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Mangrove diversity and its relationships with environmental conditions in Kuala Bubon Village, West Aceh, Indonesia

WINTAH[1,2,♥], KISWANTO[1], ENDANG HILMI[3], MOH. HUSEIN SASTRANEGARA[4]

[1]Public Health Science, Faculty of Public Health, Universitas Teuku Umar. Jl. Alue Peunyareng, Ujong Tanoh Darat, Meureubo, West Aceh 23681, Aceh, Indonesia. Tel./Fax.: +62-281-642360, ♥email wintah@utu.ac.id

[2]Master of Fisheries Science Study Programme, Universitas Teuku Umar. Jl. Alue Peunyareng, Ujong Tanoh Darat, Meureubo, West Aceh 23681, Aceh, Indonesia.

[3]Faculty of Fisheries and Marine Sciences, Universitas Jenderal Soedirman. Jl. Dr. Soeparno, Purwokerto Utara, Banyumas 53122, Central Java, Indonesia

[4]Faculty of Biology, Universitas Jenderal Soedirman. Jl. Dr. Soeparno No.63, Purwokerto Utara, Banyumas53122, Central Java, Indonesia

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Abstract. *Wintah, Kiswanto, Hilmi E, Sastranegara MH. 2023. Mangrove diversity and its relationships with environmental conditions in Kuala Bubon Village, West Aceh, Indonesia. Biodiversitas 24: 4599-4605.* Mangrove ecosystem plays various ecological and socio-economic roles. Indonesia has the largest extent of mangrove forest one of which is located in West Aceh Regency, Aceh Province. The aim of this study was to assess the diversity and structure of mangrove forest in Kuala Bubon Village, West Aceh, and to analyze the relationships between the existence of mangrove species and the environmental conditions. Field survey was conducted from May to August 2022 using plot sampling method on three stations representing various habitat characteristics. Vegetation sampling using a 10 x 10 m^2 plot as well as measurement on physical parameters (pH, salinity, and temperature) and chemical parameters (sediment texture and organic carbon content) were conducted. The relationship between the presence of mangrove species and the environmental parameters was analyzed using Principal Component Analysis (PCA). The result of vegetation sampling recorded 6 mangrove species, i.e., *Rhizophora stylosa* Griff, *Sonneratia alba* Sm, *Avicennia marina* (Blume), *c*, and *Sonneratia caseolaris* (L) Engl. This study revealed that the presence of *Rhizophora stylosa* Griff was related to the conditions of the clay substrate, pH and temperature values. Meanwhile, the existence of *Rhizophora apiculata* Blume, *Rhizophora mucronata* Lamk, *Sonneratia alba* Sm, *Sonneratia caseolaris* (L) Engl, and *Avicennia marina* (Blume) was related to the conditions of the silt substrate, diameter and salinity. Based on the results of relationship analysis, silt substrate and salinity have a correlation to maintain the mangrove ecosystem.

Keywords: Diameter at breast height, mangrove, sediment, West Aceh

INTRODUCTION

Mangroves are woody trees and shrubs that grow on different salinity gradients (Ahmed et al. 2023). Mangrove is a unique ecosystem located in the transition zone between terrestrial and marine realms, and only occurs in tropical regions. Mangrove forests provide a range of ecosystem services, which are important for the well-being of humankind (Njana 2020), from serving as the barrier from strong waves, storm and tsunami, mitigating coastline from abrasion, providing habitat of flora and fauna to providing sources of livelihood to local communities. In the context of climate change mitigation, Syakti et al. (2013) highlighted the ability of the mangrove ecosystem to sequester and store carbon from air, water and soil. Many studies also revealed that mangroves have potential as sources of antimicrobials (Pringgenies et al. 2021), potential of marine natural ingredients (Pringgenies et al. 2023), amino acid (Ningsih et al. 2020), micro and macro element contents (Ariyanto et al. 2019a) and chemical profiles (Ariyanto et al. 2019b).

Mangroves generally grow on intertidal area with a fine textured soil and high salt content. Dewiyanti et al. (2021) indicate that different mangrove habitats have different characteristics in physico-chemical soil properties as well as water conditions. As a result, there are different types of flora and fauna in mangrove habitats with different environmental characteristics (Chen et al. 2023). Mangrove ecosystem with good condition certainly provides various benefits in terms of ecological functions (e.g., spawning ground, feeding ground, and nursery ground) and economic functions. In a good mangrove ecosystem, a high diversity of marine biota can be found, such as gastropods (Ariyanto et al. 2018a; Ariyanto et al. 2020), bivalves (Yahya et al. 2020), fishes (Hasan et al. 2021), crabs (Mégevand et al. 2022), and shrimps (Alam et al. 2022).

The condition of mangrove is influenced by the abiotic and biotic components of the environment. The abiotic variables that affect mangrove ecosystem include pH, temperature, salinity, sediment texture, and organic matter. For example, a study found that the growth and survival of mangrove seedlings are affected by salinity in which over 30 weeks, period the seedlings showed categories of low (3-5 psu), moderate (15-17 psu), and high (33-36 psu) (Kodikara et al. 2018). In addition, nutrients and organic carbon also affect the existence of mangrove forests (Chen and Ye 2014; Sasmito et al. 2020). On the other hand, biotic environment that affect mangrove condition include mangrove decomposition (Ariyanto et al. 2018b), litter dynamics (Ariyanto et al. 2019c), and the presence of food sources for marine biota (Ariyanto 2019; Wintah et al. 2021). The high variability of organic matter largely influences the overall carbon dynamics in the mangrove ecosystem (Kusumaningtyas et al. 2018). Among various types of disturbance in mangroves, deforestation and hydrological changes are the most devastating to soil nutrient-plant relations and mangrove productivity (Alongi 2018). Mangrove deforestation also causes decreased biodiversity, freshwater loss, sedimentation on coral reefs and coastal sediment acidification.

The ecological study in mangrove forest is largely focused on forest structure, which shows the composition of species and the distribution of size, growth and yield of the vegetation composing the forest. The information on forest structure is useful as the basis for management planning and decision making to achieve sustainable management of mangrove forests and their associated ecosystem services (Njana 2020). Other studies have also been focused on various themes, including species diversity (Perera et al. 2013), habitat suitability for mangrove conservation (Samal et al. 2023), mangrove growth and survivorship (Kathiresan et al. 2019; Goldberg and Heine 2021) and mangrove adaptation in extreme environment (Erftemeijer et al. 2021). Distribution of species and tree sizes, growth and yield provide useful information on management planning

Indonesia has the largest extent of mangroves in the world, scattered along the coastline of the provinces on the country. One area with distribution and diversity of mangrove forests is West Aceh, Aceh, which is located in Sumatra Island. Similar to mangrove ecosystems across the world, mangroves in West Aceh are likely affected by the environmental conditions. Therefore, this study aimed to determine the relationship between the effects of environmental conditions and the existence of mangrove species in Kuala Bubon Village, West Aceh District, Aceh, Indonesia. This study aimed to determine the relationship between the effects of environmental conditions on mangrove species in Kuala Bubon Village, West Aceh District, Aceh, Indonesia.

MATERIALS AND METHODS

Study area and period

This study was conducted in mangrove forest in Kuala Bubon Village, Samatiga Sub-district, West Aceh District, Aceh, Indonesia (Figure 1). This research was conducted from May to August 2022. The research location was divided into three stations, i.e., Station 1, which was located in the mangrove forest facing the sea and thus directly affected by tidal wave (4°12'39.84"N, 96° 2'54.20"E), Station 2 which was located in middle area of mangrove forests (4°12'39.92"N, 96° 2'51.01"E), and Station 3 which was located area near the ponds (Station 3: 4°12'41.18"N, 96° 2'48.27"E).

Data collection

Vegetation sampling

Mangrove vegetation was sampled using quadrat plot method. Observations were conducted at a 10 × 10 m^2 plot with distance between plots was 100 m, and total plot had 9 plots. There were three plots at each station for the monitoring and measurement of mangrove species and diameter at breast height (DBH). Mangrove species were identified using an identification book, and DBH was measured.

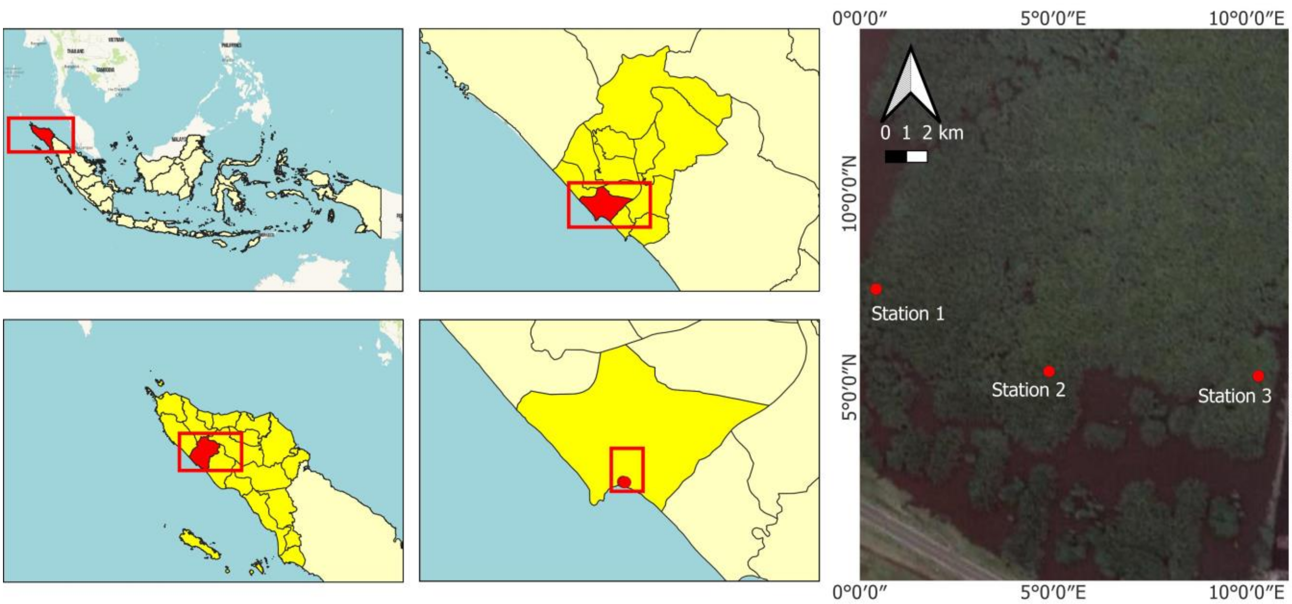

Figure 1. Mangrove forest in Samatiga Sub-district, West Aceh District, Aceh, Indonesia

Physical and chemical soil parameters

There were three samples for each station for measurement, including pH, salinity, temperature, organic carbon and sediment texture. Water qualities were measured on site with a water quality meter (model 8603). Organic carbon and sediment were analyzed in the laboratory.

Organic carbon

The grain size of sediments and organic carbon content were determined with the Walkley-Black method (FAO 2020) at the Soil Science Laboratory, State University of Surakarta. For the texture determination, organic matter was oxidized with H_2O_2 and soluble salts were removed from the soil with HCl, while heating. The remaining material was minerals and consisted of sand, silt, and clay. The sand was separated by wet sieving, while dust and clay were separated by deposition according to Stoke's law.

Sediment texture

Sediment of 0.500 g was collected and placed into a 100 mL volumetric flask. Then, 5 mL of $K_2Cr_2O_7$ 1 N was added, and the mix was shaked. 7.5 mL of concentrated H_2SO_4 were added, shaked, and the mix was left to stand for 30 minutes. The mix was diluted with ionized water, and allowed to cool. The next day, the absorbance of the clear solution was measured using a spectrophotometer at a wavelength of 561 nm. As a comparison, 0 and 250 ppm of standards were made by pipetting 0 and 5 mL of 5,000 ppm standard solution into a 100 mL volumetric flask.

Data analysis

All data were statistically analyzed using Principal Component Analysis (PCA) using XLstat 2022 to determine the relationship between the environmental parameters and the presence of mangrove species.

RESULTS AND DISCUSSION

Mangrove diversity, size and abundance

Table 1 shows the species diversity, distribution, size and abundance of mangrove the studied area. Station A had species, i.e., *Rhizophora apiculata* Blume, *Rhizophora mucronata* Lamk, and *Rhizophora stylosa* Griff, while Station B had 4 species, i.e., *R. apiculata*, *Sonneratia caseolaris* (L) Engl, *R.* Blume and *Sonneratia alba* Sm., and Station C consisted of 3 species, i.e., *R. apiculata, R. mucronata* Lamk and *Avicennia marina* (Blume). In total, there were 6 species of mangroves in the studied area. Species with the highest abundance at Station A was *R. stylosa* (14), Station B was *S. alba* Sm (12), and Station C was *A. marina* (7) and *R. mucronata* (7).

Environmental parameters

Table 2 shows the environmental parameters in the studied area. Station A had water temperature (ºC), pH, and salinity (psu) of 25.83-26.67 ºC, 6.02-6.1, and 26.0-32 psu, while Station B of 26.67 ºC, 6.15-6.17, and 23.33-29 psu; and Station C of 25.67-27.33 ºC, 5.83-6.13, and 27-28 psu. Station C showed a higher temperature than Station A and B. The pH conditions of the three stations did not show a significantly different range of values. The salinity condition showed that Station C had higher salinity compared to Station A and B. Water temperature, pH, and salinity play a significant role in the regeneration of mangrove species especially true mangroves (Win et al. 2019). Waramit et al. (2023) reported that the rate of mangrove growth was slow in the first 5 years, and the growth rate increased rapidly over 6-15 years, with increasing plant height at the rates of 0.9, 1.8, and 2.4 m y^{-1} for both mangrove ecotypes in the first 5 years, 6-10 years, and 11-15 years, respectively, with an increase in DBH at the rates of 0.5, 0.8, and 1.4 cm $year^{-1}$, respectively.

Table 1. The diversity, size and abundance of mangrove species in mangrove forests of Kuala Bubon Village, Samatiga Sub-district, West Aceh District, Aceh, Indonesia

Station	Plot	Mangrove species	DBH (cm)	Number of trees
A	A1	*Rhizophora apiculata*	20.63±3.08	9
		Rhizophora mucronata	11.61±0.86	4
	A2	*Rhizophora apiculata*	24.34±1.11	2
		Rhizophora stylosa	12.45±1.47	7
	A3	*Rhizophora apiculata*	17.18±4.74	3
		Rhizophora stylosa	15.86±4.45	14
B	B1	*Rhizophora apiculata*	18.14±7.20	9
	B2	*Rhizophora apiculata*	20.63±1.56	6
		Sonneratia caseolaris	16.07±4.11	4
	B3	*Rhizophora apiculata*	15.17±4.30	4
		Sonneratia alba	16.97±3.72	12
C	C1	*Rhizophora apiculata*	15.43±4.29	2
		Rhizophora mucronata	10.34±0.16	2
		Avicennia marina	13.27±3.94	7
	C2	*Rhizophora apiculata*	20.05±3.29	2
		Rhizophora mucronata	15.59±0	2
	C3	*Rhizophora apiculata*	16.44±3.97	3
		Rhizophora mucronata	16.59±3.09	7

The vegetation composition, age and structure of mangrove forests along with tidal oscillation have strong relationship with soil properties, mangrove zone and inhabitant fauna. Very high salinity can affect water movement and mineral distribution, thereby reducing water uptake by plants and other living things. In mangroves, soil water salinity and the corresponding osmotic potential are the main drivers of plant water supply (Peters et al. 2019). Chowdhury et al. (2019) found that strong salinity is the primary cause of mangrove degradation as increased salinity inhibits nutrient cycling and the release of microbial decomposers, subsequently resulting in nutrient-poor soil. Optimum salinity level might facilitate seedlings to grow best, but the growth rate declined with decreasing irradiance. In addition to water salinity, tidal inundation period and ground elevation can affect the diversity of mangrove, zone and growth rate (Win et al. 2019). A study in East Java revealed that the optimal habitat condition for mangrove has water temperature between 28-29°C, salinity of 29 psu-31 psu, and water pH of 6.8-7.5 (Hariyanto et al. 2019). Table 2 shows the difference in pH among stations. Jayachandran et al. (2018) found that the sedimentation of Cu and organic matter increases as pH increases.

Sediment conditions

Figure 2 shows the composition of sediment in the three stations. In general, clay had the highest composition followed by silt and sand. Station C had the lowest clay proportion than Stations A and B, while it had the highest proportion of sand. This result indicate that station C had the closest condition to pond compared to other stations. Matos et al. (2020) stated that the mudflats play a major role in carbon and nutrients sequestration, directly related to grain size and organic matter. Site with high elevation enhances diazotrophic network stability in mangrove sediments, thus making it more suitable and recommended for mangrove restoration (Huang et al. 2023).

Organic contents

Figure 3 shows that the highest organic content was at Station A with 12.33-14%, followed by Station B wit 10.33- 10.67%, and Station C wit 9.33-1.63%. This result implies that the closer the station from the sea, the higher organic matter contained in mangrove ecosystem. In addition, the difference in organic content can also be caused by the litter produced by mangrove forest since it is the main source of organic matter. Organic carbon in the soil is the amount of original carbon materials supplied through a decomposition process (Alongi 2014). Sediments tend to be trapped and retained in mangrove forests, and this is attributed to mangrove's widespread stem and root structure (Krauss et al. 2014). The low decomposition rate leads to the buildup of many organic carbon materials. Mamidala et al. (2023) added that variations in leaf litter decomposition can increase the nutrient release in the coastal waters.

The difference in organic carbon can also be caused by mangrove stand age. Tang et al. (2023) state that mature mangrove stand produced high C organic stock. Other study in Makassar found that organic carbon in mangrove forest ranged from 2.53% to 2.60% (Kaseng 2018). The mature mangrove stand generally has trees with large diameter and great number of density, thus producing a great amount of litter, which is then composed as organic carbon.

Table 2. Environmental parameters in mangrove forest in Samatiga Sub-district, West Aceh District, Aceh, Indonesia

Station	Plot	Water temperature (°C)	pH	Salinity (psu)
	A1	26.33±0.58	6.02±0.16	32±2
A	A2	26.67±0.57	6.1±0.17	28±1
	A3	25.83±0.29	6.07±0.05	28±1
B	C1	26.67±0.57	6.15±0.13	28 ±1
	C2	29.67±1.15	6.17±0.06	26±1
	C3	29.67±1.15	6.17±0.05	26±1
C	C1	25.67±0.57	6.13±0.23	26±1
	C2	27.33±1.15	5.83±0.21	27±0
	C3	27±1	6±1	27±1

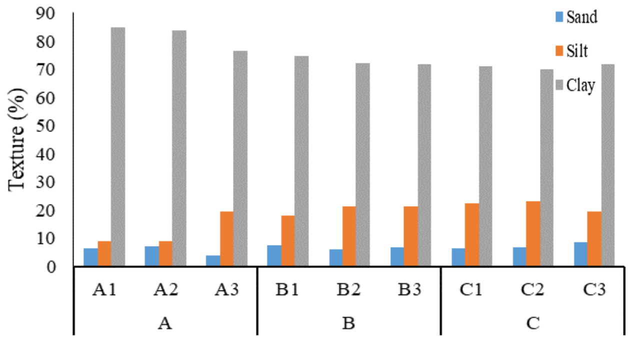

Figure 2. The composition of sediment texture in mangrove forest in Samatiga Sub-district, West Aceh District, Aceh, Indonesia

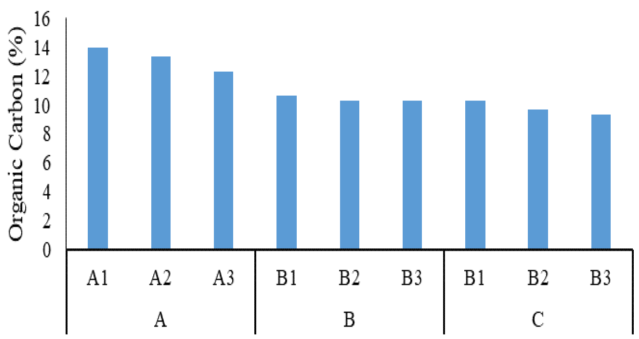

Figure 3. Organic carbon (%) in mangrove forest in Samatiga Sub-district, West Aceh District, Aceh, Indonesia

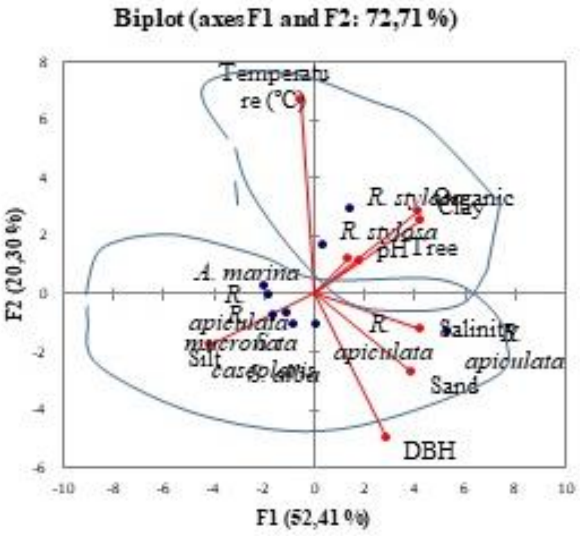

Figure 4. The PCA result of the relationships between environmental parameters and mangrove species

Relationships between environmental parameters and mangrove existence

The relationship between the environmental parameters and the existence of mangrove species is presented in Figure 4. The PCA result showed that environmental parameters measured in this study can explain 77.71% to the diversity of mangrove species, consisting of Function 1 (F1) with contribution of 52.41% and F2 with contribution of 20.30%. The PCA result revealed that the presence of *R. stylosa* was related to the conditions of the clay substrate, pH and temperature values. Meanwhile, the existence of *R. apiculata*, *R. mucronata*, *S. alba*, *S. caseolaris*, and *A. marina* was related to the conditions of the silt substrate, DBH size and salinity values.

Organic matter also has an influence on the diversity of mangrove species. *R. mucronata* showed the highest growth performance and survival rate under all salinity conditions. Therefore, *R. mucronata* is the preferred species for mangrove plantings (Kodikara et al. 2017). Another study revealed that salinity and pH also caused an increase in Pb translocation to leaves (Cabañas-Mendoza et al. 2020).

The increase in stem diameter and growth rate of *R. mucronata* was higher than that of *A. marina*. Certain mangrove species are more sensitive to extreme temperatures with the genus *Sonneratia* being the most sensitive (Chen and Ye 2014). Mangroves are typically stunted due to a combination of extremely low rainfall, high salinity and low nutrient availability (Adame et al. 2021). The availability of nutrients to support mangrove growth is determined by a variety of biotic and abiotic factors such as tidal inundation and elevation, redox status, microbial activities, plant species, litter production and decomposition (Ellison 2021). Nutrient limitations have been reported among mangroves responding to it by developing physiological strategies such as increasing root biomass (Alhassan and Aljahdali 2021). Carbonate sediments which low in organic matter can be sourced from the adjacent seafloor of the shallow shoal surrounding the island (Erftemeijer et al. 2021).

Figure 4 also indicates the impact of salinity and sand to the growth in *R. apiculata*. A study showed a contribution of salinity and sand to the overall water quality in Gurupura River is an indication of the increasing seawater flow into the estuaries (Sulochanan et al. 2022) which also be impacted by sea level rise caused by climate change (Fanous et al. 2023). Mangrove diversity is also affected by direct inputs from wastewater effluents, runoff, aquaculture, fishing, and tourism in adjacent areas, the delivery of plastic debris by surface currents, wind, and tides, as well as the trapping of plastic debris by well-developed root system of mangroves (Duan et al. 2021; Luo et al. 2021). The density of soil organic carbon indicates the sediment characteristics which can be used to inform the optimal rehabilitation technique (Balke and Friess 2016; Twilley et al. 2018). Eid and Shaltout (2015) found that organic content in the mud flat declined significantly with depth and afforestation can increase soil carbon even at the young age (Lunstrum and Chen 2014).

Figure 4 shows that the conditions of the clay substrate, pH and temperature value have strong relationships with *R. stylosa*. Rahim et al. (2017) reported optimal range of temperatures that supports mangrove growth in the coastal mangrove forests Torosiaje Jaya Village. Bassar et al. (2023) added the significant effect of soil pH in the fine root production.

In conclusion, the diversity of mangrove species can be affected by organic matter in Samatiga Sub-district, West Aceh District, Aceh, Indonesia. Furthermore, every various mangrove can be affected by different environmental water. This study also revealed that the presence of *R. stylosa* was related to the conditions of the clay substrate, pH and temperature. Meanwhile, the existence of *R. apiculata*, *R. mucronata*, *S. alba*, *S. caseolaris*, and *A. marina* was related to the conditions of the silt substrate, DBH and salinity values.

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