

Short Communication:

A comparison of stand structure, species diversity and aboveground biomass between natural and planted mangroves in Sikka, East Nusa Tenggara, Indonesia

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Manuscript received: 19 January 2021. Revision accepted: 30 January 2021.

Abstract. *Matatula J, Afandi AY, Wirabuana PYAP. 2021. Short Communication: A comparison of stand structure, species diversity and aboveground biomass between natural and planted mangroves in Sikka, East Nusa Tenggara, Indonesia. Biodiversitas 22: 1098-1103.* The effectiveness of mangroves reforestation can be evaluated by comparing the stand dynamics of planted mangroves with natural mangroves in similar site conditions. This study investigated stand structure, species diversity and aboveground biomass between natural and planted mangroves in Sikka, East Nusa Tenggara, Indonesia. A field survey was conducted using quadrat transect method for vegetation measurement, especially related to species composition and its size distribution. Several parameters were recorded in field observation, including number of species, diameter, height, volume, and aboveground biomass. The stand structure of both mangroves was demonstrated by the distribution of diameter class while the species diversity was described using three parameters, i.e., richness, heterogeneity, and evenness. Moreover, the IVI of each species recorded was also calculated to understand the contribution of species in the mangrove ecosystems. The comparison of stand characteristics between natural and planted mangroves was examined by Mann-Whitney test and Spearman Correlation was also applied to understand the relationship between IVI and aboveground biomass. The results showed that the diameter and height between the natural and planted mangroves significantly differed ($P < 0.05$). In contrast, there was no significant difference in tree density, volume, and aboveground biomass ($P < 0.05$). The stand structure of both mangrove stands followed the pattern of J-inverse in which the frequency of trees decreased with the increase in diameter class. Species diversity in both stands was statistically equal in richness, heterogeneity, and evenness ($P > 0.05$) even though there were some specific species which only observed in the natural or planted mangroves. The most superior species in the planted mangroves was *Rhizophora mucronata* (IVI = 96.99) while the most important plant in the natural mangroves was *Sonneratia alba* (IVI = 82.49). Our study found there was a significant correlation between IVI and aboveground biomass in which species with higher IVI indicated greater aboveground biomass. Based on these findings, restoration efforts of degraded mangroves in Sikka have been effective. The restoration, which has been conducted for almost three decades, has not only brought back its vegetation cover but also the functional traits of the mangrove stand to mimic with natural mangroves in the area.

Keywords: Mangroves, heterogeneity, richness, reforestation, stand dynamics

INTRODUCTION

Sustainable management of mangroves currently becomes an essential issue globally since this is the key to maintain the stability of coastal areas. Besides becoming a habitat for a large number of biotas (Sihombing et al. 2017), mangroves play an important role in preventing abrasion and inhibiting sea-water intrusion (Sadono et al. 2020a). This ecosystem also has a significant contribution to climate change mitigation by storing rich amount of carbon in the form of biomass of its vegetation as well as in the soils (Taillardat et al. 2018). Some literature reported carbon stock in mangroves ranges from 3.4 to 218.2 Mg ha⁻¹ depending on age of stand and site characteristics (Luo et al. 2010). In the context of economic development, mangroves also provide a positive advantage to improve the prosperity of communities living in coastal areas (Kusmana and Sukristijono, 2016). Mangrove forest is a

source of non-timber forest products with high economic value, particularly related to fisheries and tannins (Debrot et al. 2020).

Indonesia is one of the tropical countries which has a large extent of mangroves. A study stated that there are more than 4.5 million hectares of mangrove ecosystems in the country (Susilo et al. 2017). It is equivalent to 23% of the total mangrove forests in the world, making Indonesia the nation with largest extent of mangrove areas globally (Richards and Friess, 2016). However, the mangroves cover in Indonesia has declined rapidly due to the impact of human activities, such as timber extraction, the development of infrastructures and human settlements, land conversion for fish and shrimp ponds, sand-mining and environmental pollution (Sadono et al. 2020b). Not only triggering mangrove deforestation, but such activities also cause mangrove degradation which reduces the function of mangrove ecosystems in delivering environmental services

in the coastal area. Several studies also provide evidence that the deforestation and degradation of mangroves have strong relationships with the occurrence of natural disturbances in coastal areas, primarily those related to wind-damage and sea-water flooding (Marois and Mitsch, 2015; Koh et al. 2018; Dasgupta et al. 2019). Therefore, to maintain the existence of mangroves and to minimize the negative impacts of mangrove deforestation and degradation, reforestation efforts have been extensively conducted in many countries, including in Indonesia. However, the implementation of mangrove re-vegetation is not easy since it requires active participation of community as the main actor to ensure the success of reforestation program. In addition, the primary challenge of mangrove rehabilitation is not only about re-planting to increase the mangrove cover, but also to recover the ecosystem functions of mangrove ecosystems. This condition leads a question of whether the activity of reforestation in mangroves is effective to maintain its existence and to revive its ecological attributes.

Therefore, it is important to understand the differences in stand characteristics between the planted mangroves and those that grow naturally. If both mangroves have similar stand attributes, it indicates that the activity of reforestation is effective to support the recovery of mangrove forests. For that reason, this study aimed to compare the stand structure, species diversity, and aboveground biomass between natural mangrove stands and planted mangroves after long-term reforestation program. The study area was focused on the mangrove forest in Sikka, East Nusa Tenggara Province, Indonesia. Our study provides a unique

context of study as not many studies in the theme of mangroves have been conducted in Sikka, and more broadly in the eastern region of Indonesia, let alone on the specific issue of mangrove restoration. As such, we believe that this study is the first to fill such knowledge gap and adds a new understanding of mangrove restoration in eastern part of Indonesia.

MATERIALS AND METHODS

Study area

This study was conducted in mangrove ecosystems in the coast of Sikka, East Nusa Tenggara, Indonesia. This area has geographic coordinates of 8°22'-8°50' S and 121°55'-122°41' E (Figure 1). The study site had two different types of mangrove stand, namely natural and planted mangroves. The area of natural mangroves was a remnant mangrove that survived the tsunami disaster in 1992. The planted mangroves were developed from a long-term reforestation program since 1993. The biophysical conditions of both mangroves were relatively similar since the area of natural mangroves was located alongside the planted mangroves. The study site had dry climate with the annual rainfall ranging from 1,000 to 1,500 mm year⁻¹ and air humidity varied from 64 to 86%. The mean daily temperature reached 31°C with a minimum of 20°C and a maximum of 33°C. The dry season was generally longer than 7 months, starting from April to November.

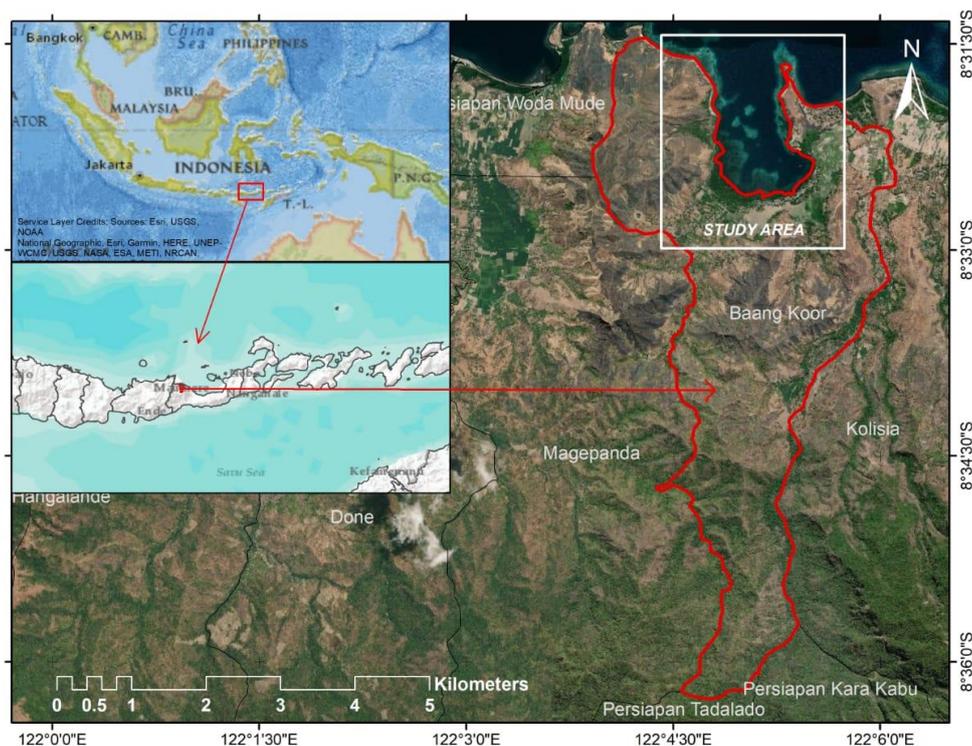


Figure 1. The study area of mangrove ecosystems at the coast of Sikka, East Nusa Tenggara, Indonesia. The white polygon indicated the area of mangrove forest for observation location

Data collection

Data collection was conducted from October to November 2020. A field survey was designed to measure the vegetation condition in natural and planted mangroves using a quadrat transect method. There were six transects established which were evenly distributed in both types of mangrove stands with the size of quadrat plot in each transect was 10 m x 10 m and the distance of each quadrat was 50 m x 50 m (Figure 2). It was placed systematically to represent the environmental variation of mangrove forests. Several parameters were recorded from the observation plot, including type of species, diameter, and height. During the field measurement, there were no seedlings and saplings in all of the transects both in natural or planted mangroves.

Data analysis

The data were analyzed to obtain the number of species density (individual ha⁻¹), basal area (m² ha⁻¹), and frequency (%) (Eddy et al. 2019). Then, those parameters were transformed into relative abundance, relative dominance, and relative frequency (Kasim et al. 2019). The importance value index (IVI) for every species in mangroves was determined based on the accumulation of those three indicators. In the context of ecological studies, the availability of information about IVI is essentially necessary to understand the fundamental position of species present in ecosystems (Yuliana et al. 2019). The diversity of species between the natural and planted mangroves was also assessed using three parameters, namely richness (Margalef Index), heterogeneity (Shannon-Wiener Index), and evenness (Pielou Index) (Singh, 2020).

To evaluate the regeneration capacity of the natural and planted mangroves, an analysis of stand structure was undertaken using the pattern of diameter distribution. This approach is generally used to describe the stand structure of even-aged and uneven-aged forests (Sghaier et al. 2016). In forest ecosystems, tree diameter is a growth attribute which commonly used to categorize the life form of woody species (Pamoengkas et al. 2018). The size of tree diameter commonly increases following the age of tree. A good regeneration capacity of forests can be reviewed from the balance distribution of tree density in each diameter class (Gebeyehu et al. 2019). Principally, it would be better if the population of young trees is relatively higher than that of older trees to ensure the continuity of regeneration process.

The growth performance of stand between the natural and planted mangroves was also analyzed using several parameters, including mean diameter, average height, wood volume, and aboveground biomass. Individual tree volume and aboveground biomass of each species were calculated as follows:

$$V = 0.25\pi \times D^2 \times H \quad [1]$$

$$AGB = V \times WD \times BEF \quad [2]$$

Where; V is tree volume, D is diameter at breast height, H is tree height, AGB is aboveground biomass, WD is wood density, and BEF is biomass expansion factor. The details of WD and BEF of each mangrove species are presented in Table 1.

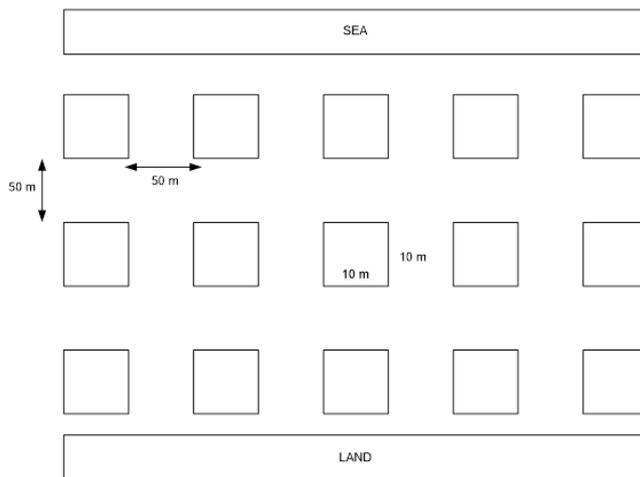


Figure 2. The design of field survey using quadrat transect method to measure observed variables in the natural and planted mangroves at the coast of Sikka, East Nusa Tenggara, Indonesia. The transect was made from the land toward the sea to cover mangroves zonation

Table 1. Wood density and biomass expansion factor of each mangrove species

Species	WD (kg m ⁻³)	BEF	Reference
<i>Avicennia marina</i>	731.6	1.74	Dinilhuda et al. (2020)
<i>Ceriops tagal</i>	885.9	1.53	Hossain et al. (2016)
<i>Rhizophora mucronata</i>	848.3	1.34	Krisnawati et al. (2012)
<i>Aegiceras corniculatum</i>	596.7	1.57	Komiyama et al. (2000)
<i>Avicennia alba</i>	698.7	1.25	Njana (2017)
<i>Bruguiera gymnorrhiza</i>	784.2	1.61	Krisnawati et al. (2012)
<i>Lumnitzera racemosa</i>	832.5	1.41	Kangkuso et al. (2016)
<i>Rhizophora apiculata</i>	881.4	1.55	Krisnawati et al. (2012)
<i>Sonneratia alba</i>	644.3	1.62	Njana (2017)

Note: the data of wood density were obtained from ICRAF database while the information about biomass expansion factor was derived from literature study.

Statistical analyses were conducted using R software 4.2.1 with a significant level of 5%. The normality of data was evaluated using Shapiro-Wilk test. The comparison of stand characteristics between the natural and planted mangroves was examined using Mann-Whitney test. Analysis of Spearman Correlation was also applied to assess the relationship between IVI and aboveground biomass of mangrove species.

RESULTS AND DISCUSSION

The results of the observation showed that tree density in varying diameter classes between the natural and planted mangroves in Sikka is relatively similar which follows the pattern of J-inverse (Figure 3). The highest tree density was recorded in small diameter class while the lowest was found in big diameter class. Despite having a similar pattern, the tree density in small and medium diameter class from the planted mangroves was slightly higher than that in the natural mangroves. In contrast, a different trend

was noted in big diameter class in which the tree density of the natural mangroves was substantially higher than that in the planted mangroves. The similarity in stand structure between the natural and planted mangroves in Sikka was likely due to the implementation of reforestation in planted mangroves that was conducted gradually from 1993 to 2008. Therefore, the stand condition in planted mangroves also had high variation in age and growth.

Several literature explains that forest with uneven ages tends to have the pattern of J-inverse in stand structure due to the multispecies nature and high variation in growth (Bauhus et al. 2002; Westphal et al. 2006; Pukkala et al. 2010). This pattern also indicates that the forest ecosystems in both stands had good regeneration capacity since there were adequate young trees to support stand regeneration (Sinha et al. 2017). This condition also directly suggest that both mangrove forest stands had a complex vertical structure with dense crown layer (Angelini et al. 2015). Based on these findings, it was clearly confirmed that the planted mangroves in Sikka had sufficient regeneration capacity similar to the natural mangroves.

While there was a similar pattern in stand structure between the natural and planted mangrove stands, this study observed the species composition between both stands was comparatively different. In this case, the number of species in the natural mangroves was slightly higher than that in the planted mangroves (Table 2). In the planted mangroves, there were only six species found, i.e., *Avicennia marina*, *Ceriops tagal*, *Lumnitzera racemosa*, *Rhizophora apiculata*, *Rhizophora mucronata* and *Sonneratia alba*. On the other hand, the natural mangroves consisted of seven plant species, namely *A. marina*, *C. tagal*, *R. mucronata*, *S. alba*, *Aegiceras corniculatum*, *A. alba*, and *B. gymnorrhiza*. Based on these results, it seems that there were several specific species which only observed in certain mangrove ecosystems. *Aegiceras corniculatum*, *A. alba*, and *B. gymnorrhiza* were only found in natural mangroves while *L. racemosa* and *R. apiculata* were only recorded in planted mangroves. This circumstance has occurred because of the availability of planting materials when conducting reforestation program which still depended on plants that produce large number of seeds, such as *A. marina*, *C. tagal*, *R. mucronata* and *S. alba*.

Our study recorded the most important species between in the natural mangrove stand and the planted mangrove was also different (Table 2). In the planted mangroves, *S. alba* was the most superior with IVI 82.49, while *R. mucronata* was the most important species in the natural mangroves with IVI of 96.99. Many studies reported that species with higher IVI play more important contribution in forest ecosystems, particularly related to forest productivity (Guèze et al. 2014; Turkis and Elmas, 2018; Yuliana et al. 2019). It was also supported by our findings wherein there was a significant correlation between IVI and aboveground biomass of each species (Figure 4). The higher IVI demonstrated a greater biomass accumulation from species in mangrove ecosystems. This fact was also strengthened by our results in which the accumulation of aboveground biomass from *R. mucronata* was the greatest in the natural

mangroves and *S. alba* was the highest in the planted mangroves (Figure 5).

Despite having different species composition, our study found the species diversity of both mangrove stands was statistically similar in richness, evenness and heterogeneity (Table 3). A similar trend was also shown in tree density, wood volume, and aboveground biomass. However, the mean diameter and average height between the natural and planted mangroves differed significantly ($P < 0.05$). This difference was likely caused by the different growth performance of species in each forest in which based on four similar species that lived in both mangroves, the majority of plants in the natural mangroves demonstrated better growth than trees in the planted mangroves, except for *S. alba* (Figure 6). This fact explained why the wood volume and aboveground biomass in both mangrove stands were statistically similar even though the number of tree densities in natural mangroves was lower than that in the planted mangroves.

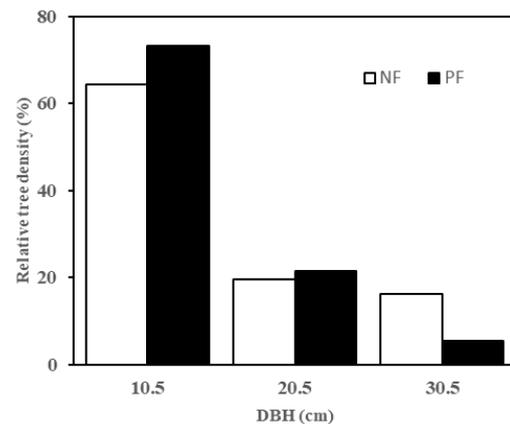


Figure 3. Comparison stand structure between the natural mangroves (NF) and the planted mangroves (PF) in the coast of Sikka, East Nusa Tenggara, Indonesia. The number of tree densities in each diameter class was showed in relative frequency.

Table 2. Relative abundance (RA), relative dominance (RD), relative frequency (RF), and important value index (IVI) of each mangrove species in the natural and planted mangroves stands

Species	RA	RD	RF	IVI	Rank
Natural mangrove forest					
<i>Avicennia marina</i>	20.00	16.20	26.32	62.52	II
<i>Ceriops tagal</i>	6.67	0.79	5.26	12.72	VI
<i>Rhizophora mucronata</i>	30.00	40.68	26.32	96.99	I
<i>Sonneratia alba</i>	16.67	23.13	21.05	60.85	III
<i>Aegiceras corniculatum</i>	20.00	18.08	5.26	43.34	IV
<i>Avicennia alba</i>	3.33	0.90	10.53	14.76	V
<i>Bruguiera gymnorrhiza</i>	3.33	0.23	5.26	8.82	VII
Planted mangrove forest					
<i>Avicennia marina</i>	14.19	9.48	10.00	33.67	V
<i>Ceriops tagal</i>	12.14	6.94	30.00	49.08	IV
<i>Lumnitzera racemosa</i>	1.41	0.09	5.00	6.50	VI
<i>Rhizophora apiculata</i>	25.45	30.49	20.00	75.95	II
<i>Rhizophora mucronata</i>	19.47	17.84	15.00	52.32	III
<i>Sonneratia alba</i>	27.33	35.15	20.00	82.49	I

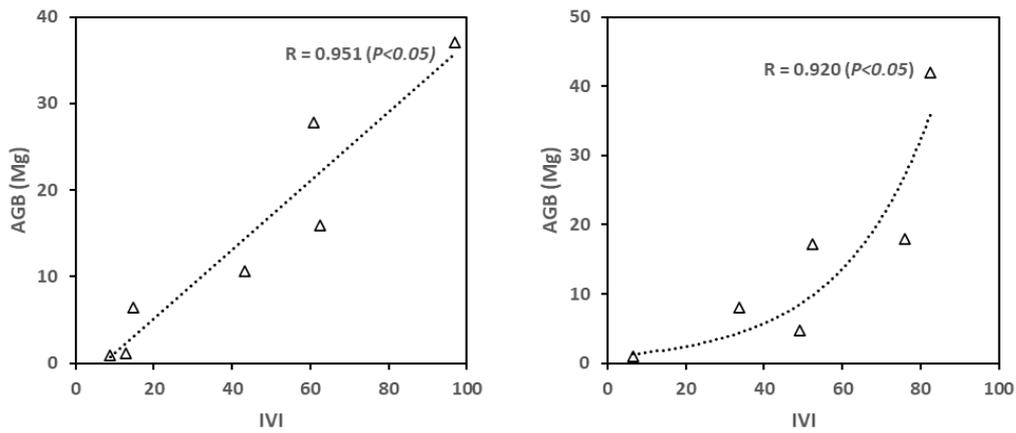


Figure 4. The relationship between important value index (IVI) and aboveground biomass (AGB) of each species in the natural mangroves (NF) and planted mangroves (PF)

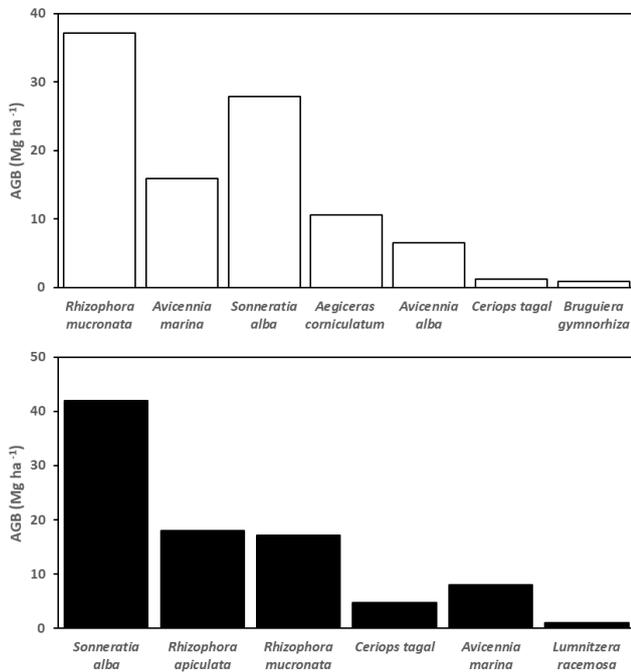


Figure 5. The aboveground biomass of each species in the natural mangroves (NF) and planted mangroves (PF) on the coast of Sikka, East Nusa Tenggara, Indonesia

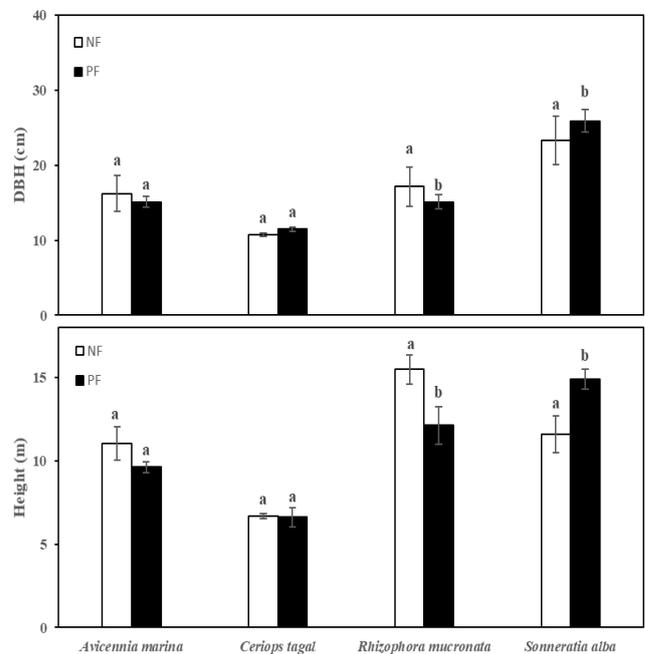


Figure 6. Comparison of the average diameter at breast height (DBH) and height from similar species found in the natural mangroves (NF) and planted mangroves (PF) in the coast of Sikka, East Nusa Tenggara, Indonesia

Table 3. Comparison growth, aboveground biomass, and species diversity between the natural mangroves (NF) and the planted mangroves (PF) in Sikka, East Nusa Tenggara, Indonesia

Stand parameters	Unit	Type of mangrove		P
		NF	PF	
Tree density	plant ha ⁻¹	280 ± 44	363 ± 74	0.773 ^{ns}
DBH	cm	14.77 ± 4.81	14.64 ± 3.68	0.003 ^{**}
Height	m	11.34 ± 4.15	11.33 ± 1.63	0.005 ^{**}
Wood volume	m ³ ha ⁻¹	62.16 ± 16.99	62.57 ± 24.51	0.727 ^{ns}
AGB	Mg ha ⁻¹	66.74 ± 16.79	71.04 ± 25.32	0.806 ^{ns}
Margallef index	-	0.84 ± 0.09	0.74 ± 0.40	0.772 ^{ns}
Shannon-Wiener Index	-	1.07 ± 0.18	0.84 ± 0.48	0.738 ^{ns}
Pielou evenness index	-	0.62 ± 0.11	0.52 ± 0.30	0.563 ^{ns}

Note: Data are presented in mean ± standard deviation. The mark of ^{**} indicates significantly different while ^{ns} means not significantly different

In conclusion, it was clearly exhibited that the stand structure, species diversity, and aboveground biomass between natural and planted mangroves in Sikka, East Nusa Tenggara was relatively equal. The findings of this study suggest that restoration efforts of degraded mangroves in Sikka have been effective. The restoration, which has been conducted for almost three decades, has not only brought back its vegetation cover but also the functional traits of the mangrove stand to mimic with natural mangroves in the area.

ACKNOWLEDGEMENTS

Authors deliver their gratitude to the Department of Research and Development of Trofosit Institute which provided financial support to conduct this study through the scheme of research collaboration about “Long-term Monitoring of Mangrove Reforestation in Flores Island” with a contract number 001/TRF/FLR/20. We also express our gratitude to the reviewer for their suggestion to improve the quality of the article.

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