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Full Length Research Article

Growth Pattern and Survival of Mangrove Seedlings on the Coast of Peunaga Cut Ujong, West Aceh

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ABSTRACT

Mangroves are coastal ecosystems with different abilities to adapt to changing environmental conditions. Habitat characteristics that continue to change cause morphological, anatomical, and physiological adaptations of mangrove species. This study aims to observe the survival and growth rate of *Rhizhopora mucronata* in Peunaga Cut Ujong, Meurebo, West Aceh. The mangroves were planted in 2022 and observed one year after planting. The observation and data collection of 35 tree samples were conducted every two weeks. The results showed a decrease in the survival rate from the third month of observation until the end, showing a decrease of 78%. In contrast, tree growth increased from months 1 to 5. Salinity conditions and substrates dominated by sand with minimal nutrients indicate adaptation to the growth of some relatively small mangrove species. Fluctuating salinity conditions with the dominance of sand have the potential to support the survival of *R. mucronata*, although with low growth. Its main influence still needs to be studied over a longer period.

1. Introduction

Mangroves can survive in extreme conditions such as low rainfall, high solar radiation, drastic temperature fluctuations, and hypersalinity. Each mangrove species has different adaptations to environmental changes, such as unsuitable abiotic conditions. Another study also concluded that the growth of mangrove seedlings varies depending on the type of species and the environment (Hastuti and Rini 2018). Mangroves respond to environmental changes such as air warming by adapting to their high growth rates. The effect of warming on mangrove growth is highly dependent on site characteristics and measured growth parameters (Chapman et al. 2021). Mangroves have complex morphological, anatomical, physiological, and molecular adaptations that can enable survival and success in high-stress habitats (Srikanth et al. 2016).

Mangroves are known to be unique due to their distinct geomorphology, hydrology, forest structure, physiology, and soil biogeochemistry (Adame et al. 2021). However, mangrove habitats continue to suffer alarming degradation due to the direct impacts of anthropogenic activities and global climate change, which have fuelled the loss of 1.9 million ha of mangroves in Indo-Malaya along the coast of South and Southeast Asia (Carugati et al. 2018; Wang and Gu 2021). Coastal zone vulnerability is increasing globally due to climate change and exacerbated by unsustainable development (Sunkur et al. 2023). Human activities in increasing the accumulation of heavy metals (Nyangon et al. 2023; Ur Rahman et al. 2024) and microplastics (Huang et al. 2024) in coastal areas pose a threat to mangrove, such as facilitating increased secretion of organic acids in plants and triggering shifts in the structure of microbial communities in sediments that can be an obstacle in mangrove ecosystem restoration efforts (Yadav et al. 2023), damage to mangrove ecosystems that lead to loss of ecosystem function can have a huge impact on the community, such as a decrease in vegetation strength and changes in oil conditions characterized by increased salinity (Mishra et al. 2024). Chen et al. (2024) also added that increasingly dense mangrove vegetation could be used for disaster mitigation by dampening the effects of waves and providing protection against tsunami energy blows. Protected mangrove ecosystems have the potential to sequester carbon (Ledheng et al. 2022; Manoj 2024), absorbing more CO_2 from the atmosphere than terrestrial forests. Cui et al. (2018) stated the increasing importance of protecting mangrove ecosystems from damage and loss of ecosystem function. The loss of mangrove ecosystem function due to the decreasing area requires efforts to preserve and restore mangrove forests to restore ecosystem function and support biodiversity.

One of the efforts that can be taken to increase the expansion of mangroves is planting. Planting efforts are carried out to restore native species habitats, such as propagule care, seedling production, evaluation of optimal periods in propagule planting and seedling transplanting, planting procedures, and post-planting monitoring (Costa et al. 2016). Mangrove planting using seedlings with certain methods can produce optimal growth (Haris and Kusmana 2019). Choosing planting sites that get direct sunlight exposure can help the high growth of seedlings because of the much greater availability of light (Goldberg and Heine 2021). The growth and survival of *R. Mangle* L propagules can grow twice as fast in microhabitats than under the mangrove canopy (Goldberg and Heine 2021). The success of mangrove planting depends largely on the type of restoration and seeding techniques used for scale and time efficiency to improve cost and benefit estimates (Rodríguez et al. 2021). This result is further corroborated by Mahmoudi et al. (2022), who found a link between the success of mangrove rehabilitation and reforestation based on a review of successful site selection and planting techniques. However, the study by Van Bijsterveldt et al. (2022) emphasizes that the growth and survival of mangrove seedlings are highly dependent on the type planted.

Studies on the growth and survival of mangroves in coastal areas have been widely conducted and focus on the factors determining their growth zoning patterns. Studies on growth have also been conducted in forests to determine optimal mangrove growth rates. The number of deaths and damage is more prevalent at the tree level than at the saplings. Canopy cover increased from 40% at 1–2 months after damage occurred and increased at 3–6 months by 60% (Radabaugh et al. 2020). Villamayor et al. (2016) also added that mangrove mortality is closely related to the age of the stands. Those aged less than eight years require a recovery time of at least two years after damage. The success of mangrove planting is often associated with selecting the right location, the seeds used, and the environmental conditions supporting mangrove survival.

These studies usually experiment with planting mangrove seedlings under various conditions on a laboratory scale. These experimental studies yield important information on the type of seedlings that are suitable for the habitat characteristics to be selected for the restoration of degraded ecosystems to ensure survival and accelerate the regeneration process of the ecosystem as a whole. For example, in Gillis et al. (2019), planting mangrove seedlings in temperature-controlled rooms (23ºC and 33ºC), applying organic matter and dissolved nutrients showed that temperature and nutrient regulation can cause significant differences in root morphology. Salinity enhancement experiments are thought to be capable of decreasing leaf and root biomass, although the total biomass of mangroves remains unchanged at different salinity treatments (Shiau et al. 2017). Tides and salinity are also known to have a significant effect on root growth and development in both young and old seedling germination (Chen and Ye 2014; Chen and Wang 2017; Erftemeijer et al. 2021). Uche et al. (2023) added the results of a study that showed the survival ability and growth performance of *R. racemosa* seedlings can reach 95% with varying nutrient concentrations in sediments. The increase in photosynthesis rate and leaf biomass is significantly proportional to the increase in N availability (Kao et al. 2001). Many studies observing the growth response of mangrove seedlings related to environmental changes are related to salinity conditions. Mangrove planting in locations with low salinity conditions has not been found much. The location of the study has the characteristic of salinity changes that tend to be very small, as evidenced by values that range from 0–1.09%. In addition, not many studies have revealed the response of mangrove growth after one year of planting with varying environmental conditions, which is expected to be a reference in designing mangrove planting.

This study focuses on the growth rate of mangrove seedlings after planting the *R. mucronata* mangrove species on the coast of Peunaga Cut Ujong, West Aceh. Mangrove species from the Rhizophoraceae family were selected because they are one of the dominant species in Southeast Asian mangrove forests (Gerona-Daga and Salmo 2022; Tomlinson 2016). This study assessed the survival and mortality of seedlings planted using seedlings of the same age and type. Assessments of mangrove survival and growth were based on leaf growth, leaf thickness, changes in tree trunk circumference, and tree height.

2. Materials and Methods

2.1. Study Area

This research was conducted on the coast of Peunaga Cut Ujong. Peunaga Cut Ujong is one of the villages in the Meurebo, West Aceh. This research was located on private land that, before the tsunami in 2004, was the location of the Pemuda Hamlet community, Peunaga Cut Ujong (**Fig. 1**). After the tsunami, the local community only used this coastal area to catch shrimp and fish. Mangrove planting in this location results from coordination between PT Mifa Bersaudara in West Aceh and the landowner who facilitated the trial planting of mangrove seedlings in an area of 0.30 km^2. The plants observed were mangrove seedlings that had been growing for a year at the research site. This location was chosen as a research area because it is considered to have the potential for success in mangrove growth succession. This is based on observations of the condition of mangrove seedlings planted in a year, substrate conditions, tides, and salinity levels, and literature studies conducted by researchers support it. This collection of information determines decision-making regarding the implementation of mangrove revegetation research. Determining planting types and techniques follows the consideration of the availability of mangrove species in the West Aceh Region.

2.2. Sample Determination

Mangroves planted in 2022 are mangrove seedlings collected from the Aceh Jaya conservation area. The mangrove seedlings collected earlier came from mature propagules (naturally fallen propagules) and were planted in sand-filled polybags with a depth of ± 30 cm. Propagules that have been sown begin to grow roots and successfully grow roots and successfully grow leaves (maximum four leaves) are prepared to be used as seedlings in mangrove planting in Peunaga Cut Ujong. A total of 150 mangrove seedlings of *R. mucronata* and *R. apiculata* species were planted using the same planting technique, namely removing mangrove seedlings from polybags and planting directly at the research site. The study began after one year of planting, assuming that the planted seedlings had adapted to the environment. A total of 35 trees with the same or almost the same type and size criteria were selected for sampling, namely from mangrove species *R. mucronata*. Observation was conducted for five months, from May to October 2023.

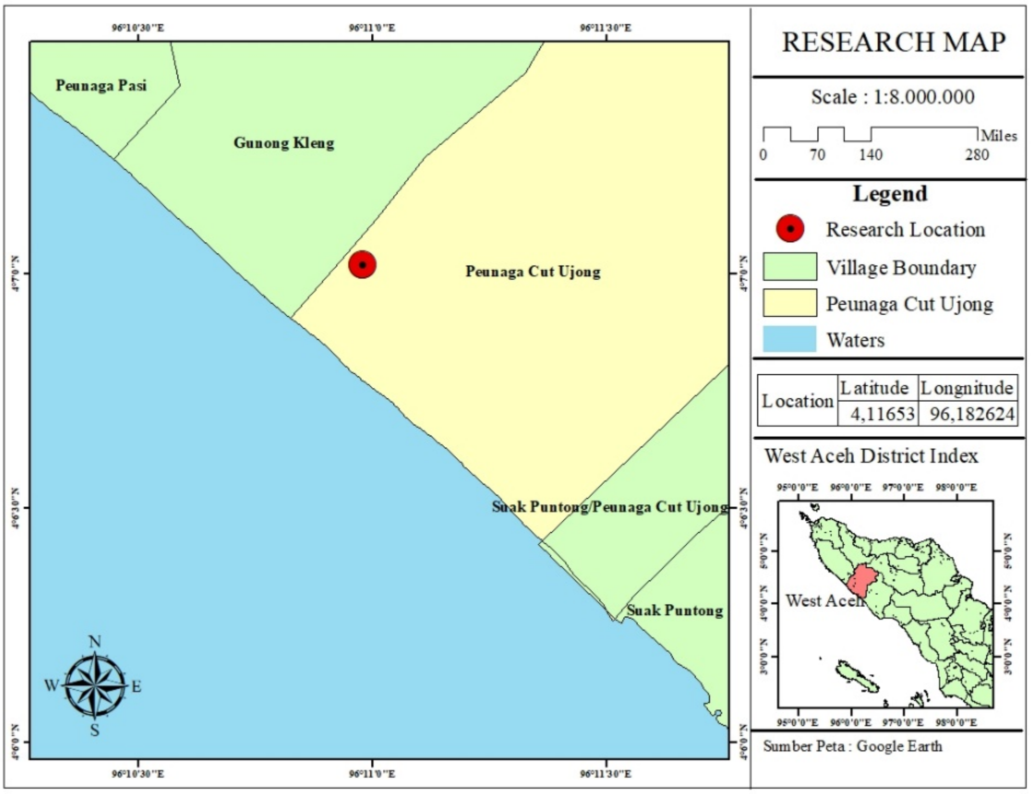

Fig. 1. Planting location and observation of growth and survival of mangrove seedlings.

2.3. Data Collection

The coast of Peunaga Cut Ujong is about 0.25 km from the sea. This area still gets the influence of tides dominated by semi-diurnal tides with an average range of the highest tide of about 30–50 cm. Coastal plants that dominate this area are from the Arecaceae family. The data collected in this study include the seedling survival (after a year of planting) based on the growth of the increase in the number of leaves, the level of leaf thickness, changes in the circumference of the tree trunk, and tree height. The selection of tree seeds used as observation samples are trees with almost the same morphological conditions, both from the number of leaves, tree height, and root. This is done to reduce bias from the beginning (T0) to the end of the observation.

2.4. Stages of Research Activities

A total of 35 research samples were in one selected sample plot, assuming that environmental conditions did not vary too much. The following figure (**Fig. 2**) shows the distribution of samples observed by marking each tree with numbering labels.

Fig. 2. Research plot the coast of Peunaga Cut Ujong.

Measurement of mangrove leaf growth pays attention to the number of leaves and changes in the ratio of length and width of mangrove leaves each time the observation is done. Changes in leaf length and width ratio are measured using a clear plastic bag (mm). The height and width of mangrove leaves were measured using needles with a modified marking method (**Fig. 3**). The selected leaves are young and in good condition, with as many as three leaves representing one stand. This marking was carried out repeatedly every time data was collected in the field to anticipate the loss of the marks placed at the beginning of the research. The thickness of mangrove leaves was measured using a caliper (Sigmat Type 54–808). Furthermore, the circumference and height of the tree trunk are measured using a diameter tape. The circumference of the tree trunk is measured at the position of the trunk circumference, which is 30 cm above ground level (Muharrahmi et al. 2016).

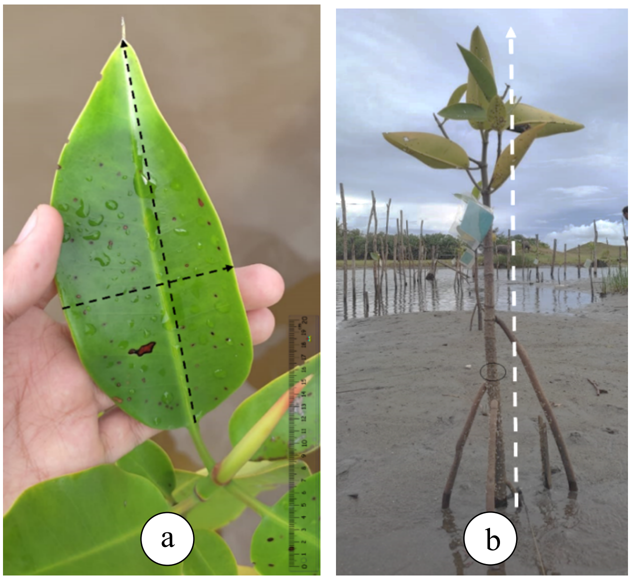

Fig. 3. (a) Growth measurement of leaf length and width, (b) height and circumference of mangrove tree trunk.

In addition to observing the survival rate and growth of mangrove seedlings, data collection on substrate type and water quality was also carried out. Substrate and water sampling using the illustration scheme in **Fig. 4**. Each observation station was taken three times (the total number of samples was 9 sample bags) so that the results could represent the research location well. A wet substrate sample of ±1 kg is put into a sample bag for analysis in the laboratory, such as soil texture analysis and organic content. Like water samples collected from 9 points, each test was taken as much as 1L to analyze total phosphate and nitrate. In-situ water quality observations are also carried out at predetermined points.

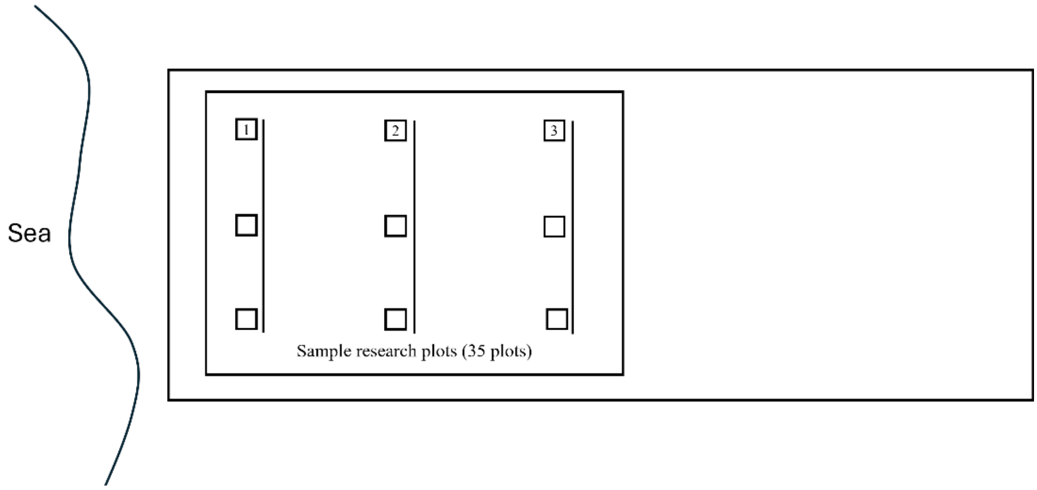

Fig. 4. Schematic of water and substrate sampling at the sample plot location.

Substrate and water analysis were observed in the laboratory for one observation by analyzing soil texture, divided into three categories: sand, dust, and clay. C-organic content (organic C, Walkley and Black), N-total (total N, Kjeldahl), available P such as Bray II P (Bray II extracted P). Water test parameters Chemical oxygen demand (COD), total phosphate (PO_4^{3-}), and nitrate using spectrophotometric test method. Water quality observations observed each time and carried out in situ are Salt and temperature using a multifunction water quality tester with model number EZ-9909SP.

2.5. Data Analysis

All data collected during the six months of observation was analyzed using Microsoft Excel. Data from 35 trees with observations every two weeks resulted in nine data points that were averaged and graphed. All data collected are averaged per observation time so that the data entered in the graph includes nine observations.

3. Results and Discussion

3.1. Results

Observations on seedlings *Rhizophora mucronata* species planted on the coast of Peunaga Cut Ujong focused on mangrove survival and growth. Mangrove survival and growth (**Table 1** and **Fig. 5**) can be observed by observing the increase in the number of leaves, the ratio of leaf length and width, leaf thickness, circumference, and height of the tree trunk.

The average leaf growth of *R. mucronata* during the five months of observation showed an average increase of 1–2 leaves every two weeks. Observations in the 18th week showed declining results, from an average of 25 to 23.22. The results show a continuous increase in the length and width of mangrove leaves until the 18th week. Some data show a decrease in the 12th week but increased again in the 14th week and then decreased again in the 18th week. This contrasts with the data obtained at the level of leaf thickness, showing an increase occurred until week 6 of observation. After that, the leaf thickness level decreased, even reaching 0.25 mm in the 12th week.

Table 1. Average leaf growth, increase in length width, and leaf thickness of *Rhizophora mucronata* mangrove leaves every two weeks during five months of observation

Sequence of observations	The average number of leaves	Mangrove leaf morphometrics (mm)		Mangrove leaf thickness level (mm)
		Leaf length	Leaf width	
1	18.61	1078	557	0.40
2	18.88	1085	525	0.43
3	19.00	1090	531	0.51
4	21.00	1118	558	0.41
5	22.11	1123	549	0.35
6	23.61	1108	539	0.25
7	23.72	1137	554	0.31
8	25.00	1129	551	0.36
9	23.22	1104	544	0.34

The same thing was also shown in the data on the increase in circumference and height of tree trunks of *R. mucronata*. Accretion begins at the 4th week and continues at the 18th week. The average increase in the tree trunk circumference during the five months of observation was 0.5 cm (**Fig. 5a**). At the same time, the average increase in height of mangrove tree trunks during data collection reached 3.3 cm (**Fig. 5b**).

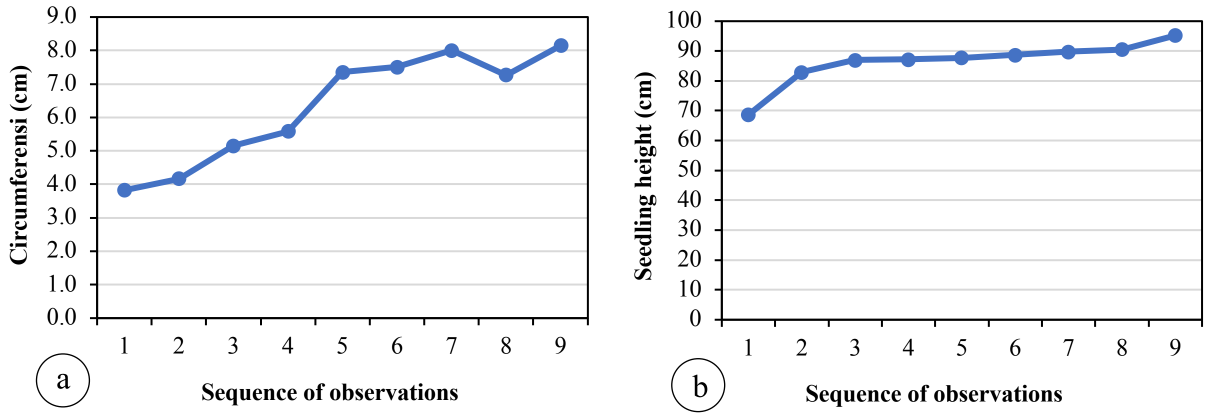

Fig. 5. Average increase in circumference (a) and height (b) of tree trunks in 5 months of observation.

The laboratory analysis results of substrate and water at the observation site are presented in **Table 2**. Laboratory analysis showed that the substrate texture at the study site was dominated by sand (89.44%), mud (5.56%), and clay (5%). In addition to laboratory analysis testing, water quality data for each observation, such as salinity data, was also collected. The results showed that the average salinity on the coast of Peunaga Cut Ujong was between 0.19–1.09% (**Fig. 6a**). The occurring tides can cause high and low salinity values at each observation. In addition, the location of the estuary, which is easily covered by piles of sand due to waves, causes water conditions that are not well circulated so that salinity can be very low or very high. The temperature parameter ranged between 26.82ºC–33.68ºC (**Fig. 6b**).

Table 2. Results of soil texture analysis and water quality parameters at mangrove planting sites

No.	Laboratory analysis results	Unit	Value per observation station		
			S1	S2	S3
1	Soil texture				
	- Sand	%	88.33	90	90
	- Silt	%	6.67	5	5
	- Clay	%	5	5	5
	- Texture classes	%	S	S	S
2	Organic C (Walkley & Black)	%	0.60	0.64	0.63
3	Total N (Kjeldahl)	%	0.05	0.04	0.04
4	Bray II (Extracted P)	mg/kg	29.72	29.05	27.03
5	Water quality				
	- COD	mg/L	31.42	32.01	29.18
	- Total phosphate (PO_4^{3-})	mg/L	0.29	0.32	0.38
	- Nitrate	mg/L	14.70	16.04	14.52

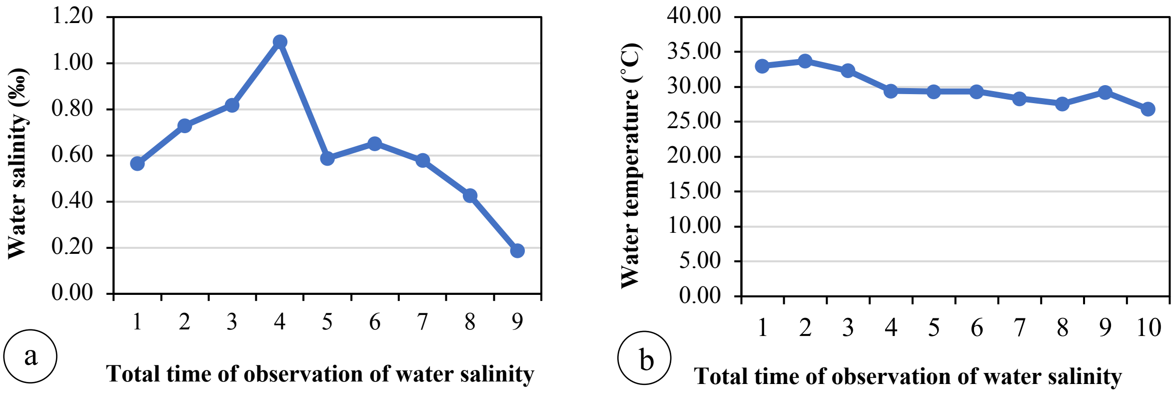

Fig. 6. Observation of salinity (a) and water temperature (b) parameters in the waters of Peunaga Cut Ujong, Meurebo, West Aceh.

3.2. Discussion

This study reveals the response of mangrove seedlings and the survival of *R. mucronata* planted on the coast of Peunaga Cut Ujong with dominant sand substrate conditions. Mangrove seedlings observed as many as 35 trees after planting one year showed a survival rate of 100% until the 3rd month observation, but at the 5th month observation, the survival rate began to decline to 78%. 22% of the mangrove trees included in the observations experienced death, with signs of trees experiencing dryness and leaves drastically disappearing. However, the trees experienced death; until the end of the observation, the eight trees could not be re-recorded because of the condition that drained and lost leaves. Peunaga Cut Ujong coastal environmental conditions with a dominant soil texture of sand (**Table 2**) support the growth of mangrove species *R. mucronata*. Plant adaptation to its environment can be adapted to the morphology of roots, stems, and leaves (Naidoo 2016).

Several studies of mangrove seedling growth show different tolerance to existing environmental conditions. The results showed the response of leaf thickness to salinity conditions; the increase in salinity levels in the 4th week showed that the level of leaf thickness decreased by 0.10 mm. Peng et al. (2016) showed Rhizophora seedlings' response to light and salinity variations. However, the plant responds with no reddened leaves in high salinity conditions. Nguyen et al. (2017) revealed that salinity conditions and water availability influence the increase in leaf thickness, leaf ratio, and water content. Mangrove seedlings at high salinity can show significantly lower performance in survival rate, growth, shoot height, leaf area ratio, and average dry weight. Low salinity is the best condition for early establishment and growth of seedlings up to 15–20 weeks and shows significantly better performance under moderate salinity after 15–20 weeks of age (Kodikara et al. 2017). This suggests that adaptation to changes in salinity and the physiological requirements of mangrove seedlings vary with seedling age. Massive mangrove mortality and regeneration failure are often associated with continuous submergence and changing salinity. Mangora et al. (2014) described the effect of three weeks of immersion in water with different salinities on photosynthetic rates in the mangrove species *Bruguiera gymnorrhiza, Avicennia marina,* and *Heritiera littoralis*. Prolonged immersion can cause a significant reduction in photosynthetic rate. Tolerance to salinity and waterlogging in mangroves is often associated with efficient water use for photosynthetic carbon gain in favor of increased productivity, leading to increased CO_2 (Lovelock et al. 2016). In this study, the immersion conditions did not occur continuously. However, the changing salinity conditions continued to change every time the observation was likely to affect the morphometrics of mangrove leaves.

Leaf water storage capacity and total leaf water storage increased with increasing salinity and drought (Yu et al. 2023). The same results were shown in this study, showing a decrease in the leaf width ratio with the decrease in salinity at each observation, unlike the case with leaf length, which does not show a significant change in average value. Research by Ahmed et al. (2022) revealed that increased salinity can significantly inhibit growth and produce dwarf species, affecting leaf area unlike the case with leaf length, which did not show significant changes in average values. This aligns with Basyuni et al. (2014), which revealed that the *Rhizophora stylosa* type is susceptible to increased salinity, and salt stress can affect its growth parameters, such as plant height and diameter. However, in this study, the tree height and diameter parameters had no significant changes in conditions. The tree height and diameter parameters did not influence the decreasing salinity conditions at the study site. Tree height and diameter continued to increase even though salinity continued to decrease. Some mangrove seedlings showed tolerance to increased salinity. In *Avicennia germinans* and *Laguncularia racemosa*, the slow increase in salinity caused an acclimatization stage to increase tolerance to salinity. The *A. germinans* and *Rhizophora mangle* species are unaffected by decreasing salinity until salinity reaches 0 (Bompy et al. 2014). Similarly, an increase in temperature can affect respiration, photosynthesis, and plant productivity (Ellison 2014).

The addition of stem circumference diameter and tree height in this study sequentially starting from the first month to the end of observation ranged from 3.8–8.1 cm and 68.7–95.2 cm. These results show that the average increase in stem diameter and height during the five months of observation in *R. mucronata* is 4.3 cm and 26.5 cm. The response to the increase in biomass in this study cannot be ascertained about the existing environmental conditions. This is because no experiments related to water or soil quality influence on growth data or mangrove survival were carried out in this study. However, the results of research by Chapman et al. (2021) explain that there is a relationship between mangrove height growth rates and the event of increased air temperature warming.

This study also revealed the condition of organic matter in soil and water on the coast of Peunaga Cut Ujong. Organic matter accumulation is often associated with biotic and abiotic factors in water or land. Although the accumulation of organic matter obtained at the research site was relatively low compared to ideal conditions for mangroves, growth and survival continued to increase with each observation (**Table 1 and Fig. 5**). The study site was a new location for mangrove planting and was a trial planting. The characteristics of the research site Zhang et al. (2021) showed a similar value in the flat soil location category with soil total N and P values of 0.6% and 63.3%, respectively. It was also added that mangrove root production and decomposition are important for accumulating organic matter, especially in the terrestrial zone, so this organic matter is highly dependent on vegetation biomass.

4. Conclusions

Mangrove survival and growth rates were observed one year after planting in *R. mucronata*. Survival rate during the five months of observation showed a decrease from the first three months to the end of the observation. Mangrove seedlings experienced death reached 22%, characterized by drying stems and missing leaves. Low availability of organic matter in the substrate, warming air temperature, tidal patterns that tend to be inconsistent, and dominant sand substrates are the most likely factors in the death of the eight trees. Tree growth characterized by the addition of leaves, the leaf length and width ratio, leaf thickness, circumference, and tree height continued to increase every observation for five months. This indicates the adaptation process of mangrove species *R. mucronata* to conditions of low organic matter, sand-dominated substrate, salinity, and low water temperature. The results of this study can be used as a reference in mangrove planting with the selection of the suitable species that can adapted to existing environmental conditions. It is also important to conduct further research over a longer period to understand the factors most likely to affect the growth of *R. mucronata* species.

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