Comparison of mangrove vegetation in natural and ex-fisheries area in Benoa Bay, Bali

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Abstract. Mangroves provide many ecological functions, but in contrast also experienced many ecosystem damages, especially land-use change to aquaculture. The land-use change inhibits mangrove rejuvenation due to the loss of the land's ecological memory. In Bali, mangrove in Benoa Bay is showing rejuvenation since the fisheries pond conversion in 1908. This study aimed to compare community structures found in natural and ex-fishery areas on Benoa Bay, Bali. The structure and composition of mangrove vegetation were assessed by using the plot method (n=18), followed by the vegetation analysis of trees, saplings and seedlings, and by the canopy closure estimation through hemispherical photography. Vegetation index such as Shannon-Wiener index of diversity, dominance index, and evenness index were used to assess the community status, while the mangrove health assessment used a protocol from the Decree of the Minister of Environment number 201 of 2004 and the mangrove health index (MHI). The results showed that the ex-fisheries area have more species richness than the natural area, but both were dominated by *Sonneratia alba* trees. The saplings and seedlings categories, were dominated by *Bruguiera gymnorrhiza* in the natural area, while in the ex-fisheries area they were dominated by *Rhizophora apiculata*. The Shannon-Wiener diversity index showed a higher value in the ex-fisheries area, while the dominance index and evenness index were fairly similar. In mangrove health assessment, each location was considered in a good condition, based on the canopy closure and tree density and also categorized as in a moderate condition, according to the MHI.

Key Words: mangrove assessment, mangrove health index, mangrove succession.

Introduction. Mangrove is an essential marine ecosystem that indirectly maintains the land and sea biodiversity by connecting them (Carugati et al 2018). Mangrove ecosystem has several essential functions: coastal area protection, marine biota nursery ground (Arifanti et al 2022; Fickert 2020; Wang & Gu 2021) and pollution trap in the coastal environment (Wang & Gu 2021). Mangroves also play an essential role in coping with sea level rise effects, controlling saltwater intrusion in the depths of the coastal areas (Gilman et al 2006) and providing sources of construction materials, food, and medical properties (Mojiol et al 2016; Walters et al 2008). Current research considers the mangrove one of the most effective carbon sequestration areas for reducing the atmospheric greenhouse gas and mitigating the global warming (Maher et al 2018).

Mangroves are primarily distributed in tropical and subtropical coastal from 30° North to 30° South latitudes (Twilley 2019). On a community scale, their distribution is shown by zoning patterns from land to sea due to differences in salinity gradients and anoxic substrates (Naidoo 2016; Srikanth et al 2016). Several conditions, i.e., coastal geomorphological type and nutrient availability, also affect the mangrove types of distribution (Darmadi et al 2012; Lovelock et al 2009). Usually, the land zone mangrove has the highest diversity compared to the zone near the sea direction since only a tiny number of mangroves tolerate high salinity, e.g. *Rhizophora*, *Sonneratia* and *Avicennia* genus.

Indonesia has the largest mangrove area of 3,364,080 ha or around 22.4% of the total mangrove area in the world (Giri et al 2011). A massive decrease in mangrove areas began two decades ago, about 48,025 ha, predominantly caused by land-use change for aquaculture and oil palm cultivation (Arifanti et al 2019; Kusmana 2014; Richards & Friess 2016; Tosiani 2020). To solve the problems, the Indonesian Government decided to plant mangrove seeds to restore the mangrove area. Reforestation is mainly done by planting homogeneous mangrove types, i.e., *Rhizophora* spp., since this mangrove is accessible to breed. However, many of these activities failed for several reasons, i.e., incompatibility of the topography of the planting site, inadequate post-planting care, and predation by crabs and insects (Iftekhar 2008; Kodikara et al 2017; Lee et al 2019). Meanwhile, evidence has been produced about the mangroves' resilience after severe disturbance, by a natural regeneration within a reasonable period (Fickert 2020). Each mangrove type's resilience level was based on environmental conditions that can be observed through the mangrove community structure measurements (Chen et al 2018).

This study aimed to compare community structures found in natural and ex-fishery areas on Benoa Bay, Bali. The mangrove forest in the bay was included in a national forest management area in the form of Ngurah Rai Forest Park (locally known as Taman Hutan Raya (Tahura) Ngurah Rai Bali) under the authority of the Ministry of Forestry and Environment. Some mangrove forests resulted from fishery ponds conversion in 1980, but others are naturally regenerated. The results provided an overview of the condition of mangrove areas which experienced natural and anthropogenic disturbed successions.

Material and Method

Study sites. The study area was located in the semi-enclosed Benoa Bay mangrove forest, which is popularly known as Ngurah Rai Grand Forest Park, Bali (8°42′16″ S - 8°47′48″ S, 115°14′50″-115°10′28″) (Figure 1). Mangrove forest in the bay consists of a protection and utilization area of about 1.132,00 ha; the rest is a settlement, open land and waterbody, approximately 209.63 ha. The mangrove types are dominated mainly by *Sonneratia*, *Rhizophora* and *Bruguiera* (Andiani et al 2021; Dewi et al 2021; Sugiana et al 2022), but other mangrove types were also found, i.e., *Aegiceras*, *Avicennia* and *Ceriops* (Prinasti et al 2020; Wiyanto & Faiqoh 2015), which in total has 19 identified species (As-syakur et al 2023). Mangrove substrates ranged from fine sand to gravel with dominant coarse sand (Imamsyah et al 2020; Prinasti et al 2020) and there was a gradience in water salinity from landward to seaward (Sugiana et al 2021).

Mangrove community structure measurement. The vegetation data were collected using the plot method. Nine quadratic 10×10 m^2 plots were distributed randomly in each mangrove area (natural and ex-fisheries, n (total plots) = 18) (Figure 1). Mangrove density, frequency, and dominance for each species at the stands level was determined by measuring the Diameter Breast Height (DBH) value. Based on DBH value, mangrove stands were separated into three categories: trees (DBH>10 cm), saplings (2 < DBH < 10 cm), and seedlings (DBH<2 cm). Those parameters were used to calculate Density (D), Relative Density (DR), Frequency (F), Relative Frequency (FR), Dominance (Do), Relative Dominance (DR), and Important Value Index (IVI). Mangrove species identification used Kitamura et al (1997) and Tomlinson (2016). Mangrove canopy cover was taken using the modified hemispherical photography method of Jennings et al (1999) and Ishida (2004), based on digital analysis (photo and image processing) in the ImageJ program. There were nine photos taken for every square plot (in total, 81 for the whole mangrove area).

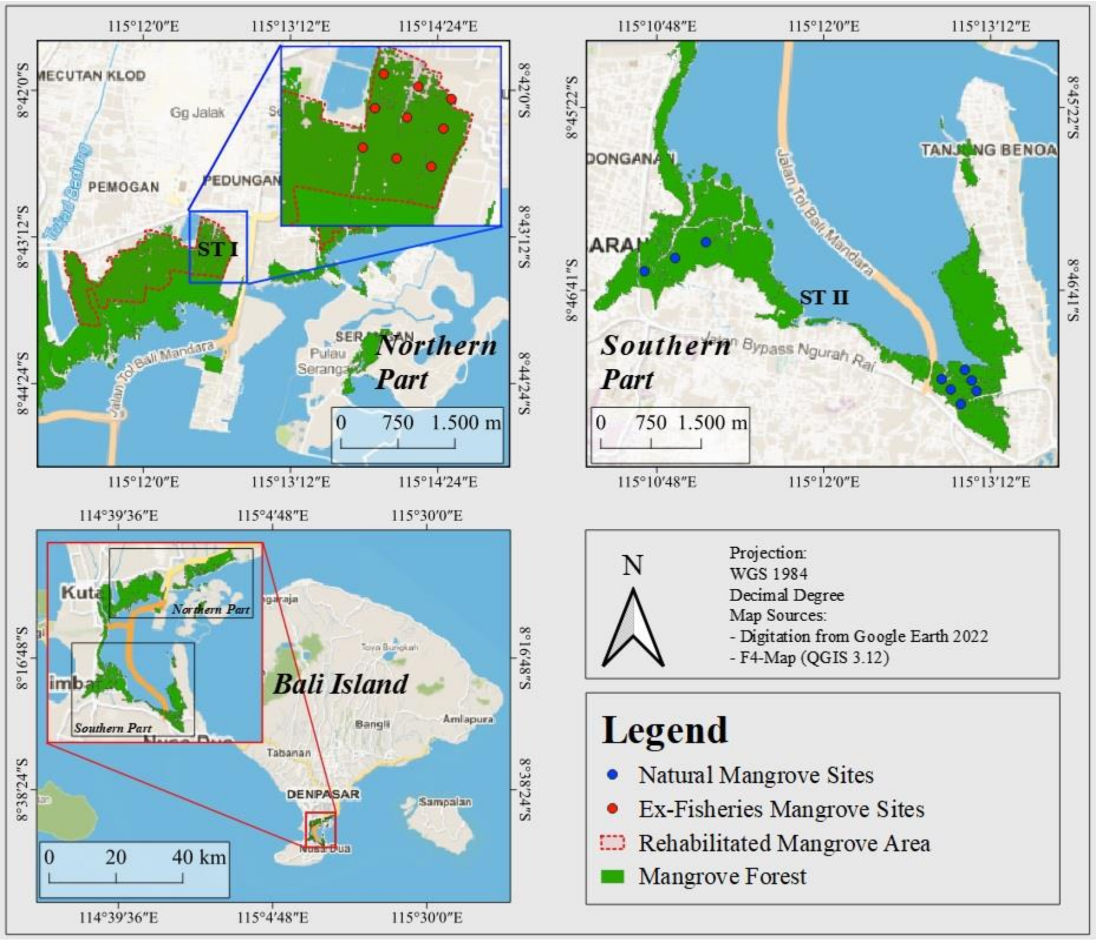


Figure 1. The research site of mangrove vegetation sampling in Benoa Bay, Denpasar, Bali.

Data analysis. Shannon-Wiener Index of Diversity (H'), Dominance Index (C), and Evenness Index (E) were used for mangrove analysis. Mangrove healthiness was also calculated based on the Decree of the Minister of Environment number 201 of 2004 regarding the Standard Criteria and Guidelines for Determining Mangrove Damage, and the Mangrove Health Index formula of Dharmawan & Ulumuddin (2021), derived from a combined sapling density, canopy cover and total diameter. The analysis (Table 1) resulted from comparing natural and ex-fisheries Shannon-Wiener Index and mangrove healthiness.

Table 1

Criteria for mangrove assessment from the Decree of the minister of environment number 201 of 2004 regarding standard criteria and guidelines for determining mangrove damage

Criteria		*Coverage (%)*	*Density (tree ha^{-1})*
Good	Dense	≥75%	≥1500
	Moderate	50-75%	≥1000-1500
Poor	Sparse	<50%	<1000

Results

Structure of mangrove community. The community structure of mangrove forests was different between natural and ex-fishery areas. The number of species of a mangrove tree in the ex-fisheries area was nearly twice, compared to the natural area, with three species in the natural area and five in the ex-fisheries area (Table 2).

Sonneratia alba and *Rhizophora apiculata* were the species that occurred in both areas. In contrast, the tree of *Bruguiera gymnorrhiza* only occurs in the natural area, and the rest of the species (*Thespesia populnea* and *Xylocarpus granatum*) are present only in the ex-fisheries area. The tree density in ex-fisheries was 722 ind ha^{-1}, while in the natural area it was 1,422 ind ha^{-1}. *S. alba* has the highest IVI value, about 182.47% in natural and 136.48% in ex-fishery areas (Figure 2).

Mangrove saplings also varied between mangrove areas. The ex-fisheries mangrove area had eight species of saplings, more diverse than the natural area with only five mangrove saplings. *B. gymnorrhiza* has the highest IVI value (108.82%), followed by *R. apiculata* (85.07%) and *S. alba* (76.46%) in the natural area. Meanwhile, *R. apiculata* IVI was the highest in the ex-fisheries (122.09%), followed by *X. granatum* (63.44%) and *B. gymnorrhiza* (46.62%). The sapling density pattern in both areas is the opposite of tree density pattern because the ex-fisheries area has a higher sapling density, (3,011 ind ha^{-1}), than the natural area (2,089 ind ha^{-1}). Like for the tree and sapling composition, seedling species number in ex-fisheries was higher than in natural mangrove areas. The natural area has four species, while the ex-fisheries have six sapling species. The seedling density in the natural area was two times higher than the ex-fisheries area with only 967 ind ha^{-1} (Table 3). *B. gymnorrhiza* has the highest IVI value of 86.45% in the natural area, followed by *R. apiculata* (65.73%), *S. alba* (38.42%), and *X. granatum* (9.40%). Meanwhile, *R. apiculata* had the highest IVI in the ex-fisheries seedling (84.77%), followed by *B. gymnorrhiza* (58.62%) and *R. mucronata* (27.01%) (Figure 2c).

Table 2

The structure of mangrove vegetation in natural area of Benoa Bay, Bali

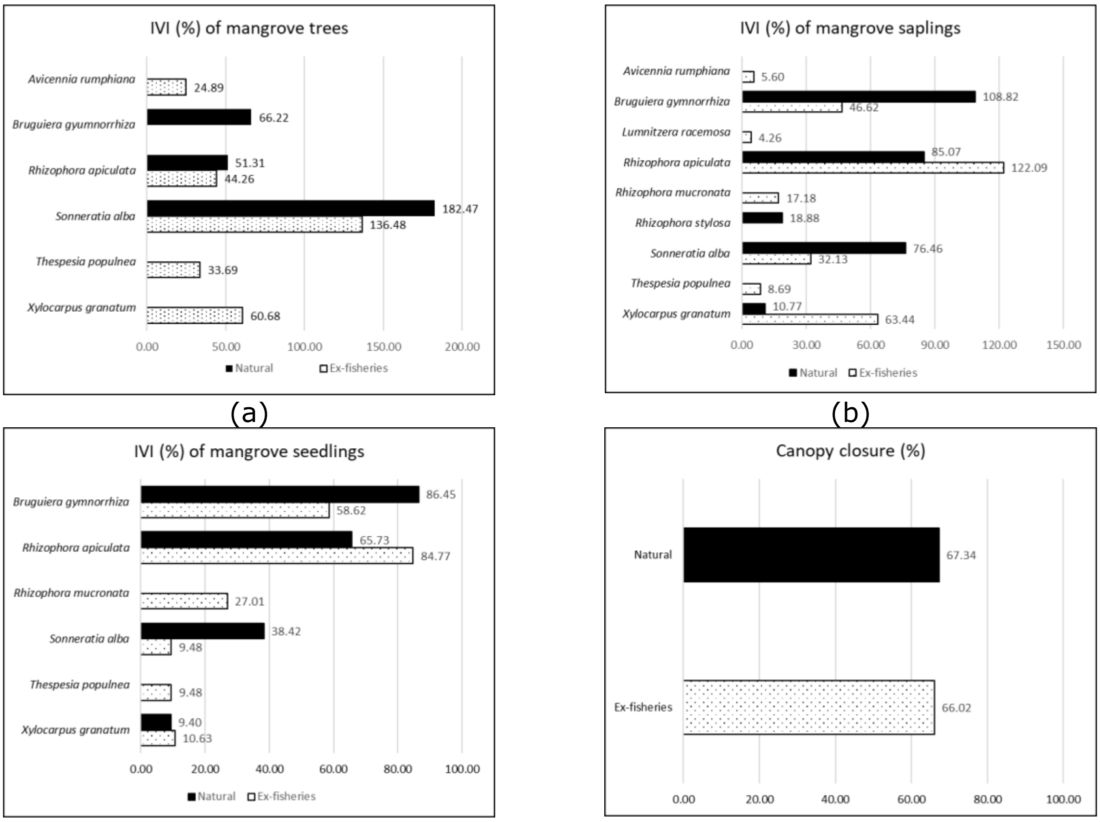
No	*Species*	*D (100 m^{-2})*	*DR (%)*	*F (%)*	*FR (%)*	*Do (100 m^{-2})*	*DoR (%)*	*IVI (%)*
Tree								
1	*Bruguiera gymnorrhiza*	3.11	21.88	44.44	23.53	597.15	20.82	66.22
2	*Rhizophora apiculata*	1.78	12.50	55.56	29.41	269.70	9.40	51.31
3	*Sonneratia alba*	9.33	65.63	88.89	47.06	2001.93	69.78	182.47
	TOTAL	14.22	100.00	188.89	100.00	2868.78	100.00	300.00
Sapling								
1	*Bruguiera gymnorrhiza*	9.11	43.62	44.44	22.22	263.79	42.98	108.82
2	*Rhizophora apiculata*	5.33	25.53	66.67	33.33	160.81	26.20	85.07
3	*Rhizophora stylosa*	1.89	9.04	11.11	5.56	26.27	4.28	18.88
4	*Sonneratia alba*	3.78	18.09	66.67	33.33	153.70	25.05	76.46
5	*Xylocarpus granatum*	0.78	3.72	11.11	5.56	9.12	1.49	10.77
	TOTAL	20.89	100.00	200.00	100.00	613.69	100.00	300.00
Seedling								
1	*Bruguiera gymnorrhiza*	10.89	55.68	44.44	30.77			86.45
2	*Rhizophora apiculata*	5.33	27.27	55.56	38.46			65.73
3	*Sonneratia alba*	3.00	15.34	33.33	23.08			38.42
4	*Xylocarpus granatum*	0.33	1.70	11.11	7.69			
	TOTAL	19.56	100.00	144.44	100.00			200.00

Table 3

The structure of mangrove vegetation in ex-fisheries area of Benoa Bay, Bali

Num	*Species*	*D (100m^{-2})*	*DR (%)*	*F (%)*	*FR (%)*	*Do (100m^{-2})*	*DoR (%)*	*IVI (%)*
				Tree				
1	*Avicennia rumphiana*	0.44	6.15	22.22	11.11	118.23	7.63	24.89
2	*Rhizophora apiculata*	1.11	15.38	44.44	22.22	103.09	6.65	44.26
3	*Sonneratia alba*	3.00	41.54	66.67	33.33	955.06	61.61	136.48
4	*Thespesia populnea*	1.00	13.85	22.22	11.11	135.34	8.73	33.69
5	*Xylocarpus granatum*	1.67	23.08	44.44	22.22	238.41	15.38	60.68
	TOTAL	7.22	100.00	200.00	100.00	1550.13	100.00	300.00
				Sapling				
1	*Avicennia rumphiana*	0.44	1.48	11.11	3.13	9.74	1.00	5.60
2	*Bruguiera gymnorrhiza*	5.44	18.08	55.56	15.63	125.90	12.91	46.62
3	*Lumnitzera racemosa*	0.11	0.37	11.11	3.13	7.43	0.76	4.26
4	*Rhizophora apiculata*	14.56	48.34	88.89	25.00	475.48	48.75	122.09
5	*Rhizophora mucronata*	1.00	3.32	33.33	9.38	43.73	4.48	17.18
6	*Sonneratia alba*	2.67	8.86	44.44	12.50	105.07	10.77	32.13
7	*Thespesia populnea*	0.33	1.11	22.22	6.25	13.02	1.33	8.69
8	*Xylocarpus granatum*	5.56	18.45	88.89	25.00	194.94	19.99	63.44
	TOTAL	30.11	100.00	355.56	100.00	975.32	100.00	300.00
				Seedling				
1	*Bruguiera gymnorrhiza*	2.44	25.29	44.44	33.33			58.62
2	*Rhizophora apiculata*	5.78	59.77	33.33	25.00			84.77
3	*Rhizophora mucronata*	1.00	10.34	22.22	16.67			27.01
4	*Sonneratia alba*	0.11	1.15	11.11	8.33			9.48
5	*Thespesia populnea*	0.11	1.15	11.11	8.33			9.48
6	*Xylocarpus granatum*	0.22	2.30	11.11	8.33			10.63
	TOTAL	9.67	100.00	133.33	100.00			200.00

Although the trees and saplings' composition varied, the canopy closure in both locations was quite similar. The natural mangrove area has 67.34% of canopy closure little bit higher than the ex-fisheries area of 66.02% (Figure 2d). It means that composition and mangrove density does not affect the canopy closure value in both mangrove areas. Even so, compared with the density, canopy closure in the natural area was mainly due to the trees, while in the ex-fisheries area it mostly due to the saplings.



(a) (b)

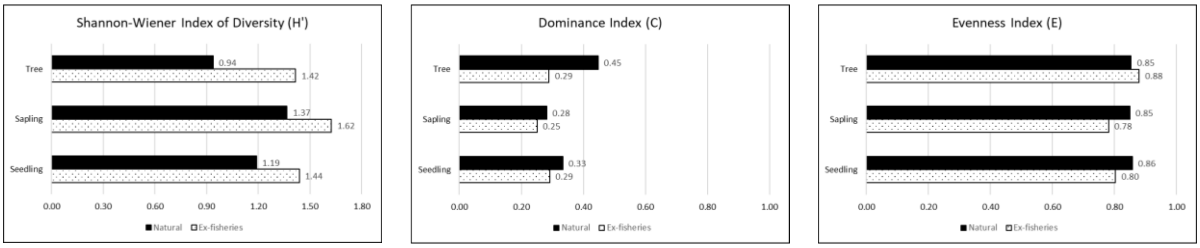
(c) (d)

Figure 2. The comparison of mangrove vegetation structure and indexes between natural and ex-fisheries area (a) the IVI of mangrove trees; (b) the IVI of mangrove saplings; (c) the IVI of mangrove seedlings; and (d) the percentage of canopy closure.

Index of mangrove community and healthiness. The Shannon-Wiener Index of Diversity (H’) showed different values along tree, sapling and seedling categories, between natural and ex-fisheries mangrove areas. The H’ of all vegetation growth forms in the ex-fisheries area was 1.42, 1.62 and 1.37, which were higher than the natural area with 0.94, 1.37 and 1.19 for tree, sapling and seedling categories consecutively (Figure 3a). All H’ were categorized as moderate diversity except for the tree in the natural area, which has a low category (H’<1).

The Dominance Index (C) also showed varied values between mangrove areas. High differences of C were found in each mangrove category in the natural area, while the ex-fisheries only have a few differences. All C values were lower than 0.4, which means a slight dominance of a species, except for the tree in the natural area (Figure 3b). It was caused by the lack of tree species in the natural area (only three species), and the differences in IVI between *S. alba* and the other two species were too far (the IVI of *S. alba* was 182.47%, while the *B. gymnorrhiza* and *R. apiculata* were 66.22% and 51.31% respectively).

The evenness Index (E) value is usually inversely correlated with the C value. A low C value corresponds to a high E value (close to 1.00), indicating a more stable community. For the tree growth form, the E value in ex-fisheries was higher (0.88) than in the natural area (0.85), in concordance with a lower C value in ex-fisheries than in natural area. The C value turns out to correspond to a lower E value in saplings (0.85 in natural area and 0.78 in ex-fisheries) and seedlings (0.86 in natural area and 0.80 in ex-fisheries) (Figure 3c).



(a) (b) (c)

Figure 3. The comparison of mangrove indexes between natural and ex-fisheries area (a) the Shannon-Wiener index of diversity; (b) the dominance index; and (c) the evenness index.

Based on the Decree of the Minister of Environment number 201 of 2004, the mangrove healthiness index of the natural and ex-fishery areas was classified as good canopy cover and good mangrove density, respectively. The mangrove density was different of the community structure analysis, because the Decree of the Minister of Environment number 201 of 2004 regulation classifies plants with more than 15 cm circumference as tree, while the community structure analysis only classifies plants with a circumference of more than 31.4 (10 cm in diameter) as tree. The ex-fisheries area can support a higher mangrove density (2,822±842) than the natural area (1,633±966). Meanwhile, based on the mangrove criteria used by Dharmawan & Ulumuddin (2021), both of these mangrove areas have a moderate health index.

Table 4

Mangrove healthiness category

Mangrove area	*Parameters*	*Value*	*Criteria*	
			Decree of the Minister of Environment number 201 of 2004	*MHI (Dharmawan & Ulumuddin 2021)*
Natural	Canopy cover (%)	67.34±5.98	Good	NA
	Mangrove density (ind ha^{-1})	1,633±966	Good	NA
	MHI (%)	65.23±3.24	NA	Moderate
Ex-fisheries	Canopy cover (%)	66.02±9.72	Good	NA
	Mangrove density (ind ha^{-1})	2,822±842	Good	NA
	MHI (%)	63.41±5.62	NA	Moderate

MHI-mangrove health index; NA-not available.

Discussion. Ex-fishery areas generally have a higher species richness than natural areas. However, the total density in ex-fisheries tends to be lower than in natural areas. The ongoing succession process i.e., by land use change, increased the colonization rate of the mangrove species in new areas and caused the high species richness in the ex-fisheries area. However, the population size of each species tends to be low. Small-scale succession can speed up the mangrove restoration by providing temporary habitat for fast-growing species (Chen et al 2021). The *Sonneratia* dominated area expected to have different impact in small-scale succession compared with the *Rhizophora* dominated area. *Sonneratia* has few main branches but has a wide canopy closure, while canopy closure in *Rhizophora* is caused by many short branching stems. When the branch is broken in small-scale succession, the *Sonneratia* dominated area will form a wider canopy gap than *Rhizophora* dominated area, thereby increasing the chances of other plants to colonize (Chen et al 2021; Twilley 2019). This is one of the mangroves unique characteristics, which is an active succession that causes spatial and temporal variations in vegetation (Eddy et al 2019).

In natural and ex-fishery areas, the tree life form is dominated by *S. alba*. *Sonneratia* is a genus of mangrove that has large pneumatophores. This species has horizontal root branches that grow radially, then from those root branches will appear pneumatophores that grow vertically until it emerges above ground. This root system will act as physical barrier for other species invasion. *Sonneratia* also produces allelochemical compounds which chemically inhibit the growth and development of other species (Hasegawa et al 2014; Sasamoto et al 2018; Xin et al 2013). So, the area with big *Sonneratia* tree tend to have a low species diversity (Andiani et al 2021; Dewi et al 2021; Sugiana et al 2021).

The Shannon-Wiener diversity index of mangrove tree in the natural area was categorized as low diversity, while in ex-fisheries area it was categorized as moderate diversity. Mangroves communities that are in the condition of climax will show the dominance of species from major mangrove components, such as *Avicennia*, *Bruguiera*, *Ceriops*, *Rhizophora*, *Sonneratia*, and *Xylocarpus*. The dominance of the major component will inhibit other species to grow, so it will be natural to notice mangrove zonation based on the major mangrove species.

Rhizophoraceae mangrove family, i.e., *Bruguiera*, *Ceriops*, *Rhizophora*, produce vivipary seeds that colonize easily and dominate the mangrove forest (Fickert 2020; Tomlinson & Cox 2000; Twilley 2019). On Belitung Island, the three mangrove genera that dominate the island are *Rhizophora* (*R. mucronata*, *R. apiculata*, *R. stylosa*), *Bruguiera* (*B. gymnorrhiza*, *B. parviflora*, *B. cylindrica*, *B. sexangula*), and *Ceriops* (*C. tagal*) (Irawan et al 2021). Globally, mangrove species composition tends to be dominated by *Rhizophora* (Kauffman et al 2020). The genus of *Rhizophora* have relatively wider habitat preferences, such as *R. mucronata* which prefers in landwards and near streams while *R. apiculata* tends to grow in relatively saline seawards (Setyadi et al 2021).

The comparison of mangrove succession from the abandoned fisheries in 1992 (as the study site) is shown at Figure 4a, while the Figure 4b shown the early stage of succession in ex-fisheries area. Both areas have constraints in water circulation. In the area from Figure 4a, water is not prone to stagnate and has a fairly thick mud deposit, while in Figure 4b it is fully inundated by water. The propagules of *Rhizophora* and *Sonneratia* are able to grow in flooded areas, thereby giving an advantage in the formation of climax species in the late stages of succession. *Sonneratia* tends to be difficult to find in seedling growth forms in established plant communities. In Papua, areas that are experiencing succession or in the early stages of colonization tend to be dominated by several mangrove species, among which *Sonneratia alba* (Setyadi et al 2021).

(a) (b)

Figure 4. Ex-fisheries mangrove area (a) the remnant of walking path in fisheries in the research station; and (b) the colonization of *Sonneratia* and *Rhizophora* in ex-fishery areas located out of the research area (original photos).

Although it grows in ex-fishery areas with constraints in water dynamic, the process of succession and growth of mangroves were fairly good and quickly. The high growth rate of mangroves in ex-fishery areas can be caused by the nutrient availability.

The aboveground root and lower stems or trunks of mangrove can trap the sediment, which directly accumulates the pollutant and nutrient compounds (Azman et al 2021; Wang & Gu 2021). If the pollutants content is high, it will lead to mass death, slow colonization, and stunted growth. In ex-fishery locations, the nutrients deposition on the substrate can be one of the important factors in the growth and development of mangroves. Substrate conditions, such as nutrients and texture, will affect the composition of vegetation at the time of succession (Rovai et al 2012).

The mangrove succession in ex-fisheries area is important in climate change mitigation. The recovery of mangrove coverage not only increases carbon storage, but also maintains carbon loss because most of the carbon stores in mangroves are found in the soil (Arifanti et al 2022; Kauffman et al 2020). In addition, dense vegetation will inhibit air flow, so the leaves will immediately fall to the bottom of the mangrove and accumulate to form carbon deposits (Priscillia et al 2021). The climate change, which causes sea level rise, needs to be considered: this phenomenon will be the main factor causing mangrove damage in the future (Giri 2021). Despite the vegetation index (H’, C, and E) and mangrove health index (Decree of the Minister of Environment number 201 of 2004 and MHI) values, there is no significant difference between natural and ex-fishery areas. The conversion of mangrove into fisheries has a major impact on the stability of mangrove ecosystems. The fisheries can induce loss of the ecological memory in an area (Fickert 2020). In addition, the mangroves in disturbed areas do not reach an optimal height (Setyadi et al 2021). After an ecological disturbance, the mangrove tends to rejuvenate in its natural pathway. The natural regeneration might be slower than by assisted reforestation, depending on the diaspore availability in surrounded area. Eventually, mangroves will produce viable propagules and accelerate the regeneration rate, followed by the ecosystem restoration. There are few differences in mangrove succession in natural and ex-fisheries area, but in term of mangrove restoration, the natural regeneration provides more diverse ecological functions, ecological services, species richness, heterogeneity structures, and litterfall (Azman et al 2021; Rovai et al 2021). Chen et al (2018) explained that the macrobenthic fauna, as ecological function, is affected by the composition of mangrove successional stages, primarily the plant density, canopy, and nutrients. The macrobenthic community has a primary role in detritus-based food chains in the mangrove. A random animal cannot consume the mangrove detritus as the primary energy source, due to its deterrent compounds (such as tannins and polyphenols). So, the existence of mangrove macrobenthic fauna can link the food chains (Chen et al 2018).

Conclusions. The ex-fisheries area has more species richness and higher diversity index than the natural area as the impact of succession, while the index of dominance and index of evenness were fairly similar in both areas. *S. alba* was the dominating tree species in natural and ex-fishery areas. In the saplings and seedlings categories, *B. gymnorrhiza* was the dominant species in natural area, while *R. apiculata* was the dominant species in ex-fisheries area. In mangrove health assessment, each location was classified, considering the canopy closure and tree density, as in a good condition based on the Decree of the Minister of Environment number 201 of 2004 and as in a moderate condition, based on the MHI.

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References

Andiani A. A. E., Karang I. W. G. A., Putra I. N. G., Dharmawan I. W. E., 2021 [Relationship among mangrove stand structure parameters in estimating the community scale of aboveground carbon stock]. Jurnal Ilmu dan Teknologi Kelautan Tropis 13:485–498. [In Indonesian].

Arifanti V. B., Kauffman J. B., Hadriyanto D., Murdiyarso D., Diana R., 2019 Carbon dynamics and land use carbon footprints in mangrove-converted aquaculture: The case of the Mahakam Delta, Indonesia. Forest Ecology and Management 432:17–29.

Arifanti V. B., Kauffman J. B., Subarno, Ilman M., Tosiani A., Novita N., 2022 Contributions of mangrove conservation and restoration to climate change mitigation in Indonesia. Global Change Biology 28:4523-4538.

As-syakur A. R., Wijaya I. M. S., Andiani A. A. E., Dewi I. G. A. I. P., Sugiana I. P., Faiqoh E., Wiyanto D. B., Rachman H. A., 2023 [Mangrove identification guide in Bali]. PenerbitAVI, Badung, Indonesia, 57 p. [In Indonesian].

Azman M. S., Sharma S., Shaharudin M. A. M., Hamzah M. L., Adibah S. N., Zakaria R. M., MacKenzie R. A., 2021 Stand structure, biomass and dynamics of naturally regenerated and restored mangroves in Malaysia. Forest Ecology and Management 482:118852.

Carugati L., Gatto B., Rastelli E., Lo Martire M., Coral C., Greco S., Danovaro R., 2018 Impact of mangrove forests degradation on biodiversity and ecosystem functioning. Scientific Report 8:1–11.

Chen L., Lin Q., Krauss K. W., Zhang Y., Cormier N., Yang Q., 2021 Forest thinning in the seaward fringe speeds up surface elevation increment and carbon accumulation in managed mangrove forests. Journal of Applied Ecology 58:1899–1909.

Chen Q., Zhao Q., Jian S., Chen P., 2018 Changes in the functional feeding groups of macrobenthic fauna during mangrove forest succession in Zhanjiang, China. Ecological Research 33:959–970.

Darmadi D., Lewaru M. W., Khan A. M., 2012 [Community structure of mangrove vegetation based on substrate characteristics in Muara Harmin Cangkring Village District of Cantigi, Indramayu Regency]. Jurnal Perikanan dan Kelautan Unpad 3:347–358. [In Indonesian].

Dewi I. G. A. I. P., Faiqoh E., As-syakur A. R., Dharmawan I. W. E., 2021 [Natural regeneration of mangrove seedlings in Benoa Bay, Bali]. Jurnal Ilmu dan Teknologi Kelautan Tropis 13:395–410. [In Indonesian].

Dharmawan I. W. E., Ulumuddin Y. I., 2021 Field survey and data collecton a guidebook for mangrove health index (MHI) training field survey and data collection. Nas Media Pustaka, Makassar, Indonesia, 26 p.

Eddy S., Ridho M. R., Iskandar I., Mulyana A., 2019 Species composition and structure of degraded mangrove vegetation in the Air Telang Protected Forest, South Sumatra, Indonesia. Biodiversitas 20:2119–2127.

Fickert T., 2020 To plant or not to plant, that is the question: Reforestation vs. natural regeneration of hurricane-disturbed mangrove forests in Guanaja (Honduras). Forests 11:1–17.

Gilman E. L., Ellison J., Jungblut V., Van Lavieren H., Wilson L., Areki F., Brighouse G., Bungitak J., Dus E., Henry M., Kilman M., Matthews E., Sauni I., Teariki-Ruatu N., Tukia S., Yuknavage K., 2006 Adapting to Pacific Island mangrove responses to sea level rise and climate change. Climate Research 32:161–176.

Giri C., 2021 Recent advancement in mangrove forests mapping and monitoring of the world using earth observation satellite data. Remote Sensing 13:1–6.

Giri C., Ochieng E., Tieszen L. L., Zhu Z., Singh A., Loveland T., Masek J., Duke N., 2011 Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography 20:154–159.

Hasegawa A., Oyanagi T., Minagawa R., Fujii Y., Sasamoto H., 2014 An inverse relationship between allelopathic activity and salt tolerance in suspension cultures of three mangrove species, *Sonneratia alba*, *S. caseolaris* and *S. ovata*: development of a bioassay method for allelopathy, the protoplast co-culture method. Journal of Plant Research 127:755–761.

Iftekhar M. S., 2008 Functions and development of reforested mangrove areas: A review. International Journal on Biodiversity & Science Management 4:1–14.

Imamsyah A., Bengen D. G., Ismet M. S., 2020 [Structure of mangrove vegetation based on biophysical environmental quality in Ngurah Rai Forest Park Bali]. Ecotrophic 14:88–99. [In Indonesian].

Irawan A., Chikmawati T., Sulistijorini, 2021 Diversity and zonation of mangrove flora in belitung Island, Indonesia. Biodiversitas 22:2981–2992.

Ishida M., 2004 Automatic thresholding for digital hemispherical photography. Canadian Journal of Forest Reseach 34:2208–2216.

Jennings S. B., Brown N. D., Sheil D., 1999 Assessing forest canopies and understorey illumination: Canopy closure, canopy cover and other measures. Forestry 72:59–73.

Kauffman J. B., Adame M. F., Arifanti V. B., Schile-Beers L. M., Bernardino A. F., Bhomia R. K., Donato D. C., Feller I. C., Ferreira T. O., Jesus Garcia M. del C., MacKenzie R. A., Megonigal J. P., Murdiyarso D., Simpson L., Hernández Trejo H., 2020 Total ecosystem carbon stocks of mangroves across broad global environmental and physical gradients. Ecological Monographs 90:1–18.

Kitamura S., Anwar C., Chaniago A., Baba S., 1997 Buku Panduan Mangrove di Indonesia: Bali & Lombok. International Society fo Mangrove Ecosystems, Denpasar, Indonesia, pp. 17-77.

Kodikara K. A. S., Mukherjee N., Jayatissa L. P., Dahdouh-Guebas F., Koedam N., 2017 Have mangrove restoration projects worked? An in-depth study in Sri Lanka. Restoration Ecology 25:705–716.

Kusmana C., 2014 Distribution and current status of mangrove forests in Indonesia. Mangrove Ecosystems of Asia: Status, Challenges, and Management Strategies, pp. 1–28.

Lee S. Y., Hamilton S., Barbier E. B., Primavera, J. Lewis, R. R., 2019. Better restoration policies are needed to conserve mangrove ecosystems. Nature Ecology & Evolution 3:870–872.

Lovelock C. E., Ball M. C., Martin K. C., Feller I. C., 2009 Nutrient enrichment increases mortality of mangroves. PLoS One 4:4–7.

Maher D. T., Call M., Santos I. R., Sanders C. J., 2018 Beyond burial: Lateral exchange is a significant atmospheric carbon sink in mangrove forests. Biology Letter 14:20180200.

Mojiol A. R., Kodoh J., Wahab R., Majuki M., Wahyudi W., 2016 Contribution of non-wood forest product to the local community living near mangrove forest in Kudat, Sabah. Journal of Tropical Resources and Sustainable Science 4:38–41.

Naidoo G., 2016 The mangroves of South Africa: An ecophysiological review. South African Journal of Botany 107:101–113.

Pricillia C. C., Patria M. P., Herdiansyah H., 2021 Environmental conditions to support blue carbon storage in mangrove forest: A case study in the mangrove forest, nusa lembongan, bali, indonesia. Biodiversitas 22:3304–3314.

Prinasti N. K. D., Dharma I. G. B. S., Suteja Y., 2020 [Community structure of mangrove vegetation based on the substrate characteristics in Ngurah Rai Forest Park, Bali]. Journal of Marine and Aquatic Science 6:90–99. [In Indonesian].

Richards D. R., Friess D. A., 2016 Rates and drivers of mangrove deforestation in Southeast Asia, 2000-2012. Proceedings of the National Academy of Science of the United States of America 113:344–349.

Rovai A. S., Soriano-Sierra E. J., Pagliosa P. R., Cintrón G., Schaeffer-Novelli Y., Menghini R. P., Coelho-Jr C., Horta P. A., Lewis R. R., Simonassi J. C., Alves J. A. A., Boscatto F., Dutra S. J., 2012 Secondary succession impairment in restored mangroves. Wetlands Ecology and Management 20:447–459.

Sasamoto H., Iwashina T., Suzuki S., Azumi Y., Fujii Y., 2018 Evaluation of an anthocyanin, cyanidin 3,5-di-o-glucoside, as an allelochemical in red callus of a mangrove *Sonneratia ovata*, using protoplast co-culture bioassay method with digital image analysis. Journal of Plant Studies 7:1–10.

Setyadi G., Pribadi R., Wijayanti D. P., Sugianto D. N., 2021 Mangrove diversity and community structure of mimika District, Papua, Indonesia. Biodiversitas 22:3562–3570.

Srikanth S., Lum S. K. Y., Chen Z., 2016 Mangrove root: adaptations and ecological importance. Trees 30:451–465.

Sugiana I. P., Andiani A. A. E., Dewi I. G. A. I. P., Karang I. W. G. A., As-syakur A. R., Dharmawan I. W. E., 2022 Spatial distribution of mangrove health index on three genera dominated zones in Benoa Bay, Bali, Indonesia. Biodiversitas 23:3407–3418.

Sugiana I. P., Faiqoh E., Indrawan G. S., Dharmawan I. W. E., 2021 Methane concentration on three mangrove zones in Ngurah Rai Forest Park, Bali. Jurnal Ilmu Lingkungan 19:422–431.

Tomlinson P. B., 2016 The botany of mangroves 2nd edition. Cambridge University Press.

Tomlinson P. B., Cox P. A., 2000 Systematic and functional anatomy of seedlings in mangrove Rhizophoraceae: Vivipary explained? Botanical Journal of Linnean Society 134:215–231.

Tosiani A., 2020 [The accuracy of national land cover data of 1990-2016]. Directorate of Inventory and Monitoring of Forest Resources, Directorate General of Forestry Planning and Environmental Management, Ministry of Environment and Forestry, Indonesia, pp. 4-16. [In Indonesian].

Twilley R. R., 2019 Mangrove wetlands. Southern Forested Wetlands Ecology and Managements. Routledge, London, pp. 445–473.

Walters B. B., Rönnbäck P., Kovacs J. M., Crona B., Hussain S. A., Badola R., Primavera J. H., Barbier E., Dahdouh-Guebas F., 2008 Ethnobiology, socio-economics and management of mangrove forests: A review. Aquatic Botany 89:220–236.

Wang Y. S., Gu J. D., 2021 Ecological responses, adaptation and mechanisms of mangrove wetland ecosystem to global climate change and anthropogenic activities. International Biodeterioration and Biodegradation 162:105248.

Wiyanto D. B., Faiqoh E., 2015 [Vegetation analysis and structure of mangrove community in Benoa Bay, Bali]. Journal of Marine and Aquatic Science 1:1–7. [In Indonesian].

Xin K., Zhou Q., Arndt S. K., Yang X., 2013 Invasive capacity of the mangrove Sonneratia apetala in Hainan Island, China. Journal of Tropical Forest Science 25:70–78.

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