0001±0.0000 a	0.0001±0.0000 a	0.0963±0.0550 c	0.0502±0.0376 b	0.0613±0.0096 bc	0.01
Oil and Fat (mg/L)	1.31±0.57 a	1.83±0.29 a	0.90±0.00 a	1.37±0.26 a	0.97±0.06 a	2.56±2.48 a	1.61±0.44 a	1
Dissolved Pb (mg/L)	0.0014±0.0000 a	0.0014±0.0000 a	0.0022±0.0024 a	0.0015±0.0000 a	0.0042±0.0048 a	0.0019±0.0008 a	0.0024±0.0015 a	0.008

Note: The same letter notation at the same parameter showed no significant difference between location based on the ANOVA test followed by Tukey HSD α 0.05; n=3

Table 3. The species diversity and abundance of mangrove trees on the Southern Coast of East Java, Indonesia

Location	Species diversity and abundance of mangrove trees				
	Total density (individuals/100m^2)	Species richness	Shannon-Wiener diversity index	Evenness	Dominance index
Cengkrong	54	14	2.796	0.734	0.215
Sine	30	4	0.718	0.359	0.774
Getem	41	3	1.374	0.867	0.419
CMC	18	7	2.235	0.796	0.232
Kondang Merak	5	2	0.353	0.353	0.867
Sempu Island	28	9	2.356	0.743	0.245
Alas Purwo	26	12	2.953	0.824	0.165

Crabs and gastropods mangroves are part of the macrozoobenthos. In general, the highest density of macrozoobenthos (Figure 2) was found in TNAP (5275 individuals/m^2). Mangrove ecosystems in Cengkrong, Sine, and Getem had moderate macrozoobenthos density ranging from 449-1367 individuals/m^2. Meanwhile, other mangrove ecosystems had low densities (46-123 individuals/m^2). The species richness of macrozoobenthos in Cengkrong (42 species) was higher than the TNAP reference site (27 species) and Sempu island (31 species). Mangrove ecosystems in other locations have a species richness of 6-16. Species richness and abundance affect the value of the macrozoobenthos species diversity index (Figure 2). The Cengkrong and CMC mangrove ecosystems had a macrozoobenthos diversity index (4.37 and 3.47), almost the same as that in Sempu Island and TNAP reference sites (3.45 and 3.88). Macrozoobenthos diversity index values in other locations were moderate to high and ranged from 1.33 to 2.60. This shows that the restoration results in Cengkrong and CMC have been successful.

The low species richness and macrozoobenthos diversity at the Sine, Getem, and Kondang Merak mangrove locations are caused by anthropogenic activities such as settlements, tourism, and land conversion. The impacts of anthropogenic activities, such as waste pollution and ecosystem damage, can disrupt the survival of aquatic organisms (providing nutrients and habitat) and reduce the quality of the ecosystem (Biswas and Biswas, 2019; Zanardi-Lamardo et al. 2019). The existence of macrozoobenthos, especially mangrove crabs, is strongly influenced by the substrate type and can live intertidal with a cosmopolitan distribution in both the tropics and subtropics (Shih et al. 2016).

The Evenness index and Simpson's dominance index showed that the abundance of macrozoobenthos (gastropods and crabs) at the research site was uniform with the Evenness index (E) value >0.6 (except Kondang Merak with an E value of 0.52). Meanwhile, the dominance index (D) was low to moderate, ranging from 0.06 to 0.47 (Figure 2). Evenness value >0.6, according to Wu et al. (2014), indicates an even distribution of species, while a D value below 0.4 indicates the absence of dominance in an ecosystem.

Correlation between water quality, macrozoobenthos community structure and the species diversity of mangrove trees

The Biplot using PCA (Figure 3) showed that the study sites were divided into three groups. The mangrove ecosystems in Cengkrong and CMC had similar characteristics, characterized by the high diversity of gastropods and crabs, low nitrate, and H_2S with moderate levels of DO and BOD. The high species diversity of macrozoobenthos in this location was also supported by the high species diversity of trees.

The second group is the reference site mangrove ecosystem, namely Sempu island and TNAP, characterized by a high diversity of trees and macrozoobenthos (crabs), high DO and BOD levels, moderate H_2S levels, and low nitrate levels. The mangrove ecosystem of this reference site had almost the same characteristics as Cengkrong and CMC mangrove ecosystems, except for DO and BOD levels. Thus, it can be stated that the restoration activities in the Cengkrong and CMC mangrove ecosystems have been successful, with almost the same quality as the reference site mangrove ecosystem.

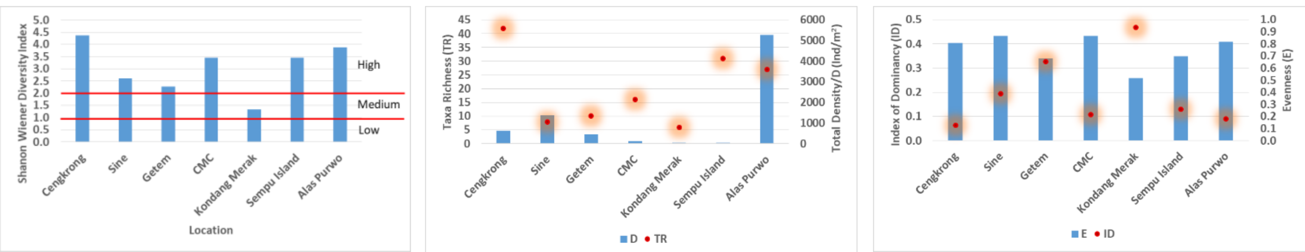

Figure 2. The species diversity and abundance of macrozoobenthos (crabs and gastropods) in mangrove ecosystems in Southern Coast of East Java, Indonesia

Table 4. Variations in species diversity and abundance of mangrove crabs on the southern coast of East Java, Indonesia

Family	Genus/Species	Crabs abundance (individu/m^2)						
		Cengkrong	**Sine**	**Getem**	**CMC**	**Kondang Merak**	**Sempu Island**	**Alas Purwo**
Dotillidae	*Ilyoplax* sp.	0.0	0.0	0.0	0.0	1.3	0.0	0.0
Grapsidae	*Grapsus longitarsis*	15.2	0.0	0.0	0.0	0.0	0.0	0.0
	Grapsus sp.	0.0	0.0	0.0	0.0	0.0	0.0	12.5
	Ilyograpsus sp.	3.8	0.0	0.0	0.0	0.0	0.0	0.0
	Metopograpsus latifrons	0.0	0.0	0.0	0.0	0.0	0.0	25.0
Ocypodidae	*Ocypode kuhlii*	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	Ocypode pallidula	0.0	0.0	0.0	0.0	0.0	0.3	0.0
	Ocypode quadrata	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	Ocypode sp.	6.0	0.0	0.0	2.5	0.0	0.7	0.0
	Uca annulipes	20.1	0.0	0.0	0.0	0.0	0.2	0.0
	Uca bellator	0.0	0.0	0.0	0.0	0.0	0.0	12.5
	Uca coarctata	4.5	200.0	0.0	0.0	0.0	0.6	25.0
	Uca crassipes	0.7	0.0	0.0	0.6	0.0	0.0	0.0
	Uca dussumieri	0.7	33.3	0.0	2.5	0.0	1.4	50.0
	Uca jocelynae	0.0	0.0	0.0	0.0	0.0	0.2	0.0
	Uca lactea	10.9	0.0	0.0	9.9	0.0	0.0	0.0
	Uca panacea	0.0	0.0	0.0	0.6	0.0	0.0	0.0
	Uca perplexa	2.3	0.0	0.0	3.7	0.0	0.0	12.5
	Uca rosea	3.0	0.0	0.0	0.0	0.0	0.9	0.0
	Uca sp.	1.1	0.0	0.0	9.3	0.0	0.0	0.0
	Uca tetragonom	0.8	0.0	0.0	3.7	0.0	0.1	0.0
	Uca triangularis	62.3	133.3	0.0	6.8	0.0	13.1	75.0
	Uca vocans	0.0	0.0	0.0	0.0	0.0	0.9	0.0
Sesarmidae	*Chiromantes* sp.	0.8	0.0	0.0	0.0	0.0	0.0	0.0
	Episesarma versicolor	0.0	0.0	2.1	4.3	0.0	0.0	0.0
	Paraserma spp.	10.2	433.3	0.0	0.0	16.1	4.5	337.5
	Sesarma guttatum	0.0	0.0	31.5	0.0	0.0	0.0	0.0
Varunidae	*Hemigrapsus* spp.	0.0	66.7	0.0	4.3	0.0	0.0	200.0
Xanthidae	*Etsus* spp.	0.0	0.0	0.0	0.0	0.0	0.3	0.0
n		11	3	3	9	3	7	8
Total Abundance (Individu/m^2)		142	867	34	48	17	23	750
Taxa Richness		15	5	2	11	2	14	9
Shannon Wiener Diversity Index (H')		2.74	1.87	0.34	3.12	0.39	2.20	2.24
Evenness (E)		0.70	0.80	0.34	0.90	0.39	0.58	0.71
Dominance Index (D)		0.23	0.33	0.88	0.11	0.85	0.33	0.29

The third group is the Kondang Merak, Sine, and Getem mangrove ecosystems with high nitrate levels, moderate H_2S and DO levels, low BOD and salinity levels, and low diversity of mangroves poles, crabs, gastropods, and macrozoobenthos. The mangrove ecosystem in these three locations has already been degraded, possibly caused by high human activities around the mangrove ecosystem, so more intensive mangrove vegetation revegetation is needed.

The Biplot (Figure 3) shows the species diversity of trees had the same direction as the diversity of crabs and gastropods, indicating that these variables had a positive correlation. This correlation was confirmed with the Pearson correlation test (Table 6), showing a significant positive correlation (α 0.05-0.10) to very significant (α<0.05) between the species diversity of mangrove trees and macrozoobenthos (crabs and gastropods). Therefore, the diversity of macrozoobenthos (crabs and gastropods) can be used as bioindicators of mangrove ecosystem quality. The biplot also shows a positive correlation between BOD levels and the diversity of crabs, indicating that crabs can survive at high levels of organic matter because crabs are detritivores that can decompose organic matter from detritus in their habitat (Li et al. 2015). However, the correlation between BOD and crabs was not significant based on Pearson correlation analysis (Table 6). The biplot indicated negative correlation between nitrate level and species diversity of trees. This negative correlation was confirmed by the Pearson correlation showing a very significant negative correlation between the two variables. This showed that the growth of mangrove vegetation cannot be optimal if the nitrate level in the waters is too high. Nitrogen is a nutrient for the growth and development of aquatic organisms (Laverman et al. 2021).

High nitrate levels have negative impacts on the environment such as eutrophication, increasing the growth of harmful algal blooms (HABs), decreasing water oxygen levels, and worsening the balance of the N biogeochemical cycle (Roberts et al. 2012; Li et al. 2014; Wei et al. 2020), although mangrove vegetation can denitrify nitrate in the waters and sediment (Alongi 2020; Hao et al. 2022). High nitrate levels will significantly disrupt mangrove growth and cause death because mangroves have reached a certain tolerance range (Hao et al. 2022).

Table 5. Variations in community structure and diversity of mangrove gastropods on the southern coast of East Java, Indonesia

Family	Genus/species	Gastropods abundance (individual/m^2)						
		Cengkrong	Sine	Getem	CMC	Kondang Merak	Sempu Island	Alas Purwo
Acteonidae	*Acteon tornatilis*	0.0	0.0	0.0	21.0	0.0	0.0	0.0
Arcidae	*Anadara granosa*	0.0	0.0	0.0	0.0	0.0	0.0	25.0
Assimineidae	*Assiminea brevicula*	23.4	0.0	0.0	0.0	0.0	0.0	0.0
	Sphaerassimineta miniata	26.4	0.0	38.7	0.0	0.0	0.0	937.5
Balanidae	*Balanus* sp	6.2	0.0	10.1	0.0	0.0	0.0	625.0
Batillariidae	*Batillaria* sp	0.0	0.0	0.0	0.0	0.0	4.6	0.0
Bithyniidae	*Bithynia truncatum*	0.0	266.7	0.0	0.0	0.0	0.0	0.0
Bivalveae	*Geloina expansa*	68.9	0.0	0.0	0.0	0.0	0.0	0.0
Cerithiidae	*Cerithidea cingulata*	0.0	0.0	0.0	0.0	0.0	0.0	125.0
	Cerithidea quoyii	50.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cerithideopsilla alata	0.0	0.0	0.0	0.0	0.0	0.1	62.5
Ellobiidae	*Cassidula aurisfelis*	0.0	0.0	0.0	0.0	1.3	0.2	12.5
	Cassidula nucleus	0.0	0.0	0.0	0.0	0.0	0.1	25.0
	Cerithium sp	0.0	0.0	0.0	0.0	0.0	0.0	375.0
	Ellobium sp	0.0	0.0	0.0	0.0	0.3	0.0	0.0
	Melampus nuxeastaneus	0.0	0.0	0.0	0.0	0.0	0.0	12.5
	Melampus parvulus	0.0	0.0	0.0	0.0	0.0	3.4	0.0
	Melampus sincaporensis	0.0	0.0	0.0	0.0	0.0	9.0	100.0
Isognomonidae	*Isognomon ephippium*	0.0	0.0	0.0	0.0	0.0	0.0	562.5
Littorinidae	*Littoraria angulifera*	2.6	0.0	0.0	0.0	0.0	0.0	0.0
	Littoraria intermedia	6.1	0.0	0.0	9.3	0.0	0.0	0.0
	Littoraria scabra	13.1	0.0	17.3	0.0	0.0	0.0	200.0
Mactridae	*Lutraria lutraria*	14.4	0.0	5.1	0.0	0.0	0.0	0.0
Muricidae	*Chicoreus capucinus*	0.0	0.0	0.0	0.0	0.0	0.0	262.5
Nassariidae	*Ilyanassa obsoleta*	0.0	0.0	0.0	0.0	30.3	0.0	0.0
	Nassarius incrassatus	1.5	0.0	0.0	0.0	0.0	2.0	0.0
	Nassarius olivaceus	0.0	0.0	0.0	0.0	0.0	0.3	125.0
Naticidae	*Polinices* sp	0.8	0.0	0.0	0.0	0.0	0.0	0.0
	Clithon bicolor	0.0	0.0	0.0	0.0	0.0	0.3	0.0
	Clithon corona	4.5	33.3	0.0	0.0	0.0	0.0	0.0
	Clithon faba	0.0	0.0	14.9	0.0	0.0	0.0	0.0
	Clithon ovalunensis	0.8	0.0	0.0	0.0	0.0	0.1	0.0
	Clithon sp	6.1	0.0	0.0	0.0	0.0	0.0	0.0
	Nerita costata	0.0	0.0	0.0	0.0	0.0	0.0	187.5
	Nerita incerta	0.0	0.0	0.0	0.0	0.0	0.5	0.0
	Nerita marina	0.0	0.0	0.0	0.0	0.0	0.4	0.0
	Nerita signata	0.0	0.0	0.0	0.0	0.0	0.3	0.0
	Nerita turrita	5.3	0.0	55.5	0.0	0.0	0.0	0.0
	Nerita undata	0.0	0.0	0.0	0.0	0.0	0.4	262.5
	Neritina natalensis	0.0	0.0	31.0	0.0	0.0	0.0	0.0
	Theodoxus sp	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Olivoidae	*Oliva* sp	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Ostreidae	*Crassostrea* sp	1.1	0.0	0.0	0.0	0.0	0.0	587.5
	Crassostrea angulata	41.5	0.0	0.0	3.7	0.0	0.0	0.0
Pachychilidae	*Faunus ater*	28.0	0.0	0.0	25.3	0.0	0.0	0.0
Planorbidae	*Physastra stagnalis*	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Potamididae	*Pirenella cingulata*	70.2	0.0	0.0	0.0	0.0	0.4	0.0
	Pirenella conica	1.5	0.0	0.0	0.0	0.0	0.0	0.0
	Telescopium telescopium	0.0	0.0	0.0	0.0	0.0	0.0	37.5
	Terebralia palustris	3.0	0.0	0.0	15.7	0.0	0.0	0.0
Tellinidae	*Tellina timorensis*	43.2	0.0	0.0	0.0	0.0	0.0	0.0
Thiaridae	*Melanoides riquerti*	47.0	200.0	243.3	0.0	0.0	0.0	0.0
	Melanoides sp	12.1	0.0	0.0	0.0	0.0	0.0	0.0
Turridae	*Turridrupa* sp	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Veneridae	*Callista lilacina*	2.3	0.0	0.0	0.0	0.0	0.0	0.0
	Paphia gallus	3.8	0.0	0.0	0.0	0.0	0.0	0.0
n		11	3	3	9	3	7	8
Total Abundance (Individu/m^2)		484.39	500.00	415.93	75.00	32.26	22.56	4525.00
Taxa Richness		27.00	3.00	8.00	5.00	4.00	17.00	18.00
Shannon Wiener Diversity Index (H')		1.95	0.53	1.71	0.47	0.07	1.96	1.44
Evenness (E)		0.41	0.33	0.57	0.20	0.03	0.48	0.35
Dominance Index (D)		0.04	0.16	0.37	0.04	0.88	0.16	0.05

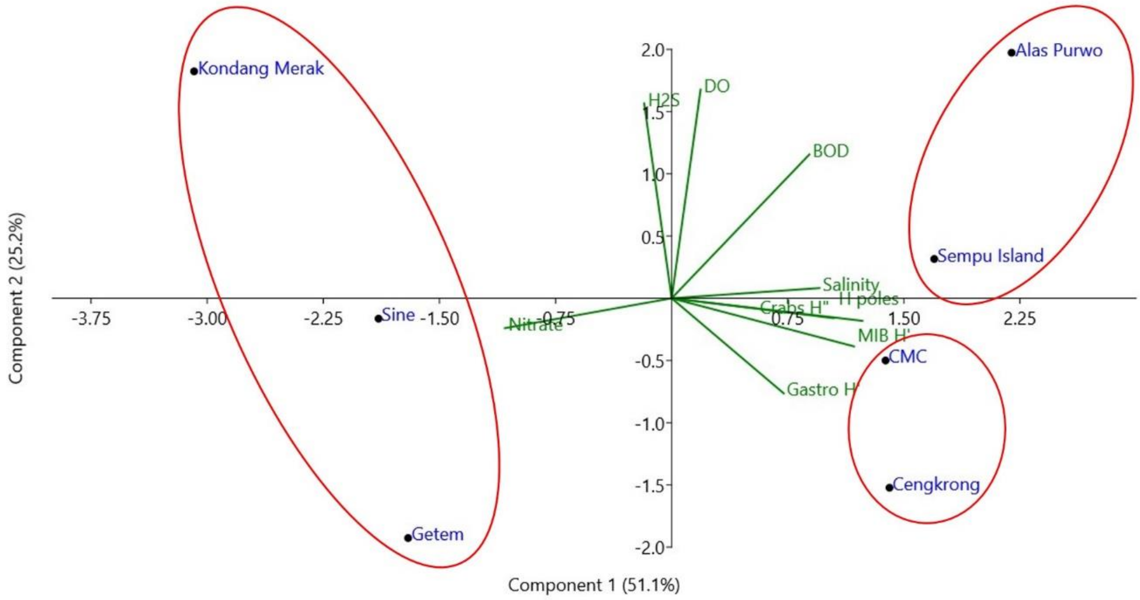

Figure 3. Biplot using PCA showing clusters of mangrove ecosystems on the southern coast of East Java based on similarity in water quality, and diversity and abundance of macrozoobenthos and trees

Table 6. Pearson correlation between some parameters observed in the study, the southern coast of East Java, Indonesia

	DO	BOD	Salinity	Nitrate	H2S	H poles	Crabs H"	Gastro H'	MIB H'
DO									
BOD	0.742*								
Salinity	0.102	0.436							
Nitrate	-0.079	-0.568	-0.760**						
H2S	0.689*	0.333	-0.066	-0.178					
H poles	0.035	0.630	0.615	-0.832**	-0.172				
Crabs H"	0.080	0.576	0.579	-0.538	-0.365	0.723*			
Gastro H'	-0.243	0.058	0.328	-0.447	-0.238	0.681*	0.188		
MIB H'	0.000	0.569	0.505	-0.638	-0.361	0.935**	0.860**	0.617	

Note: blue color is a positive correlation, red color is a negative correlation, numbers indicate the strength of the relationship, *significant 0.05-0.1 and **significant <0.05.

Based on the results of this study, it can be concluded that the evaluation of the quality of the mangrove ecosystem, both restoration, and natural ecosystems, can be carried out using the diversity of macrozoobenthos, especially crabs and gastropods as bioindicators. The higher the diversity index value for crabs or gastropods or a combination of both, the better the quality of the mangrove ecosystem.

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