JoMS | Journal of Marine Studies

Research article

OPEN ACCESS

Structural characterization and species composition of mangrove vegetation in Lhokseumawe, Indonesia: Insight from multivariate analysis

Adinda Aulia Putri [1], Erlangga Erlangga [1], Syahrial Syahrial [1,*], Riri Ezraneti [1], Hayatun Nufus [2], Yusyam Leni [3], Febrina Rolin [3]

[1] Department of Marine Science, Faculty of Agriculture, Universitas Malikussaleh, North Aceh, Indonesia.
[2] Department of Marine Science, Faculty of Fisheries and Marine Sciences, Teuku Umar University, West Aceh, Indonesia.
[3] Department of Fisheries Resource Utilization, Faculty of Animal Science, University of Jambi, Muaro Jambi, Indonesia.

Check for updates

Citation:
Putri, A. A., Erlangga, E., Syahrial, S., Ezraneti, R., Nufus, H., Leni, Y., & Rolin, F. (2024). Structural characterization and species composition of mangrove vegetation in Lhokseumawe, Indonesia: Insight from multivariate analysis. *Journal of Marine Studies, 1*(3), 1303. https://doi.org/10.29103/joms.v1i3.19052.

Received: October 20, 2024
Revised: November 14, 2024
Accepted: November 14, 2024
Published: November 15, 2024

Subject areas:
Marine ecology, marine botany

***Correspondence**:
Syahrial Syahrial
e-mail: syahrial.marine@unimal.ac.id

Abstract

The structure of the plant community significantly influences the equilibrium of the surrounding environment, affecting the trophic interactions within its ecosystem. The investigation of mangrove vegetation in Cut Mamplam village was carried out in September 2021 to determine the condition and structural characteristics of the mangrove ecosystem by multivariate analysis. The mangrove vegetation in Cut Mamplam Village was sampled at three observation stations by establishing a transect parallel to the coast. Subsequently, the community structure was examined and assessed using cluster analysis and nonmetric multidimensional scaling using the PRIMER v7 software. The study findings indicate that the mangrove forest vegetation in Cut Mamplam Village consists of five species from three families. *Avicennia alba, A. lanata, Bruguiera gymnorrhiza, Rhizophora mucronata* and *Sonneratia alba*. The highest density of mangrove vegetation was observed in *A. alba* in all categories: trees (616.67 ind/ha), seedlings (833.33 ind/ha) and saplings (66666.67 ind/ha). Additionally, the highest important value index (IVI) was recorded in *A. alba* for all categories: trees (232.16%), seedlings (102.40%), and saplings (228.43%). A similarity of mangrove density between species was noted at 60%, resulting in the formation of two distinct groups. Regarding the basal area, the vegetation stands of *A. alba* and *A. lanata* exhibited the highest values (280.61 and 266.03 m^2/ha, respectively). The similarity of basal area among the observed species was 20%, resulting in the formation of two distinct groups. Additionally, Station II, classified as having mature vegetation, demonstrated a maturity similarity of 80% between observation stations.

Keywords: Multivariate statistic, cluster analysis, MDS, mangrove vegetation

Introduction

Multivariate analysis is a statistical method that involves a dataset comprising measurements of multiple individuals or objects (Rencher, 2002; Anderson, 2003). It facilitates the interpretation of complex systems (Indelicato et al., 2018) and serves as a tool for data scaling (Junior et al., 2019). This analysis enables the grouping and optimization of similarities among data (Cruz-Cardenas et al., 2017) to understand the variations present within the data set (Kumar et al., 2018). Multivariate analysis is extensively used to interpret environmental data, including differentiation between natural inputs and anthropogenic activities (Facchinelli et al., 2001; Lucho-Constantino et al., 2005; da Silva et al., 2016; Filho et al., 2017), selection or determination of soil, sediment, and air characteristics (Araujo et al., 2013; Khwedim et al., 2015; Singh & Ramanathan, 2015; Junior et al., 2019), identification of sources of water pollution (Delshab et al., 2016; Ezraneti et al., 2021), and evaluation of the structure of mangrove community (Syahrial et al., 2023; Efriyeldi et al., 2023).

In botany, multivariate analysis is extensively used for morphological assessment, distribution research, and the estimation of the maturity level of vegetative stands. Vegetation refers to a group of plants or crops that inhabit a certain area or region within an ecosystem. These plant communities may exhibit distribution patterns based on spatial and temporal factors (Campbell et al., 2004). According to van der Maarel (2005), not all plants that develop are capable of becoming vegetation; for instance, fields cultivated with maize or gardens planted with flowers. Kartawinata (2010) asserted that vegetation consists solely of plants; however, when physical and biotic components are integrated, an ecosystem is formed. Vegetation structure or analysis is used to forecast the condition of plant vegetation in a given area. This structure results from the spatial arrangement of plant stands and life forms, stratification or vegetation cover, characterized by parameters such as diameter, height, distribution, canopy diversity, and species continuity (Fachrul, 2007). The parameters utilized include density, frequency, and dominance (Mueller-Dombois & Ellenberg, 1974). Moreover, vegetation analysis serves to determine the proportion of plant species, ranging from dominant to nondominant (Sriyani, 2012), with mangroves being a frequently seen or scientifically examined vegetation type.

Mangroves are coastal plants that establish forests and ecosystems in tropical and subtropical regions (Maiti & Chowdhury, 2013; Polania et al., 2015; Alongi, 2018). They are located in protected estuaries (Analuddin et al., 2013; Maiti & Chowdhury, 2013), along riverbanks (Maiti & Chowdhury, 2013; Duke, 2016; Ismoyo et al., 2017), and in lagoons (Maiti & Chowdhury, 2013). These plants have distinct characteristics compared to others (Chakraborty, 2013; Motamedi et al., 2014; Zakaria et al., 2018), exhibit high productivity (Wang et al., 2013; Hartati & Harudu, 2016; Osland et al., 2016), but are vulnerable (Grosholz, 2002; Lara et al., 2011) due to their proximity to anthropogenic activities (Zhang et al., 2014; Eddy et al., 2015; Kepel et al., 2018) and the impacts of climate change (Lara et al., 2011). Menendez et al. (2020) indicated that mangrove ecosystems are currently undergoing significant damage and loss. This phenomenon is attributable to the transformation of aquaculture, agriculture and coastal development (Alongi, 2002; Lovelock et al., 2015; Adame et al., 2018; Schuerch et al., 2018), leading to increased erosion and decreased coastal fisheries production, as evidenced in the Indo-Pacific and Caribbean (Lovelock et al., 2015), Sri Lanka (Harkes et al., 2015), and the northern coast of Java, Indonesia (Ilman et al., 2016).

The highest density of mangrove vegetation was observed in *Avicennia alba* in all categories: trees (616.67 ind/ha), seedlings (833.33 ind/ha) and saplings (66666.67 ind/ha). Furthermore, the highest important value index (IVI) was recorded in *A. alba* for all categories: trees (232.16%), seedlings (102.40%) and saplings (228.43%). A similarity in mangrove density between species was observed at 60%, resulting in the formation of two distinct groups. Regarding the basal area, *A. alba* and *A. lanata* vegetation exhibited the highest values (280.61 and 266.03 m^2/ha, respectively). The similarity of the basal area among the observed species was 20%, resulting in the formation of two distinct groups. Furthermore, Station II, classified as having mature vegetation, demonstrated a maturity similarity of 80% between observation stations.

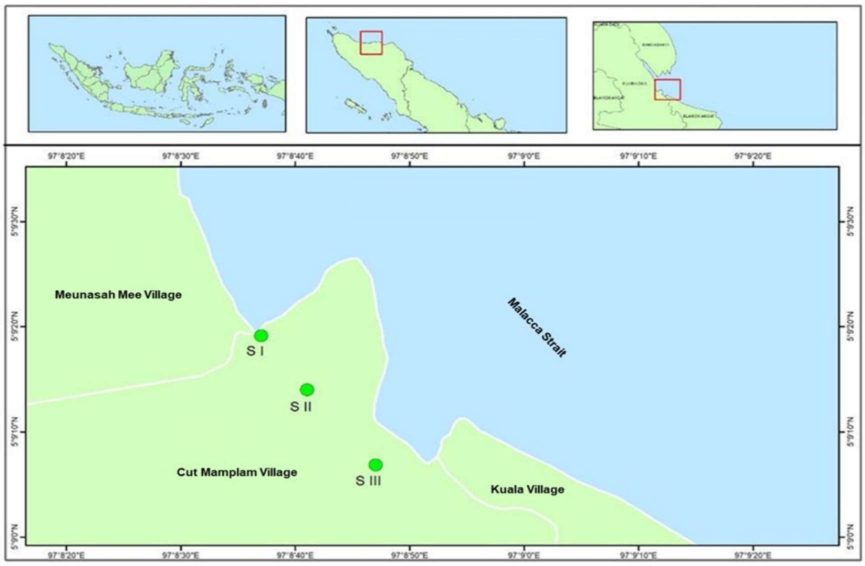

Figure 1. Map of mangrove vegetation study site in Cut Mamplam Village, Lhokseumawe.

Methods

The study was carried out in September 2021 in the mangrove forest of Cut Mamplam Village, Muara Dua District, Lhokseumawe City, Aceh Province, with three observation stations. Station I is at coordinates 05°09'19" E and 97°08'38" N, while Station II is at coordinates 05°09'16" E and 97°08'41" N, and Station III is at coordinates 05°09'13" E and 97° 08'43" N (Figure 1).

Mangrove vegetation data in Cut Mamplam Village was obtained by establishing a 40 m long line transect (SNI, 2011) perpendicular to the coastline. This transect was divided into sample plots of 10 x 10 m for the tree category, with 5 x 5 m plots designated for the sapling category within each tree plot, and 1 x 1 m plots for the seedling category. The measuring requirements for the circumference of the mangrove trunk are based on MNLH (2004), where as the categorization criteria for the trunk's circumference or diameter in the tree, sapling, and seedling categories are derived from Bengen (2000). The mangrove vegetation data collected were subsequently analyzed for community structure (density, relative density, frequency, relative frequency, dominance, relative dominance, and IVI) according to Fachrul (2007). This analysis was further evaluated using cluster analysis and nonmetric multidimensional scaling (MDS) via the PRIMER v7 program, with basal area analysis of mangrove vegetation adhering to the equation of Kasim and Lamalango (2019).

Results

Mangrove diversity and distribution

The diversity of mangrove vegetation in Cut Mamplam Village comprises five species in three families. Acanthaceae (*A. alba* and *A. lanata*), Rhizophoraceae (*Bruguiera gymnorrhiza* and *Rhizophora mucronata*), and Sonneratiaceae (*Sonneratia alba*). *A. alba* was observed in all tree category stations, while *S. alba, R. mucronata, B. gymnorrhiza* and *A. alba* were observed in the seedling category, and *A. lanata* and *A. alba* were also present in the seedling category (Table 1). Furthermore, members of the Acanthaceae family (*A. alba* and *A. lanata*) were observed to thrive in coastal areas (front zone) or near community ponds and land (back zone), while in the middle zone, species from the Rhizophoraceae family (*B. gymnorrhiza* and *R. mucronata*) and Sonneratiaceae (*S. alba*) were identified as growing (Figure 2).

Table 1. Diversity and distribution of mangrove vegetation in Cut Mamplam Village, Lhokseumawe. Species found (+); Species not found (-).

Species	Family	Observation station		
		I	II	III
Tree category				
A. alba	*Acanthaceae*	+	+	+
A. lanata	*Acanthaceae*	+	+	-
B. gymnorrhiza	*Rhizophoraceae*	+	-	+
R. mucronata	*Rhizophoraceae*	+	-	+
S. alba	*Sonneratiaceae*	+	-	+
Sapling category				
Avicennia alba	*Acanthaceae*	+	+	+
Avicennia lanata	*Acanthaceae*	+	-	-
Bruguiera gymnorrhiza	*Rhizophoraceae*	+	+	+
Rhizophora mucronata	*Rhizophoraceae*	+	+	+
Sonneratia alba	*Sonneratiaceae*	+	+	+
Seedling category				
Avicennia alba	*Acanthaceae*	+	+	+
Avicennia lanata	*Acanthaceae*	+	+	+
Bruguiera gymnorrhiza	*Rhizophoraceae*	+	-	+
Rhizophora mucronata	*Rhizophoraceae*	-	-	+
Sonneratia alba	*Sonneratiaceae*	-	-	-

Mangrove density and important value index (IVI)

The density of *A. alba* mangrove vegetation in Cut Mamplam Village exceeds that of other species in the tree, sapling and seedling categories, with densities of 616.67 ind/ha, 833.33 ind/ha, and 66666.67 ind/ha, respectively (Table 2). Cluster analysis using the Bray-Curtis similarity index, followed by MDS

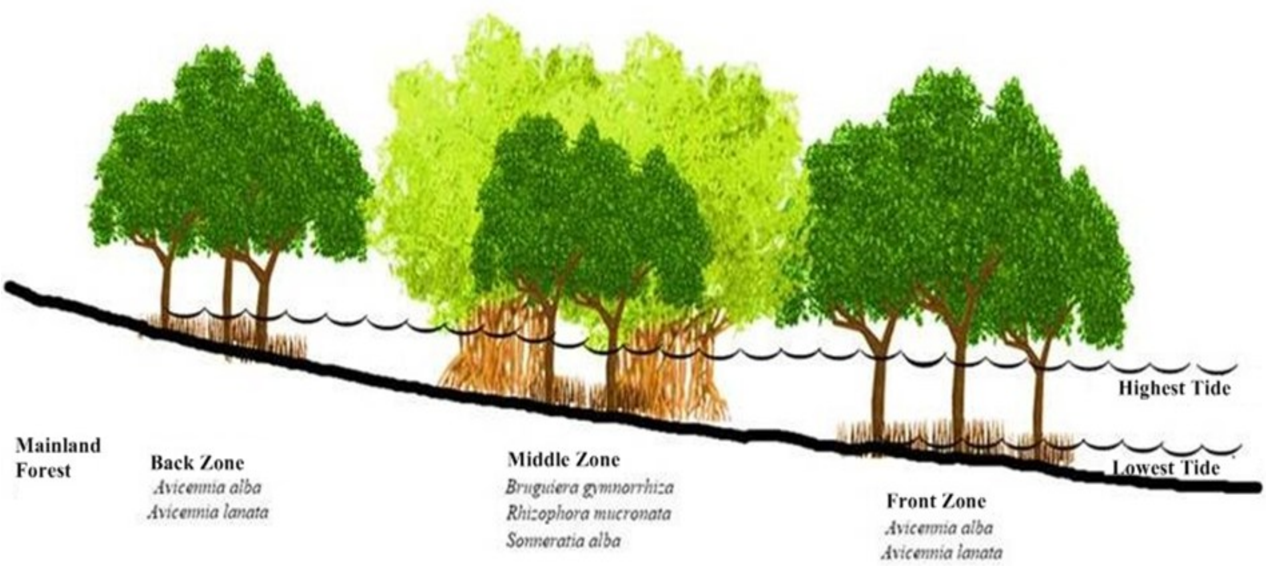

Figure 2. Mangrove vegetation distribution zone in Cut Mamplam Village, Lhokseumawe.

Table 2. Density and IVI of mangrove vegetation in Cut Mamplam Village, Lhokseumawe. AA = *A. alba*; AL = *A. lanata*; BG = *B. gymnorrhiza*; RM = *R. mucronata*; SA = *S. Alba*.

Species	Density (ind/ha)			IVI (%)		
	St. I	St. II	St. III	St. I	St. II	St. III
Tree category						
AA	616.67	341.67	383.33	214.25	245.44	236.78
AL	141.67	75	0	52.98	54.56	0
BG	33.33	0	41.67	13.12	0	29.23
RM	16.67	0	41.67	6.55	0	13.48
SA	33.33	0	50	13.1	0	20.51
Total	841.67	416.67	516.67	300	300	300
Sapling category						
AA	833.33	100	633.33	143.6	25.62	137.98
AL	33.33	0	0	17.93	0	0
BG	633.33	266.67	566.67	116.57	113.33	123.14
RM	100	266.67	100	12.02	85.12	19.36
SA	66.67	200	100	9.87	75.93	19.52
Total	1666.67	833.33	1400	300	300	300
Seedling category						
AA	25000	25000	66666.67	196.71	220.69	267.9
AL	6666.67	15000	3333.33	64.57	79.31	12.02
BG	2500	0	1666.67	38.72	0	9.44
RM	0	0	2500	0	0	10.64
SA	0	0	0	0	0	0
Total	34166.67	40000	74166.67	300	300	300

comprising *R. mucronata, S. alba,* and *B. gymnorrhiza*, and the second group consisting of *A. alba* and *A. lanata* (Figure 3). The first group comprised species located on the mainland, but the second group was located directly facing the sea, consistently obstructing the waves. Furthermore, the Importance Value Index (IVI) of mangrove vegetation in Cut Mamplam Village indicates that the *A. alba* species exhibits the highest values relative to other species, across the tree category (average categories was recorded at Station II (245.44% and 267.90%), while the highest value for seedlings was observed at Station I (143.60%) (Table 2).

Basal area vegetation

The basal area of mangrove vegetation in Cut Mamplam Village shows that the vegetation stands of *A. alba* and *A. lanata* have higher values (280.61 and 266.03 m^2/ha), while the basal area

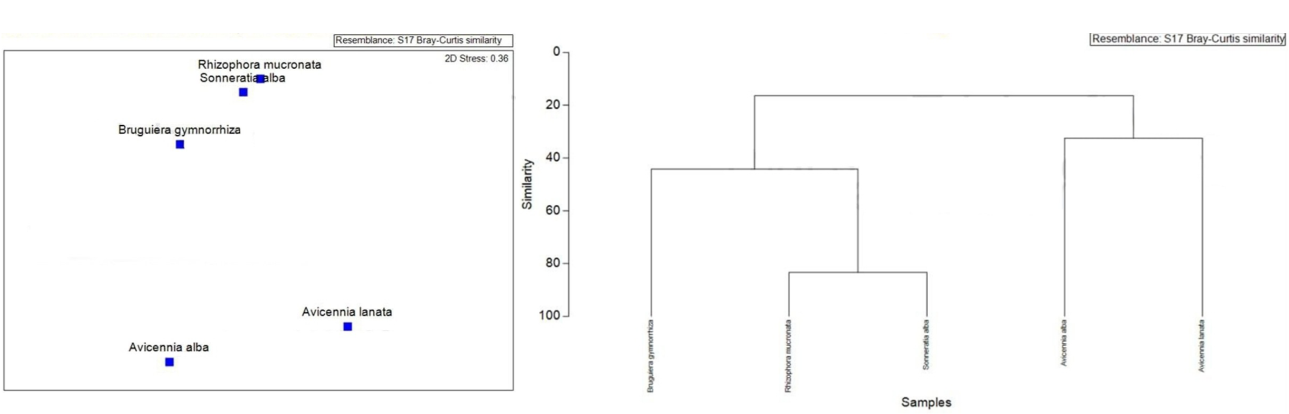

Figure 3. Dendrogram of density similarities among mangrove species in the coastal area of Cut Mamplam Village, Lhokseumawe.

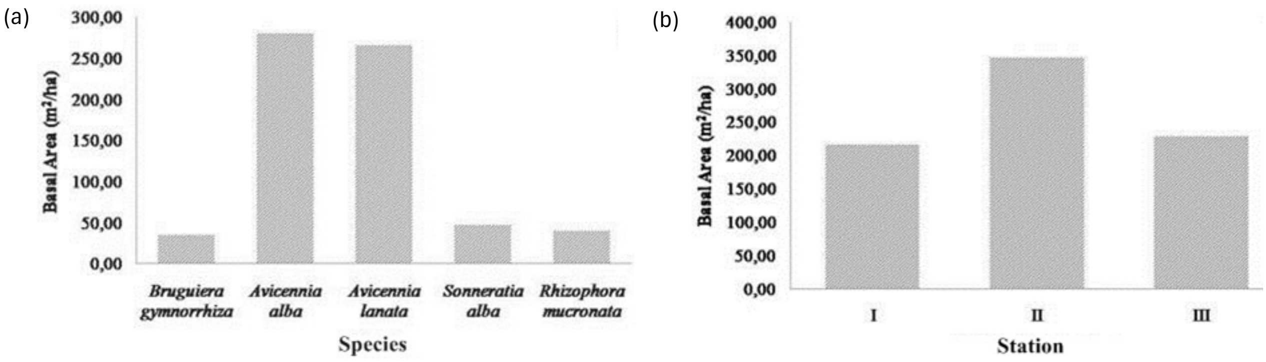

Figure 4. Basal area of mangrove vegetation in Cut Mamplam Village, Lhokseumawe. (a) between species; (b) between observation stations.

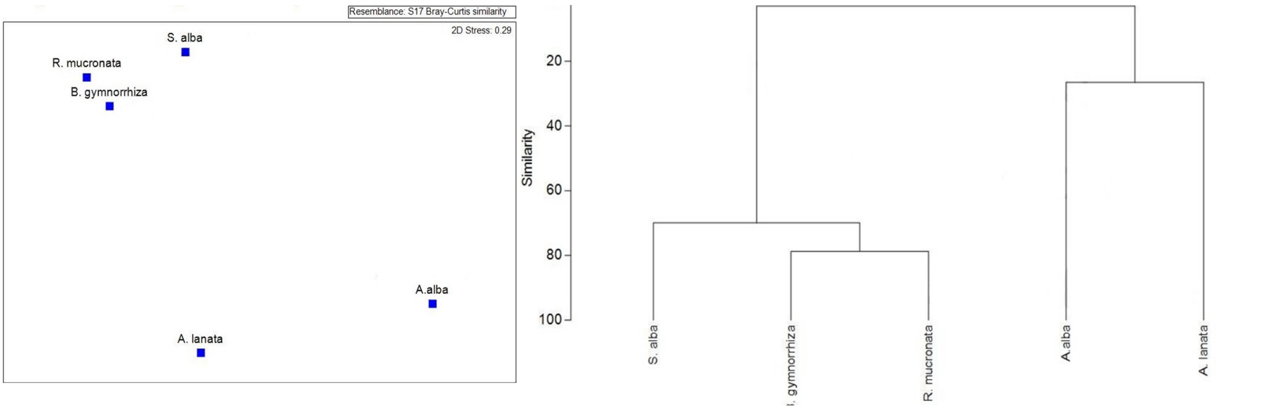

Figure 5. Dendrogram of basal area similarities among mangrove species in the coastal area of Cut Mamplam Village, Lhokseumawe.

between observation stations, the highest value was found at Station II (345.61 m^2/ha) (Figure 4).

Figure 5 illustrates that the basal area cluster analysis of mangroves in Cut Mamplam Village, which was followed by MDS ordination, revealed a 20% similarity between the observed species, with the basal areas of the species grouped into two groups. The first group is comprised of *S. alba*, *B. gymnorrhiza*, and *R. mucronata*, which are classified as embryonic mangrove vegetation (juveniles). The second group is composed of *A. alba* and *A. lanata*, which are classified as mature mangrove vegetation. Additionally, the mangrove vegetation at Stations I and II is designated as more mature than that at Station III, as evidenced by the cluster analysis (Figure 6), which indicates that the similarity between the two observation stations is 80%.

Discussion

The *A. alba* species is a mangrove that exhibits salinity tolerance, capable of thriving in both high and low salinity environments, including freshwater locations. The growth and development of *A. alba* in high salinity regions necessitates robust root systems to endure the impact of waves during tidal events (Hamka et al., 2012). Bengen (2004) states that the coastal regions, frequently dominated by mangroves, are primarily inhabited by the species *A. alba* and *A. lanata*, which typically coexist with *S. alba*. Inland, these areas consist of various stands of other mangrove species, including members of the genera *Rhizophora* and *Bruguiera*, as well as the species *Aegialitis annulata*.

On coastlines, the *A. alba* species can compete effectively for nutrients, its population is unaffected, and it is particularly tolerant of changing circumstances. This leads *A. alba* population and IVI to be greater in Cut Mamplam Village than other species, where a species' high density may be attributed to a suitable environment and strong adaptation (Lahabu et al., 2015). Meanwhile, a species' high value stems from its frequent occurrence (Syarifuddin & Zulharman, 2012), which causes a plant to dominate in each site.

Araujo and Shideler (2019) defined basal area as the land area occupied by the cross-section of a plant's stem or trunk at the point of measuring diameter at stem (DBH). Basal area is also correlated with biomass (Araujo & Shideler, 2019), wood volume (ACES, 2010; Araujo & Shideler, 2019), and plant growth, making it a critical metric for forest management decisions, such as assessing forest regeneration needs and wildlife habitat requirements (ACES, 2010).

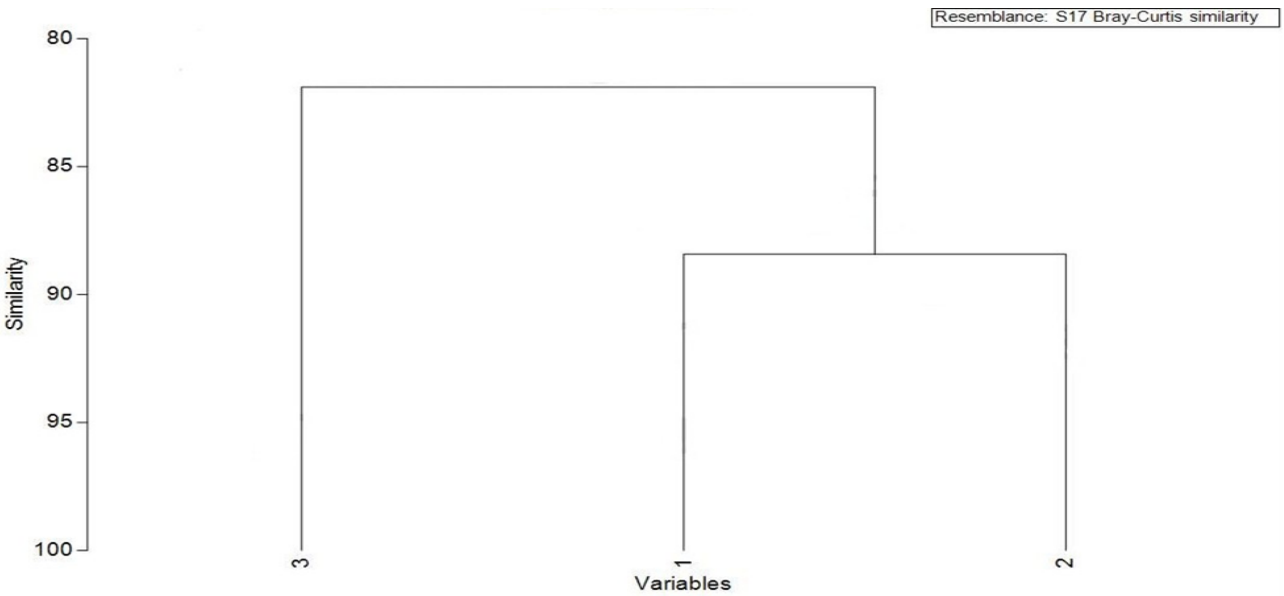

Figure 6. Basal area cluster diagram of mangrove observation stations based on Bray–Curtis similarity in Cut Mamplam Village,

Conclusions

The mangrove forest vegetation in Cut Mamplam Village consists of five species from three families. Members of the Acanthaceae family thrive in zones adjacent to the sea or bordering the land, while those of the Rhizophoraceae family are located in the central zone. Moreover, the greatest density and IVI of mangrove vegetation in Cut Mamplam Village were seen in *A. alba*, with comparable mangrove density across species categorized into two groups. In terms of basal area, the vegetation stands of *A. alba* and *A. lanata* exhibit the greatest values and demonstrate more maturity compared to other species, with the vegetation maturity at the observation station identified at Station II.

Acknowledgements

We would like to acknowledge the Head of Cut Mamplam Village, Muara Dua District, Lhokseumawe City, for granting permission to conduct this research. We also extend our sincere gratitude to the local community of Cut Mamplam Village for their cooperation, assistance, and support, which were essential for the successful completion of this study.

Authorship contribution

Adinda Aulia Putri: Conceptualization, methodology, investigation, resources, sample processing and analysis, data curation, formal analysis, visualization, original draft preparation writing, review and editing. **Erlangga Erlangga**: Methodology. **Syahrial Syahrial**: Writing - review and editing, supervision. **Riri Ezraneti**: Conceptualization, methodology, formal analysis, writing - original draft preparation, writing - review and editing, supervision. **Hayatun Nufus**: Writing - review and editing. **Yusyam Leni**: Writing - review and editing. **Febrina Rolin**: Writing - review and editing. All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Data availability

Datasets generated during and/or analysed throughout the present study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare no conflict of interest.

Funding

No external funding or financial support was received while conducting this research.

References

ACES (Alabama Cooperative Extension System) (2010). *Basal area: A measure made for management* (ANR-1371).

Adame, M. F., Brown, C. J., Bejarano, M., Herrera-Silveira, J. A., Ezcurra, P., Kauffman, J. B., & Birdsey, R. (2018). The undervalued contribution of mangrove protection in Mexico to carbon emission targets. *Conservation Letters, 11*, Article e12445. https://doi.org/10.1111/conl.12445.

Alongi, D. M. (2002). Present state and future of the world's mangrove forests. *Environmental Conservation, 29*(3), 331-349. https://doi.org/10.1017/S0376892902000231.

Alongi, D. M. (2018). Impact of global change on nutrient dynamics in mangrove forests. *Forests, 9*(10), 596. https://doi.org/10.3390/f9100596.

Analuddin, K., Jamili, R., Raya, R., Septiana, A., & Rahim, S.

(2013). The spatial trends in the structural characteristics of mangrove forest at the Rawa Aopa Watumohai National Park, Southeast Sulawesi, Indonesia. *International Research Journal of Plant Science, 4*(7), 214 -221.

Anderson, T. W. (2003). *An introduction to multivariate statistical analysis* (3rd ed.). John Wiley & Sons, Inc.

Araujo, A. O., Mendonça, L. A. R., de Sousa Lima, M. G., Feitosa, J. V., da Silva, F. J. A., Ness, R. L. L., Frischkorn, H., Simplicio, A. A. F., & Kerntopf, M. R. (2013). Changes in soil properties of a forest management area on the Araripe Plateau. *Revista Brasileira de Ciência do Solo, 37*, 754-762. https://doi.org/10.1590/S0100-06832013000300022.

Araujo, R. J., & Shideler, G. S. (2019). An R package for computation of mangrove forest structural parameters using plot and plotless methods. *Madera y Bosques, 25*, Article e2511696. https://doi.org/10.21829/myb.2019.2511696.

Bengen, D. G. (2000). *Sampling techniques and biophysical data analysis of coastal resources*. Center for Coastal and Marine Resources Studies, IPB.

Bengen, D. G. (2004). *Technical guidelines for introduction and management of mangrove ecosystems*. Center for Coastal and Marine Resources Studies, IPB.

Campbell, N. A., Reece, J. B., & Mitchell, L. G. (2004). *Biologi* (Vol. 3, 5th ed.). Erlangga.

Chakraborty, S. K. (2013). Interactions of environmental variables determining the biodiversity of coastal-mangrove ecosystem of West Bengal, India. *The Ecoscan, 3*, 251-265.

Cruz-Cardenas, G., Silva, J. T., Ochoa-Estrada, S., Estrada-Godoy, F., & Nava-Velazquez, J. (2017). Delineation of environmental units by multivariate techniques in the Duero River Watershed, Michoacan, Mexico. *Environmental Modeling and Assessment, 22*, 257-266. https://doi.org/10.1007/s10666-016-9534-2.

da Silva, F. B. V., do Nascimento, C. W. A., Araujo, P. R. M., da Silva, L. H. V., & da Silva, R. F. (2016). Assessing heavy metal sources in sugarcane Brazilian soils: An approach using multivariate analysis. *Environmental Monitoring and Assessment, 188*, 1-12. https://doi.org/10.1007/s10661-016-5409-x.

Delshab, H., Farshchi, P., & Keshavarzi, B. (2016). Geochemical distribution, fractionation, and contamination assessment of heavy metals in marine sediments of the Asaluyeh port, Persian Gulf. *Marine Pollution Bulletin, 115*, 401-411. https://doi.org/10.1016/j.marpolbul.2016.11.033.

Duke, N. C. (2016). Oil spill impacts on mangroves: Recommendations for operational planning and action based on a global review. *Marine Pollution Bulletin, 109*, 700-715. https://doi.org/10.1016/j.marpolbul.2016.06.082.

Eddy, S., Mulyana, A., Ridho, M. R., & Iskandar, I. (2015). The anthropogenic activities impact to mangrove forests degradation in Indonesia. *Lingkungan dan Pembangunan, 1*, 240-254.

Efriyeldi, E., Syahrial, S., Effendi, I., Almanar, I. P., & Syakti, A. D. (2023). The mangrove ecosystem in a harbor-impacted city in Dumai, Indonesia: A conservation status. *Regional Studies in Marine Science, 65*, Article 103092. https://doi.org/10.1016/j.rsma.2023.103092.

Ezraneti, R., Syahrial, & Erniati. (2021). Assessment of non-metallic pollutant sources in saltwater reservoir Pusong in Lhokseumawe City based on multivariate analysis. *Kelautan Tropis, 24*, 34-44. https://doi.org/10.14710/jkt.v24i1.9617.

Facchinelli, A., Sacchi, E., & Mallen, L. (2001). Multivariate statistical and GIS-based approach to identify heavy metal sources in soils. *Environmental Pollution, 114*, 313-324. https://doi.org/10.1016/S0269-7491(00)00243-8.

Fachrul, M. F. (2007). *Metode sampling bioekologi*. PT. Bumi Aksara.

Filho, C. A. D. C., Moreira, R. M., Branco, O. E. A., Dutra, P. H., Santos, E. A. D., Moura, I. F. S., Fleming, P. M., & Palmieri, H. E. L. (2017). Combined hydrochemical, isotopic, and multivariate statistics techniques to assess the effects of discharges from a uranium mine on water quality in neighboring streams. *Environmental Earth Sciences, 76*, Article 830. https://doi.org/10.1007/s12665-017-7165-9.

Grosholz, E. (2002). Ecological and evolutionary consequences of coastal invasions. *Trends in Ecology and Evolution, 7*, 22-27. https://doi.org/10.1016/S0169-5347(01)02358-8.

Hamka, M., Basyuni, M., & Agustina, L. (2012). Characterization of isoprenoid compounds and seedling growth of mangrove *Avicennia alba* Bl. *Peronema Forestry Science, 1*, 1-9.

Harkes, I. H. T., Drengstig, A., Kumara, M. P., Jayasinghe, J. M. P. K., & Huxham, M. (2015). Shrimp aquaculture as a vehicle for climate-compatible development in Sri Lanka: The case of Puttalam Lagoon. *Marine Policy, 61*, 273-283. https://doi.org/10.1016/j.marpol.2015.08.003.

Hartati, & La Harudu. (2016). Identification of types of mangrove forest ecosystem damage due to human activities in Lowulowu Village, Lea-Lea District, Baubau City. *Geographical Education Research, 1*, 30-45.

Ilman, M., Dargusch, P., Dart, P., & Onrizal. (2016). A historical analysis of the drivers of loss and degradation of Indonesia's mangroves. *Land Use Policy, 54*, 448-459. https://doi.org/10.1016/j.landusepol.2016.03.010.

Indelicato, S., Bongiorno, D., Tuzzolino, N., Mannino, M. R., Muscarella, R., Fradella, P., Gargano, M. E., Nicosia, S., & Ceraulo, L. (2018). Multivariate analysis of historical data (2004–2013) in assessing the possible environmental impact of the Bellolampo landfill (Palermo). *Environmental Monitoring and Assessment, 190*, Article 216. https://doi.org/10.1007/s10661-018-6594-6.

Ismoyo, U., Hendrarto, B., & Suryanti. (2017). Analysis of organic matter and soil quality on the size of mangrove leaves at Mojo Village, Ulujami Pemalang. *Saintek Perikanan, 12*, 134-138. https://doi.org/10.14710/ijfst.12.2.134-138.

Junior, A. I. D. O., Mendonca, L. A. R., De Brito Fontenele, S., Araujo, A. O., & De Sousa Lima Brito, M. G. (2019). Statistical multivariate analysis applied to environmental characterization of soil in Semiarid region. *Revista Caatinga, 32*, 200-210. https://doi.org/10.1590/1983-21252019v32n120rc.

Kartawinata, K. (2010). *Two centuries revealing the richness of Indonesian flora and ecosystems*. Sarwono Prawirohardjo Memorial Lecture X - LIPI.

Kasim, F., & Lamalango, A. (2019). Combination of tracking and Point Centered Quarter (PCQ) methods for carbon stock analysis of rare mangroves in Menanggu District, Boalemo Regency. Final report of collaborative research of lecturers and students with PNBP funds in fiscal year 2019. Aquatic Resources Management Study Program, Faculty of Fisheries and Marine Sciences, Gorontalo State University. Gorontalo, Indonesia.

Kepel, T. L., Ati, R. N. A., Rahayu, Y. P., & Adi, N. S. (2018). The impact of mangrove conversion on sediment properties and capacity to store carbon. *Kelautan Nasional, 13*, 145-153. https://doi.org/10.15578/jkn.v13i3.6620.

Khwedim, K., Meza-Figueroa, D., Hussien, L. A., & Rıo-Salas, R. D. (2015). Trace metals in topsoils near the Babylon Cement Factory (Euphrates River) and human health risk assessment. *Environmental Earth Sciences, 74*, 665-673. https://doi.org/10.1007/s12665-015-4071-x.

Kumar, V., Sharma, A., Kumar, R., Bhardwaj, R., Thukral, A. K., & Rodrigo-Comino, J. (2018). Assessment of heavy-metal pollution in three different Indian water bodies by combination of multivariate analysis and water pollution indices. *Human and Ecological Risk Assessment, 26*. https://doi.org/10.1080/10807039.2018.1497946.

Lahabu, Y., Schaduw, J. N. W., & Windarto, A. B. (2015). Mangrove ecological conditions in Mantehage Island, Wori District North Minahasa Regency, North Sulawesi Province. *Pesisir dan Laut Tropis, 2*, 41-52. https://doi.org/10.35800/jplt.3.2.2015.10851.

Lara, R. J., Neogi, S. B., Islam, M. S., Mahmud, Z. H., Islam, S., Paul, D., Demoz, B. B., Yamasaki, S., Nair, G. B., & Kattner, G. (2011). Vibrio cholerae in waters of the Sunderban mangrove: Relationship with biogeochemical parameters and chitin in seston size fractions. *Wetlands Ecology and Management, 19*, 109-119. https://doi.org/10.1007/s11273-010-9204-0.

Lovelock, C. E., Cahoon, D. R., Friess, D. A., Guntenspergen, G. R., Krauss, K. W., Reef, R., Rogers, K., Saunders, M. L., Sidik, F., Swales, A., Saintilan, N., Thuyen, L. X., & Triet, T. (2015). The vulnerability of Indo-Pacific mangrove forests to sea-level rise. *Nature, 526*, 559-563. https://doi.org/10.1038/nature15538.

Lucho-Constantino, C. A., Alvarez-Suarez, M., Beltran-Hernandez, R. I., Prieto-García, F., & Poggi-Varaldo, H. M. (2005). A multivariate analysis of the accumulation and fractionation of major and trace elements in agricultural soils in Hidalgo State, Mexico irrigated with raw wastewater. *Environment International, 31*, 313-323. https://doi.org/10.1016/j.envint.2004.08.002.

Maiti, S. K., & Chowdhury, A. (2013). Effects of anthropogenic pollution on mangrove biodiversity: A review. *Environmental Protection, 4*, 1428-1434. https://doi.org/10.4236/jep.2013.412163.

Menendez, P., Losada, I. J., Torres-Ortega, S., Narayan, S., & Beck, M. W. (2020). The global flood protection benefits of mangroves. *Scientific Reports, 10*, Article 4404. https://doi.org/10.1038/s41598-020-61136-6.

MNLH (Minister of State for the Environment, Republic of Indonesia) (2004). *Decree of the Minister of State for the Environment on Standard Criteria and Guidelines for Determining Mangrove Damage Number 201*. Jakarta, Indonesia.

Motamedi, S., Hashim, R., Zakaria, R., Song, K., & Sofawi, B. (2014). Long-term assessment of an innovative mangrove rehabilitation project: Case study on Carey Island, Malaysia. *The Scientific World Journal, 2014*, 1-12. https://doi.org/10.1155/2014/953830.

Mueller-Dombois, D., & Ellenberg, H. (1974). *Aims and methods of vegetation ecology*. John Wiley & Sons.

Osland, M., Feher, L., Griffith, K., Cavanaugh, K., Enwright, N., Day, R. H., Stagg, C. L., Krauss, K. W., Howard, R. J., Grace, J. B., & Rogers, K. (2016). Climatic controls on the global distribution, abundance, and species richness of mangrove forests. *Ecological Monographs, 87*, 341-359. https://doi.org/10.1002/ecm.1248.

Polania, J., Urrego, L. E., & Agudelo, C. M. (2015). Recent advances in understanding Colombian mangroves. *Acta Oecologica, 63*, 82-90. https://doi.org/10.1016/j.actao.2015.01.001.

Rencher, A. C. (2002). *Methods of multivariate analysis* (2nd ed.). John Wiley & Sons, Inc. https://doi.org/10.1002/0471271357.

Schuerch, M., Spencer, T., Temmerman, S., Kirwan, M. L., Wolff, C., Lincke, D., McOwen, C. J., Pickering, M. D., Reef, R., Vafeidis, A. T., Hinke, J., Nicholls, R. J., & Brown, S. (2018). Future response of global coastal wetlands to sea-level rise. *Nature, 561*, 231-234. https://doi.org/10.1038/s41586-018-0476-5.

Singh, V. B., & Ramanathan, A. L. (2015). Assessment of solute and suspended sediments acquisition processes in the Bara Shigri glacier meltwater (Western Himalaya, India). *Environmental Earth Sciences, 74*, 2009-2018. https://doi.org/10.1007/s12665-015-4584-3.

Indonesian National Standardization. (2011). *Mangrove survey and mapping - BNS 7717*. National Standardization Agency.

Sriyani, N. (2012). *Practical guide for weed control science and engineering*. Department of Agricultural Cultivation, Faculty of Agriculture, University of Lampung.

Syahrial, Hatta, M., Larasati, C. E., Ruzanna, A., Muzafri, A., Hasidu, L. O. A. F., Syahrian, W., & Zibar, Z. (2023). Multivariate analysis on mangrove community structure in North Rupat District, Bengkalis Regency, Riau Province. *Kelautan Tropis, 26*, 223-237. https://doi.org/10.14710/jkt.v26i2.15622.

Syarifuddin, A., & Zulharman. (2012). Analysis of mangrove forest vegetation in Lembar Port, West Lombok Regency, West Nusa Tenggara. *Gamma, 7*, 1-13.

van der Maarel, E. (2005). *Vegetation ecology*. Blackwell Publishing.

Wang, Y., Qiu, Q., Xin, G., Yang, Z., Zheng, J., Ye, Z., & Li, S. (2013). Heavy metal contamination in a vulnerable mangrove swamp in South China. *Environmental Monitoring and Assessment, 185*, 5775-5787. https://doi.org/10.1007/s10661-012-2983-4.

Zakaria, R. M., Sofawi, A. B., Joharee, N. A., & Pauzi, A. Z. (2018). Stand structure and biomass estimation in the Klang Islands Mangrove Forest, Peninsular Malaysia. *Environmental Earth Sciences, 77*, Article 486. https://doi.org/10.1007/s12665-018-7636-7.

Zhang, Z., Xu, X., Sun, Y., Yu, S., Chen, Y., & Peng, J. (2014). Heavy metal and organic contaminants in mangrove ecosystems of China: A review. *Environmental Science and Pollution Research, 21*, 11938-11950. https://doi.org/10.1007/s11356-014-3100-8.