Analysis of the influence of environmental factors on mangrove distribution: a case study in Mangunharjo

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Abstract. This study aimed to analyse the impact of physico-chemical factors in the environment on the distribution of mangroves in the Mangunharjo area. The purposive sampling method determined the sampling locations, and samples of mangrove vegetation were acquired using a quadrant transect method. Statistical data analysis employed a multiple linear regression test. The results revealed a correlation value of 0.960 between environmental physico-chemical factors and mangrove distribution, signifying a relatively strong correlation. Physico-chemical factors such as nitrate, phosphate, as well as dust and clay fractions significantly influenced mangrove distribution, collectively explaining 92.1% of the observed patterns, with the remaining variance attributed to other factors. Nitrate levels ranged from 1.83 to 3.05 mg kg^{-1}, while phosphate levels ranged from 16.89 to 29.96 mg kg^{-1}. Sandy loam texture dominated the Mangunharjo village area in terms of the sand fraction. The availability of nutrients and substrate is expected to impact the mangrove structure in the Mangunharjo village.

Key Words: mangrove distribution, nutrient, substrate, vegetation composition and structure.

Introduction. Mangroves exhibit a close interconnection with the physico-chemical factors within their environment, with salinity, nutrients, and substrate among the pivotal environmental components. These factors have a very significant role in the growth and development of mangrove ecosystems (Saenger 2002). Nutrient content and availability stand out as crucial elements, constituting one of the three dominant components that influence the composition, structure, and productivity of mangroves (Hossain & Nuruddin 2016). Mangrove nutrients originate from various sources, including the mangrove itself in the form of twigs, fallen leaves, and decomposed organisms (Budiasih et al 2015). Nitrate and phosphate present in the sediment are essential nutrients required for the growth of mangroves. The sediment's organic matter content exhibits variations, with the organic matter content at the water bottom registering a higher value compared to that on the surface (Muchtar 2012).

The composition and structure of mangroves is also closely related to the type of soil or soil texture such as sand, clay and dust, as well as to other parameters such as seawater temperature, salinity, and tides (Rahim et al 2017). Natural mangrove ecosystems exhibit distinct zoning, a pattern influenced by the physiological properties of the mangroves themselves and their individual adaptability to the environment (Noor et al 2015). Moreover, variations in habitat conditions within a specific mangrove area can lead to differences in the functional roles of mangroves in supporting the surrounding environment (Saputra et al 2020). Spatial disparities in soil salinity exert an influence on the species composition and distribution of mangrove forests, reflecting variations in their capacity to withstand high and fluctuating salinity levels (Hossain & Nuruddin 2016).

The mangrove ecosystem plays a crucial role as a biofilter, binding agent, and pollution trap, while also exhibiting a remarkable tolerance for heavy metals (MacFarlane & Burchett 2001; Gunarto 2004). Along coastal areas, mangroves function as vital barriers against environmental changes, including coastal erosion, storms, and rising sea levels. Additionally, they have the capability to mitigate tidal waves of seawater (Cudiamat et al 2017). Given the importance of mangrove ecosystems, this study aimed to analyse the influence of the physico-chemical factors in the environment on the distribution of mangroves in the Mangunharjo Probolinggo area. Understanding these dynamics is essential for comprehending the ecological significance of mangroves in their coastal environment.

Material and Method

***Location determination technique**.* This research was conducted between December 2019 and January 2020 in the Mangunharjo mangrove area, located in the Mayangan Sub-district of Probolinggo City. Determination of sampling locations at five sites used a purposive sampling method (Valerio et al 2016). In this study, site 1, the focus of the first sampling location, represented a mangrove area situated in a former fishpond. Moving on, site 2 was a mangrove area positioned in a zone near the fishpond but closer to the sea, characterized as a natural mangrove. Following this, site 3 was a mangrove area situated adjacent to the river. Subsequently, site 4 encompassed a mangrove area designated for mangrove tourism; however, it remained unaffected by tourism activities, maintaining its classification as a natural mangrove free from human intervention. Finally, site 5 comprised a mangrove area within the Bee Jay Bakau Resort mangrove tourism site.

***Nutrient measurement procedure for nitrate and phosphate**.* A 100 g quantity of sediment samples was collected and subsequently diluted. The measurements of nitrate (SNI 2011) and phosphate (SNI 2005) were carried out using a spectrophotometric method at the Unit of Analysis and Measurement within the Chemistry Department, Faculty of Mathematics and Natural Sciences Universitas Brawijaya, Malang.

***Sampling technique**.* Mangrove vegetation samples were obtained using a quadrant transect method. The data collection process involved plot sizes of 10 m x 10 m for tree-level vegetation with a diameter exceeding 10 cm, 5 m x 5 m for sapling-level (local term: "belta") vegetation with a diameter less than 10 cm, and 2 m x 2 m for seedling-level vegetation with a diameter less than 2 cm (Kusmana 1997). The diameter of the main stem of the vegetation, commonly referred to as the diameter at breast height (dbh), was measured at 1.3 m above the ground. This measurement was consistently performed using a diameter tape (Howard et al 2014). Substrate sampling was executed with a masonry trowel within one of the transect plots, collecting approximately 100 grams of substrate, which was subsequently placed into a plastic container (Krisnawati et al 2018). The mangrove substrate samples were used to determine its texture and characteristics as well as to determine the content of nitrate and phosphate in the sampling location. Substrate samples were analysed at the Soil Chemistry Laboratory, Faculty of Agriculture, Universitas Brawijaya.

***Mangrove vegetation data**.* Data on mangrove species that had been collected were then analysed descriptively by describing the species characteristics of mangroves and their taxonomy based on Noor et al (2006). The calculation of the mangrove vegetation structure included species density (Di), which is the number of individuals of species I in a unit area (Malik et al 2015) and the relative density of a species RDi, which is the ratio between the number of individual species and the total number of individuals of all species, as formulated below (English et al 1997):

$$Di = \frac{ni}{A}$$

$$RDi = \frac{ni}{\Sigma n} \times 100$$

where: Di is the density of species i (individuals ha^{-1}), RDi is the relative density of species i (%), ni is the number per species i, n is the number of all species, A is the total area of the sample observed (ha).

Species frequency (Fi) is the probability that a species will be found in each plot of the entire site (Malik et al 2015), while the relative frequency (RFi) is the percent chance that a species will be found in each plot of the entire site with the following formula (English et al 1997):

$$Fi = \frac{Pi}{\Sigma p}$$

$$RFi = \frac{Fi}{\Sigma F} \times 100$$

where: Fi is the frequency of species i, RFi is the relative frequency of species i (%), pi is the number of plots of species i, F is the number of all species, p is the number of plots observed.

Species dominance (Di) is the number of species in a community which determines or controls the presence of other species, or whose number exceeds the number of other species, while relative dominance (RDi) is the percentage of the number of species in a community with the following formulae (English et al 1997):

$$Di = \frac{BA}{A}$$

$$RDi = \frac{Di}{\Sigma D} \times 100$$

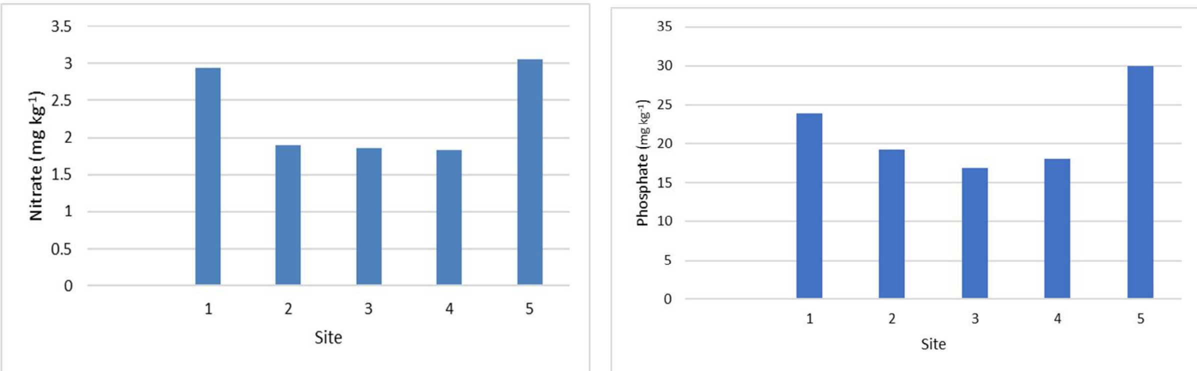
where: Di is the dominance of species i, BA is $DBH^2/4$ where BA is a basal area (cm) and DBH is a trunk diameter at breast height, A is the plot area (m^2), RDi is the relative dominance, and D is dominance for all species.

Data analysis. The research data were processed statistically using a multiple linear regression test with a significance level of 5%, which had previously been tested for normality and homogeneity. The data obtained were later analysed using SPSS version 16.00.

Results and Discussion

Analysis of the relationship between environmental factors and mangrove distribution. The impact of environmental physico-chemical factors on mangrove distribution was assessed through a multiple linear regression analysis. The results revealed a correlation coefficient (R) of 0.96 and an R-square of 0.92 (α = 0.05). This indicates a robust relationship between environmental physico-chemical factors - specifically nitrate and phosphate nutrients, as well as dust and clay fractions - and the distribution of mangroves. A significant 92.1% of the variance in mangrove distribution was simultaneously explained by these environmental factors, leaving 7.9% influenced by other factors. Nitrate and phosphate, crucial nutrients for mangroves that cannot be substituted by other elements, were identified as influential factors in mangrove species distribution. These nutrients play a vital role in determining the stability and growth of mangrove vegetation (Supriyantini et al 2017). Nutrient availability emerged as a key determinant in the spatial distribution of mangrove vegetation, with higher concentrations of nitrate and phosphate positively correlating with increased mangrove diversity (Chowdhury et al 2019). The research findings align with Perry & Berkeley's (2009) study, highlighting a strong correlation between substrate particles and mangrove distribution. Finer substrate particles, characterized by higher organic matter content, supported better and more diverse mangrove growth (Windusari et al 2014). The interrelation between vegetation and soil, as emphasized by Eni et al (2011), underscores the reciprocal influence of vegetation on soil characteristics, including volume, chemistry, and texture. This interconnectedness contributes to ecosystem functions, impacting density, potential, and diversity of vegetation, encompassing factors such as productivity, structure, and flora composition.

Analysis of nitrate and phosphate nutrients. Nutrients constitute essential parameters influencing the growth, reproduction, and metabolic activity of mangrove biotic components. The distribution of nutrients is subject to seasonal variations, tidal conditions, and the inflow of fresh water from the land (Saravanakumar et al 2008). The concentrations of nitrate and phosphate are illustrated in Figure 1.



(a) (b)

Figure 1. Measurement of (a) nitrate and (b) phosphate.

According to the measurement results, nitrate levels ranged from 1.83 to 3.05 mg kg^{-1}, while phosphate levels ranged between 16.89 and 29.96 mg kg^{-1}. Site 5 exhibited the highest concentrations of nitrate and phosphate, recording values of 3.05 and 29.96 mg kg^{-1}, respectively. This elevation in nutrient content at site 5 can be attributed to its location within a tourist area, characterized by a silty clay loam substrate. The finer texture of the mangrove substrate at this site enhances the availability of nitrate and phosphate (Tang et al 2014). Finer-textured substrates possess the capacity to absorb water and retain or trap nutrients beneficial for mangroves (Zakaria et al 2017). The nutrient content in sediment is influenced by both abiotic and biotic factors, including tides, soil type, redox status, soil microbial activity, mangrove species, and litter production (Reef et al 2010). These factors collectively contribute to the observed variations in nutrient concentrations across the sampled sites.

Mangrove vegetation substrate analysis. The substrate's characteristics play a crucial role in selecting suitable vegetation types for rehabilitation efforts. The physical composition of soil in the mangrove area comprising mud, loam, and sand, contributes to the dynamics of accretion and erosion. During the tidal cycles, substrate particles become trapped at the base of the vegetation, leading to increased sedimentation, especially in areas with high mangrove vegetation density (Motamedi et al 2014). Mangrove sediments undergo changes due to the processes of erosion. Both accretion and erosion can alter the physical properties of the soil, potentially causing shifts in mangrove species zoning (Sofawi et al 2017). Zoning is closely linked to soil type or texture (sand, clay or silt), sea water temperature, seawater salinity and tides (Rahim et al 2017). According to Bunt & Williams (1981), mangrove zoning is influenced by the type of substrate. The analysis of mangrove vegetation substrate is detailed in Table 1.

Table 1

Mangrove vegetation substrate analysis

Site	Percentage of soil fraction			Soil texture
	Sand (%)	Silt (%)	Clay (%)	
1	48	15	37	Sandy clay
2	62	19	19	Sandy loam
3	54	20	26	Sandy clay loam
4	79	5	16	Sandy loam
5	16	45	39	Silty clay loam

The soil measurements conducted using the sieve shaker method at sites 1-4 revealed a higher percentage of the sand soil fraction in comparison to clay and silt. However, at site 5, a higher silt content was observed than sand and clay. Specifically, site 1 exhibited a sandy clay texture, while sites 2-4 displayed a sandy loam texture. Site 5, on the other hand, demonstrated a silty clay loam texture. This variation can be attributed to the fact that sites 2-4 are located adjacent to the shoreline. The research findings indicate that the soil in Mangunharjo village is predominantly composed of the sand fraction, with the prevalent texture being sandy loam. Mangrove genera such as *Sonneratia* and *Rhizophora* are typically found in loam substrates, whereas *Avicennia marina* is commonly associated with sandy substrates (Jalil et al 2020). Understanding the soil composition and texture is essential for identifying suitable vegetation for mangrove rehabilitation and conservation initiatives in the Mangunharjo village area.

***Composition and structure of vegetation*.** Based on the constituent vegetation, mangrove forests can be categorized into three types known as major mangroves, minor mangroves, and mangrove associations. Major mangroves are adapted to high salinity conditions and tidal environments. Minor mangroves, on the other hand, thrive in lower salinity conditions and coastal areas near the mainland (Nurrohman et al 2020). Mangrove associations typically flourish in terrestrial habitats (Tomlinson 1986). The families Acanthaceae, Combretaceae, Arecaceae, Rhizophoraceae and Lythraceae are included in major mangroves (Hoque & Datta 2005). Understanding these distinctions in mangrove types is crucial for comprehending the ecological dynamics and planning conservation strategies tailored to the specific needs of each mangrove ecosystem.

Based on the observational results, the mangrove area in Mangunharjo Village is home to 6 species of mangroves, as detailed in Table 2. Among these, two species belong to the Acanthaceae family, namely *Avicennia alba* and *Avicennia marina*. Additionally, three species from the Rhizophoraceae family are present, including *Rhizophora mucronata*, *Rhizophora apiculata* and *Bruguiera gymnorrhiza*. Furthermore, one species from the Lythraceae family, *Sonneratia alba*, is identified. The number of trees categorized based on their regeneration or diameter size at the five sites is illustrated in Figure 2.

Table 2

Mangrove species found in Mangunharjo

Scientific name	Local name	Family	Observation site				
			1	2	3	4	5
Avicennia alba	Api-api	Acanthaceae	+	+	+	+	+
Avicennia marina	Api-api putih	Acanthaceae	+	+	+	+	
Bruguiera gymnorrhiza	Tanjang Putut	Rhizophoraceae	+				
Rhizophora apiculata	Tanjang	Rhizophoraceae	+	+			
Rhizophora mucronata	Tanjang	Rhizophoraceae	+	+	+	+	+
Sonneratia alba	Perepat	Lythraceae	+	+	+	+	+

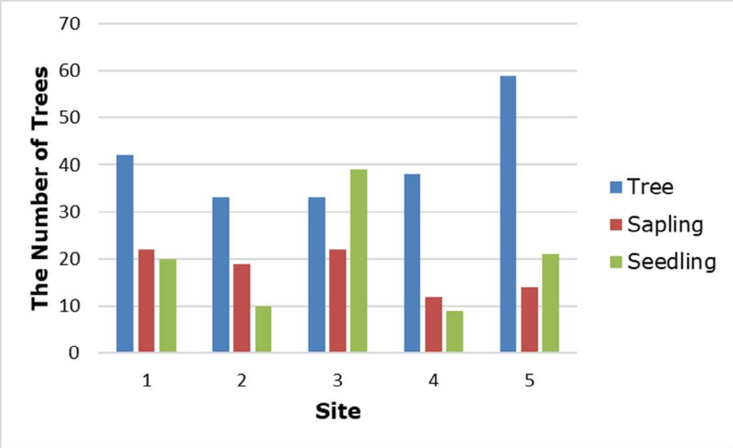


Figure 2. Number of trees by category of regeneration/diameter size in the mangrove forest of Mangunharjo village.

Species density. Mangrove density serves as a parameter to estimate the density of mangrove species in a specific community and is indicative of the health status of mangrove forests (Sari & Rosalina 2016). The quality standards for mangrove density are established by the Decree of the Minister of State for the Environment (Kepmen LH) No. 201 of 2004. According to these standards, mangrove density can be categorized as follows: mangrove density ≥ 1,500 trees ha^{-1} is considered high density, mangrove density in the range of 1,000-1,500 trees ha^{-1} is categorized as medium density, and mangrove density ≤ 1000 trees ha^{-1} is classified as rare density.

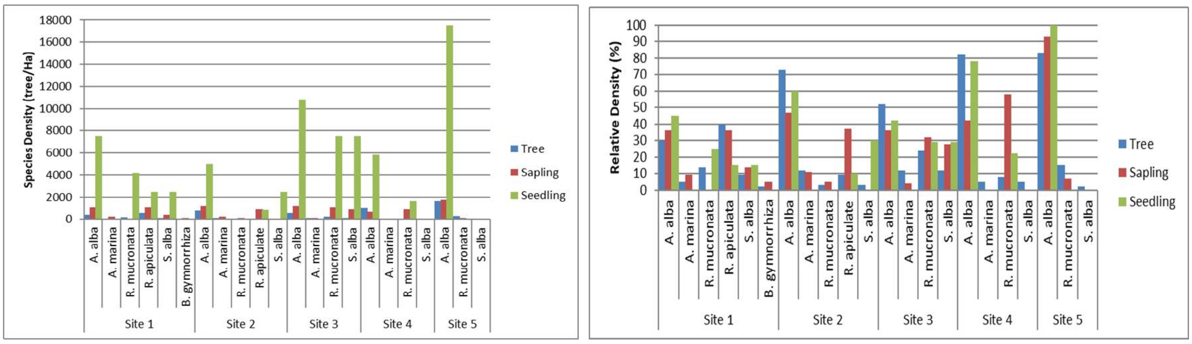
Based on the data obtained, the overall tree category density at the five sites was as follows: 1,433 trees ha^{-1} at site 1, 1,099 trees ha^{-1} at site 2, 1,100 trees ha^{-1} at site 3, 1,267 trees ha^{-1} at site 4 and 1,965 trees ha^{-1} at site 5. According to the classification outlined in Kepmen LH No. 201 (2004), the density of the average tree category across these sites falls within the range of moderate to high density. These categories help assess and monitor the ecological health and vitality of mangrove ecosystems.

Based on the sapling category, the density obtained at each site is as follows: 2,934 trees ha^{-1} at site 1, 2,533 trees ha^{-1} at site 2, 3,333 trees ha^{-1} at site 3, 1,600 trees ha^{-1} at site 4, and 1,866 trees ha^{-1} at site 5. According to the criteria established by Kepmen LH No. 201 (2004), the average density within the sapling category is considered high. This observation provides valuable information about the regeneration potential and overall health of the mangrove ecosystem in the respective sites, especially in terms of sapling populations.

Based on the seedling category, the density obtained at each site is as follows: 16,667 trees ha^{-1} at site 1, 8,333 trees ha^{-1} at site 2, 25,833 trees ha^{-1} at site 3, 7,500 trees ha^{-1} at site 4, and 1,965 trees ha^{-1} at site 5. According to the criteria established by Kepmen LH No. 201 (2004), the average density within the seedling category is considered high. This observation provides valuable insights into the regenerative capacity and potential for future growth of the mangrove ecosystem in the respective sites, particularly with regard to seedling populations.

Species with high densities tend to occupy more space compared to species with low densities. High-density species have the capacity to compete with other species and demonstrate adaptability to environmental conditions (Nelly et al 2020). Conversely, low density may result from the inadaptability of a mangrove species to its environment (Sambu et al 2014). Understanding the density dynamics of mangrove species is crucial for assessing their ecological roles, competitiveness, and adaptability within a given ecosystem.

Figure 3 illustrates that the highest mangrove density in the tree, sapling, and seedling categories was observed in *A. alba* and *R. mucronata*. In contrast, the lowest density was recorded in *A. marina* and *S. alba*. *B. gymnorrhiza* was infrequently found at the research site, and *R. apiculata* was only identified at site 1. This distribution may be attributed to the fact that at site 1, *R. apiculata* was planted in a former fishpond area, contributing to its presence in that specific location.



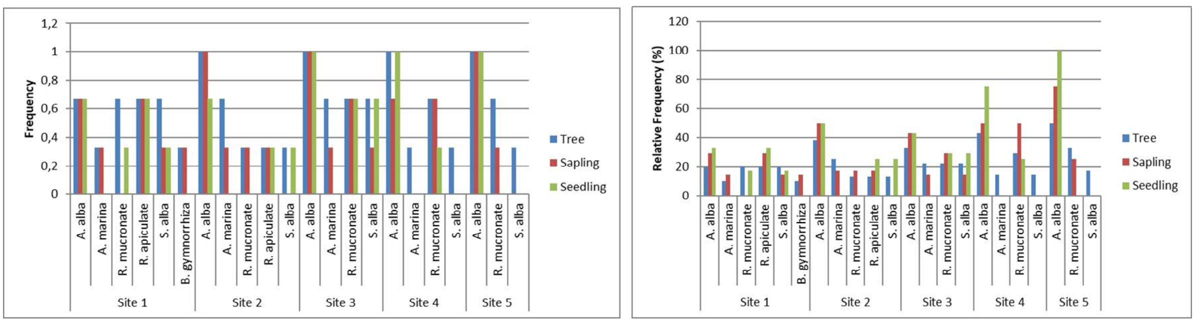
(a) (b)

Figure 3. (a) Species density, and (b) relative mangrove density.

Specifically, *A. alba* dominated in areas affected by diurnal tides. *A. alba* exhibits adaptability to soils with high salinity (Joshi & Ghose 2003). Similarly, *R. mucronata* species is known for its ability to thrive in soils with high salinity (Schmitz et al 2006). This aligns with the location of the study, which is in proximity to tides and features high salinity soil. In contrast, *B. gymnorrhiza* was primarily found in the middle and upper intertidal zones and was infrequently observed in the lower intertidal areas or closer to the sea (Allen & Duke 2006).

***Species frequency**.* Species frequency is a crucial vegetation parameter that characterizes the distribution pattern of plant species within an ecosystem. The frequency of a species is influenced by the sample plots of mangrove vegetation (Nelly et al 2020). The species frequency value plays a significant role in determining the distribution of a mangrove species in the mangrove community. A high frequency value indicates that the species has an even distribution and is frequently encountered in a forest area. Conversely, a low frequency value suggests an uneven distribution within a forest area (Kerry et al 2017).

In all research sites, *A. alba* dominated both relative frequency and species frequency, followed by *R. mucronata*, *S. alba*, *A. marina*, and *R. apiculata* as depicted in Figure 4. This dominance can be attributed to various environmental factors, including soil pH and soil texture. Each mangrove species exhibits different tolerances to environmental conditions (Krauss & Allen 2003). Zones closer the sea and characterized by sandy soil were predominantly occupied by *Avicennia* spp., whereas the middle zone with muddy soil was dominated by *Rhizophora* spp. (Sofawi et al 2017).

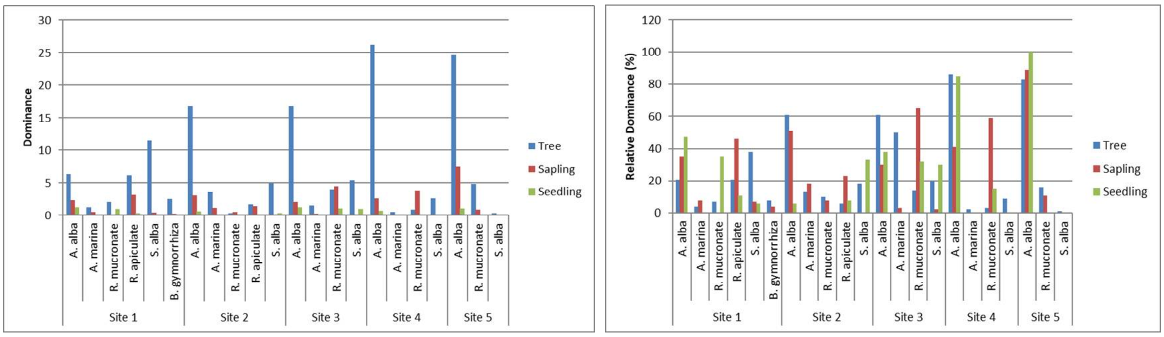


(a) (b)

Figure 4. (a) Type frequency, and (b) mangrove relative species frequency.

***Species dominance**.* The dominance of mangrove species in an area is influenced by environmental factors such as humidity, temperature, and a species' ability to either survive or compete with other species. This competition can involve factors like nutrients, sunlight, and growing space, all of which significantly impact the tree growth and trunk diameter. Dominant species typically exhibit high productivity, and their prevalence in the research area serves as an indicator that the community thrives in a suitable habitat, supporting its growth (Kapitan et al 2020).

Based on Figure 5, the results of this study indicate that the most dominant species in all sites was *A. alba*, followed by *S. alba*, *R. mucronata* and *R. apiculata*. Generally, *Avicennia* spp. and *Sonneratia* spp. thrive well in sandy soil. The zone closest to the sea was dominated by *Avicennia* spp. and *Sonneratia* spp. with muddy soil type, rich in organic content. *R. mucronata* and *R. apiculata* can grow in wet habitat conditions with a salinity ranging from 10 to 30‰ (Hidayat et al 2010).



(a) (b)

Figure 5. (a) Species dominance, and (b) relative dominance of mangrove species.

Conclusions. Based on the study findings, it is shown that physico-chemical factors in the environment play a crucial role in shaping the distribution pattern of mangroves in Mangunharjo village, Probolinggo City. The simultaneous impact of these factors, including nitrate and phosphate nutrients, as well as dust and clay fractions, accounted for a substantial 92% in influencing mangrove distribution. The prevailing soil texture in Mangunharjo village is characterized by a dominant sand fraction, resulting a sandy loam texture. Furthermore, the composition of the mangrove community (*A. alba*, *A. marina*, *R. mucronata*, *R. apiculata*, and *S. alba*) in Mangunharjo village is intricately linked to the availability of nutrients and substrate. These insights underscore the intricate relationship between environmental conditions and the dynamics of the mangrove ecosystem in Mangunharjo village.

Conflict of interest. The authors declare that there is no conflict of interest.

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