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Bio-ecological study on Aceh coast to determine mangrove ecosystem restoration areas suitability

Meilinda Suriani Harefa[1,*], Nur Rohim[2], Imam Pramuja[3], Putri Ramadayanti Harahap[3], Suciati Agustin[4], Kamaluddin Siregar[3], Jonatan Pardamean Sitanggang[3]

[1]*Department of Geography, Faculty of Social Sciences, Universitas Negeri Medan, Deli Serdang, Indonesia.*
[2]*Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, IPB University, Bogor, Indonesia.*
[3]*Department of Research and Monitoring, Yagasu Aceh Foundation, Medan, Indonesia.*
[4]*Department of English, Faculty of Humanities, Andalas University, Padang, Indonesia*

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ABSTRACT

Mangrove forests in Aceh are significant because of their roles in ecological, socio-economic, and socio-cultural aspects. Mangrove restoration efforts must be based on adequate land assessment and regular evaluation of the viability of planted mangroves. Therefore, this study aimed to analyze the bio-ecological characteristics of mangrove planting locations and evaluate land suitability in the restoration areas in Aceh Besar (Layeun Village) and Aceh Jaya (Babah Ie, Ujong Sudeun and Keude Unga Villages). This study was conducted in the YAGASU restoration area in Aceh Besar and Aceh Jaya Regencies in September 2022. The primary data consisted of the physicochemical characteristics of the environment, biodiversity, land suitability index, and plant survival rates after 3- 6 months planted. Data were analyzed using correlation, principal component analysis (PCA), cluster analysis (CA), descriptive statistics, and land suitability index. The result showed that the physical-chemical parameters of the environment are suitable for supporting the growth of mangroves and the livelihoods of various communities. In the study areas, the communities include 8 mangroves, 15 fish, 19 benthic, 11 zooplankton, and 22 phytoplankton species. Layeun, Ujong Sudeun, and Keude Unga Villages were found to have better land suitability than Babah Ie Village. However, an evaluation of the results of planting monitoring showed that Layeun has the highest survival rate compared to the other three villages. The results showed that pests, including buffalo and crustaceans, as well as sea waves, and the duration of the tides inundating the water are the main factors causing mangrove mortality.

Introduction

The mangrove ecosystem is an important coastal ecosystem dominated by several types of trees that grow and develop in fluctuating salinity and oxygen (Dewiyanti *et al.,* 2021). It has unique characteristics, withlives that are influenced by soil conditions, water salinity, waterlogging, tides, and oxygen content (Akbar *et al.,* 2019). The mixture of saltwater and freshwater is very important for the survival of mangrove trees, which has adapted to tolerate saltwater but requires freshwater to do so survive (Baubekova *et al.*, 2023). Mangrove ecosystems have significant ecological, socio-economic, and socio-cultural roles, such as the maintenance of coastal stability from abrasion, a source of fish, shrimp, and some other biodiversity. Additionally, mangroves provide resources, such as firewood and building wood, and also serve conservation, education, ecotourism, and cultural identity functions (Saputra *et al.,* 2021). Many of these benefits contribute to securing and increasing local livelihoods through the direct extraction of provisioning services, supporting fishering, or opportunities for cultural services (Friess *et al.*, 2022). The ecosystem services provided

* Corresponding author.
Email address: meilindasuriani@unimed.ac.id

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by mangroves globally are estimated to be over USD 1.6 billion per year (Ofori *et al.*, 2023).

In recent years, mangroves have received increasing attention from governments and non-governmental organizations around the world, but this attention contrasts with their stability in many regions (Alexandra *et al.*, 2021). Globally, the decline in mangrove forest area has reached 1-2% per year (Iswahyudi *et al.*, 2020). Based on the National Mangrove Map released by the Ministry of Environment and Forestry in 2021, mangrove forests in Indonesia cover an area of 3,364,080 ha (KLHK, 2021). This area is spread across various provinces in Indonesia, including Aceh, covering about 84.32 ha before the tsunami. According to Maulida and Agustina (2021), the 2004 tsunami destroyed 79% of the land area and only 18.08 ha remained. A decrease in the area of mangrove areas in Indonesia will result in decreased biodiversity and environmental services of the mangrove ecosystem (JC *et al.*, 2016). Aceh Besar and Aceh Jaya are districts in Aceh Province that were also impacted by changes in mangrove areas due to the tsunami disaster. The results of observations in various areas in the Jaya Regency regarding the quantity of post-tsunami coastal vegetation showed that the physiognomy of the coast has a fundamental change, resulting in a limited number of mangroves growing in the area (Syahputra *et al.*, 2021).

In addition to natural factors, human activities significantly affect the sustainability of mangrove forests. These include the conversion of land into fish and shrimp ponds, illegal logging of mangrove forests, inadequate guidance and control, weak consistency of coastal and mangrove management policies, lack of firmness in the attitude of the authorities, and differences in perceptions between various community development sectors (Saru *et al.*, 2014). According to Whardani (2014), using mangrove resources without considering ecological interests can threaten the sustainability of the ecosystem. The use of mangrove ecosystems for other purposes or their destruction can decrease the productivity of fisheries and forestry in coastal areas. One of the essential steps for planning and implementing restoration and conservation programs in mangrove forests, apart from quantitatively identifying such losses, is to know the economic value of the loss, and the social benefits of restoring the lost resource (Pham *et al.*, 2018). Restoration efforts should integrate an understanding of ecosystem services and community preferences (Su and Gasparatos, 2023).

The existence of mangrove forests in Aceh is fundamental due to their complex functions. This necessitates the implementation of innovations in rehabilitation, restoration, and conservation efforts in mangrove areas. After the tsunami in Aceh, many mangrove rehabilitations have been carried out by both local and foreign organizations. However, it is not optimal due to several factors, such as low-quality seeds, unsuitable seeds for planting locations, wrong choice of planting types, and inexperienced implementation (Azhar *et al.*, 2021). According to Rakhmadi *et al.* (2019), mangrove rehabilitation is often interpreted simply, including planting mangroves without adequate assessment and evaluation of its success and the ecosystem level. To provide a top-level design for mangrove restoration planning, it is necessary to map areas that are ecologically suitbale for mangrove and those that are potentially restorable (Hu *et al.*, 2020). Quantitative assessments of mangrove conservation are necessary to evaluate current achievements and provide scientific support for future planning (Zheng *et al.*, 2023). This serves as the background for conducting this study, to evaluate and determine land suitability for mangrove restoration in the spectrum of the bio-ecological conditions of the planting sites in Jaya and Besar districts. Therefore, this study aimed to analyze the bio-ecological characteristics of mangrove planting locations and evaluate land suitability in mangrove restoration areas in Aceh Besar (Layeun Village) and Aceh Jaya (Babah Ie, Ujong Sudeun and Keude Unga).

Materials and Methods

Location and time of research

The study was conducted in mangrove restoration areas in Aceh Besar (Leyeun Village) and Aceh Jaya (Babah Ie, Ujong Sudeun, and Keude Unga) (Table 1 and Figure 1). Data were collected at 4 stations in September 2022. The purposive sampling method was used to determine the location for data collection, based on the location and age of the mangrove planting.

The instruments were environmental physicochemical parameters consisting of a digital pH meter Atago DPH-2 (for measuring pH), a refractometer Atago Master 20 T (for measuring salinity), dissolved oxygen meter Lutron DO-5510 (for measuring measure dissolved oxygen and temperature), digital HM TDS/EC meter (to measure TDS and conductivity), probe (to calculate current), secchi disk (for water transparency), scale board (to measure depth), Garmin GPS 68S (to measure taking GPS coordinates), digital camera (to

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document samples and activities), 500 ml sample bottles (to store water samples), planktonet (to take plankton samples), 100 ml plankton sample bottles (to store plankton samples), millimeter block (to measuring and sample documentation mat), cooler box 50s (to store samples), stationery (to record data collection results), plastic (to store samples), senses to see and smell the characteristics of the observation site, soil pH tester (to measure pH and soil moisture) and soil conductivity tester (to measure soil conductivity and temperature). The materials used were water samples, H_2SO_4 (to preserve water samples), lugol (to preserve plankton samples), and 10% formalin (to preserve fish samples).

The primary data included assessments of the physicochemical parameters of water and biodiversity consisting of mangroves, nekton, benthos, and plankton. Measurement of water physical and chemical parameters refers to APHA (2017). Furthermore, the calculation of mangrove, nekton, benthos, and plankton data refers to Kusmana *et al.,* (2015).

Temperature (water and soil), salinity, DO, pH (water and soil), currents, transparency, substrate, depth, tides, odor, color, conductivity (water and soil) and TDS were measured in-situ at the surface. For ex-situ parameters, water samples taken were 500 ml without preservatives for TSS analysis and 1000 ml with H_2SO_4 for nitrate and phosphate analysis and then stored at 4^{0}C. These water samples were analyzed at the Laboratory of The Center for Environmental Health Engineering and Disease Control, Medan City.

The plot sizes used in measuring mangroves at each station were 10 m x 10 m for the tree category, 5 m x 5 m for the sapling category, and 1 m x 1 m for the seedling category. Sampling of nekton, specifically in fish around the study location, was carried out through the use of nets assisted by fishermen at each observation station. The fish were identified using Kottelat *et al.* (1993), White *et al.* (2013), and Fishbase. The benthic sampling technique was carried out using a surbernet at each station. Nekton and benthos samples were stored in plastic and preserved using 10% formalin for further identification.

Plankton sampling using planktonet was carried out at each observation station. The plankton samples obtained were put into sample bottles and preserved using Lugol's. The samples were placed into bottles, preserved using Lugol, and analyzed at the Biology Laboratory at the Faculty of Mathematics and Natural Sciences of North Sumatra University.

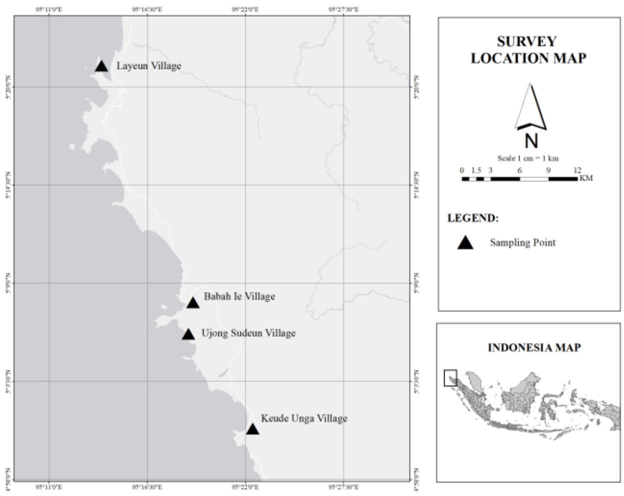

Figure 1. Survey location map

Table 1. Position of five data collection stations

Stations	Positions
Station 1 (Layeun Village)	S 05.353338^{o} and E 95.23244^{o}
Station 2 (Babah Ie Village)	S 05.132484^{o} and E 95.31782^{o}
Station 3 (Ujong Sudeun Village)	S 05.102998^{o} and E 95.31363^{o}
Station 4 (Keude Unga Village)	S 05.014346^{o} and E 95.37362^{o}

Data analysis

The data analysis methods used in this study consisted of correlation analysis, principal component analysis (PCA), and cluster analysis (CA) on Microsoft Excel and PAST (Paleotogical Statistics) 4.03. Water physicochemical parameter data were also compared with the quality standard of seawater based on the Government Regulation of the Republic of Indonesia Number 22 of 2021 to obtain management recommendations.

Land suitability index analysis was also carried out to determine the level of land suitability for each observation station. This is based on the multiplication of the scores and weights obtained from each parameter. The percentage level from the sum of the values of all parameters shows the area suitability (Magdalena *et al.*, 2015). Furthermore, the criteria of these parameters function to determine the suitability of a conservation area, each describing the level for a particular use, as shown in Table 2.

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The total score from the multiplication of the parameter values with their weights is used to determine the mangrove land suitability class based on the physical and chemical factors of the mangrove ecosystem with reference to the following equation:

$$LSI = \sum_{i=1}^{n}(Wi \; x \; Si)$$

Information:
LSI = Land suitability index
Wi = The weight of the i-th parameter
Si = The score of the i-th parameter

The maximum value of the suitability level is 300 and is divided into four classes (Magdalena *et al.*, 2015) as follows:

S1 = Strongly suitable with score 226-300
S2 = Suitable with score 151-225
S3 = Conditional suitable with score 76-150
S4 = Unsuitable with score 0-75

Table 2. Mangrove Forest Conservation Land Suitability Matrix

No.	Parameter	Bobot	S1	S2	S3	N
1	Mangrove density (100 m^2)	25	>15-25	>10-15	5-10	<5
2	Number of mangrove species	25	>5	3-5	1-2	0
3	Substrate	10	Sandy mud	Muddy sand	Sand	Rocky
4	Tide (m)	10	0-1	>1-2	>2-5	>5
5	pH	10	6-7	5-<6 and >7-8	4-<5 and >8-9	<4 and >9
6	Current (m/s)	10	<0.3	0.3-0.4	>0.4-0.5	>0.5
7	Salinity (ppt)	10	25-<29 or >33-37	29-33	0-1	0

Source: Khomsin (2005)
Score Description: Class S1 = 3, Class S2 = 2, Class S3 = 1 and Class N = 0

Results

Table 3 showed the results of measuring the physical-chemical parameters of the environment at each station, which is mangrove restoration area. The environmental characteristics were water temperature (31.3^{0}C-33.3^{0}C), soil temperature (38^{0}C -46^{0}C), water pH (7.06-8.4), soil pH (5.3-7.3), TDS (4715-21000 mg/l), TSS (5 mg/l), water conductivity (9430-41700 S/m), land conductivity (4 S/m), total P (0.1-6.4 mg/l), N (6.3-6.5 mg/l), depth (10-200 cm), transparency (10-12.5 cm), current (0.04-0.26 m/s), salinity (3-25.1 ppt), color (clear brown and green), substrate (sandy mud and muddy sand), and tide (1-5 m).

Table 3. The Result of Environmental Physical and Chemical Parameters Assessment

Parameter	Station			
	Layeun	Babah Ie	Ujong Sudeun	Keude Unga
Water Temperature (^{0}C)	33.3	32.3	33.2	31.3
Land Temperature (^{0}C)	46	39	40	38
DO (mg/l)	7.3	6	5.8	6.5
Water pH	8.4	7.18	7.25	7.06
Land pH	5.3	7.3	7.5	7.2
TDS (mg/l)	20000	13000	21000	4715
TSS (mg/l)	5	5	5	5
Land Conductivity (S/m)	4	4	4	4
Water Conductivity (S/m)	39900	25900	41700	9430
Total Phospate (P) (mg/l)	0.09	0.16	0.11	0.1
Nitrate (N) (mg/l)	6.4	6.4	6.5	6.3
Smell	No Smell	Buffalo feces	No Smell	No Smell

Depth (cm)	20-100	10-200	15-200	30-150
Transparency (cm)	20	10	12.5	12.5
Current (m/s)	0.10	0.26	0.25	0.04
Salinity (ppt)	3	13.1	25.1	15
Colour	Clear Brown	Clear Brown	Clear Green	Clear Green
Substrate Texture	Sand-Mud	Mud-Sand	Mud-Sand	Sand-Mud
Tide (m)	0-1	>1-2	0-1	>2-5
Main Pest	Benthic/Crustacea	Buffalo	Buffalo	Benthic

The Principan Component Analysis (PCA) results showed that the contribution of the two main components to the total variant value reaches 87.05% of 100%. The eigenvalues of the two main components are 5.95 and 5.37, with the respective percentages being 45.75% and 41.30%.

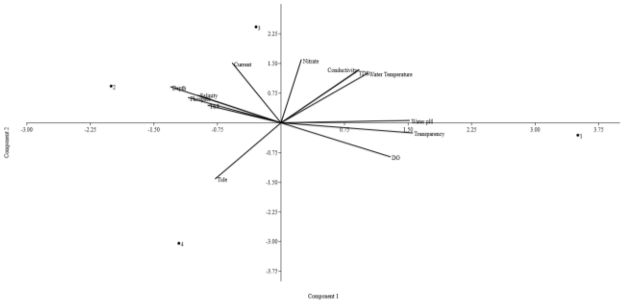

Figure 2. PCA biplot ordinance between water physical-chemical parameters by stations

The two main components, with a variance of 87.05% of the total variance, indicated that the two main components have sufficiently explained the variation in the data. Figure 2 and Table 4 show the results of PCA analysis and the correlation between environmental physicochemical parameters.

Cluster Analysis (CA) was used to determine the degree of similarity between stations. CA results in the form of a dendrogram (Figure 3) showed that the observation stations are in the same cluster but have different levels of similarity. Geographically, all observation stations are in coastal areas but have different distances. Station 2 and Station 3 have the closest level of similarity due to their close proximity geographically.

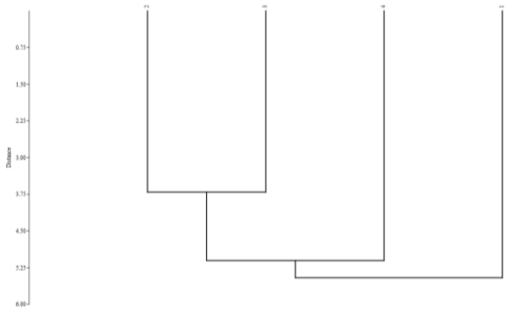

Figure 3. Dendogram of aquatic areas grouping based on water quality conditions

Table 4. Correlation between physical-chemical parameters of water

Parameter	Water Temperature	Depth	Transparency	Current	Salinity	Water pH	DO	TDS	TSS	Conductivity	Phosphate	Nitrate	Tide
Temperature	1												
Depth	-0.12	1											
Transparency	0.53	-0.90	1										
Current	0.44	0.79	-0.51	1									
Salinity	-0.08	0.81	-0.68	0.48	1								
pH	0.65	-0.81	0.95	-0.28	-0.76	1							
DO	0.14	-0.99	0.89	-0.73	-0.89	0.84	1						
TDS	0.99	-0.03	0.45	0.51	0.02	0.57	0.04	1					
TSS	-0.16	0.52	-0.58	0.60	-0.07	-0.31	-0.40	-0.15	1				
Conductivity	0.99	-0.03	0.45	0.50	0.01	0.58	0.04	0.99	-0.15	1			
Phospate	-0.167	0.73	-0.74	0.72	0.19	-0.49	-0.62	-0.13	0.96	-0.13	1		
Nitrate	0.83	0.43	0.00	0.77	0.46	0.12	-0.43	0.82	0.00	0.87	0.13	1	
Tide	-0.97	-0.05	-0.36	-0.62	0.06	-0.55	0.00	-0.97	-0.09	-0.97	-0.08	-0.86	1

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The results of land suitability index calculations in Table 5 showed that Layeun, Ujong Sudeun, and Keude Unga have land characteristics suitable for the conservation of mangrove ecosystem. In contrast, Babah Ie has conditional land characteristics. Keude Unga has the highest parameters of mangrove density and the number of mangrove species, while the smallest was found in Babah Ie. Land suitability index parameter score at each observation station has different results but exhibited similarities in substrate parameters (S2), current velocity (S1), and salinity (S1).

Table 5. Land suitability index values at each station

Parameter	Land Suitability Index Score			
	Layeun	Babah Ie	Ujong Sudeun	Keude Unga
Mangrove density (100 m^2)	25	0	0	50
Number of mangrove species	50	25	50	50
Substrate	20	20	20	20
Tide (m)	30	20	30	10
pH	10	20	20	20
Current (m/s)	30	30	30	30
Salinity (ppt)	30	30	30	30
Total	195	145	180	210

The results of biodiversity observations showed that each station has a complex community of living things. Mangrove vegetation, groups of nekton, benthos, and plankton (zooplankton and phytoplankton) were found at each observation location. This shows the significance of carrying out conservation efforts in the area to ensure the sustainability of various communities, including those living around the restoration area. Tables 6 to 10 show the results of observations of biodiversity at each station.

Table 6. Species distribution of fish around the restoration area

No.	Species	Station				Conservation Status (IUCN, 2023)
		Layeun	Babah Ie	Ujong Sudeun	Keude Unga	
1	*Boleophthalmus boddarti*	+				LC
2	*Periophthalmonodon schlosseri*			+		LC
3	*Caranx ignobilis*	+				LC
4	*Anguilla bicolor*				+	NT
5	*Chanos chanos*	+				LC
6	*Scatophagus argus*		+			LC
7	*Siganus vermiculatus*				+	LC
8	*Lutjanus kasmira*				+	LC
9	*Plectropomus leopardus*				+	LC
10	*Sphyraena jello*				+	NE
11	*Lutjanus gibbus*				+	LC
12	*Epinephelus fuscoguttatus*				+	VU
13	*Inegocia japonica*				+	NE
14	*Oreochromis mosambicus*				+	VU
15	*Terapon jarbua*				+	LC

Notes: LC (Least Concern), NT (Near Threatened), NE (Not Evaluated), and VU (Vulnerable)

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Table 7. Species distribution of mangroves around the restoration area

No.	Species	Station				Conservation Status (IUCN, 2023)
		Layeun	Babah Ie	Ujong Sudeun	Keude Unga	
1	*Rhizophora mucronata*	+				LC
2	*Rhizophora stylosa*	+	+	+	+	LC
3	*Lumnitzera littorea*	+				LC
4	*Terminalia catappa*	+	+	+		LC
5	*Avicennia marina*			+	+	LC
6	*Casuarina equisetifolia*				+	LC
7	*Sonneratia alba*				+	LC
8	*Thespesia populnea*				+	LC

Notes: LC (Least Concern), NT (Near Threatened), NE (Not Evaluated), and VU (Vulnerable)

Table 8. Species distribution of benthos around the restoration area

No	Species	Station				Conservation Status (IUCN, 2023)
		Layeun	Babah Ie	Ujong Sudeun	Keude Unga	
1	*Polymesoda erosa*		+			LC
2	*Terebralia palustris*	+				NE
3	*Anadara tuberculosa*	+				NE
4	*Anadara granosa*	+				NE
5	*Tympanotonos sp*		+			LC
6	*Mytella sp*	+				NE
7	*Cerithium sp*	+				LC
8	*Penaeus monodon*		+		+	NE
9	*Penaeus merguiensis*		+	+	+	NE
10	*Litopenaeus vannamei*		+	+	+	NE
11	*Harpiosquilla raphidea*				+	NE
12	*Panulirus homarus*			+	+	LC
13	*Austruca annulipes*	+	+	+	+	NE
14	*Hepatus epheliticus*				+	NE
15	*Portunus sanguinolentus*			+	+	NE
16	*Xantho sp*				+	NE
17	*Libinia sp*				+	NE
18	*Charybdis feriata*				+	NE
19	*Tubuca alcocki*	+				NE

Notes: LC (Least Concern), NT (Near Threatened), NE (Not Evaluated), and VU (Vulnerable)

Table 9. Genera distribution of zooplankton around the restoration area

No.	Species	Station			
		Layeun Laut	Ujong Sudeun	Babah Ie	Keude Unga
1	*Drepanomonas sp*	+	+	+	
2	*Moina sp*	+	+		
3	*Nauplius sp*	+		+	
4	*Calanus sp*	+		+	+
5	*Cyclops sp*	+	+		+
6	*Diaptomus sp*	+		+	+
7	*Eusirus sp*	+	+		

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8	*Metis sp*	+			+
9	*Lecane sp*		+		
10	*Monostyla sp*		+		
11	*Pedipartia sp*	+		+	+

Table 10. Genera distribution of phytoplankton around the restoration area

No.	Species	Station			
		Layeun	Ujong Sudeun	Babah Ie	Keude Unga
1	*Amphora sp*	+			+
2	*Asterionella sp*	+			
3	*Chaetoceros sp*	+	+		
4	*Coscinodiscus sp*	+		+	
5	*Cyclotella sp*	+		+	
6	*Fragilaria sp*		+		
7	*Gyrosigma sp*				+
8	*Melosira sp*	+		+	
9	*Meridion sp*	+			
10	*Navicula sp*	+	+		+
11	*Nitzschia sp*				+
12	*Odontella sp*	+			
13	*Pinnularia sp*	+			
14	*Pleurosigma sp*	+			
15	*Synedra sp*	+	+		+
16	*Closterium sp*	+	+	+	
17	*Eremosphaera sp*	+	+		+
18	*Entosiphon sp*	+			
19	*Euglenopsis sp*	+		+	
20	*Hormidium sp*	+			
21	*Roya sp*	+	+		
22	*Oscillatoria sp*		+	+	+

The monitoring results of mangroves planted on plants aged 3-6 months showed that the highest survival rate was obtained in Layeun Village (54.19%), while the lowest survival rate was found in Keude Unga Village (5%) (Table 11). This result is contradictory to the land suitability index score, where Keude Unga gets the highest score (210). The cause of the low percentage of mangrove survival rate in Keude Unga is due to other factors that are not included in the land suitability index parameters, such as the number of seedlings, the area of the restoration area, the potential for pests, and the duration of the tides.

Table 11. The survival rate of mangroves after 3-6 months planted

No	Location	Monitoring Result			Survival Rate (%)
		Number of Dead Seeds	Number of Live Seeds	Total Seed Initial Planting	
1	Layeun	11,243	13,299	24,543	54.19
2	Babah Ie	15,360	9,870	25,230	39.12
3	Keude Unga	3,398	179	3,577	5
4	Ujong Sudeun	16,015	9,597	25,612	37.47

Discussion

Restoration and conservation of mangrove ecosystems are a major center of attention in the contemporary world due to the critical role of mangroves in mitigating climate change. Therefore, restoration and conservation efforts must have appropriate technical guidelines and be evaluated periodically to improve achievements and success in maintaining the sustainability of mangrove ecosystems. The management of mangrove restoration needs to pay attention to aspects of land suitability, biodiversity, and the behavior of the people living around the restoration area.

In the study, the values of the physical, chemical, and biological parameters at each station were compared with the Seawater quality standards for Marine Biota based on the Government Regulation of the Republic of Indonesia Number 22 of 2021. The results showed that the parameters pH, salinity, DO, TSS, and plankton at all stations do not exceed the threshold or follow the natural character of mangrove ecosystem. However, some parameters exceeded the threshold, namely temperature, phosphate, and nitrate.

The pH value of the waters at the study station ranged from 7.06 to 8.4, with an average of 7.05, indicating suitability for mangrove growth. Furthermore, the pH tolerance ranges between 6 and 9, and the optimal pH is around 7 to 8.5 (Wantasen, 2013). Several pH characteristics in mangrove ecosystems in other areas also show a range of values that are not significantly different. These include Reuleung River, Aceh Besar 6.4-7.4 in Zulfikar *et al.* (2019), Aceh Singkil 7.9-8.8 in Aidil *et al.* (2016) and East Aceh 6.2-6.4 in Balqis *et al.* (2021). The soil pH in the study area ranged from 5.3 to 7.5, with an average of 6.8. According to Bachtiar *et al.* (2023), soil pH between 6 and 7 is ideal for mangrove growth. DO ranged between 5.8 and 7.3 mg/l, averaging 6.4, showing that the waters fulfilled the oxygen needs of aquatic organisms. Madyowati and Kusyairi (2020) stated that the DO level needed by macrobenthos is around 4-6 mg/l.

The low TSS value at all study stations (5 mg/l) shows that the restoration area has typical parameter values and is consistent with the high transparency value, where the substrate can be seen from the surface. This is directly proportional to the correlation value between TSS and Transparency (-0.58), where an increase in TSS value results in low transparency and vice versa. Salinity ranges between 3 and 25.1 ppt, indicating that the study station is an estuarine area that complies with quality standards (0-34 ppt). It also possesses the characteristics of mangrove ecosystems. Several studies with similar salinity values have been conducted. Hafizi *et al.* (2017) reported a salinity range of 14 to 23 ppt in Kuala Langsa, while Agustini *et al.* (2016) showed a range of 9 to 20 ppt in mangrove communities on Enggano Island, Bengkulu. The values of phosphate (0.09-0.16 mg/l) and nitrate (6.3-6.5 mg/l) in this study exceeded the quality standards of the Government Regulation of the Republic of Indonesia Number 22 of 2021. This difference can be attributed to the presence of livestock in the areas. Specifically, in the Babah Ie and Ujong Sudeun areas, where cows and their droppings are frequently observed in water bodies around the plantation areas. The nutrient content in cow manure considered important for plants is the elements nitrogen (N), phosphorus (P), and potassium (K) (Melsasail *et al.*, 2019).

PCA analysis in Figure 2 shows that the main water physical-chemical parameters affected each observation location. These include pH, transparency, and DO in Layeun Village, TSS, phosphate, depth and salinity in Babah Ie Village, nitrate, temperature, currents, TDS, and Conductivity in Ujong Sudeun Village, and Tide in Keude Unga Village. According to Muttaqin (2017), PCA analysis is a multivariate method that groups variables with linear correlations into one principal component.

The cluster analysis results show that the observation stations are in the same cluster but have different levels of similarity. Geographically, all observation stations are in coastal areas but have different distances. Figure 3 shows that the Euclidean distance of Station 2 (Babah Ie) is closer to 3 (Ujong Sudeun) compared to 4 (Keude Unga) and 1 (Layeun). Layeun and Keude Unga are directly facing the beach. Therefore, the Euclidean distance between stations 1 and 4 is pretty close, different from the distance between 1 and stations 2 and 3. Babah Ie and Ujong Sudeun are geographically not directly facing the beach. The villages of Babah Ie and Ujong Sudeun are located next to each other and are more likely to be affected by human activity. CA is a multivariate analysis commonly used to group objects based on distance or similarity in characteristics (Radiarta *et al.*, 2013).

Mangrove restoration efforts also support the survival of various terrestrial and aquatic biodiversity. One of the fish species found in Keude Unga is Anguilla bicolor. It is a species that migrates from fresh to sea waters for spawning and from sea to fresh waters to grow and find food. Anguillid eels have diverse migration patterns between freshwater and marine habitats (Arai *et al*., 2020). According to Sugianti *et al*. (2020), after hatching in the sea, the eel larvae metamorphose into seeds and migrate to the beach, from the coast of the eel seeds to the estuaries and upstream of the river. Then the seeds turn into pigmented eels and enter fresh waters to grow up. The migration journey of the eel passes through estuarine waters, namely mangrove ecosystems. Furthermore, the restoration activities around Keude Unga, which is the Anguila bicolor migration route support the continuation of its life cycle in Keude Unga.

In the study location, certain species were also facing threats, necessitating careful consideration of their conservation aspects based on the categories determined by the ICUN Redlist. These species include Anguilla bicolor (Near Threatened/NT), Epinephelus fuscogutatus (Vulnerable/VU), and Oreochromis mosambicus (Vulnerable/VU).

The measurement of plankton diversity in all observation stations yielded 11 zooplankton and 22 phytoplankton species. The availability of these species showed that the mangrove restoration area can be a food source for various aquatic organisms and maintain the stability of mangrove ecosystem food chain. According to Purnamasari (2016), zooplankton plays a significant role because it is a connecting link between primary producers and other biotas. Its presence is influenced by phytoplankton, which serves as a food source for zooplankton. Furthermore, the absence of a blooming phenomenon from the presence of plankton at the study location is an indicator of land suitability for the rehabilitation of mangrove ecosystems.

Land suitability index at each observation station showed that Layeun, Ujong Sudeun, and Keude Unga villages are in class 2 (appropriate), with values of 195, 180, and 210, respectively. Meanwhile, Babah Ie village is in class 3 (conditionally appropriate) with a value of 145, as shown in Table 5. The low land suitability value in Babah Ie Village compared to other stations is due to the relatively low number of mangrove species and density around the restoration area. This number is different from Keude Unga, which has the highest density and mangrove species compared to the other three villages.

The results from the monitoring of plants aged 3-6 months in Layeun, Babah Ie, Ujong Sudeun, and Keude Unga showed the respective percentages of plant life as 54.19%, 39.12%, 37.47%, and 5% (Table 11). Additionally, the results of monitoring the survival rate of these plants are similar to the reports of Makaruku and Aliman (2019), which range between 13.5 and 40.5%. Suppose land suitability value is compared with the percentage of plant life as an evaluation of the restoration program in Layeun Village. Then, land suitability value is directly proportional to the high percentage of plant life, which is >50%, compared to the other stations with a survival rate of <50%. Meanwhile, Keude Unga Village is inversely proportional to the percentage of people living, which only reaches 5%. Based on field monitoring results, the main factors for the high mortality in Keude Unga are strong waves, high tides, and the duration of the tides inundating plants. In Babah Ie and Keude Unga, the main factor for the high mortality of the plants was attributed to the grazing and trampling activities of cows and buffaloes when crossing the planting site. This study showed that other parameters/factors must be considered in analyzing land suitability of mangrove restoration, such as sea waves, duration of the tide for planting around the beach, and potential pests, namely buffalo, crabs, and caterpillars.

Conclusion

In conclusion, the bio-ecological characteristics of the mangrove restoration areas showed that the physical-chemical parameters of the environment are suitable for supporting the growth of mangroves and the livelihoods of various communities. The communities at the study station consisted of 8 mangroves, 15 fish, 19 benthic, 11 zooplankton, and 22 phytoplankton species. The result of the study showed that Layeun, Ujong Sudeun, and Keude Unga had better land suitability than Babah Ie Village. However, an evaluation of the results of planting monitoring showed that Layeun had the highest survival rate compared to the other three villages. The main factors causing mangrove mortality are pests (buffalo, crabs, and caterpillars), sea waves, and the duration of the tides inundating the water..

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