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Species Composition and Distribution in the Mangrove Ecosystem in the City of Bengkulu, Indonesia

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Abstract: Most of the cities of Bengkulu are coastal areas (71.87%) under substantial pressure due to infrastructure development. This condition has affected the mangrove ecosystem and ecological degradation and has induced abrasion. In this study, we aimed to analyze the existing conditions of the mangrove ecosystems in the city of Bengkulu, particularly the composition and distribution of the mangrove species and the determination of the water quality. We collected vegetation data using exploratory methods and direct observation at 13 research sites. We measured the water quality in situ in terms of the temperature, salinity, pH, and dissolved oxygen (DO) at the sites, performed a vegetation analysis, and analyzed the turbidity, total dissolved solids (TDSs), biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate, nitrite content, ammonia, and phosphate concentrations ex situ in the laboratory. We found 52 vegetation species in the research sites, which included 11 true mangrove species, 9 associated mangrove species, and 31 coastal and land flora. A total of 24 species are categorized under the least-concern (LC) category of the IUCN (International Union for Conservation of Nature) Red List, and one species is in the data-deficient (DD) category. We categorized the water quality of the mangrove ecosystems in the city of Bengkulu as relatively good, with all the parameters below the national water quality threshold, except for the nitrite concentration in the Bengkulu River estuary. Proper management needs to be developed for the conservation and restoration of mangrove ecosystems to sustain their functions.

Keywords: mangrove; Bengkulu; water quality; abrasion; accretion; IUCN Red List

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1. Introduction

Mangroves are freshwater or marine vegetation communities with high adaptability to extreme environmental changes, with anaerobic soils and high salinities, temperatures, and sedimentation. They are generally found along the coasts and estuaries in tropical and subtropical areas affected by tides [1]. Mangrove communities are determined as intermediate zones because they are dominated by vegetation that substantially differs from marine communities but has similar characteristics to land communities. Mangroves occupy an area of 0.7% of the tropical forests on Earth [2–4], have high productivity, and provide various ecosystem services, including biological, physical, and socioeconomic benefits for the environment and society [5].

Biologically, the mangrove ecosystem provides spawning, nursery, and feeding grounds for marine biota and pollutant filters [6–8]. On a global scale, the mangrove ecosystem is the most important carbon sink, reducing the CO_2 emissions in the atmosphere and with the potential for climate change mitigation [9,10]. Mangroves physically and ecologically function as natural barriers and accumulations of sediments to protect coastal areas from rising sea levels, abrasion, waves, and storms [11]. Economically, mangrove forests are a renewable resource for timber, fish, and tourism [12]. However, despite their many ecological functions and services, mangrove ecosystems have experienced pressure and decline due to anthropogenic factors, such as deforestation and the conversion to aquaculture and agriculture [13]. In addition, the decline of the mangrove ecosystem is also exacerbated by global climate change, which causes temperature changes, rising sea levels, abrasion, and other conditions, which can affect its stability [14].

Indonesia has the largest mangrove ecosystem in the world, accounting for around 26–29% of the world's mangrove ecosystem. However, mangrove forests also have high deforestation rates, with an average of 0.26–0.66% per year [15]. The decline of the mangrove ecosystems in Indonesia is mainly due to the land-use changes for settlements, tourism, industry, mining, agriculture, logging, aquaculture, and other uses [16,17].

Climate change influences the viability of the mangrove ecosystem in Indonesia's coastal regions, particularly in terms of the abrasion that is induced by rising sea levels. In 1990, the mangrove forest along the coastline of Indonesia was 3.5 million hectares. However, the mangrove forest cover has been degrading yearly, and in 2016, it was reduced to 2.9 million hectares. The loss of the mangrove ecosystem has contributed to greenhouse gas emissions and 20% of the land-use emissions [18]. Therefore, Indonesia's government initiated mangrove conservation and restoration as a national priority program to fulfill the national climate commitments and for sustainability management [19]. Technically, the Badan Restorasi Gambut dan Mangrove (the Peat and Mangrove Restoration Agency) developed the restoration of peat and mangrove [20]. The Presidential Regulation of the Republic of Indonesia No. 120 of 2020 targeted the mangrove rehabilitation for 2021–2024 at 60,000 hectares [21].

The city of Bengkulu is located in the southwest part of Sumatra Island, which borders the provinces of West Sumatra, Jambi, South Sumatra, and Lampung. Bengkulu consists of coastal areas (71.87%), rivers, and estuaries, and it is an area with enormous potential for mangrove ecosystems. Its location is directly opposite the Indian Ocean; therefore, the coastal area of Bengkulu also has a high potential for abrasion due to large waves and rising sea levels [22]. In addition, researchers have observed accretion due to sedimentation along the coast of Bengkulu [23]. As the capital of the province of Bengkulu, the coastal areas of the city of Bengkulu are also under tremendous pressure due to infrastructure development and overexploitation, inducing ecological change due to the imbalance between the carrying capacity and the utilization of the coastal zone [24]. This pressure increases the susceptibility of the coastal areas of the city of Bengkulu, particularly if they are not sustainably managed [25]. Recently, researchers proved that periodic underwater breakwaters could be used to protect coastal areas and maintain mangrove ecosystems that face extremely high waves [26].

Considering the vital role of the mangrove ecosystem as a natural barrier that can protect coastal areas from various disasters, in this study, we aimed to identify the composition and distribution of the existing mangrove vegetation and determine the water quality in the city of Bengkulu. The findings of this study provide an overview of the current conditions of the mangrove ecosystems and coastal areas, and they can be used as a scientific reference for the development of sustainable mangrove management in the city of Bengkulu.

2. Materials and Methods

2.1. Study Area

The mangrove ecosystem in the city of Bengkulu is located around the Jenggalu River estuary and along the muddy coast [27]. Geographically, the city is located between $30°45'$ and $30°59'$ S and between $102°14'$ and $102°22'$ E, with a land area of 151.7 km^2 and a sea area of 387.6 km^2. Seven districts are located along the coast of Bengkulu: Muara

Bangkahulu; Sungai Serut; Teluk Segara; Ratu Samban; Ratu Agung; Gading Cempaka; Kampung Melayu. Bengkulu has a tropical climate and a mean annual temperature of 27 °C. The highest average temperature occurs in May (34 °C), and the lowest average temperature occurs in August (20 °C). The mean yearly rainfall of Bengkulu is 354 mm, with the highest peak occurring in November (555.70 mm) and the lowest peak occurring in August (118.60 mm). The tidal type in Bengkulu is mixed semidiurnal, with two high tides and two low tides at different heights and times. The coastal waters of Bengkulu have relatively flat bathymetric conditions, with a slope of <1° and a maximum depth of 65 m to a distance of 2 nautical miles. The deeper waters are to the west of Pulau Baai Harbor, with a depth of more than 65 m [28].

2.2. Data Collection and Analyses

We conducted the fieldwork in November–December 2021 for 13 research sites, which we determined based on the purposive random sampling method (Figure 1): (1) The estuaries of Jenggalu River; (2) Bengkulu River; (3) Black River; (4) a nature tourism park (TWA 3); (5) A nature tourism park (TWA 2); (6) A nature tourism park (TWA 1); (7) An oil catcher; (8) Lentera Merah 1; (9) Lentera Merah 2; (10) Mangrove forest tourism; (11) The PLTU intake water; (12) The PLTU wastewater outlet; (13) Sepang Bay. Those sites were chosen as they represent impacted sites from the settlement (Sites 1–3), tourism area (Sites 4–6, 10), oil Pertamina (Sites 7–9), power plant (Sites 11–12), and bay (Site 13). The non-destructive multiple square plots (quadratic transect) [29] were used to create 39 research plots of 10×10 m^2 with a total sampling area of 0.039 ha and distributed across 13 study sites. The number of plots at each research site was determined by considering the proportion of mangrove forest area at each location. All trees with a diameter of >10 cm in each research plot were identified, and the range of the number per individual species was calculated.

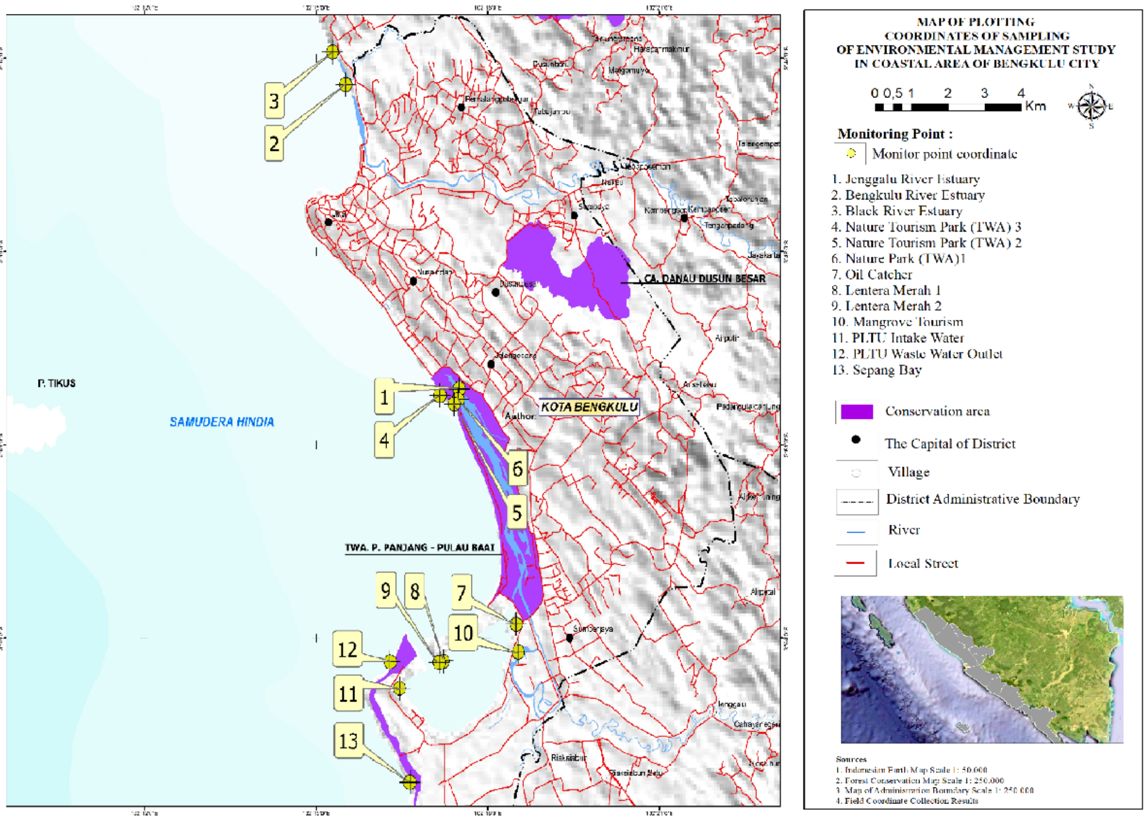


Figure 1. Research sites of coastal areas and mangrove ecosystems in Bengkulu.

We performed the data collection on the vegetation types using the exploration method and direct observation in all the research sites. We conducted the data analysis by identifying the vegetation using the following sources [30–32]; PictureThis (2022) [33]; Plant. id (2022) [34]; Pl@ntNet (2022) [35]; TPL (2021) [36]; WFO (2021) [37]. We conducted the in situ water quality analysis with the HORIBA water checker for the water temperature, salinity, pH, DO, and TDS parameters at the sites. We took water samples at all the research sites, except for Site 13 (Sepang Bay), due to the high tide during the fieldwork. We then analyzed the water samples in the Fisheries Laboratory of the Faculty of Agriculture, Bengkulu University, to determine the turbidity, BOD, COD, nitrate, nitrate content, ammonia, and phosphate concentrations. The analysis of turbidity was performed with Nephelometric Method (180.1), BOD was performed with the 5-Day BOD test (5210 B), and COD was performed with the Closed Reflux Colorimetric Method (5220 D). The analysis of nitrate, ammonia, and phosphate were performed with colorimetric method (353.2), (350.1) and (4500 P), respectively [38].

We present the vegetation data in a semiquantitative table, with the + sign (species i $<$ 10 individu) indicating that we found the vegetation in small abundances, ++ (10 $<$ species i $\geq$ 20) individu indicating moderate abundances, and +++ (species i $>$ 20 individu) indicating large abundances. Furthermore, we determined the species included on the IUCN (International Union for Conservation of Nature) Red List, which includes a list of plants threatened with extinction, which need to be preserved. We displayed the water quality data in a bar chart, and we compared them with the national water quality standards, especially the quality standard of seawater (Appendix VIII of Government Regulation Number 22 of 2021 on the Implementation of Environmental Management Protection) [39].

3. Results

3.1. Composition of Vegetation in the Coastal Area of the City of Bengkulu

Based on the identification of the vegetation in the study area, we found 52 plant species (Tables 1–3), which included 11 true mangrove species from 6 families, including Avicenniaceae, Rhizphoraceae, Sonneratiaceae, Euphorbiaceae, Acanthaceae, and Arecaceae. A total of 10 species were included on the IUCN Red List under the least-concern (LC) category (Table 1).

Table 1. List of true mangrove species in Bengkulu.

Number	Species	Family	Local Name	IUCN Red List
1	*Acanthus ilicifolius*	Acanthaceae	jeruju	LC [40]
2	*Avicennia alba*	Avicenniaceae	api api hitam	LC [41]
3	*Avicennia marina*	Avicenniaceae	apiapi putih	LC [42]
4	*Bruguiera gymnorhiza*	Rhizophoraceae	putut	LC [43]
5	*Excoecaria agallocha*	Euphorbiaceae	kayu buto	LC [44]
6	*Nypha fruticans*	Arecaceae	nipah	-
7	*Rhizophora mucronata*	Rhizophoraceae	bakau biru	LC [45]
8	*Rhizophora stylosa*	Rhizophoraceae	bakau putih	LC [46]
9	*Rhizophora apiculata*	Rhizophoraceae	bakau merah	LC [47]
10	*Sonneratia alba*	Sonneratiaceae	pedada	LC [48]
11	*Sonneratia caseolaris*	Sonneratiaceae	apel mangrove	LC [49]

Table 2. List of associated mangrove species in the City of Bengkulu.

Number	Species	Family	Local Name	IUCN Red List
1	*Acrostichum aureum*	Pteridaceae	paku kulit	-
2	*Conocarpus erectus*	Combretaceae	buton mangrove	LC [50]
3	*Hibiscus tiliaceus*	Malvaceae	waru laut	LC [51]
4	*Ipomoea cordatotriloba*	Convolvulaceae	tievine	LC [52]
5	*Ipomoea pes caprae*	Convolvulaceae	batata pantai	LC [53]
6	*Pandanus helicopus*	Pandanaceae	pandan	DD [54]
7	*Sesuvium portulacastrum*	Aizoaceae	krokot laut	LC [55]
8	*Terminalia catappa*	Combretaceae	ketapang	LC [56]
9	*Wedelia biflora*	Asteraceae	sernai	-

Table 3. List of land flora species in the City of Bengkulu.

Number	Species	Family	Local Name	IUCN Red List
1	*Acacia* sp.	Fabaceae	Akasia	-
2	*Artocarpus altilis*	Moraceae	sukun	-
3	*Artocarpus heterophyllum*	Moraceae	nangka	-
4	*Bauhinia purpurea*	Fabaceae	tayuman	LC [57]
5	*Casuarina equisetifolia*	Casuarinaceae	cemara udang	LC [58]
6	*Cervera manghas*	Apocynaceae	bintaro	-
7	*Chloris barbata*	Poaceae	giant finger	-
8	*Crepis foetida*	Asteraceae	foetida	-
9	*Cyperus fuscus*	Cyperaceae	rumput teki	LC [59]
10	*Cyperus iria*	Cyperaceae	rumput jekeng	-
11	*Dactyloctenium aegyptium*	Poaceae	rumput katelan	-
12	*Desmodium tortuosum*	Fabaceae	jukut jarem	-
13	*Elaeis* sp.	Arecaceae	sawit	-
14	*Enterolobium cyclocarpum*	Fabaceae	sengon buto	LC [60]
15	*Ficus benghalensis*	Moraceae	beringin	-
16	*Heliconia psittacorum*	Heliconiaceae	pisang hias	-
17	*Leucaena leucocephala*	Fabaceae	lamtoro	-
18	*Lonicera fragrantissima*	Caprifoliaceae	january jasmine	-
19	*Macaranga trichocarpa*	Euphorbiaceae	sapat	-
20	*Manilkara zapota*	Sapotaceae	sawo kecik	LC [61]
21	*Phylanthus*	Phyllanthaceae	meniran	-
22	*Pinus pinea*	Pinaceae	tusam	-
23	*Populus* sp.	Salicaceae	-	LC *
24	*Schefflera arboricola*	Araliaceae	pohon gurita	-
25	*Silene antirrhina*	Caryophyllaceae	sleepy catchfly	-
26	*Spigelia anthelmia*	Loganiaceae	kemangi cina	-
27	*Stachytarpheta jamaicensis*	Verbenaceae	pecut kuda	LC [62]
28	*Tabernaemontana divaricata*	Apocynaceae	mondokaki	LC [63]
29	*Typha angustifolia*	Typhaceae	lembang	-
30	*Tridax procumbens*	Asteraceae	songgo langit	-
31	*Vitis* sp.	Vitaceae	anggur-angguran	-

Note: * Several species of Populus are under the LC category, but we could not identify the species level for the Populus genus in this research.

We identified nine species of associate mangrove vegetation from nine different families, of which eight species are classified as LC, while one species is classified as data deficient (DD) (Table 2).

The Rhizophoraceae and Fabaceae families had the highest percentages of all the species identified in the study area (Figure 2). The Rhizhophoraceae family in the study area consisted of five species: *B. gymnorhiza*; *R. mucronata*; *R. apiculata*; *R. stylosa*; *C. multiflora*. The Fabaceae family also consisted of five species: *E. cyclocarpum*; *Acacia* sp.; *B. purpurea*; *D. tortuosum*; *L. leucocephala*.

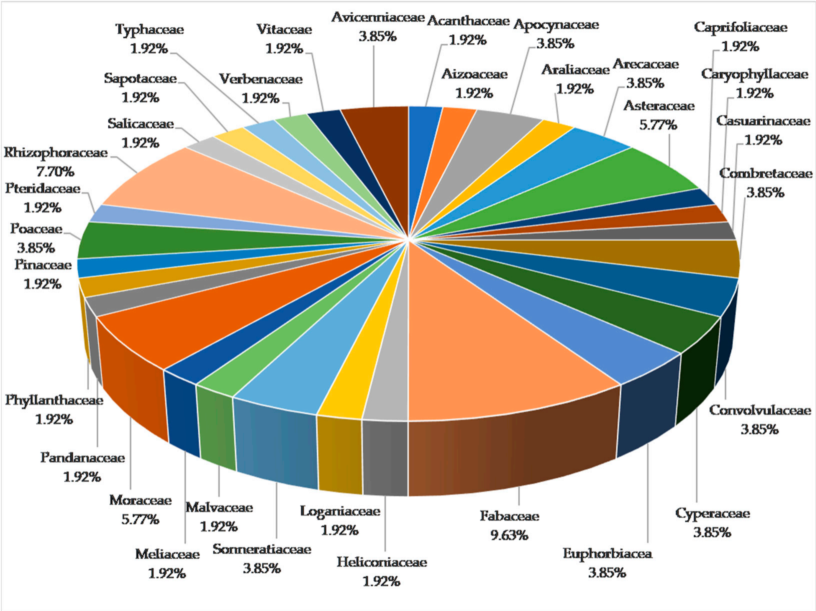


Figure 2. Percentages of coastal vegetation families.

3.2. *Distribution of True Mangrove Species in the City of Bengkulu*

We found true mangrove species in Bengkulu at almost all the study sites except for 7, 11, and 12. We found the highest number of true mangrove species at Sites 4–6 and S9. We found the lowest number of true mangrove species at Sites 3 and 13 (Table 4).

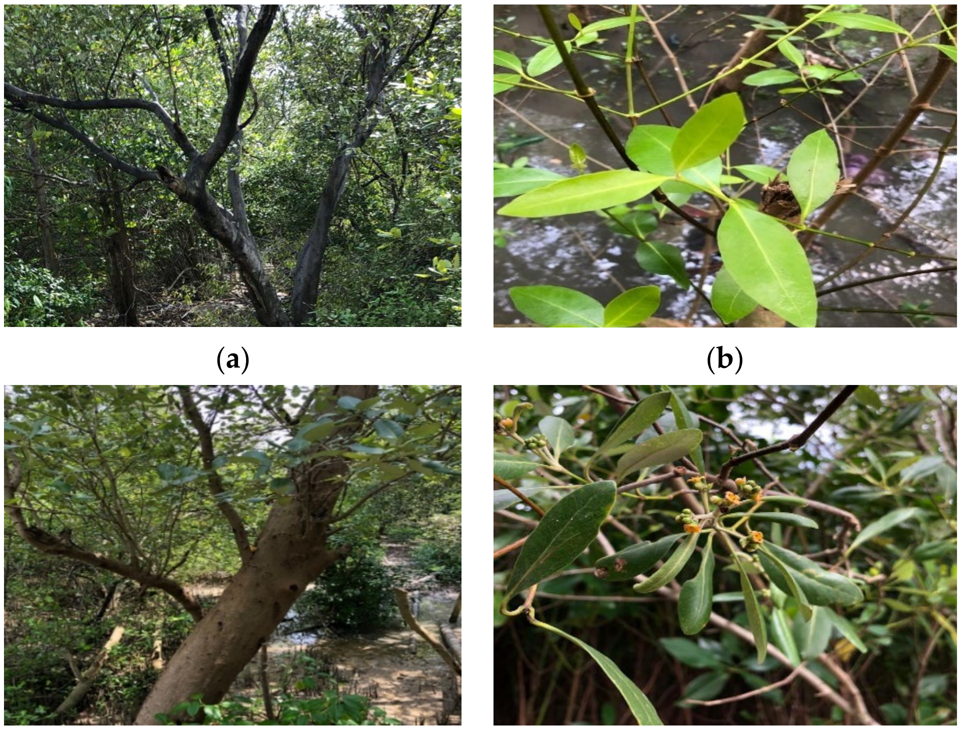
Table 4. Distribution of true mangrove species at study sites in Bengkulu. The + sign (species i < 10 individu) indicating that the vegetation in small abundances, ++ (10 < species i ≥ 20) individu indicating moderate abundances, and +++ (species i > 20 individu) indicating large abundances.

Number	Species	Study Sites												
		1	2	3	4	5	6	7	8	9	10	11	12	13
1	*A. alba*					+	+							
2	*A. marina*					++	++							
3	*B. gymnorhiza*				+				+					
4	*R. mucronata*				+	+	+							
5	*R. stylosa*									+				
6	*R. apiculata*				+	++	+			+++	+			
7	*S. alba*	+	+		+++	+++	+++			++	+++			
8	*S. caseolaris*				+		++							
9	*E. agallocha*									+				
10	*A. ilicifolius*								+	+				
11	*N. fruticans*	+	+	++	++									+
	Total	2	2	1	6	5	6	-	2	6	2	-	-	1

3.3. *Characteristic Mangrove Species in the City of Bengkulu*

3.3.1. *Avicennia alba*

A. alba is a pioneer species found in mangrove swamp habitats, along riverbanks, and along coastlines affected by tides. We found *A. alba*, commonly known as *api-api hitam*, in smaller amounts at Sites 5 and 6. *A. alba* has a respiratory root structure and it can grow to a height of 25 m. The respiratory roots are usually thin, finger-shaped, and covered by lenticels. The bark of *A. alba* is from dark grey to black and has small bumps (Figure 3a). This species has smooth-surfaced elliptical leaves with tapering ends, bright green tops, and pale undersides (Figure 3b).



(**a**) (**b**) (**c**) (**d**)

Figure 3. *Avicennia* sp. in Bengkulu: (**a**) branches of *A. alba*; (**b**) leaves of *A. alba*; (**c**) branches of *A. marina*; (**d**) leaves and flowers of *A. marina*.

3.3.2. *Avicennia marina*

We found *A. marina* (*api-api putih*) in moderate amounts at Sites 5 and 6. This species can grow to a height of above 30 m, and it has respiratory roots that are pencil-shaped. The bark on the stem of *A. marina* is light grey or pale, and it has stiff, brittle, and thin flakes (Figure 3c). The leaves are elliptical, small, and regular, with round tips (Figure 3d), terminal flowers, and orange or dark-orange waxy surfaces (Figure 3d). *A. marina* is also a pioneer species in the protected coastal areas. This species is one of the most common plants found in tidal habitats. The roots of this species play an important role in binding the sediment and accelerating the process of soil formation. In certain habitats, this species typically forms groups.

3.3.3. *Bruguiera gymnorhiza*

We discovered small populations of *B. gymnorhiza* at Sites 4 and 8. The bark of this species is dark grey and brown with lenticels. *B. gymnorhiza* has plank-shaped roots with several knee roots. The underside of the leaves of this species is yellowish green with black spots, and the upper layer is dark green. This species has pink-to-red flowers that hang between the leaf axils (Figure 4). *B. gymnorhiza* is generally found in the middle-backward zone of the mangrove forest near the mainland. This species grows in dry and low-salinity areas. The type of substrate suitable for this species generally consists of mud, sand, and black peat soil.

Figure 4. *Bruguiera gymnorhiza* in the city of Bengkulu.

3.3.4. *Excoecaria agallocha*

We only found *Excoecaria agallocha* in small quantities at Site 9. This species is generally found on the margins of the mainland mangroves, or sometimes above the high-tide line, and can grow up to 15 m in height. Its local name is buta-buta, which means blind, which is because the exudes of the sap or latex from the broken bark, twigs, and leaves can irritate the skin and cause temporary blindness. This species commonly grows in muddy and stony soil and has spreading roots (Figure 5).

Figure 5. *Excoecaria agallocha* at Site 6 in the city of Bengkulu.

3.3.5. *Rhizophora mucronata*

We only found *R. mucronata* in low abundance at the natural tourism parks (Sites 4–6). Typically, this species grows in tidal areas, including in river estuaries and along coasts. The optimum growth conditions for this species are in areas with humus-rich soils. *R. mucronata* is more adaptable to hard and sandy soils than *R. apiculata*. This species can reach a height of up to 27 m, and it has dark-to-black bark. The roots and aerial roots of this species grow from the lower branches. The leaves are skinned and elliptical-shaped with pointed tips. The fruits are brownish green and elongated, with lengths of 40–80 cm and diameters of 2–3 cm (Figure 6a).

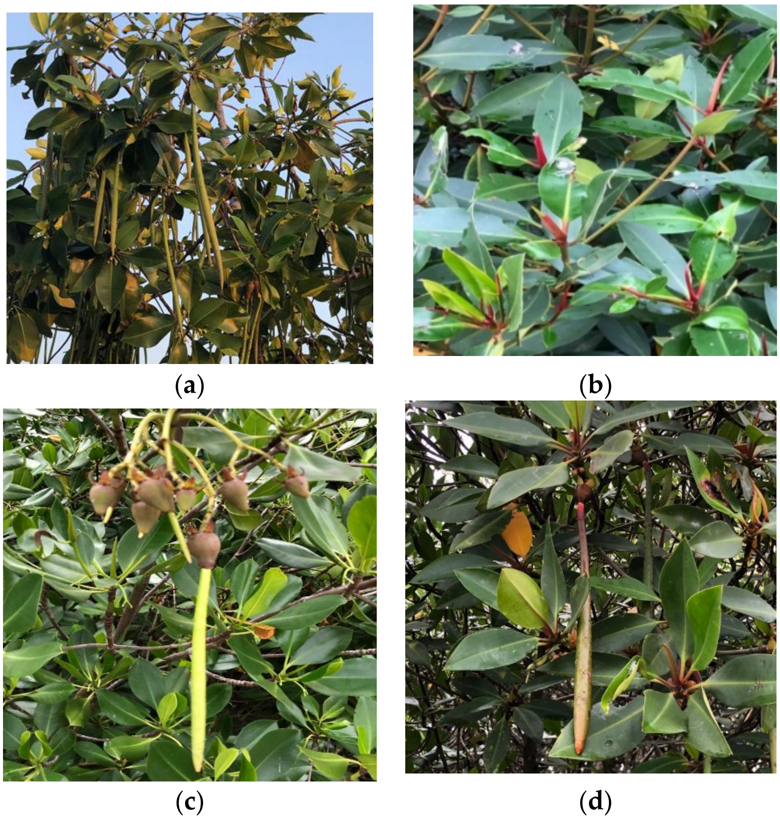


Figure 6. (**a**) Fruit of *R. mucronata*; (**b**) leaf of *R. apiculata*; (**c**) fruit of *R. stylosa*; (**d**) fruit of *R. apiculata*.

3.3.6. *Rhizophora apiculata*

R. apiculata is more widely distributed and abundant than the other species of the Rhizoporaceae family found in Bengkulu. We found this species in low-to-medium abundances at Sites 4–6 and in high abundance at Site 10. Due to its unique characteristic (reddish leaf tips), this species is known as the *bakau merah* (Figure 6b). This species also has a leaf shape that tends to be more pointed than those of *R. mucronata* and *R. stylosa*. Generally, this species prefers tidal areas, and it strongly influences the permanent freshwater input. The substrate type that is suitable for the growth of this species is a fine muddy substrate that is deep and flooded during normal tides. The local community uses the wood of *R. apiculata* as building material, firewood, and charcoal.

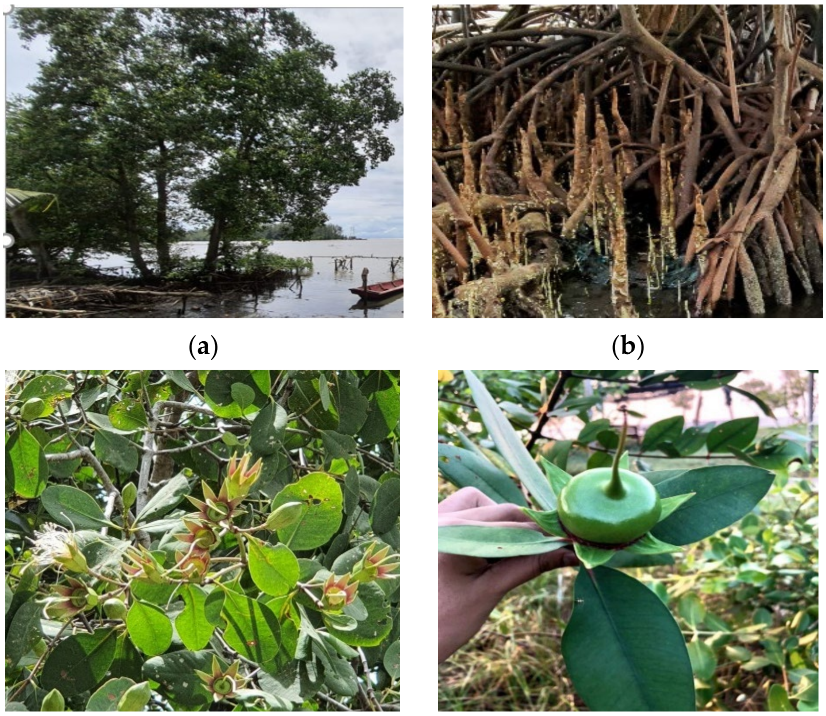
3.3.7. *Rhizophora stylosa*

We only found *R. stylosa*, locally known as *bakau putih*, in low abundance at Site 10. This species typically grows in tidal areas in mud, sand, and rocky substrates. Generally, this species is found in the estuaries along coasts or in the middle zones of mangrove forests. This species can grow up to 10 m in height, and it has a blackish-grey bark with a smooth surface. *R. stylosa* has similar characteristics to *R. mucronata*, and it is difficult to distinguish them from one another. The key characteristics that distinguish *R. stylosa* from *R. mucronata* are the shape and color of the leaves and the length of the propagules. *R. stylosa* has dark-green leaves, the lengths of the propagules vary between 26 and 65 cm, and it tends to be shorter than *R. mucronata* (Figure 6c).

3.3.8. *Sonneratia alba*

S. alba is a true mangrove species with high abundance in the city of Bengkulu. This species was widely distributed at Sites 1–2, 4–6, 9, and 10 (Figure 7a). This species has cord-shaped roots that emerge as conical respiratory roots (Figure 7b). The flowers of *S. alba* are bell-shaped, with green outer petals, reddish inner petals, and white filaments

(Figure 7c). *S. alba* is a pioneer species intolerant of freshwater inundation for extended periods. The substrate that is suitable for the growth of this species is a mixed substrate of mud and sand, and at times rock and coral. This species is often found in coastal locations protected from wave action, as well as in estuaries and around offshore islands.



(**a**) (**b**) (**c**) (**d**)

Figure 7. (**a**) *S. alba* at the estuary of Jenggalu River; (**b**) conical respiratory roots of *Sonneratia* sp.; (**c**) flower of *S. alba*; (**d**) fruit of *S. caseolaris*.

3.3.9. *Sonneratia caseolaris*

We only found *S. caseolaris* in small numbers at Sites 4–6. Morphologically, this species has similarities to *S. alba*. Some morphological characteristics commonly used to distinguish these two species are the flowers, fruits, leaves, and stems. The flowers of *S. caseolaris* have a shape similar to those of *S. alba*; however, the petals and filaments tend to be almost entirely red, while those of *S. alba* tend to be white. Likewise, the fruits of these two species have similar shapes (rounded) and are wrapped in petals. The fruit size of *S. caseolaris* (Figure 7d) is larger, and the fruit contains more seeds (up to 800 seeds) than that of *S. alba.* The fruit of the *Sonneratia* sp. is edible, and the wood is commonly used as a material for making boats and buildings. The leaves of *S. caseolaris* are round and elongated, while the leaves of *S. alba* are shaped like an inverted egg. The *Sonneratia* sp. is generally a pioneer species that grows well on sandy substrates.

3.3.10. *Acanthus ilicifolius*

A. ilicifolius, also known as *Jeruju*, is a low perennial shrub that grows in groups on riverbanks and tidal areas, low wetlands, and mangrove forests. The leaves of *A. ilicifolius* are elongated, the bases and tips are pointed, and the edges of the leaves are jagged and have thorns (Figure 8a). The flowers of *A. ilicifolius* have a bluish-purple crown, with a flower bunch length of 10–20 cm and a flower length of 5–4 cm (Figure 8b). We only found *Acanthus ilicifolius* in small amounts at Sites 8 and 9.

(a) (b)

Figure 8. (**a**) Leaves of *A. ilicifolius*; (**b**) flower of *A. ilicifolius*.

3.3.11. *Nypha fruticans*

We found *N. fruticans* in low-to-moderate abundance at Sites 1–4 and 13. *N. fruticans* is a clump-forming palm plant that can reach a height of 4–9 m. The leaves are shaped like coconut leaves, and the lengths of the leaf bunches can range from 4 to 9 m. This species generally grows in areas with smooth substrates that receive high freshwater input. *N. fruticans* is rarely found outside coastal zones, and it usually grows in clumped stands.

3.3.12. *Casuarina equisetifolia*

We found widespread *C. equisetifolia*, locally known as *cemara udang* (Figure 9), at almost all the research sites, except for Sites 5–7 and 11. We found this species in large amounts at Sites 1–3, and 12. This species grows well in tidal areas, especially in back and open areas, and it can live in areas with many disturbances. The leaves are small, cylindrical, and scaly, and the tips are needle-like. The leaves are thick and sharp and can be shaped as desired. The stems are covered with stiff coarse-textured bark (Figure 9). The snaking branches induce a beautiful shape, and the trunks run from reddish brown to grey. Usually, *C. equisetifolia* is associated with *Hibiscus tiliaceus*.

Figure 9. *Casuarina equisetifolia* at estuaries of Sites 2 and 11 in Bengkulu.

3.4. Water Quality in Mangrove Ecosystem Areas

The water quality in the mangrove and coastal ecosystems was relatively good, with temperatures between 29 and 33 °C (Figure 10a), dissolved oxygen contents of 2.9–9.5 mg/L (Figure 10b), pH values of 7–8 (Figure 10c), TDS values of 0–25 g/L (Figure 10d), and salinities of 2–27 ppt (Figure 10e). We found the lowest oxygen content (2.9 mg/L) at Site 5, with a relatively high BOD and COD (Figure 10g,h).

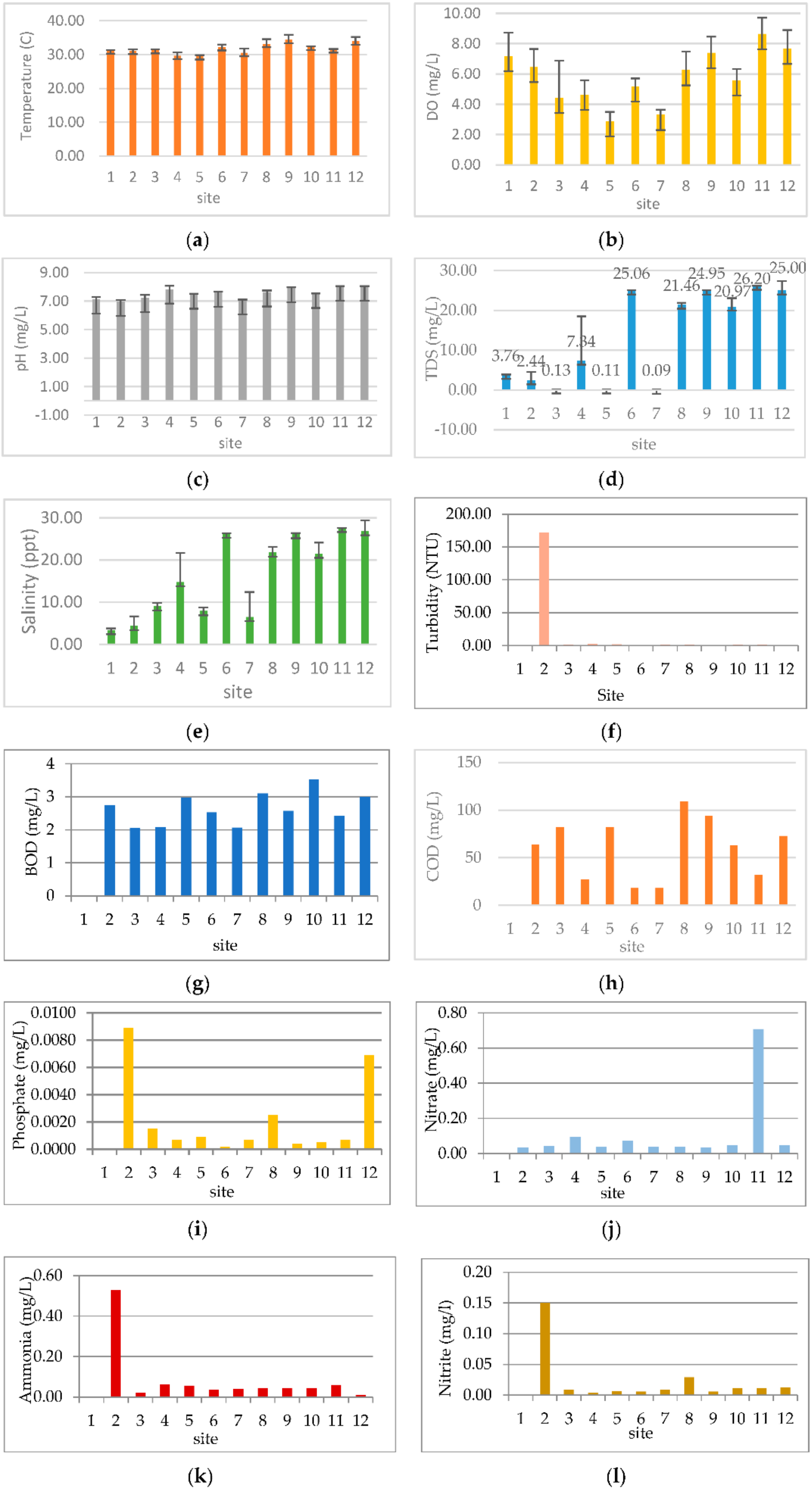


Figure 10. Water quality of (**a**) temperature, (**b**) DO, (**c**) pH, (**d**) TDS, (**e**) salinity, (**f**) turbidity, (**g**) BOD, (**h**) COD, (**i**) phosphate, (**j**) nitrate, (**k**) ammonia, and (**l**) nitrite at mangrove ecosystems in the city of Bengkulu (November 2021).

We found the highest turbidity and phosphate content (Figure 10i) at Site 2, the estuary of Bengkulu River (179 NTU) (Figure 9f). However, the values were below the national water quality threshold Government Regulation No 22/2021.

The nitrate (Figure 10j), nitrite content (Figure 10k), and ammonia (Figure 10l) were below the national water quality threshold for seawaters (0.06 mg/L), except for the nitrite content at Site 2 (0.15 mg/L) (Figure 10k).

4. Discussion

The city of Bengkulu has enormous potential for the mangrove ecosystems located in several locations, including estuaries, river deltas, and muddy coasts. There are 11 species of true mangroves, 9 species of mangrove associates, and 31 species of coastal flora from the 52 species of vegetation we identified from the 13 sites in the city of Bengkulu. A total of 24 species are under the least-concern (LC) category on the IUCN Red List of threatened species, while one species is classified as data deficient (DD) [64]. Ten of the true mangrove species we found in the city of Bengkulu are included under the LC category of the IUCN Red List: *A. alba*; *A. marina*; *B. gymnorhiza*; *R. mucronata*; *R. stylosa*; *R. apiculata*; *S. alba*; *S. caseolaris*; *E. agallocha*; *A. ilicifollius*. Only *N. fruticans* is not included on the IUCN Red List. Therefore, sustainable conservation efforts in the coastal areas of Bengkulu are crucial because they can contribute to global conservation.

The true mangrove species with the widest distributions and highest abundances of all the species found in Bengkulu are *S. alba* from the Sonneraticeae family, followed by several species from the *Rhizophoraceae* family, including *R. apiculata* and *R. mucronata*, as well as *N. fruticans* from the Arecaceae family. These findings are in line with previous studies [27], in which the authors reported *S. alba* as the most dominant mangrove species with the highest important value index (IVI) in the mangrove ecosystem of Bengkulu. The substrate type is the factor that substantially affects the distribution of mangrove plants [65]. The *Sonneratia* sp. tends to grow in locations with sandy substrates [66]. Therefore, this species tends to be more abundant in coastal areas than in river estuaries. It has also become one of the pioneer species in the mangrove frontier zone in the study area. *Avicennia* sp. and *Rhizopohora* sp. tend to dominate in areas with muddy substrates located in the middle zones of mangrove forests [32]. The Rhizoporaceae sp. with the widest distribution in the study area is *R. apiculata* because it adapts well to aerial systems [67] and tolerates sediment accretion [68]. The species widely distributed along the river and bay estuaries in the study area is *N. fruticans. N. fruticans* belongs to the Arecaceae family, which optimally grows in muddy substrates along river estuaries or brackish water forests [69].

The substrate type is a limiting factor for the growth of mangrove vegetation [70]. The dominant species in a particular place might provide insight into the compatibility of the type of substrate for a specific species of mangrove. We can use the knowledge of the suitability of the substrate types for certain mangrove species to determine the suitable species for rehabilitation activities and support the success of these efforts [71]. Another critical factor in the growth of mangroves is the water quality, which is mainly influenced by anthropogenic activities [72]. Anthropogenic activities, such as household, agricultural, and aquaculture activities, and waste disposal into the waters, have caused water pollution, which could disrupt the mangrove ecosystem [73]. In general, the water quality at several research sites in Bengkulu was in relatively good condition for all the parameters, including the temperature, salinity, pH, DO, BOD, COD, turbidity, phosphate, nitrate content, and ammonia content. These results are in line with a previous study [74], in which the authors report that the water pollution index in the city of Bengkulu was still classified as from good to lightly polluted. The only parameter that exceeded the national river water quality threshold (Government Regulation No 22/2021 [39]) was the nitrite content at Site 2. The nitrite and nitrate content enter the waters through several sources, including synthetic nitrogen fertilizers, pesticides used in agricultural and plantation activities, septic tank waste, infiltration wells, liquid waste, and other sources [75].

The decline of mangrove ecosystems has a substantial correlation with water, soil, and air pollutants; therefore, the decision-making in the management of mangrove ecosystems requires a predictive model of the environmental quality that describes the interaction between the condition of the mangrove ecosystem and the pollutants in the water, soil, and air [76]. Researchers can use the monitoring of the water quality from rivers to estuaries to determine the impact of human activities on mangrove ecosystems, as well as the water quality in coastal areas, as a basis for recommendations for sustainable mangrove ecosystem management [73]. Researchers can use paleoecological and geochemical proxy studies to determine the long-term anthropogenic impacts and climate disturbances to support the effectiveness of the attempts to restore degraded mangrove ecosystems [77]. The mangrove ecosystem in the city of Bengkulu is distributed among several locations, grouped into two status areas: the conservation forest areas in the Panjang Beach–Baai Island natural tourism parks (Sites 4–6) and other designated areas outside the conservation forests [27]. Sites 6, 8, and 9 are the areas with the highest abundances of true mangrove species. However, there is a substantial difference in the conditions of the mangroves in the two status areas: the condition of the mangroves in the conservation area of the Pantai Panjang–Pulau Baai natural tourism park (Site 6) is relatively better than the mangroves in Lentera Merah, and in other areas that were not included in the conservation areas. Mangroves outside of conservation areas frequently experience high levels of degradation, due mainly to the absence of regulations for maintaining their existence.

The status of the mangrove ecosystem area in the city of Bengkulu has substantially influenced the level of degradation. Globally, the degradation of mangrove ecosystems is mainly due to coastal development [78], land conversion activities (e.g., into fish ponds) [79], settlements [17], oil palm plantations [80], illegal logging [16], and the excessive use of the wood for building, boat materials, and charcoal [81]. The impact of climate change also exacerbates the destruction of the mangrove ecosystem [82–84]. Extreme climate events, in combination with land-use changes, may lead to mangrove mortality and inhibit mangrove resilience to the rising sea level [85]. The synergistic impacts of anthropogenic activities and climate change may lead to unpredictable outcomes in mangrove ecosystems [86].

The degradation of the mangrove ecosystem area in the city of Bengkulu impacts the severity of the abrasion in the coastal areas. Most of the area of Bengkulu has been substantially impacted by coastal degradation, which has also resulted in damage to various types of infrastructure, including public roads and electricity poles. In a previous study, the authors revealed 14 coastal areas in the city of Bengkulu were facing degradation [87]. The main areas in Bengkulu that are severely affected by erosion and accretion include Sites 1–6, 9, and 12.

The leading causes of coastal degradation in Bengkulu are the giant waves, rising sea levels, high rainfall, and degradation of the mangrove ecosystems due to land conversion and overexploitation [88]. The Bengkulu coastal region is located directly adjacent to the Indian Ocean, meaning the area is more prone to geological disasters. This condition also occurs in several places in Indonesia, including the Lesser Sunda Islands, North Sulawesi, and the north coast of Papua [89]. Therefore, it is necessary to make integrated and ecoregional efforts that combine coastal and watershed management to handle abrasion and accretion.

The protection and rehabilitation of the mangrove ecosystem are also important, considering its role as a natural barrier that can protect coastal areas from various disasters, including large waves and abrasion. Multiple parties have initiated various initiatives to rehabilitate the mangrove ecosystem in the city of Bengkulu, including government agencies, nongovernmental organizations (NGOs), and the local community [87]. These rehabilitation efforts were estimated to substantially impact the 54.45 ha increase in the mangrove area in the city of Bengkulu from 2010 to 2021. Mangrove rehabilitation activities in Bengkulu have been taking place since 2011. In 2013, these initiatives included planting more than 1000 mangroves in a five-hectare tidal land area, comprising two hectares in TWA Pantai Panjang and three hectares in Pondok Besi, through the collaboration between the local community and Natural Resources Conservation Center (BKSDA) of Bengkulu [90]. Furthermore, in 2018, the Bengkulu Naval Base (Lanal), in collaboration with the Mukomuko Regency Government, prepared 1500 mangrove trunks for mangrove rehabilitation activities in Bengkulu [91]. In 2020, the mangrove rehabilitation activities in the province of Bengkulu, including the coastal city of Bengkulu, targeted (Pantai Panjang Natural Tourism Park) an area covering 50 hectares.

The findings of this study, the city of Bengkulu has the potential for the protection and rehabilitation of the mangrove ecosystems, considering the high susceptibility to various coastal disasters in Bengkulu. The government agencies in the mangrove rehabilitation efforts in Bengkulu are quite good in terms of funding and providing seeds for replanting, but monitoring and evaluation efforts are still lacking [71]. Mangrove ecosystem management is not only limited to rehabilitation efforts through replanting but must also be supported by continuous monitoring and evaluation [92]. In addition, a sustainable mangrove ecosystem management strategy also requires law enforcement, innovation, research, and strong participation and cooperation among all the stakeholders, particularly coastal communities.

5. Conclusions

According to this study, the city of Bengkulu has considerable mangrove ecosystem potential. It must be protected, considering that 24 of its species are included on the IUCN Red List under the least concern (LC) category of the IUCN (International Union for Conservation of Nature) Red List, and one species is in the data-deficient (DD) category. The ten species of true mangroves in Bengkulu on the IUCN Red List are: *A. alba*; *A. marina*; *B. gymnorhiza*; *R. mucronata*; *R. stylosa*; *R. apiculata*; *S. alba*; *S. caseolaris*; *E. agallocha*; *A. ilicifollius*. Only *N. fruticans* is not included on the IUCN Red List. The water quality of the mangrove ecosystems in the city of Bengkulu is relatively good. All the parameters are below the national water quality threshold for seawater, except for the nitrite concentration in the Bengkulu River estuary. The integration of sustainable mangrove ecosystem management through involving multiple parties of stakeholders is an essential solution to the protection and restoration of the mangrove ecosystems in the city of Bengkulu.

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References

1. Donato, D.C.; Kauffman, J.B.; Murdiyarso, D.; Kurnianto, S.; Stidham, M.; Kanninen, M. Mangroves among the most carbon-rich forests in the tropics. *Nat. Geosci.* **2011**, *4*, 293–297. [CrossRef]
2. Giri, C. Observation and monitoring of mangrove forests using remote sensing: Opportunities and challenges. *Global Ecol. Biogeogr.* **2016**, *20*, 154–159. [CrossRef]

3. Widyastuti, A.; Yani, E.; Nasution, E.K.; Rochmatino, R. Diversity of mangrove vegetation and carbon sink estimation of segara anakan mangrove forest, Cilacap, central Java, Indonesia. *Biodiversitas* **2018**, *19*, 246–252. [CrossRef]
4. Nyanga, C. The Role of Mangroves Forests in Decarbonizing the Atmosphere. In *Carbon-Based Material for Environmental Protection and Remediation*; IntechOpen: London, UK, 2020; pp. 153–163. [CrossRef]
5. Getzner, M.; Islam, M.S. Ecosystem services of mangrove forests: Results of a meta-analysis of economic values. *Int. J. Environ. Res. Public Health* **2020**, *17*, 5830. [CrossRef]
6. Widagdo, R.F.; Sugiri, A. Study of Control in Overcoming Damage to Mangrove Ecosystems in Pekalongan Regency Coastal Areas (Kajian Pengendalian Dalam Mengatasi Kerusakan Ekosistem Mangrove Di Kawasan Pesisir Kabupaten Pekalongan). *Teknik PWK* **2014**, *3*, 285–294. (In Indonesian) [CrossRef]
7. Umilia, E.; Asbar. Formulation of Mangrove Ecosystem Management Model Based on Eco-minawisata in the Coastal Sinjai, South Sulawesi. *Procedia—Soc. Behav. Sci.* **2016**, *227*, 704–711. [CrossRef]
8. Eddy, S.; Rasyid, R.M.; Iskandar, I.; Mulyana, A. Community-Based Mangrove Forests Conservation for Sustainable Fisheries. *J. Silvikultur Trop.* **2016**, *7*, 42–47. [CrossRef]
9. Alongi, D.M. Impact of global change on nutrient dynamics in Mangrove Forests. *Forests* **2018**, *9*, 596. [CrossRef]
10. Alongi, D.M. Impacts of Climate Change on Blue Carbon Stocks and Fluxes in Mangrove Forests. *Forests* **2022**, *13*, 149. [CrossRef]
11. Nur, S.H.; Hilmi, E. The correlation between mangrove ecosystem with shoreline change in Indramayu coast. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *819*, 012015. [CrossRef]
12. Sarhan, M.; Tawfik, R. The Economic Valuation of Mangrove Forest Ecosystem Services: A Review. *Georg. Wright Forum* **2018**, *35*, 341–349.
13. Goldberg, L.; Lagomasino, D.; Thomas, N.; Fatoyinbo, T. Global declines in human-driven mangrove loss. *Glob. Chang. Biol.* **2020**, *26*, 5844–5855. [CrossRef] [PubMed]
14. Ward, R.D.; Friess, D.A.; Day, R.H.; Mackenzie, R.A. Impacts of climate change on mangrove ecosystems: A region by region overview. *Ecosyst. Health Sustain.* **2016**, *2*, e01211. [CrossRef]
15. Hamilton, S.E.; Casey, D. Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). *Glob. Ecol. Biogeogr.* **2016**, *25*, 729–738. [CrossRef]
16. Rudianto, R.; Bengen, D.G.; Kurniawan, F. Causes and effects of mangrove ecosystem damage on carbon stocks and absorption in East Java, Indonesia. *Sustainability* **2020**, *12*, 10319. [CrossRef]
17. Cahyaningsih, A.P.; Deanova, A.K.; Pristiawati, C.M. Review: Causes and impacts of anthropogenic activities on mangrove deforestation and degradation in Indonesia. *Bonorowo Wetl.* **2022**, *12*, 12–22. [CrossRef]
18. Murdiyarso, D.; Purbopuspito, J.; Kauffman, J.B.; Warren, M.W.; Sasmito, S.D.; Donato, D.C. The potential of Indonesian mangrove forests for global climate change mitigation. *Nat. Clim. Chang.* **2015**, *5*, 1089–1092. [CrossRef]
19. Arifanti, V.B.; Sidik, F.; Mulyanto, B.; Susilowati, A.; Wahyuni, T.; Yuniarti, N.; Aminah, A.; Suita, E.; Karlina, E.; Suharti, S.; et al. Challenges and Strategies for Sustainable Mangrove Management in Indonesia: A Review. *Forests* **2022**, *13*, 695. [CrossRef]
20. Presidential Regulation of the Republic of Indonesia No. 1 of 2016, about Peat Restoration Agency. (Peraturan Presiden Republik Indonesia No.1 Tahun 2016, Tentang Badan Restorasi Gambut). (In Indonesian). Available online: https://peraturan.bpk.go.id/Home/Details/38084/perpres-no-1-tahun-2016 (accessed on 7 March 2022).
21. Presidential Regulation of the Republic of Indonesia No. 120 of 2020, about Peat and Mangrove Restoration Agency. (Peraturan Presiden Republik Indonesia No. 120 Tahun 2020, Tentang Badan Restorasi Gambut dan Mangrove). (In Indonesian). Available online: https://peraturan.bpk.go.id/Home/Details/161452/perpres-no-120-tahun-2020 (accessed on 7 March 2022).
22. Sumartono, E.; Mulyasari, G.; Sukiyono, K. Assessment Model Impact of Climate Change on Potential Production for Food and Energy Needs for the Coastal Areas of Bengkulu, Indonesia. *Agro Bali Agric. J.* **2021**, *4*, 159–169. [CrossRef]
23. Hasanudin, M.; Kusmanto, E. Coastal Abrasion and Sedimentation in the Coastal Area of Bengkulu City (Abrasi dan Sedimentasi Pantai di Kawasan Pesisir Kota Bengkulu). *Oseanologi Limnolo. Indones.* **2018**, *3*, 245–252. (In Indonesian) [CrossRef]
24. Lestari, D.A.; Susiloningtyas, D.; Supriatna, S. Spatial dynamics model of land availability and population growth prediction in Bengkulu City. *Indonesia J. Geogr.* **2020**, *52*, 427–436. [CrossRef]
25. Permana, E.; Kamaludin, K.; Yefriza, Y. Perspective of Integrated Management of Bengkulu Coastal Areas Based on Space, Social and Economic Utilization. In *BISIC 2020: Proceedings of the 3rd Beehive International Social Innovation Conference, BISIC 2020, Bengkulu, Indonesia, 3–4 October 2020*; European Alliance for Innovation: Gent, Belgium, 2021; pp. 52–65.
26. Gao, J.; Ma, X.; Dong, G.; Chen, H.; Liu, Q.; Zang, J. Investigation on the effects of Bragg reflection on harbor oscillations. *Coast. Eng.* **2021**, *170*, 103977. [CrossRef]
27. Senoaji, G.; Hidayat, M.F. The Role of Mangrove Ecosystem in the Coastal City of Bengkulu in Mitigating Global Warming through Carbon sequestration. *J. Mns Lingkung* **2017**, *23*, 327. [CrossRef]
28. BPS-Statistic of Bengkulu Municipality. *Bengkulu Municipality in Figures*; BPS-Statistic of Bengkulu Municipality: Bengkulu, Indonesia, 2021; 72p.
29. English, S.; Wilkinson, C.; Baker, V. *Survey Manual for Marine Resources*, 2nd ed.; Australian Institute of Marine Science: Townsville, QLD, Australia, 1997; 408p.
30. Backer, C.A.; Bakhuisen van den Brink, R.C. *Flora of Java (Spermatophytes Only)*; Wolters-Noordhoff N.V.: Groningen, The Netherlands, 1968; Volume 3, 761p.

31. Berg, C.C.; Corner, E.J.H. *Flora Malesiana (Moraceae-Ficus)*; National Herbarium Nederland, Universiteit Leiden: Leiden, The Netherlands, 2005; Volume 17, 702p.
32. Noor, Y.R.; Khazali, M.; Suryadiputra, I.N.N. *Pengenalan Mangrove di Indonesia*; Dirjen Perlindungan Hutan dan Konservasi Alam (PHKA)/Wetlands Indonesia- Indonesia Programme (WI-IP): Bogor, Indonesia, 2006; 219p. (In Indonesian)
33. PictureThis. Available online: https://www.picturethisai.com/ (accessed on 20 June 2022).
34. Plant.id. Available online: https://plant.id/ (accessed on 25 June 2022).
35. Pl@ntNet. Available online: https://identify.plantnet.org/idtle (accessed on 15 June 2022).
36. The Plant List (TPL). Available online: http://www.theplantlist.org/ (accessed on 4 July 2022).
37. WFO. Available online: http://www.worldfloraonline.org/ (accessed on 10 July 2022).
38. American Public Health Association (APHA). *Standard Methods for the Examination of Water and Wastewater*, 19th ed.; ASTM Anuual Book of Standards; American Society for Testing & Materials: Philadelphia, PA, USA, 1995.
39. Government Regulation Number 22 of 2021 about Implementation of Environmental Management Protection. (Peraturan Pemeintah No. 22 Tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup). (In Indonesian). Available online: https://peraturan.bpk.go.id/Home/Details/161852/pp-no-22-tahun-2021 (accessed on 4 July 2022).
40. Bignoli, J.D. *Acanthus ilicifolius*. In *The IUCN Red List of Threatened Species 2013*; e.T168780A6536949; IUCN: Gland, Switzerland, 2013.
41. Duke, N.; Kathiresan, K.; Salmo, S.G., III; Fernando, E.S.; Peras, J.R.; Sukardjo, S.; Miyagi, T. *Avicennia alba*. In *The IUCN Red List of Threatened Species 2010*; e.T178830A7620385; IUCN: Gland, Switzerland, 2010.
42. Duke, N.; Kathiresan, K.; Salmo, S.G., III; Fernando, E.S.; Peras, J.R.; Sukardjo, S.; Miyagi, T.; Ellison, J.; Koedam, N.E.; Wang, Y.; et al. *Avicennia marina*. In *The IUCN Red List of Threatened Species 2010*; e.T178828A7619457; IUCN: Gland, Switzerland, 2010.
43. Duke, N.; Kathiresan, K.; Salmo, S.G., III; Fernando, E.S.; Peras, J.R.; Sukardjo, S.; Miyagi, T. *Bruguiera gymnorhiza*. In *The IUCN Red List of Threatened Species 2010*; e.T178803A7610926; IUCN: Gland, Switzerland, 2010.
44. Ellison, J.; Koedam, N.E.; Wang, Y.; Primavera, J.; Jin Eong, O.; Wang-Hong Yong, J.; Ngoc Nam, V. *Excoecaria agallocha*. In *The IUCN Red List of Threatened Species 2010*; e.T178842A7623953; IUCN: Gland, Switzerland, 2010.
45. Duke, N.; Kathiresan, K.; Salmo, S.G., III; Fernando, E.S.; Peras, J.R.; Sukardjo, S.; Miyagi, T. *Rhizophora mucronata*. In *The IUCN Red List of Threatened Species 2010*; e.T178825A7618520; IUCN: Gland, Switzerland, 2010.
46. Ellison, J.; Duke, N.; Kathiresan, K.; Salmo, S.G., III; Fernando, E.S.; Peras, J.R.; Sukardjo, S.; Miyagi, T. *Rhizophora stylosa*. In *The IUCN Red List of Threatened Species 2010*; e.T178850A7626520; IUCN: Gland, Switzerland, 2010.
47. Duke, N.; Kathiresan, K.; Salmo, S.G., III; Fernando, E.S.; Peras, J.R.; Sukardjo, S.; Miyagi, T. *Rhizophora Apiculata*. In *The IUCN Red List of Threatened Species 2010*; e.T31382A9623321; IUCN: Gland, Switzerland, 2010.
48. Kathiresan, K.; Salmo, S.G., III; Fernando, E.S.; Peras, J.R.; Sukardjo, S.; Miyagi, T.; Ellison, J.; Koedam, N.E.; Wang, Y.; Primavera, J.; et al. *Sonneratia alba*. In *The IUCN Red List of Threatened Species 2010*; e.T178804A7611432; IUCN: Gland, Switzerland, 2010.
49. Kathiresan, K.; Salmo, S.G., III; Fernando, E.S.; Peras, J.R.; Sukardjo, S.; Miyagi, T.; Ellison, J.; Koedam, N.E.; Wang, Y.; Primavera, J.; et al. *Sonneratia caseolaris*. In *The IUCN Red List of Threatened Species 2010*; e.T178796A7608551; IUCN: Gland, Switzerland, 2010.
50. Ellison, A.; Farnsworth, E.; Moore, G. *Conocarpus erectus*. In *The IUCN Red List of Threatened Species 2010*; e.T178806A7612125; IUCN: Gland, Switzerland, 2010.
51. Rivers, M.C.; Mark, J. *Hibiscus tilliaceus* (Amended Version of 2018 Assessment). In *The IUCN Red List of Threatened Species 2019*; e.T61786470A143753393; IUCN: Gland, Switzerland, 2019.
52. Rowe, J.; Wood, J.; Scotland, R.; Muñoz-Rodríguez, P. *Ipomoea cordatotriloba*. In *The IUCN Red List of Threatened Species 2019*; e.T20681691A20694946; IUCN: Gland, Switzerland, 2019.
53. Bárrios, S.; Copeland, A. *Ipomoea pes-caprae*. In *The IUCN Red List of Threatened Species 2021*; e.T68149961A192132442; IUCN: Gland, Switzerland, 2021.
54. IUCN SSC Global Tree Specialist Group; Botanic Gardens Conservation International (BGCI). *Pandanus helicopus*. In *The IUCN Red List of Threatened Species 2020*; e.T180379456A180379458; IUCN: Gland, Switzerland, 2020.
55. Bárrios, S.; Copeland, A. *Sesuvium portulacastrum*. In *The IUCN Red List of Threatened Species 2021*; e.T124232167A192137469; IUCN: Gland, Switzerland, 2021.
56. Thomson, L.; Evans, B. *Terminalia catappa*. In *The IUCN Red List of Threatened Species 2019*; e.T61989853A61989855; IUCN: Gland, Switzerland, 2019.
57. Contu, S. *Bauhinia purpurea*. In *The IUCN Red List of Threatened Species 2012*; e.T19891953A20027617; IUCN: Gland, Switzerland, 2012.
58. Barstow, M. *Casuarina equisetifolia*. In *The IUCN Red List of Threatened Species 2019*; e.T16728404A16728408; IUCN: Gland, Switzerland, 2019.
59. Lansdown, R.V. *Cyperus fuscus*. In *The IUCN Red List of Threatened Species 2013*; e.T164079A13545918; IUCN: Gland, Switzerland, 2013.
60. Botanic Gardens Conservation International (BGCI); IUCN SSC Global Tree Specialist Group. *Enterolobium cyclocarpum*. In *The IUCN Red List of Threatened Species 2019*; e.T62025161A149017370; IUCN: Gland, Switzerland, 2019.
61. Martínez Salas, E.; Samain, M.; Oldfield, S. *Manilkara zapota*. In *The IUCN Red List of Threatened Species 2021*; e.T61964429A61964470; IUCN: Gland, Switzerland, 2021.
62. Bárrios, S.; Copeland, A. *Stachytarpheta jamaicensis*. In *The IUCN Red List of Threatened Species 2021*; e.T96816126A192132046; IUCN: Gland, Switzerland, 2021.
63. Lakhey, P.; Pathak, J. *Tabernaemontana divaricata*. In *The IUCN Red List of Threatened Species 2020*; e.T149853146A149853842; IUCN: Gland, Switzerland, 2020.

64. IUCN. The IUCN Red List of Threatened Species. Version 2020-1. 2020. Available online: https://www.iucnredlist.org (accessed on 4 July 2022).
65. Pang, D.; Wang, G.; Liu, Y.; Cao, J.; Wan, L.; Wu, X.; Zhou, J. The impacts of vegetation types and soil properties on soil microbial activity and metabolic diversity in subtropical forests. *Forests* **2019**, *10*, 497. [CrossRef]
66. Pillai, N.G.; Harial, C.C. Evaluation of the growth sustaining attributes of Sonneratia alba Sm. for strategic afforestation protocols. *Int. J. Basic Appl. Res.* **2018**, *8*, 626–634.
67. Amaliyah, S.; Hariyanto, S.; Purnobasuki, H. Roots morphology of Rhizophora apiculata blume as an adaptation strategy of waterlogging and sediment. *J. Biol. Sci.* **2017**, *17*, 118–126. [CrossRef]
68. Thampanya, U.; Vermaat, J.E.; Terrados, J. The effect of increasing sediment accretion on the seedlings of three common Thai mangrove species. *Aquat. Bot.* **2002**, *74*, 315–325. [CrossRef]
69. Widodo, P.; Sukarsa; Herawati, W.; Hidayah, H.A.; Chasanah, T.; Proklamasiningsih, E. Distribution and Characteristics of Nypa Palm (*Nypa fruticans* Wurmb.) in Southern Part of Cilacap Regency. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *550*, 012010. [CrossRef]
70. Frederika, Y.C.; Ihsan, Y.N.; Riyantini, I. Nutrient Profile and Mangrove Vegetation Composition in the Coastal Waters of Indramayu. *J. Ilmu Kelaut. SPERMONDE* **2021**, *7*, 42–51. [CrossRef]
71. Renta, P.P.; Saputra, Y.H.; Purnama, D.; Zamdial. Mangrove Rehabilitation in Bengkulu City. In Proceedings of the International Seminar on Promoting Local Resources for Sustainable Agriculture and Development (ISPLRSAD 2020), Bengkulu, Indonesia, 8 October 2020; Atlantis Press: Amsterdam, The Netherlands, 2021; pp. 447–456. [CrossRef]
72. Sari, K.; Soeprobowati, T.R. Impact of Water Quality Detorioration in Mangrove Forest in Semarang Coastal Area. *Indones. J. Limnol.* **2021**, *2*, 37–48. [CrossRef]
73. Guntur, G.; Sambah, A.B.; Arisandi, D.M.; Jauhari, A.; Jaziri, A.A. Study on water quality around mangrove ecosystem for coastal rehabilitation. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *106*, 012041. [CrossRef]
74. Putri, Y.D.; Yuliza, E.; Lizalidiawati. Study of Water Quality and Pollution Index in the Waters of Kampung Sejahtera Baai Island Bengkulu City. *Newton-Maxwell J. Phys.* **2021**, *2*, 46–53. (In Indonesian)
75. Mohammadpour, A.; Gharehchahi, E.; Badeenezhad, A.; Parseh, I.; Khaksefidi, R.; Golaki, M.; Dehbandi, R.; Azhdarpoor, A.; Derakhsgan, Z.; Chueca, J.G.; et al. Nitrate in Groundwater Resources of Hormozgan Province, Southern Iran: Concentration Estimation, Distribution and Probabilistic Health Risk Assessment Using Monte Carlo Simulation. *Water* **2022**, *14*, 564. [CrossRef]
76. Wong, W.Y.; Al-Ani, A.K.I.; Hasikin, K.; Khairuddin, A.S.M.; Razak, S.A.; Hizaddin, H.F.; Mokhtar, M.I.; Azizan, M.M. Water, Soil and Air Pollutants' Interaction on Mangrove Ecosystem and Corresponding Artificial Intelligence Techniques Used in Decision Support Systems—A Review. *IEEE Access* **2021**, *9*, 105532–105563. [CrossRef]
77. Nisha, K.; Ramdzan, M.; Moss, P.T.; Heijnis, H.; Harrison, M.E.; Yulianti, N. Application of Palaeoecological and Geochemical Proxies in the Context of Tropical Peatland Degradation and Restoration: A Review for Southeast Asia. *Wetlands* **2022**, *42*, 95.
78. Arifanti, V.B.; Novita, N.; Subarno, A.T. Mangrove deforestation and CO_2 emissions in Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *874*, 012006. [CrossRef]
79. Eddy, S.; Milantara, N.; Sasmito, S.D.; Kajita, T.; Bayuni, M. Anthropogenic Drivers of Mangrove Loss and Associated Carbon Emissions in Anthropogenic Drivers of Mangrove Loss and Associated Carbon Emissions in South Sumatra, Indonesia. *Forests* **2021**, *12*, 187. [CrossRef]
80. Bryan-Brown, D.N.; Connolly, R.M.; Richards, D.R.; Adame, F.; Friess, D.A.; Brown, C.J. Global trends in mangrove forest fragmentation. *Sci. Rep.* **2020**, *10*, 7117. [CrossRef]
81. Machava-António, V.; Fernando, A.; Cravo, M.; Massingue, M.; Lima, H.; Macamo, C.; Paula, J. A Comparison of Mangrove Forest Structure and Ecosystem Services in Maputo Bay and Príncipe Island (Western Africa). *Forests* **2022**, *13*, 1466. [CrossRef]
82. Godoy, M.D.P.; De Lacerda, L.D. Mangroves response to climate change: A review of recent findings on mangrove extension and distribution. *An. Acad. Bras. Cienc.* **2015**, *87*, 651–667. [CrossRef]
83. Alongi, D.M. Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. *Estuar. Coast. Shelf Sci.* **2008**, *76*, 1–13. [CrossRef]
84. Gilman, E.L.; Ellison, J.; Duke, N.C.; Field, C. Threats to mangroves from climate change and adaptation options: A review. *Aquat Bot.* **2008**, *89*, 237–250. [CrossRef]
85. Alongi, D.M. The Impact of Climate Change on Mangrove Forests. *Curr. Clim. Chang. Rep.* **2015**, *1*, 30–39. [CrossRef]
86. Sippo, J.Z.; Lovelock, C.E.; Santos, I.R.; Sanders, C.J.; Maher, D.T. Mangrove mortality in a changing climate: An overview. *Estuar. Coast. Shelf Sci.* **2018**, *215*, 241–249. [CrossRef]
87. Zamdial, A.A.; Hartono, D.; Bakhtiar, D.; Nofridiansyah, E.; Renta, P.P.; Muqsit, A. Study on Identification of Damage to Coastal Areas in North Bengkulu Regency, Bengkulu Province. *J. Enggano* **2020**, *5*, 510–528. (In Indonesian) [CrossRef]
88. Susiloningtyas, D.; Lesy, S.A.A. Dynamic System Model of Land Use Affected by Sea Level Rise in the Coastal Area of Bengkulu City, Indonesia. *J. Hunan Univ. Nat. Sci.* **2021**, *48*, 119–126.
89. Ilman, M.; Dargusch, P.; Dart, P.; Onrizal. A historical analysis of the drivers of loss and degradation of Indonesia's mangroves. *Land Use Policy* **2016**, *54*, 448–459. [CrossRef]

90. Ramadhan, A. Menanam Mangrove untuk Ekonomi dan Ekologi. Available online: https://sains.kompas.com/read/2013/11/01/2122062/Menanam.Mangrove.untuk.Ekonomi.dan.Ekologi?page=all (accessed on 4 October 2022).
91. Marini, H. Lanal Bengkulu tanam 4.500 Mangrove. Available online: https://bengkulu.antaranews.com/berita/81218/lanal-bengkulu-tanam-4500-mangrove (accessed on 4 October 2022).
92. Handayani, S.; Adrianto, L.; Nurjaya, I.W.; Bengen, D.G.; Wardiatno, Y. Strategies for optimizing mangrove ecosystem management in the rehabilitation area of Sayung coastal zone, Demak Regency, Central Java. *J. Nat. Resour. Environ. Manag.* **2021**, *11*, 387–396. [CrossRef]