Analysis of the diversity and evenness of mangrove ecosystems in the Pacitan Coast, East Java, Indonesia

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INTRODUCTION

Mangroves have a high productivity role compared to other ecosystems, making the mangrove ecosystem important for the life of living things. The characteristics of mangrove forests are also unique compared to other forest areas. This uniqueness can be seen in their habitat and diversity (Karimah 2017). Usually, mangroves can grow in muddy coastal wetlands that can be found in tropical and subtropical areas (Hakim et al. 2017). In addition, mangroves can also live in lagoon areas, river estuaries that are inundated when the tide occurs or are free from inundation at low tide. Mangroves can adapt to high salt levels and also have many functions both in terms of physical, ecological and economic (Alvarez and Leilani 2020). The benefits of mangroves in coastal areas are in the form of carbon sequestration, neutralizing the harmful pollutant materials, reducing approximately 50% of the strength of tsunami waves, protecting coastlines and enriching coastal waters where they can be used as various flora and fauna habitats, and have the potential to ecotourism (Harahab and Setiawan 2017). The diverse functions of mangroves contribute to living things and support life (Konom et al. 2019).

The mangrove areas in the world reach 16,530,000 ha, and Indonesia is one of the countries with the world's largest mangrove ecosystem, estimated at 3,489,140.68 ha along 95,181 km of coastline (Akbaruddin et al. 2020). The area of mangroves in Indonesia reaches 23% of the total mangroves in the world and a total of 50% of mangroves in Asia are in Indonesia (Junialdi et al. 2019). Mangrove forest areas in Indonesia grow and develop throughout the Indonesian archipelago from Sumatra to Papua. It is estimated that there are 202 species of mangrove species that grow in mangrove forest areas in Indonesia, which consist of 89 tree species, 5 palm species, 19 climber species, 44 herb species, 44 epiphytic species, 1 species of ferns; it can also be classified as 43 species of true mangroves and the other species are associated mangroves (Khairunnisa et al. 2020). However, according to Majid et al. (2016), the mangrove ecosystem in Indonesia is in a critical condition, namely experiencing damage which is predicted to be up to 68% or around 5.9 million hectares. The damage is due to human activities that make changes in the composition of mangroves, resulting in mangrove forests being unable to function, for example, the conversion of land functions to meet human needs (Ramena et al. 2020). Most of the damage occurred in the...
areas of Bali and Java (Eddy et al. 2015). Thus, mangrove areas in Indonesia currently require proper management (Ritohardoyo and Ardi 2014).

One of the mangrove areas is in Pacitan District, East Java, Indonesia. It is located in the southern coastal area of Java Island and the topography of this district is dominated by hills (Mardika et al. 2020). The coastal area in this district consists of 26 villages originating from 7 subdistricts with coastal areas having a slope of 0 to 2% and the coastal areas of Pacitan District having an area of about 4.36% of the total area of the district (BPS Kabupaten Pacitan). Pacitan coast faces directly to the open sea of the Indian Ocean, which has strong waves. The coastal area is dominated by karst areas from the Southern Mountains. This district has a coastline of 70.709 km, but generally it is a steep beach, while on a sloping beach, it is dominated by white sand from coral. The district is fed only by small and short rivers, and the two largest rivers are the Grindulu River (70 km) and Lorog River (60 km) (BPS Pacitan 2021). The rainfall is high, the climate is C2-C3 type (Oldeman 1975) but because it is located in a karst area and the river flow is short, the sedimentation in the estuary is relatively limited and lacks nutrients. This condition causes the area for mangrove growth to be relatively limited, and a unique mangrove ecosystem is formed according to these characteristics. For this reason, this research was conducted to find out more about mangroves in Pacitan, then to determine the mangrove diversity index and the evenness diversity index in the southern coast of Pacitan.

MATERIALS AND METHODS

Study area

This research was conducted in November 2021 and located along the Pacitan south coast, East Java, Indonesia (Figure 1). Pacitan District is located between 7°29′ - 8°29′ S and 110°90′ - 111°43′ E. In 2021, the air temperature was 26-29°C, the average humidity is 23-27.5%, the number of rainy days is 179 days with rainfall 841 mm (BPS Pacitan 2021). The locations were chosen because they have unique mangrove forests. This research data was obtained from three sampling points, namely the Teleng Ria Estuary, Grindulu Beach, Siwil Beach. The coordinate of each location is presented in Table 1.

Procedures

Mangrove survey was conducted using 10 square plots in each station. Each plot was divided by 10 x 10 m² for tree, 5 x 5 m² for sapling and pole, and 2 x 2 m² for seedling (Figure 2). The mangrove classification based on the growth level refers to Kasmadi (2015): seedling is the initial growing stage with less than 1.5 m height (i), sapling is the stage with a height more than 1.5 m and less than 10 cm in diameter (ii), pole has a diameter range from 10 to 20 cm (iii); and tree category with a diameter above 20 cm (iv). The observation includes species identification within the square plot, the total number of mangrove species, a height and DBH measurement of 10 cm above the still roots. Both assessments are used to differentiate the mangrove species into different growth stages. Furthermore, abiotic factors measurement including temperature, salinity and pH were also carried out at each observation location. For identification purposes, Rusila Noor et al. (1999) and Giesen et al. (2007), were used based analysis of morphological characters. Subsequently, key characters from unidentified species samples (e.g. flower and fruit) were taken and photographed for further identification in the Laboratory of Environment, Universitas Sebelas Maret, Surakarta, Indonesia.
Table 1. Coordinate research stations

| Site              | Location            | Coordinate point                  | Estimation of mangrove area width | Characteristic of substrate         |
|-------------------|---------------------|-----------------------------------|-----------------------------------|-------------------------------------|
| 1. Teleng Ria Estuary | 8°13’17.0”S 111°04’25.0”E | 2183 m²                         | Sandy, muddy                      |
| 2. Grindulu Beach | 8°13’50.4”S 111°06’13.5”E | 3917 m²                         | Sandy, muddy                      |
| 3. Siwil Beach    | 8°15’37.4”S 111°17’00.1”E | 1065 m²                         | Sandy, rocky, muddy               |

(iii) 0.75 < $E’$ ≤ 1: high uniformity, mangrove condition is stable (Krebs 2014).

RESULTS AND DISCUSSION

Research area condition

Mangrove abundance is hugely impacted by its habitat condition, including temperature, pH, salinity and substrate. Each mangrove develops a different range of tolerance levels to environmental factors. Based on the direct observation, the temperature in a range of 32-33°C, while pH soil level in three research locations between 6 and 7. At the same time, the salinity was documented from 5 to 10 ppt. (Table 2). Regarding temperature, it can be fluctuated according to the observation time due to the sunlight effect. It has a significant impact on mangrove growth as the connection to the photosynthesis rate. Different ranges of temperature in mangrove ecosystems were shared by some research, including at 29-32°C in Mentawai Island (Rizal and Anna 2020), between 30-31.8°C in Torsiaje Jaya Village, Gorontalo (Rahim et al. 2017), and 24-31°C in North Coast of Jakarta (Hilmi et al. 2021). Those conditions are still acceptable for mangroves to grow well because the photosynthesis process will decrease dramatically if the temperature is more than 35°C (Kusmana 2010).

In terms of pH, Teleng Ria Estuary and Siwil Beach had a similar value, when the highest level was shown in Grindulu River. These results are in the pH range for optimal mangrove species to thrive based on Kai et al. (2012) experiment. It mentioned that Avicennia alba seedling would grow optimally in the pH level from 5.16-7.72. Additionally, research conducted by Nasrin et al. (2016) showed the highest percentage of germination on mangrove association occurred at pH 0-10 and then continued to decrease along with increasing pH level until no germination occurred at pH 25-35.

Table 2. Abiotic factors in mangrove area in Pacitan District, Indonesia

| Research sites       | Temperature (°C) | pH  | Salinity |
|----------------------|------------------|-----|----------|
| Teleng Ria Estuary   | 33               | 6   | 5        |
| Grindulu River       | 32               | 7   | 10       |
| Siwil Beach          | 32               | 6.1 | 5        |
Salt concentration in Grindulu River far exceeds the remaining locations, which shared the same value at 5 ppt. The site of Grindulu has a significant impact on this result as it is situated closest to the shore, causing saline water to enter the mangrove area periodically. Even though each mangrove have different levels of sensitivity, such as proposed by Elster (2000) that Avicennia germinans was the most tolerant species in contrast to Rhizophora mangle as the most sensitive mangrove, but salinity level between 10-30 ppt serves the best condition for mangrove (Hilmi et al. 2021). Thus, the research locations in Pacitan have salinity value that is less supportive for mangrove development.

From the observation, the mangrove habitat in the Pacitan area is dominated by various sediments, including mud, sand, or both combinations. Like other abiotic factors, mangrove species have different preferences regarding the growth habitat. For instance, Avicennia is usually well-developed in the fine soil and sandy habitat, while sandy to a muddy substrate is suitable for Rhizophora and Sonneratia (Abubakar et al. 2020; Jalil et al. 2020). Furthermore, the type of sandy is correlated to the nutrient composition in a particular habitat. According to Adeney et al. (2016) study, it is mentioned that white sand is highly associated with nutrient scarcity and subsequently will impact the organism abundance in the area. In line with this, Siwil Beach is characterized by a white sandy habitat with soft soil in the inundation area.

**Mangrove species in Pacitan coastal areas**

The mangrove community of Pacitan consists of 10 species of mangrove, including seven species of major component (Avicennia alba, Avicennia marina, Rhizophora stylosa, Rhizophora mucronata, Sonneratia caseolaris, Sonneratia alba and Nypa fruticans), a species of minor component (Aegiceras comicolor), and two species of mangrove associated (Derris trifoliata and Acanthus ilicifolius). Those finding represent six families, including Acanthaceae, Arecales, Leguminosae, Lythraceae, Primulaceae, and Rhizophoraceae. Acanthaceae dominated the result consisting of three species, followed by Lythraceae and Rhizophoraceae that depicted by two species each (Table 3). This result shows that more major components have grown in Pacitan lately than the Setyawan et al. (2002) study that found two species (A. alba and S. alba). However, that previous research managed to identify eight species of mangrove association.

The mangrove species grows in three sites of Pacitan District is higher than the result in mangrove forest situated in Pasarbanggi, Central Java and Torosiaja Jaya, Gorontalo, that only four species were found in each location (Rahim et al. 2017; Wicaksono and Muhdin 2015), and five species in Kedawang, Pasuruan (Isroni et al. 2019). In contrast, a more significant number were presented in various studies, such as 24 mangrove species were identified in Segara Anakan (Hilmi et al. 2021), 14 species were reported to grow in Panjjang Island, Jepara (Utumi et al. 2017).

Moreover, Sudarmadji and Indarto (2011) was found 14 species of true mangrove (major and minor) in Banyuwangi District (Tl. Grajagan, Tl. Pangpang, Bengkak, Alas Buluh), 12 species from Situbondo (Bunyinglugur Barat, Bunyinglugur Timur, Kendit, Panarukan), and 2 species from Jember (Kali Malang). Setyawan et al. (2005) was found 36 species of which 14 species of true mangrove was found in Demak District (Wulan, Sigrogol, Serang), 12 species of which 7 species of true mangrove was found in Jepara (Bulak, Teluk Awur), 14 species of which 5 species of true mangrove was found in Rembang (Pecangakan, Pasar Bangi, Lasem), 24 species of which 13 species of true mangrove was found in Purworejo (Bogowonto, Ckrayasan, Lukulo), 16 species of which 7 species of true mangrove was found in Kebumen (Cingcingguling, Ijo), 36 of which 22 species of true mangrove was found in Cilacap (Bengawan, Serayu, Trith, Motean, Muara Dua).

An impressive number of mangroves are listed in Katungan, the Philippines, at 29 species, three listed as threatened species (Mangaoang and Flores 2019). Many aspects, including environmental factors, propagule types, and species competition, are considered a major role in the species distribution (Nakom et al. 2018). Generally, districts on the north coast of Java have more mangrove species than the south coast (Setyawan 2005).

**Teleng Ria Estuary**

This station has a characteristic of sandy and soft soil as it is a riverbank area that leads directly to the Teleng Ria beach. This research identified seven kinds of mangrove grow in this location, including A. alba, A. marina, S. caseolaris and R. stylosa in terms of major components, along with A. ilicifolius, N. fruticans, and D. trifoliata as associated species. The number of A. alba was much more significant than others species that accounted for 201 individuals (Table 3). According to Isroni et al. (2019), a big stem along with the wide canopy provide advantages for the growth of A. alba, so they often reported dominating a habit. Sedimentation also becomes a determining factor for mangrove regeneration and survival. As this station belongs to the riverbank area, it contains rich organic sediment. In line with this, A. alba experienced a lower mortality rate in a habitat with sedimentation disturbance. However, the survival rate showed a declining trend if additional pressures were presented, such as water movement and flood (Balke et al. 2013). In this station, A. alba was reported to grow with a height range between 2 and 12 meters with a fruit-like-nut shape in green (Figure 3).

At this location, 110 individuals of R. stylosa were found, followed by A. marina, S. caseolaris and A. ilicifolius in terms of true mangrove. Avicennia marina announced to have a broad tolerance for salinity. In addition, a high salinity level triggers A. marina's seedling to grow significantly, but a lower salinity has no adverse impact on plant development (Cheng et al. 2020). Another fact is that A. marina also has a wide tolerance to metals content in soil by removing excess contamination substances in the plant body through the salt glands (Naidoo et al. 2014). However, apart from its ability, it is reported that A. marina should not be used as phytoremediation agent as its ability to remove accumulated metal is only temporary and will be released later.
Avicennia marina was documented occurs in this station in a height range between 1 and 5 meters with a maximum DBH of 10 cm. Similar to the first study location, muddy clay rich in organic substance becomes a characteristic of the riverbank area. However, it has been widely reported that sandy substrate is the preferred habitat for *A. marina* and leads to its dominance (Rizal and Anna 2020). The possibility of unsuitable substrate composition at this location makes *A. marina* mostly found at the seedling level.

Another species that was identified in Teleng Ria estuary was *S. caseolaris* with 32 individuals. It grows at a range of height between 1 and 7 meters with DBH size up to 26 cm. This species is distinguished by upward-facing flower petals and red stamens (Figure 4). *Sonneratia caseolaris* fruiting and flowering stages were documented in this research. The fruit is green, round in shape, and contains lots of fruits. According to (Rahim and Bakar 2018), this fruit is able to float in the water and help this species to disperse in the tide. This species usually thrives in the upstream estuarine area with deep muddy soil as the substrate (Tatongjai et al. 2021). Thus, the characteristic that Teleng Ria estuary has in fact fit with *S. caseolaris* preferences.

Mangrove associates also identified, with *N. fruticans* as the most frequently encountered species during the research. Nipa is the only palm that is able to survive in the mangrove region and has a morphological characteristic with compound leaves that elongate like coconut leaves. This species has a height between 3 and 5 meters. Habitat with a low to moderate salinity level and high turbidity allows *N. fruticans* to adapt (Lestari and Noor’an 2019; Theerawitaya et al. 2014). *Derris trifoliata* also grew in Teleng Ria estuary with 10 individuals. It has morphological characteristics of parallel leaves with pointed ends, white flowers clustered, and small petals. The air cavities within *D. trifoliata*’s fruits help the species to float and spread in the tidal area (Raju and Kumar 2016). Both *N. fruticans* and *D. trifoliata* are only found on this site. The presence of associated mangroves supports populations in coastal areas (Rozak et al. 2020).

Physiologically, *A. ilicifolius* develop adaptation systems similar to plants that live in dry places, including salt glands and thick leaves (Hilal and Hilal 2019). The presence and dominance of this species in a particular area indicate ecosystem destruction (Irawanto et al. 2015). Furthermore, it also said that the accumulation of the wastes collected in the wetland areas, which is the habitat of this species as the main reason. In line with this statement, a study conducted by Wijayanti (2017) revealed that the heavy metal components that exceed the threshold were found in the Grindulu’s downstream. In this research station, *A. ilicifolius* was documented in the seedling phase with a maximum height of only 1 meter. It is locally known as jeruju and is commonly used as a decorative plant due to its unique leaves shape. In addition, it is considered an herbal medicine that is widely used in traditional communities as it contains numerous secondary metabolites (Tan et al. 2016). Photographs of mangrove association are presented in Figure 5.

**Grindulu River**

The Grindulu River, as the second research location, is a muddy area where a mangrove planting program is being carried out by a non-government organization and was supported by the local authorities. This effort is as a disaster management strategy for riverbank protection areas from flooding and erosion caused by overflowing rivers, especially in the rainy season (Utami and Luthfi 2019). Based on this research, four mangrove species were listed, consisting *A. alba, A. marina, S. caseolaris* and *R. stylosa*. As the data presented in Table 3, the number of *R. stylosa* far exceeds the total of other species (195 individuals). Research conducted by Mayor et al. (2017) also obtained the same results where the family Rhizophoraceae dominates the Mansur Island, Raja Ampat. The reason is Rhizophoraceae can utilize solar energy, nutrients or minerals and water to the maximum, and has competitive properties compared to other species. However, Nasir and Yusmah (2007) reported that *R. stylosa* rarely exist in muddy locations and prefer to live in soil with sandy substrate. The difference result with this research is due to the planting program in the Grindulu riverbank area, causing these species to thrive even though mostly still in a seedling category. Still, *R. stylosa* is the best option for this program as its ability to prevent erosion in the coastal area (Nasir and Yusmah 2007).

Table 3. The number of mangrove species and associations were found in Pacitan District, Indonesia

| Family       | Species            | Research sites (individuals) |
|--------------|--------------------|-------------------------------|
|              |                    | Teleng Ria Estuary | Grindulu River | Siwil Beach |
| Acanthaceae  | *Avicennia alba*   | 201              | 6              | -            |
|              | *Avicennia marina* | 42               | 3              | -            |
|              | *Acanthus ilicifolius*** | 25          | -              | -            |
| Arecales     | *Nypa fruticans*   | 23               | -              | -            |
| Leguminosae  | *Derris trifoliata*** | 10           | -              | -            |
| Lythraceae   | *Sonneratia caseolaris* | 32           | 30             | -            |
|              | *Sonneratia alba*  | -                | -              | 163          |
| Primulaceae  | *Aegiceras corniculatum* | -           | -              | 7            |
| Rhizophoraceae | *Rhizophora stylosa* | 110       | 195            | -            |
|              | *Rhizophora mucronata* | -           | -              | 3            |

Note: *: Minor component; ***: Association mangrove; -: not present
Selecting mangrove species for reforestation, apart from considering the species function, the resistance of species with the habitat condition must also take into account. *Sonneratia caseolaris* was planted in the Grindulu river area in order to support the rehabilitation program. According to Githaiga et al. (2020), pneumatophores in *Sonneratia* help to survive in poor conditions, such as inundation and flood. An insignificant number of *A. alba* and *A. marina* also found in this station, indicates those species are not suitable in with the habitat condition. This is supported by Nasir and Yusmah (2007) that *Avicennia* species can grow well in a sandy area.

**Siwil Beach**

Siwil Beach is a white sandy beach that faces directly to the Indian Ocean. This station was intended for mangrove restoration after being affected by heavy floods at the end of 2017, as well as to as a prevention approach for seasonal flooding. Two kinds of major mangroves were identified in this location, namely *S. alba* and *R. mucronata*. Also found *A. corniculatum* that is considered as minor mangrove. Interestingly, three species encountered in Siwil Beach were not identified in the other research locations. *Sonneratia alba* was the most abundant species, with 163 individuals were recorded. The height range that was documented in a range from 1 to 6 meter. This species is characterized by white stamens and downward-facing flower petals (Figure 4).

*Sonneratia alba* belongs to pioneer species with a slow-growing type and is considered a potential coastal restoration species (Balke et al. 2013; Pillai and Harilal 2018). The white sandy beach that dominates this location is a suitable habitat for *S. alba* to grow and dominate the ecosystem, although this species grows dwarf, probably due to limited nutrients. In Java, the growth of dwarf mangroves is rare, and it is interesting to investigate further regarding the physiological and environmental factors that influence it. Dharmawan and Pramudji (2020) mentioned that *S. alba* dominated the area with hard sand in Biak District. In conversely, *R. mucronata* was only listed at three individuals in Siwil Beach. Improper habitat leads to this result as this species tends to live in clay habitats. The same result was also suggested by Utami et al. (2017) that *R. mucronata* grew poorly in Panjang Island, which is characterized by a sandy beach.

*Aegiceras corniculatum* which also known pioneer species was encountered in Siwil Beach. This species, which is considered to belong to the minor mangrove group (Tomlinson 1994), has a cylindrical, horn-like curved fruit that is light green to red when ripe. It grows as a scrub habitus with a height of approximately one meter (Figure 6). In Siwil Beach, *A. corniculatum* tends to thrive in the sandy-mud substrate in seasonal inundation areas. Like other mangrove plants, *A. corniculatum* also has a special adaptation to survive in mangrove conditions, namely salt secretion and crypto-vivipary (Feng et al. 2021). The increase in soil salinity triggers increasing salt secretion from the *A. corniculatum*’s leaves to remove salt accumulation in the plant body (Jayatissa et al. 2006). Furthermore, the crypto-vivipary reproductive system allows the embryo to penetrate the seed coat but cannot penetrate the fruit wall before being in a favorable environment (Elmqvist and Cox 1996; Shi et al. 2005; Tomlinson 2016). This reproductive system enables mangroves to reproduce which is more stable and adaptive to unfavorable conditions.

**Figure 3.** *Avicennia alba* flower (A) and fruit (B) from the southern coast of Pacitan, East Java, Indonesia

**Figure 4.** Lythraceae family in the southern coast of Pacitan, East Java, Indonesia. A-B. Flower and fruit of *Sonneratia caseolaris*. C. Fruit of *Sonneratia alba*
Diversity of mangrove species

The data obtained were analyzed using the Shannon-Wiener equation. Table 4 shows that Teleng Ria Estuary has the highest diversity index and is categorized as a medium group. In contrast, both Grindulu River and Siwil Beach belong to low categories. A low diversity status in a certain area indicates an unstable condition, mainly caused by natural and anthropogenic stress (Sreelekshmi et al. 2020). In Pacitan, natural disturbance seems to be the major factor driving the low diversity index rather than the human factor. Grindulu River usually experiences seasonal flooding and erosion, making mangrove species struggle to survive. In addition, this location has functioned as an aquaculture and ecotourism spot, making lots of people access this area. At the same time, Siwil Beach also experienced a massive flood years ago, leading to the loss of the majority of mangrove species. In addition to this, the intense domination of some species also makes the declining value of the diversity index. In this case, R. stylosa and S. alba had a significant number of colonization in Grindulu River and Siwil Beach, respectively.

On the other hand, the diversity index in Teleng Ria Estuary valued 1.52. The probable reasons are the accessibility and the wide-area it has. The substrate of this location is dominated by deep mud, thus proper tool (e.g., boots) is required to reach it. That condition enables mangrove species to grow well because they witness less disturbance from humans. Another thing is this area has a wide mangrove forest and numerous species can be found here. The same result was also proposed by Poedjirahajoe et al. (2019) that the mangrove forest size heavily influences the diversity index.

Regarding growth stages in each location, it can be seen in Figure 7. Data of mangrove growth stages obtained from height and DBH calculation, then adjusted according to the criteria proposed by Kasmadi (2015). The seedling phase dominated the Grindulu station, because still in the process of planting. This also explains a small number of poles and trees there, as the mangrove is still in the regeneration stage. On the other hand, mangroves in the sapling phase are abundantly found in Teleng Estuary. In some spots, the mangrove individuals grew naturally, indicated by the uneven composition. Furthermore, most mangroves are at pole level and are rarely found in tree stage in Siwil Beach. The massive flood could be the reason because it swept away the mangrove plants and the remaining species still keep growing to reach the pole stage. Moreover, the local’s effort to conduct reforestation was demonstrated in the seedling stage recorded, even not as significant as other locations, due to the impact of seasonal flooding. A similar
result was proposed in Nicobar Island, that species regrowth had been conducted after tsunami causing mangrove species and habitat loss (Nehru and Balasubramanian 2018).

Understanding mangrove growth level is necessary to know the regeneration status in a particular wetland ecosystem. Regeneration condition is essential to determine the success of mangrove planting and reforestation. Such as proposed by Utami et al. (2017), a successful regeneration process is indicated by seedling > sapling > tree. Moreover, it can also be used to determine the age of mangrove ecosystems, such as Sudarnadjji and Indarto (2011) observation, which states that the age of mangrove forests in Banyuwangi is still relatively young to the absence of tree phase. From those statements, it can be seen that the Pacitan mangrove areas have a poor regeneration process because of the minimal number of seedlings in each area, with Grindulu River as an exception. The planting program in this location has a profound impact on regeneration progress with the abundance number of both seedling and sapling. In addition, the mangrove areas in Pacitan are considered still at an early age of development as the minimal number of trees in each location. The constant natural disturbance prevents mangroves from developing to further stages; thus, the planting program should be encouraged to preserve the sustainability of mangrove forests.

Evenness of mangrove species

The evenness index in this study ranged from 0.23–0.78 (Table 5). Teleng Ria Estuary had the most significant evenness value, while Siwil Beach and Grindulu River belonged to the low category. A high evenness index in Teleng Ria indicated that it has diverse mangroves with relatively the same proportion of individuals. On the other hand, the domination of certain species in Siwil Beach and Grindulu River makes the evenness value are classified into low. In addition, a high value also means that the mangrove ecosystem in Teleng Ria is considered stable, unlike the others that have a depressed condition. Some factors causing a low evenness are geological, anthropocentric, weather, and sustainable conservation systems (Sannigrahi et al. 2020). The dominance of several mangrove species that tend to cluster in the southern coastal area of Pacitan makes the evenness index low. In line with Farista and Virgota (2021) research, the value of the individual evenness index of mangroves in the Cendi Manik area, Sekotong, West Lombok is low due to the dominance of certain species in the community.

| Location        | Diversity index | Category |
|-----------------|-----------------|----------|
| Teleng Ria Estuary | 1.52            | Medium   |
| Grindulu River   | 0.57            | Low      |
| Siwil Beach      | 0.26            | Low      |

Table 4. Diversity Index of mangrove and associated mangrove in the southern coast of Pacitan, East Java, Indonesia

| Location        | Evenness index | Category |
|-----------------|----------------|----------|
| Teleng Ria Estuary | 0.78            | High     |
| Grindulu River   | 0.41            | Low      |
| Siwil Beach      | 0.23            | Low      |

Table 5. Evenness Index of mangrove and associated mangrove in the southern coast of Pacitan, East Java, Indonesia

Figure 7. The number of mangrove species in four growth stages in the southern coast of Pacitan, East Java, Indonesia, i.e., Teleng Ria Estuary (left), Grindulu River (middle), and Siwil Beach (right)
Human activities (anthropogenic) provide the largest contribution to the destruction of mangrove forests in Indonesia. Conversion of mangrove forests for fisheries, plantations, agriculture, salt ponds, settlements, industry, agriculture, forest logging (legal logging and illegal logging) and mining is the main anthropogenic activity that causes degradation and loss of mangrove forests (Ilman et al. 2011). However, the local communities in Pacitan show a great effort to preserve the mangrove ecosystem. It is indicated by their involvement in mangrove planting with the local government and NGOs. However, inconsistency and unsustainability in maintaining the mangrove ecosystem cause the condition of the Pacitan mangrove is not as expected. Thus, making a tourism destination based on mangrove forests in the Grindulu area is expected to trigger residents to contribute more because they benefit from the economic side.

Although Indonesia has the highest global average above-ground biomass (AGB) of mangrove forests in the world (729,075,000 tons), Indonesia is one of the countries with the highest rate of mangrove forest loss also high (Hutchison et al. 2013). The condition of the mangrove forests in Indonesia continues to experience damage and a reduction in the area, with the speed of destruction reaching 530,000 ha/year, while the rate of increase in the area of mangrove rehabilitation that can be realized is still much slower than the rate of destruction, which is only around 1,973 ha/year.

The conversion of mangrove forests into aquaculture/pond land and agriculture is the main cause of mangrove forest degradation in Indonesia. Ilman et al. (2011) and Eong (1995) in Hamzah and Setiawan (2010) argue that anthropogenic activities in the form of fisheries, plantations, agriculture, salt ponds, settlements, industry, logging (legal logging and illegal logging) and mining are the main factors of degradation and loss of mangrove forests in Indonesia. Meanwhile, Kustanti et al. (2012) argue that more than 50% of mangrove forests are degraded or lost due to several factors, such as the conversion of mangrove forests for fisheries, urbanization, oil pollution, and industrial waste lack of public awareness (Hutchison 2013).

To conclude, mangrove species in Pacitan are considered low to moderate in terms of diversity, and Teleng Ria has a high evenness index. Therefore, further management involving local communities and stakeholders is needed to improve mangrove sustainability in Pacitan.

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