

Analysis of the Mangrove Ecosystem Due to the Influence of Mount Bromo's Cold Lava Material on Permata Pilang Beach, Probolinggo

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ABSTRACT

Accretion and erosion, which are natural geological phenomena in mangrove areas, provide interesting views that have implications for sustainable area management. This research aims to analyze the ecosystem that exists in the cold lava sedimentation of Mount Bromo and explore aspects of geological attraction, which is a natural factor that cannot be avoided. This study highlights several factors that contribute to mangrove ecosystem management, including water quality, level of mangrove exploitation, canopy cover. Furthermore, this study. Research found that *Avicennia marina*, *Avicennia alba*, *Sonneratia alba*, *Sonneratia caseolaris* and *Rhizophora mucronate* are the types of mangroves on Permata Pilang beach. The density value of 1156 ind/Ha indicates medium density. The diversity index is proven by a value of 1.39 indicating adequate productivity. Mangrove canopy cover of 72.60% indicates a medium mangrove forest condition with a density of 1000–1500 ind/Ha. The results of sediment analysis show that very fine sand is dominant, namely 40.94% of the sediment composition, while the lowest percentage is very fine mud at 0.33%. Types of mangrove vegetation such as *Rhizophora* sp and *Avicennia alba* can be found in sediments ranging from very fine sand to mud. The research results show that the water quality at Permata Pilang Beach is good. The findings show an average value of temperature, pH, dissolved oxygen (DO), and salinity of 31.7 °C; 8.5; 7.8 mg/L and 30.9 ppt. Water temperature and pH are classified as good if they range between 28–32 °C and 5.6–9.4 respectively. The ideal dissolved oxygen level in a mangrove ecosystem is between 3–7 mg/L. The recommended salinity range in mangrove ecosystems is 10–30 ppt.

Keywords: mangrove ecosystem, sediment, water quality.

INTRODUCTION

Mangrove forests are important plant communities that thrive in coastal areas, playing an important role as both natural resources and environmental guardians. Indonesia, together with Australia, Brazil, Nigeria and Mexico, has more than 48% of the world's mangrove forests (Sasmito et al, 2023). Until 2000, Indonesia alone

covered 22.6% of the global mangrove area. In Indonesia, the mangrove ecosystem spans around 3.5 million hectares, consisting of 2.2 million hectares within state forest areas and 1.3 million hectares outside these areas (Giri et al. 2015). This vast expanse in Indonesia holds a rich diversity of species, some of which still have the potential to be discovered. Based on One Map Mangrove data, the area of the

mangrove ecosystem in Indonesia is 3.5 million ha, consisting of 2.2 million ha within state forest areas (forest areas) and 1.3 million ha outside state forests. Apart from its large area, mangrove forests in Indonesia are also known to have high species diversity so it is still possible to find undocumented species (Hutchison et al. 2014; Basyuni et al. 2022). Mangroves are ecosystems that can grow in coastal and marine areas, offering great potential and benefits for human life and the sustainability of the surrounding biota (Hagger et al, 2022). Mangroves have the potential to be developed from an ecological and economic perspective, function as a valuable fishery resource, encourage environmental ecotourism, and provide a food source for local residents living around the mangrove ecosystem (Mukherjee, Sutherland, Dicks, & Huges, 2014). However, these habitats face threats such as habitat loss due to activities such as aquaculture and unsustainable forest management.

Between 1990 and 2010, approximately 7,6595 hectares (23.7%) of mangrove forests in Madagascar were depleted due to increased charcoal and timber harvesting, along with the transformation of these areas into agricultural and aquaculture lands and aquaculture zones (Jones et al. 2014). This has also led to a large decline, around 90%, in mangrove forests in South and Southeast Asia, which cover a total area of 1.9 million hectares (Gupta and Shaw 2013). The main problems in mangrove habitat arise from various pressures that cause a reduction in the area of mangrove forests, especially due to activities such as aquaculture or irresponsible forest management practices (Carugati et al, 2018). The abundant wealth contained in Indonesia's oceans requires sustainable management. One area with an extensive coastal area is East Java. The coastline in East Java Province, which stretches for 3,498 kilometers, holds a wealth of coastal resources such as fish, seaweed, mangroves, seagrass, and other marine organisms (East Java Provincial Maritime Affairs and Fisheries Service, 2013). These coastal resources are future development assets that must be developed and conserved to continue to support community welfare. The very diverse coastal resources can be utilized for maritime-based industries such as fisheries, shipping, aquaculture, mineral industry, biotechnology and marine tourism (Nessa, 2018; Subagiyo et al., 2017).

The mangrove ecosystem has a dual role with direct and indirect functions. Its direct function

includes providing nutrition and sustenance for the biota that inhabit it. Meanwhile, its indirect functions include the ability to filter pollutants, improve water quality, prevent erosion, produce oxygen, absorb carbon dioxide, support biodiversity and mitigate climate change. Apart from that, mangrove ecosystems also play an important role in providing food for coastal communities. Therefore, effective management of mangrove ecosystems is a must to maintain their sustainable existence in coastal areas.

A study conducted by Hakim et al. (2017) regarding the role of mangrove ecosystems in building sustainable mangrove-based tourism conservation and development strategies in East Java shows that mangrove forests are a promising nature-based tourism destination. Although tourism in the mangrove forest area in East Java makes a significant contribution, a comprehensive program is still lacking. Sustainable use of the biodiversity of the mangrove ecosystem as a tourist attraction is very important; Therefore, it is important to understand the basic characteristics of mangroves to develop mangrove tourism programs that can support conservation efforts and provide economic benefits (Mukherjee, Sutherland, Dicks, & Huges, 2016). Therefore, it is important to analyze the mangrove ecosystem due to the influence of Mount Bromo's cold lava material on Permata Pilang Beach, Probolinggo, so that it can support conservation efforts.

Permata Pilang Beach, located in Pilang Village, Kademangan District, Probolinggo City, emerged after the eruption of Mount Bromo in 2010. The flow of cold lava caused serious damage to local beaches, ponds and rice fields. In addition, several mangrove plants that initially thrived were hit by cold lava flows and eventually died because they were buried under the lava material (Hutchison, 2014). The Probolinggo City Government is collaborating with the local community to initiate the reforestation of mangrove vegetation. With these efforts, Permata Pilang Beach has become a very promising tourist destination. Management and rehabilitation initiatives carried out by the local community and surrounding communities have had a positive impact on the environment. This research aims to determine the effect of cold lava sedimentation from Mount Bromo on the growth of mangrove species, as well as the parameters that influence their growth. Likewise with the quality of the mangroves that grow and the sedimentation in the area.

MATERIALS AND METHODS

The research was conducted in the Tempuran estuary mangrove ecosystem located in Pilang village, Kademangan subdistrict, north coast of Probolinggo, East Java. The research was carried out from April to July 2022 in the mangrove ecosystem of Permata Pilang Beach, Pilang Village, Probolinggo City. The upstream area of the Pilang River is Mount Bromo, which is an active volcano that deposits accumulated sediment into the coastal area of Pilang. The gradual accumulation of volcanic sediments causes the expansion of natural features such as coastlines in the study area. Between 1973 and 1979, the coastline in Pilang, Sumberasih and Gending districts experienced relatively rapid growth. However, a decrease in the beach accretion process occurred in all districts in Probolinggo Regency from 1989 to 1995. Interestingly, the beach erosion process became more prominent in that period compared to the accretion process. This research utilizes the Aster DEM, RBI Map, and satellite imagery for the visual appearance of the existing cold lava flow path, spatial analysis to produce the cold lava flow path of Mount Bromo so that it settles on the coast of Permata Pilang Beach, Probolinggo.

The Probolinggo City Government, in collaboration with the community, is actively involved in reforesting mangrove vegetation. Local people dependent on mangrove forests and these resources often have high levels of botanical and ecological expertise regarding their forest ecosystems (Walters et al. 2008). Thanks to these greening efforts, Permata Pilang Beach has become a very promising tourist destination. Management and rehabilitation initiatives carried out by local communities have had a positive impact on the environment. Table 1 presents changes in the mangrove ecosystem in Pilang Village from 2010–2021.

Mangrove ecological sampling

Mangrove ecological sampling was carried out using purposive sampling and the line transect plot method which was based on location representativeness. There are three stations, each with

three replications, and each replication has several plots adjusted to the thickness of the mangrove. These stations are as follows: Station I at coordinates (741953.5; 9143523.25), characterized by a cluster of mangroves bordering the beach; Station II at coordinates (741562.5; 9143718.75), marked by a cluster of mangroves near the estuary; and Station III at coordinates (741442.4; 9143298.43), marked by the presence of a cluster of mangroves located in a pond area which is thought to be less/not affected by sea water.

Data collection

Mangrove ecology data was collected nine times, with a plot size of 10 × 10 m. Sediment sampling was carried out using the coring technique. Sediment was extracted using a 3/4-inch PVC pipe with a depth of approximately 25 cm and then dried in an oven at 1000 °C for 24 hours. The sediment is then processed using a shaker filter to obtain the weight distribution of each sediment fraction based on the size of the filter. Water quality measurements are carried out to obtain data on temperature, salinity, pH and dissolved oxygen (DO).

Data analysis

Based on the type of data collected, this research uses a two-stage analysis process, namely quantitative analysis for mangrove ecological data. Mangrove ecology is analyzed using parameters such as density (species density (D_i) and relative density (RD_i)), frequency (species frequency (F_i) and relative frequency (RF_i)), coverage (species coverage (C_i) and relative cover (RC_i)), Important Value Index (IVI), mangrove diversity index, and canopy cover. Analysis of the weight distribution of each sediment fraction was carried out in the laboratory, while water quality measurements were carried out to obtain temperature, salinity, pH and DO data directly in the field.

Equations 1-6 below used to calculate the density, relative density, frequency, relative frequency, coverage, and relative coverage, respectively (Malik et al 2015).

Table 1. Changes in mangrove area 2010–2021

Location	Year			
	2010	2014	2018	2021
Pilang Village	14 hectares	19 hectares	22.8 hectares	65.05 hectares

$$Di = \frac{ni}{A} \quad (1)$$

$$RDi = \frac{ni}{\sum n} \times 100\% \quad (2)$$

where: Di – density of species i (tree/ha); RDi – relative density of species i (%); ni – number of counts per species i , $\sum n$ – the total number of counts for all species, A – total area of the sample observed (m^2).

$$Fi = \frac{Pi}{\sum p} \quad (3)$$

$$RFi = \frac{Fi}{\sum F} \times 100\% \quad (4)$$

where: Fi – frequency of species i ; RFi – relative frequency of species i (%); pi – number of the plots where species i occurs; $\sum F$ – the total number of occurrences for all species; p – the total number of plots observed.

$$Ci = \frac{BA}{A} \quad (5)$$

$$RCi = \frac{Ci}{\sum C} \times 100\% \quad (6)$$

where: Ci – areal coverage for species i ; BA – $\pi DBH^2/4$, BA – basal area (cm), DBH – diameter at breast height (cm); A – total area of the plot (m^2); $\sum C$ – total area coverage for all species; RCi – relative coverage of species i (%).

Furthermore, equation 7 was summed the value of relative density, relative frequency, and relative coverage in order to determine the importance value index (IVI) that express the dominance level of individual mangrove species (Malik et al 2015). where the value of IVI between 0 and 300.

$$IVI = RD + RF + RC \quad (7)$$

Calculating the diversity of mangrove species used the Index of Shannon-Wiener (equation 8 (Ludwig & Reynolds 1988).

$$H' = -\sum Pi \ln(Pi); Pi = \left(\frac{ni}{N}\right) \quad (8)$$

where: the range of H' between 0 to > 3 (< 1 , low diversity; $1 < H' \leq 3$, moderate diversity; $H' > 3$, high diversity), ni – a number of individual species i and N – the total number of species.

Water quality measurements are carried out directly in the field to obtain temperature, salinity,

degree of acidity (pH), and dissolved oxygen (DO) data. Water temperature measurement using a thermometer inserted water at each station. Salinometers are used to measure the salinity level of waters by inserting them into the water and observing the values listed. The degree of acidity (pH) is measured using a pH meter by inserting it into water and observing the pH value on the device. The measurement uses a DO meter that is inserted into a seawater sample and observed the resulting DO value.

RESULTS AND DISCUSSION

Mangrove ecology, Permata Pilang beach

The results of geospatial analysis show that the research location is located in an area that has sedimentary deposits of volcanic material from Mount Bromo, transported by river water and accumulated in the northern coastal area of Probolinggo. The geographical configuration of the sedimentary area is in the form of an alluvial fan (Figure 1). Giri et.al (2007) highlight that although remote sensing cannot completely replace field measurements, it offers a lot of additional information. Recent literature shows the use of remote sensing and GIS in mapping and evaluating mangrove ecosystems across global coastal areas, utilizing various types of satellite imagery.

This research identified five mangrove species at Permata Pilang Beach: *Avicennia marina*, *Avicennia alba*, *Sonneratia caseolaris*, *Sonneratia alba*, and *Rhizophora mucronate* (Table 2). *Avicennia marina* has the characteristics of a pencil-shaped pneumatophore (root structure) that protrudes above the mud and elliptical leaves, grayish green in color, and has a salt-secreting mechanism (Wirabuana et al. 2021). *Avicennia alba* has a similar appearance to *Avicennia marina* (Gray Mangrove) and is found in the Indo-Pacific region, usually in areas with brackish water (Setyawan et al. 2005). Meanwhile, in Karawang Regency, mangrove vegetation is dominated by *A. alba*, *Bruguiera gymnorrhiza*, and *R. stylosa* (Pin et al. 2021). The mangrove species found in this study are similar to Afifudin's (2019) research in Tongas, Probolinggo Regency, showing several common species. Environmental factors greatly determine the frequency of these species at the research location, thereby influencing the overall species composition. Sloping topography and suitable substrate, influenced

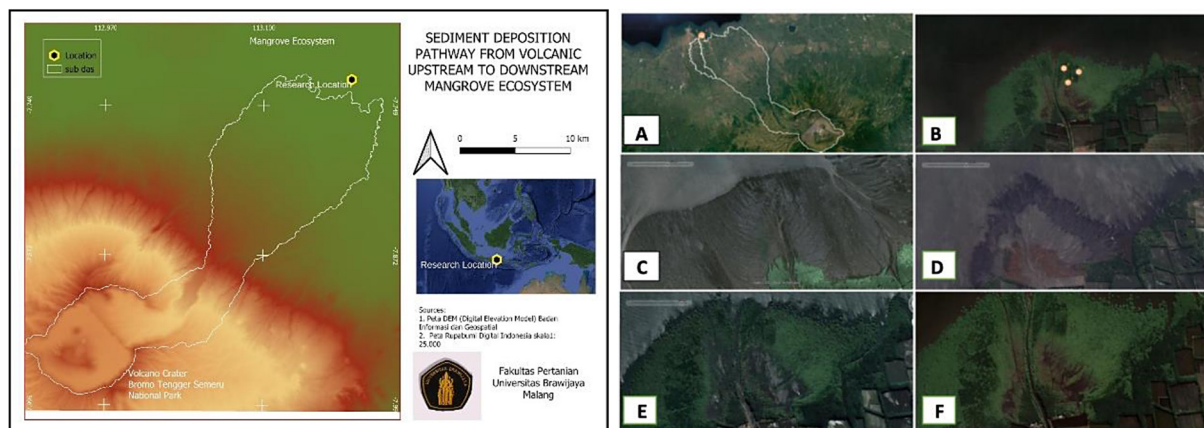


Figure 1. (a) Accretion map, (b) research location map, (c) map 09-26-2009, (d) map 05-27-2012, (e) map 07-06-2020, (f) map 04-07-2022

Table 2. Mangrove species and their local names

No.	Type	Local name	(In) (Ind/ha)	(RDi) (%)	Fi	RFi (%)	Ci	RCi (%)
1	<i>Avicennia marina</i>	Fire	144	12.50	0.44	17.39	5407.24	6.61
2	<i>Avicennia alba</i>	Fire	211	18.27	0.33	13.04	9542.61	11.66
3	<i>Rhizophora mucronate</i>	Mangi-mangi	556	48.08	1.00	39.13	52311.29	63.91
4	<i>Sonneratia alba</i>	Bogem	89	7.69	0.33	13.04	7278.44	8.89
5	<i>Sonneratia Caseolaris</i>	Bogem	156	13.46	0.44	17.39	7314.93	8.94
Total			1,156	100.00	2.56	100.00	81854.51	100.00

by oceanographic conditions, are the main factors contributing to the high prevalence of mangrove species (Schaduw, 2020). Environmental conditions such as substrate, tides, waves, beach morphology and current patterns also play an important role in their existence. Density is an index of individual density in an area, which reflects the quality of the environment supporting mangrove growth (Desmukh, 1992).

Density and relative density measurements are very important for ecological assessment and management strategies in mangrove ecosystems (Cissé, 2014). They contribute to understanding the health, biodiversity, and distribution of mangrove species, which is an important factor in conservation efforts and maintaining the overall ecological balance of these coastal habitats (Torres and Hanley, 2017). The density of mangrove and the thickness of mangrove at Permata Pilang beach every station shown at Figure 2 and Figure 3. Table 2 presents density (Di) and relative density (RDi). The highest density was found in *Rhizophora mucronate* with a density of 556 individuals per hectare (Ind/Ha) and a relative density

of 48%. *Sonneratia alba* has a density value of 89 Ind/ha and a relative density of 7.69%. The total density of mangroves at Permata Pilang Beach is 1,156 Ind/ha, indicating a medium density level according to the mangrove forest density standards in the Decree of the Minister of Environment and Forestry No. 204/2004.

Mangrove vegetation with the highest density indicates conditions rich in nutrients. These areas, based on their density values, show sufficient water quality to support mangrove growth and are supported by certain sediment characteristics,

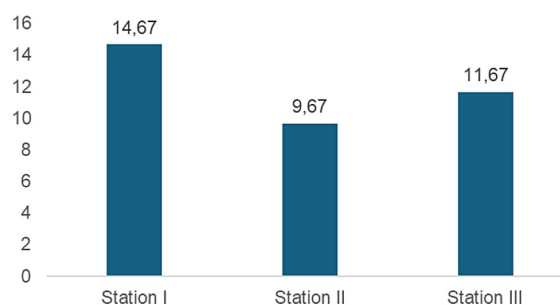


Figure 2. Density of Permata Pilang Beach mangroves

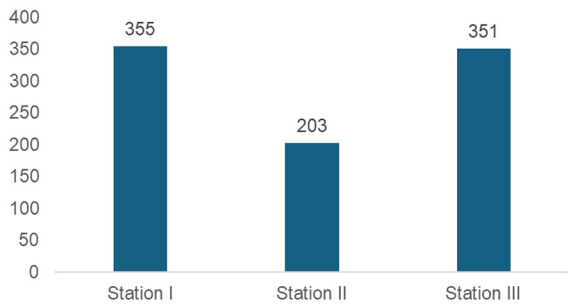


Figure 3. Permata Pilang Beach mangrove thickness

such as sandy or muddy substrates (Schaduw, 2020). The highest density of certain mangrove species can be attributed to the suitability of sediment characteristics and their adaptability to environmental conditions. The density value indicates a good level of regeneration for a particular mangrove species and its ability to grow in certain environmental conditions.

The frequency of a species represents the probability of finding the *i*th species in the observed plot, which functions as a distribution pattern parameter (Bengen, 2000). The highest value for a species is 1, which means that a mangrove species is found in every subplot in a station. Relative frequency values can show the distribution of a species in an ecosystem (Pribadi, 2020). *Rhizophora mucronata* is a type of mangrove that has the highest frequency value of 1 and a relative frequency of 39.13%, which shows its presence in every plot and its distribution is very wide. This high prevalence is caused by favorable sediment or substrate, especially clay or sandy mud, which is very suitable for the growth of *Rhizophora mucronata* (Indra Asman, 2020). Table 2 presents the frequency (*F_i*) and relative frequency (*RF_i*). Further analysis shows that *Rhizophora mucronata* is a mangrove species that inhabits tidal areas (Perbadi, 2020).

Species cover (*C_i*) represents the area covered by the *i*th species in a particular region. Relative cover (*RC_i*) is a comparison between the area

covered by species *i* (*C_i*) and the total area covered by all species (Bengen, 2002). Table 2 presents the coverage values (*C_i*) and relative coverage values (*RC_i*), it shows that *Rhizophora mucronata* has the highest cover value of 52,311.29 and relative cover of 63.91%. The relative cover of a species shows the extent of cover of that species in occupying an area within a plot area. A value close to 100 means that the species can be found in almost the entire area of the closed plot. Mangrove forests that face directly to the sea and experience tidal sea conditions provide considerable support for the growth of *Rhizophora mucronata*. Apart from that, the low value of mangrove forest cover is caused by the heterogeneous condition of mangroves. Direct interaction between mangrove forests and the sea, as well as consistent tidal conditions support the growth of *Rhizophora mucronata*. Apart from that, the low cover value is influenced by the variety of environmental conditions in the mangrove area (Indra Asman, 2020). *Sonneratia caseolaris* is also known as Mangrove Apple of Cabapple Mangrove (Geldmann et al. 2013).

The important value index (IVI) shows the contribution and importance of a population in a community or mangrove ecosystem (Bengen, 2002). Table 3 shows that the highest IVI value of 151.11% belongs to *Rhizophora mucronata*, followed by *Avicennia alba* with an IVI value of 42.97%, *Sonneratia caseolaris* with an IVI value of 39.79%, *Avicennia marina* with an IVI value of 36.50%, and the lowest IVI value of 29.63% was owned by *Sonneratia alba*. The composition and number of individuals at the research location contribute to the IVI value. The high importance index of *Rhizophora mucronata* is due to its high frequency of occurrence. The importance index shows that this species dominates at each location, with high density, cover and presence of the species. The importance value index for each species can describe the dominance of a species at each research location (Schaduw, 2020). The Permata

Table 3. Permata Pilang mangrove diversity index

Type	<i>p_i</i>	<i>lnp_i</i>	<i>p_i·lnp_i</i>
<i>Rhizophora mucronata</i>	0.48	-0.73	0.35
<i>Sonneratia alba</i>	0.08	-2.56	0.20
<i>Sonneratia caseolaris</i>	0.13	-2.01	0.27
<i>Avicennia marina</i>	0.13	-2.08	0.26
<i>Avicennia alba</i>	0.18	-1.70	0.31
Total			1.39

Table 4. Physico-chemical parameters in the mangrove ecosystem waters of Permata Pilang Beach

Physico-chemical parameters of water	Station 1	Station 2	Station 3	Average
Temperature (°C)	29.5	29.5	29.6	29.53
pH	7.03	7.2	7.13	7.12
Dissolved oxygen (DO) (mg/L)	5.03	8.67	6.3	6.67
Salinity (ppt)	27.26	19.63	26,27	24.55

Pilang mangrove diversity index is 1.39, indicating moderate diversity according to the mangrove forest diversity index (Bengen, 2000). A moderate diversity index indicates adequate levels of productivity, a fairly balanced ecosystem, and moderate ecological pressure. This moderate species diversity index can function as a representation of the range of species in a particular area or can be described as the number of species among the total population of all existing species. The number of species in a community has ecological significance because species diversity tends to increase as the community becomes more stable (Baderan, 2016). Data from Northeastern Brazil, showing high *Rhizophora m* propagule survival (70–90%) and aboveground biomass after 5 years of planting, suggest that planted mangroves (including monospecific stands) can thrive and restore some ecosystem functions (Ferreira et al., 2015).

Mangrove canopy cover was measured using the hemispherical photography method with a camera equipped with a fisheye lens. The captured images were analyzed using ImageJ software to separate pixels representing the sky from pixels depicting vegetation cover. Analysis data on the percentage of canopy cover and mangrove community structure are used to describe the status and condition of mangrove forests (Schaduw, 2013). The calculated mangrove canopy cover is 72.60% (Criteria: Medium) (Schaduw, 2020), indicating the condition of the mangrove forest is medium with a density of 1000-1500 trees/ha, in accordance with the standards set by the Indonesian government through Decree of the Minister of the Environment No. 201/2004.

Sediment and water quality of the Permata Pilang Beach mangrove ecosystem

The results of sediment analysis show that the dominant sediment fraction is very fine sand, namely 40.94% of the sediment composition, while the lowest percentage is very fine mud at 0.33%. Mangrove vegetation types such as

Rhizophora sp and *Avicennia alba* can be found in sediments ranging from very fine sand to mud (Schaduw, 2020).

Mangrove growth in each location is influenced by water quality. Factors that influence the growth of mangroves in waters include temperature, acidity (pH), dissolved oxygen (DO), and salinity. The water quality at Permata Pilang Beach is good. The findings at Table 4 show an average value of temperature, pH, dissolved oxygen, and salinity of 31.7 °C; 8.5; 7.8 mg/L and 30.9 ppt. Water temperature and pH are classified as good if they range between 28–32 °C and 5.6–9.4 respectively (according to mangrove ecosystem water quality standards established based on Minister of Environment Decree No. 51 of 2004). The ideal dissolved oxygen level in a mangrove ecosystem is between 3–7 mg/L (Kadim et al., 2017). The recommended salinity range in mangrove ecosystems is 10–30 ppt (Kusmana, 2005).

CONCLUSION

The coastal areas affected by the sedimentation of Mount Bromo's cold lava on Permata Pilang Beach, Probolinggo, show that mangroves can still grow, even though they are of limited type. Research found that *Avicennia marina*, *Avicennia alba*, *Sonneratia alba*, *Sonneratia caseolaris* and *Rhizophora mucronate* are the types of mangroves on Permata Pilang beach. The density value of 1156 ind/Ha indicates medium density. The diversity index as evidenced by a value of 1.39 indicates adequate productivity, a balanced ecosystem, and moderate ecological pressure. Mangrove canopy cover of 72.60% indicates a medium mangrove forest condition with a density of 1000–1500 ind/ha, according to Minister of Environment Decree No. 201/2004.

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vegetation such as *Rhizophora* sp and *Avicennia alba* can be found in sediments ranging from very fine sand to mud.

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