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Early performance of mangrove seedlings in abandoned fishpond rehabilitation using silvofishery approach

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Early performance of mangrove seedlings in abandoned fishpond rehabilitation using silvofishery approach

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Abstract. Mangrove is an essential ecosystem for climate change mitigation and adaptation. Yet, mangrove rehabilitation and restoration remain a huge challenge indicated by the unacceptably high failure rate particularly during the early stage after planting. Long-term monitoring and evaluation is one of the key factors to improve success rate. Hence, study on the seedlings' performance is essential. This study analyzes mangrove seedlings' health by assessing survival rate and leaf morphometrics in silvofishery sites in Buer Village, Sumbawa District, Indonesia. One-hectare plot of *Rhizophora mucronata* planted on January 2020 and one-hectare plot of *Rhizophora stylosa* planted on February 2020 were selected. To analyze leaf morphometrics variations, forty leaves were collected from each plot. The seedlings of *R. mucronata* (CV 15%) have bigger competition and lower adaptation ability compared to *R. stylosa* (CV 6%). Water quality parameters supports the growth of *Rhizophora, sp*. The species selected is appropriate for the location (middle to upper intertidal level). The success rate is high, around 95% and 80% for *R. stylosa* plot and *R. mucronata*, respectively. Factors attributed to the high success rate are (i) hydrological intervention, (ii) ownership and buy-in, (iii) international partnership, (iv) land tenure security, and (v) regular monitoring.

1. Introduction

As an ecosystem located in the intertidal zone between the sea and land, mangroves provide a synergy between Sustainable Development Goal 14 and other SDGs [1]. Mangrove restoration and conservation contribute to meeting several Sustainable Development Goals (SDGs) from SDG 14 (Life Below Water) to reducing poverty (SDG 1), and other SDGs such as SDG 13 (Climate Action) and SDG 15 (Life Above Water) [2]. The mangrove ecosystem is also one of the most efficient carbon sinking ecosystems, almost the same as tropical rain forests [3]. Some countries also carry out mangrove restoration to mitigate climate change and achieve Nationally Determined Contributions (NDC) targets such as Viet Nam, India, etc [2].

The total economic value of mangrove ecosystems in Indonesia is estimated to be between US$ 3,624.98 - US$26,734.61 per ha per year [4]. Study by Ariyanto et al (), for example, estimates the direct economic value obtained by the people of Wringinputih Village in Banyuwangi from the management of the mangrove ecosystem, which is around IDR 4,338,216,000 (USD 337,554) per month from capture fisheries, aquaculture, tourism, and education activities [5].

Despite the ecological and economic benefits provided by the mangrove ecosystem, the mangrove ecosystem continues to decline. Indonesia has the largest mangrove area in the world and has 45 species out of 75 true mangrove species in the world [6]. However, the condition of the

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mangrove ecosystem in Indonesia continues to be degraded at around 18,000 hectares per year [7]. Data from the Ministry of Forestry and Environment in 2019 shows that out of a total of about 3.4 million hectares of mangroves in Indonesia, around 1.82 million hectares of mangroves are classified as damaged [8].

Costs for restoration of vegetation cover and mangrove ecological function are reported to range from USD 225/ha to USD 216,000/ha [9]. Over the last 20 years, the number of mangrove restorations and rehabilitations projects globally has nearly tripled with the majority of those projects have been in the Southeast Asia and Brazil [10]. The failure rate of mangrove restoration and rehabilitations remains unacceptably high [11]. In the Philippines, for example, less than 20% of the planted sapling survives [12]. Large scale study estimated a median survival rate of roughly 50% [13].

The biggest cause of damage to mangrove ecosystems in Indonesia is the conversion of mangrove areas due to development activities on the coast such as settlements, roads, docks, tourist facilities, ponds, and other infrastructure [14,15]. Meanwhile, efforts to restore mangroves in Indonesia are not always successful due to physical factors, planting patterns, and social factors [16]. The rate of mangrove rehabilitation is estimated to be around 1,973 hectares per year [17]. This is still far from the target of 600,000 hectares by 2025 [15]. This is exacerbated by the fact that mangrove rehabilitation and restoration projects almost always are perceived as one-off projects with minimum attention to providing evidence or information about previous successes, failures, or technical knowledge to guide successful projects [11,18]. Follow-up monitoring has been sporadic and short-term [19].

This study aims to assess the early performance of mangrove seedlings in rehabilitation sites. The results from this study will provide information on mangrove seedlings survival rate and what factors influence its success or failure. Such information will improve transference of valuable information to support a more successful rehabilitation effort in achieving the Country’s target and optimizing mangrove ecosystem’s function.

2. Materials and methods

This study took place in Buer Village, Alas Barat Sub District, Sumbawa District, West Nusa Tenggara Province (8°27'23.0"S 117°01'47.8"E). The study site was abandoned fishpond. In 2020, mangrove rehabilitation was initiated with the support from Yamamoto Lumber Forest, Ltd, a Japan-based company. The approach used was silvofishery, a traditional technology aquaculture system that combine fisheries business with mangrove planting, which is followed by the concept of introducing a management system by minimizing inputs and reducing the impact on the environment [20]. Around 4 hectares were planted in 2020, and an additional of 5 hectares were planted in 2021. This study was carried out in the 4 hectares silvofishery ponds planted in 2020. One pond was planted with *Rhizophora mucronata* and the other one was *Rhizophora stylosa* (Figure 1).

To assess the early performance of the mangrove seedlings, leaf morphometric index was calculated. In the mangrove ecosystem, leaves are one part of the plant that changes shape according to the conditions of the aquatic environment in which they live [21]. Leaf morphometry is defined as the ratio of leaf width and length [22]. Variations in morphometric ratios can describe the condition/quality of local mangrove vegetation [23]. This is because poor mangrove conditions can affect the variation of mangrove leaf morphometry [24]. In addition, leaves are very important variables in the process of photosynthesis and respiration [25]. In mangrove species, leaves are particularly important as they help mangrove to adapt to highly saline environment through various mechanism such as ultrafiltration [26], salt-secretion [27], and ion sequestration [28].

Figure 1. Study site.

In each plot, forty healthy leaves of mangrove seedlings were collected. Leaf width and leaf length were measured to gain the morphometric ratios. Water quality parameters (dissolved oxygen, soil pH, water pH, salinity and water temperature) were collected in five spots in each plot (Figure 2). Yellow and blue dots represent the spot where environmental data were collected.

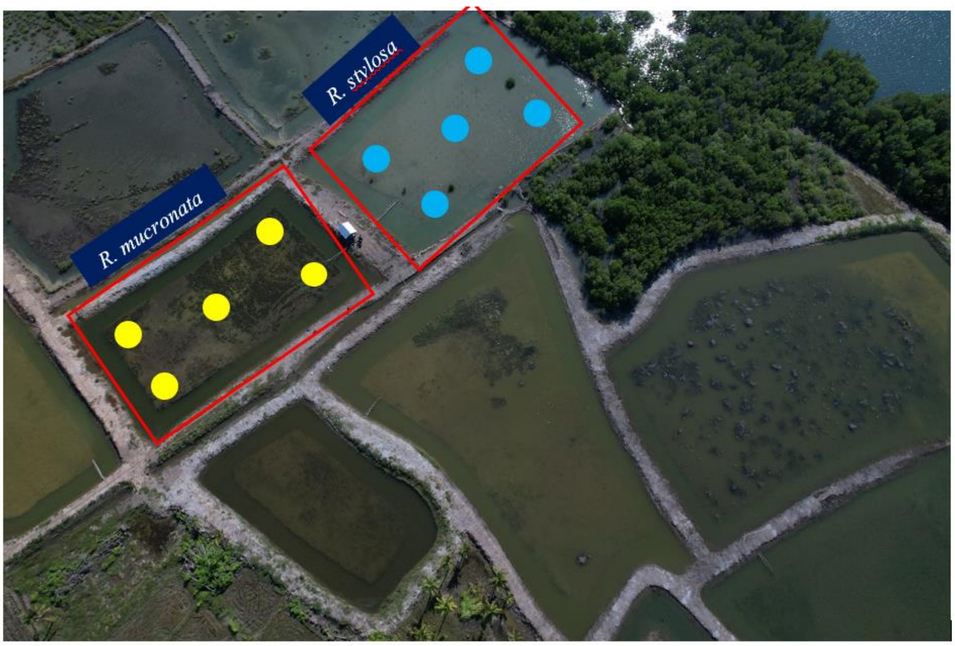

Figure 2. Water quality parameters sampling points in Silvofishery Site.

3. Results and discussion

3.1. Leaf morphometric

Leaf morphometric ratio (width/length) ranges from 0.296 to 0.680 in *R. mucronata* and 0.443 to 0.573 in *R. stylosa*. The majority of the ratio is between 0.493-0.558 with 16 leaves in *R mucronata* and 0.520-0.540 with 13 leaves in *R. stylosa*. Coefficient of variation (CV) indicates the extent of variability in relation to the mean of the population. The variable with the smaller CV is less dispersed than the variable with the larger CV. In leaf morphometric ratio, CV is used to describe the individual competition and adaptation ability of the mangrove based on the dispersion of the morphometric ratio. Bigger CV indicates that the competition is higher and adaptation is lower. In this study, based on the CV value (Table 1), the seedlings of *R. mucronata* have bigger competition and lower adaptation ability compared to *R. stylosa*.

Table 1. Leaf morphometric ratio.

Plot	Mean	St. Dev	CV (%)
R. mucronata	0.526	0.08	15%
R. stylosa	0.508	0.03	6%

CV bigger than 10% is used as an indicator that the ecosystem or the species is unhealthy [29]. *R. mucronata* CV is 15%, hence, attention should be directed to this plot. Based on observation, one possible reason for this is its distance from the coastline (sea) which results in less inundation period. *Rhizophora, sp.* grows best in areas that are inundated during at least medium tide [30] or at least 20 days a month, twice a day [31]. During the dry season, some parts of the *R. mucronata* plot is not inundated for several weeks. Less inundation has enabled grass to colonize the floor (Figure 3). There is a high competition for nutrients between the mangrove seedlings and the grass. The ability of leaves to maintain leaf area index is highly dependent on the ability of the tree to concentrate and transport nutrients and fresh water into the leaves [29].

Figure 3. Grass colonizing rehabilitation site in *R. mucronata* plot.

The CV value for the *R. stylosa* plot is less than 10% (6%) indicating that the seedlings are healthy. This plot is frequently inundated. There is no grass. Some biotas were able to dwell in this plot (Figure 4a and 4b).

Figure 4a. *R. stylosa* plot.

Figure 4b. Some biotas in *R. stylosa* plot.

3.2. Water quality parameters
Mangroves require supporting environment to grow. In this study, we collected data on some of the important parameters for mangroves such as the dissolved oxygen (DO), soil pH, water pH, salinity and water temperature. The government of Indonesia regulated water quality standards for mangroves through Minister of Environment Decree 51/2004, about Sea Water Quality Standards (Table 4). Dissolved oxygen is 4.947 mg/l and 4.764 mg/l in *R. mucronata* and *R. stylosa* plot respectively. Both are below the Sea Water Quality Standards which is 5 mg/l. However, the DO values almost meet the standard. Other parameters such as soil pH, water pH, salinity and water temperature meet the standards (Table 2 and Table 3).

Table 2. Water quality parameters in *R. mucronata* plot.

Observation Points	DO (mg/l)	DO (%)	Soil pH	Water pH	Salinity (ppt) low tide	Water temperature (Celsius)
Obs1	4.17	58.7	6	8.3	2	34
Obs2	4.42	61.6	7.5	8.59	2	34
Obs3	6.33	86.9	9	9	5	34
Obs4	4.78	66.8	8	8.65	4	34
Obs5	5.17	72.4	7	8.62	4	34
Mean	4.974	69.28	7.96	8.632	3.4	34

Table 3. Water Quality Parameters in *R. stylosa* Plot.

Observation Points	DO (mg/l)	DO (%)	Soil pH	Water pH	Salinity (ppt) low tide	Water temperature (Celsius)
Obs1	5.01	68.1	8.5	8.11	24	32
Obs2	4.41	59.9	8	8.19	25	32
Obs3	4.34	59.3	8	8.25	25	32
Obs4	4.92	68.7	8	8.27	25	32
Obs5	5.14	71.3	8	8.27	25	32
Mean	4.764	65.46	8.1	8.218	25.1	32

Table 4. Sea water quality standards.

No	Parameter	Unit	Standard
1	Temperature	^oC	coral: 28-30 mangrove:28-32 seagrass: 28-30
2	Salinity	%o	coral: 33-34 mangrove: max 34 seagrass: 33-34
3	pH	-	7 - 8,5
4	BOD	mg/l	20
5	DO	mg/l	>5

Source: Minister of Environment Decree 51/2004, about Sea Water Quality Standards.

3.3. Mangroves survivorships

Revitalizing the abandoned fishpond in this study site using silvofishery approach required hydrological intervention. In this study, the ponds were constructed to allow sea water inundation inside the pond where the mangroves were planted. The planting method used was direct planting of propagules with monoculture species. The planting distance used is 1 x 3 meters. There was no natural regenerations observed during the study period. The survival rate is 80% and 95% for *R. mucronata* and *R. stylosa*, respectively.

Many mangroves restoration and rehabilitation efforts failed due to lack of community participation, proper governance structure, and alignment of objectives and goals of stakeholders involved [32]. In this study site, the local community is favorable toward the idea of restoring mangrove and at the same time revitalizing abandoned fishpond or also known as silvofishery. This approach aligns the local community's goal with the donor's (Yamamoto Lumber Forest, Ltd) goal. In this case, the local community is able to get income from the ponds, while the donor's goal is to improve mangrove stem density through monoculture planting. The donor's views that mangrove is essential for carbon sequestration.

After agreeing about the goals, community's participation is easier to get. In this study site, regular monitoring and replanting were undertaken by the local stakeholders (private citizens) because they know mangrove functions for the fishponds. In addition, long-term commitments to funding and monitoring from the donors have improved the relationships between the donor and the individuals carrying out this rehabilitation activity. This is in line with what has been suggested by Thompson () about how to overcome asymmetric relationship between the donor and the restorer [33].

The partnership with Yamamoto Lumber Forest, Ltd has allowed the high cost yet necessary hydrological intervention. Results from the *R. mucronata* plot emphasize that better hydrological connection significantly improved survivorship and hints the need to include combinations of species which are able to tolerate less inundation after the hydrological intervention is done. The hydrological intervention was possible because the land tenure is secure and the ownership is clear. As suggested by Lovelock, land tenure considerations are key to successful mangrove restoration [34].

4. Conclusion

Mangrove seedlings morphometric ratio is better in *R. stylosa* (CV 6%) plot compared to *R. mucronata* (CV 15%). Dissolved oxygen in both plots almost meet the standard. Other parameters such as soil pH, water pH, salinity and water temperature meet the standards. Survival rate in both plots is high (80% in *R. mucronata* plot and 95% in *R. stylosa*). Factors influencing the survival rate are buy-in from local communities, monitoring, international partnership, land tenure security, and hydrological intervention.

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