HAYATI
Journal of Biosciences

Vol. 29 No. 4, July 2022 445-458
DOI:10.4308/hjb.29.4.445-458
ISSN: 1978-3019
EISSN: 2086-4094

Adaptive Mangrove Ecosystem Rehabilitation Plan based on Coastal Typology and Ecological Dynamics Approach

Aswin Rahadian[1*], Cecep Kusmana[2], Yudi Setiawan[3], Lilik Budi Prasetyo[3]

[1]*Natural Resources and Environmental Management Science, IPB University, Bogor, Indonesia*
[2]*Department of Silviculture, Faculty of Forestry and Environment, IPB University, Bogor, Indonesia*
[3]*Department of Forest Resource Conservation and Ecotourism, Faculty of Forestry and Environment, IPB University, Bogor, Indonesia*

ARTICLE INFO

Article history:
Received August 24, 2021
Received in revised form November 9, 2021
Accepted January 4, 2022

KEYWORDS:
Nature base solution,
coastal enhancement,
adaptability rehabilitation,
geospatial approach

ABSTRACT

Mangrove rehabilitation has implications for important ecological, social and economic values for coastal communities. The mangroves ecosystem Karawang Regency is still under pressure due to the management and utilization that does not pay attention to the sustainability aspect. The rehabilitation plan to mangrove management must be adapted to the nature and characteristics of the habitat. This study aims to formulate technical considerations for the direction of a rehabilitation plan based on an ecological approach and the dynamics of the mangrove ecosystem. The methods used in this study were geospatial approach that integrated with field quantitative and qualitative data. The results show that the total of mangrove potential area in Karawang Regency was 19,139.53 ha, consisting of 421.95 ha (2.2%) of vegetated area and 18,717.58 ha (97.8%) of unvegetated area. We integrate mangrove typology, mangrove stand density, physical parameters, and land use as the basis for determining the direction of rehabilitation planning. In the estuarine deltaic mangrove typology, we aim at protecting with natural regeneration. In infringe areas, we recommend constructing natural coastal structures before planting. On the backward for intensive planting. Furthermore, mangroves with low density, medium density, and high density are recommended for planting, species enrichment, and protecting respectively, and on the pond with implementing the mixed mangrove-aquaculture system to bridge between rehabilitation effort and economic needs of coastal communities.

1. Introduction

The mangrove ecosystem is a very important habitat for terrestrial and marine biodiversity (Sandilyan and Kathiresan 2012), providing several ecosystem services include carbon storage (Siikamäki *et al.* 2012; Murdiyarso *et al.* 2015; Hamilton and Friess 2018), tsunami mitigation (Danielsen *et al.* 2005; Vermaat and Thamanya 2006) as well as economic value for the community in its surrounding areas (Gunawardena *et al.* 2005; Aye *et al.* 2019). Regardless of the important function, in the last three decades, 40% of mangrove forest has been deforested and degraded on a global scale (FAO 2007). Aquaculture (Yusuf *et al.* 2017; Giesen and Macdonald 1993) and oil palm plantation expansion (Lee *et al.* 2014) are the main pressure, particularly in Indonesia. This situation has resulted in coastal areas being pressured by various activities and phenomena occurring on land and at sea. The northern coast of Java has its problems arising from the impact of rapid development and utilization of coastal space but not paying attention to environmental aspects. The main factors destroying the northern coastal area of Java are well known in science and field observations. The phenomenon of coastal erosion, sedimentation, tidal flooding (rob), as well as subsidence is the impact of the use of coastal space that does not pay attention to the interaction factor between biotic-abiotic components. Coastal erosion besides being able to occur naturally due to waves and parallel currents can also occur due to human activities such as the conversion of mangrove land into ponds, sand mining, infrastructure development (ports, piers, sea dikes, etc), and diversion of river flows for dams or irrigation. Tidal flooding can be caused by sea-level rise, and land subsidence caused by natural soil compaction, excessive groundwater extraction, excessive building loads, and or tectonic processes

* Corresponding Author
E-mail Address: ckmangrove@gmail.com

(Andreas *et al.* 2017). Undoubtedly, this is a serious challenge for the central and local governments to take the expected measures in mitigation, prevention and adaptation, because it brings changes to reduce the amount of economic and ecological losses that will continue to grow for several years.

Many mangroves restoration and rehabilitation projects have been established to address their problems. Mangrove restoration is of great importance to the important ecological, social and economic value of coastal communities (Ellison *et al.* 2020). The threats faced by mangroves vary from region to region, but in many countries, land conversion causes the greatest losses (Valiela *et al.* 2001). The importance of mangroves has led to more efforts to restore deforested mangroves, and many restoration and rehabilitation activities are expected to recombine ecosystem services to benefit local communities that protect biodiversity (Bosire *et al.* 2008).

Mangrove restoration in Indonesia provides important lessons for how to increase biodiversity and ecosystem services in coastal management associated with urban areas. The mixed project of this project demonstrates how to integrate mangrove vegetation into the traditional coastal defence structure, and has the inherent capabilities of large-scale coastal ecological projects (Rahadian *et al.* 2019a). Mangrove ecological restoration relies on natural regeneration as soon as biophysical conditions are restored, and planting is generally not required. However, there are conditions where planting is still needed. Sometimes planting is also needed because commitments have been made or to attract stakeholder involvement. In such conditions, planting efforts need to be channelled effectively and will not disturb the environment. At the same time, capacity building regarding Mangrove Ecological Restoration is urgently needed.

The mangrove ecosystem in Karawang Regency is still under pressure because it does not pay attention to the management and utilization of sustainability. The vast coastal areas of the Karawang Regency have experienced land use degradation in the form of aquaculture, rice fields, settlements, agriculture and roads. Changing the function of the mangrove ecosystem for the benefit of humanity, without paying attention to environmental factors, will exacerbate the impact of weathering on coastal areas. The rehabilitation plan for mangrove management must adapt to the nature and characteristics of the habitat. This study aims to identify and quantify the potential area of mangrove for rehabilitation efforts and formulate technical considerations for the direction of a rehabilitation plan based on an ecological approach and the dynamics of the mangrove ecosystem.

2. Materials and Methods

2.1. Study Area

This study was conducted in the entire mangrove ecosystem along coastal area of Karawang Regency which consists of ten Sub-Districts, including Batujaya, Cibuaya, Cilamaya Kulon, Cilamaya Wetan, Cilebar, Cimalaya Kulon, Pakisjaya, Pedes, Tempuran, Tirtajaya. Geographically, Karawang Regency is located between 107°02'-107°40' east longitude and 5°56'-6°34' south latitude. The topography of the Karawang Regency is mostly in the form of relatively flat plains with variations between 0-5 m above sea level (masl). Only a small part of the undulating and hilly with an altitude between 0-1,200 meters above sea level. The field survey was carried out in September 2018 and monitoring was carried out periodically until 2019. Figure 1 is a map of the location of the study area.

2.2. Material

The tools used in this study include data processing tools and field measurement tools. The data processing tools used include personal computers with ArcGIS, ERDAS IMAGINE, and Microsoft Excel. Various materials were used throughout the data collection process: tape measurement for plot and transect establishment, phiband for DBH measurement, and compass for guiding the pathway, Global Positioning System (GPS), roll meter, camera, refractometer, mangrove identification book, were used during the field survey.

2.3. Data Collection

2.3.1. Vegetation Structure Measurement

Field surveys were carried out by reviewing the locations of mangrove vegetation. The distribution of the sampling plot placement was based on purposive sampling by considering the representativeness of the type of land status and mangrove density from the initial analysis of satellite imagery (Figure 2). The quadratic sampling technique was used to collect data for vegetation analysis with the size of the plots were 20 x 20 m, 5 x 5 m, and 2 x 2 m for trees, saplings, and seedlings, respectively. A total of 12 plots were established, consisting of 3 plots in low density, 3 plots on medium density, and 6 plots in high density. The number of plant species in the measurement plot was recorded for each life stage, namely trees, diameter ≥10; saplings, diameter <10 cm, height >150 cm, seedlings, height ≤150 cm). Furthermore, tree height, diameter at breast height (±1.30m), and coordinate position were all measured.

In addition, field observations were used as a way to directly see the potential and condition of mangrove

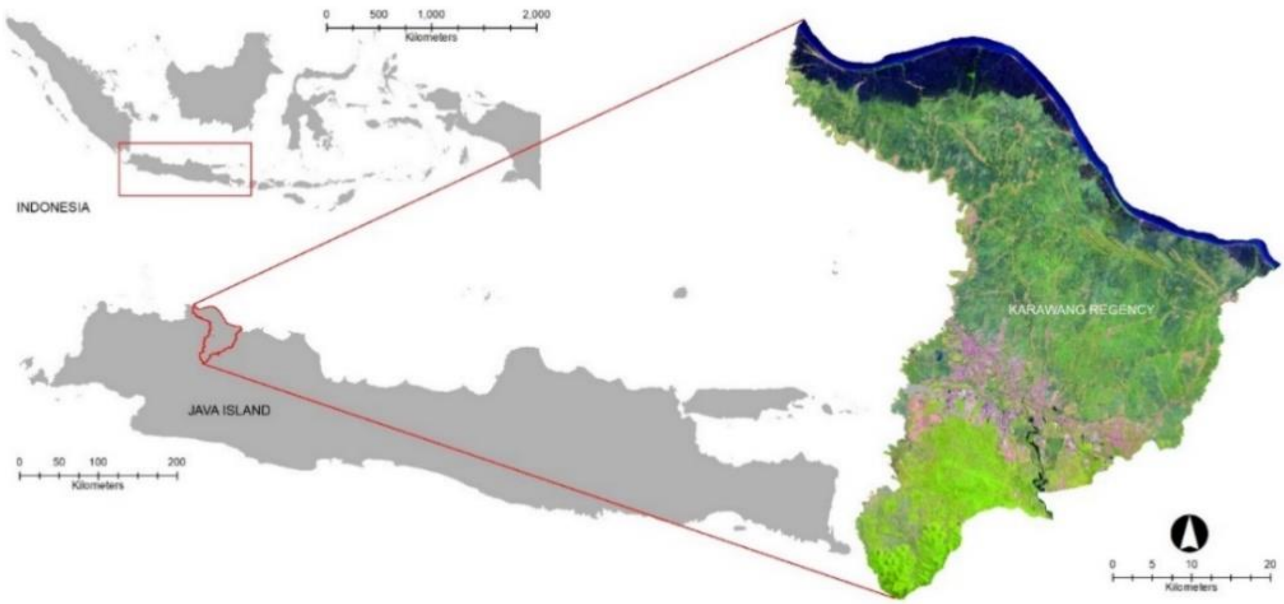

Figure 1. Location of the study area. The insert displays a combination Landsat on false colour

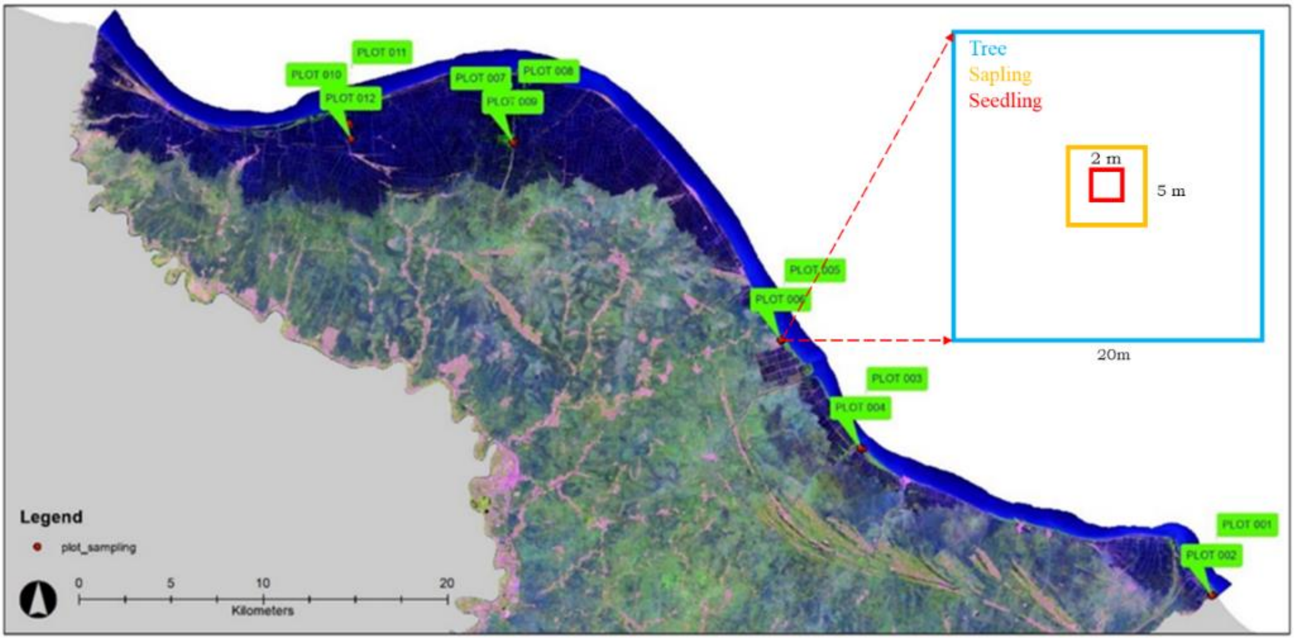

Figure 2. Plot sampling distribution and scheme of plot measurement

ecosystems and their environmental conditions in an area based on considerations of land systems, land status, and vegetation density. Mangrove species were recorded around the observation area outside the sample plots. The primary and secondary data were used in this study include satellite imageries, thematic maps, and other supporting materials (Table 1).

2.4. Data Analysis

2.4.1. Vegetation Data Analysis

The data from the field survey were further analyzed to determine the composition of the mangrove species in the study site. In addition, the Important Value Index (IVI) is also calculated, which is an index used to determine the dominance of a species over other

Table 1. Types and sources of data used in the study

Data type	Data	Remark	Source
Primary data	Sentinel-2A imagery	2018-2019	Copernicus
	Landsat MSS/TM/OLI Imagery	1970, 1990, 1995, 2000, 2005, 2010, 2015, 2020	USGS
	SPOT imagery	2018-2019	LAPAN
	Composition and vegetation structure		Field measurement
	Environmental physical parameter	Salinity and soil texture	Field measurement
	Interview		Community and local government
Secondary data	Indonesian coastal environmental map	1:50,000	Dihidros
	National marine environmental map	1:500,000	BIG (Geospatial Information Agency)
	RePPProT (Regional Physical Planning Program for Transmigration) map	1:250,000	BIG (Geospatial Information Agency)
	Topographical map of Indonesia	1:25,000	BIG
	Map of designation of forest areas	1:100,000	Ministery of environmental and forestry
	(Decree of minister of forestry No. 195/Kpts-II/2003 concerning designation of forest areas in the Province of West Java)		Ministery of environmental and forestry
	Document review		Local government

species in a particular community. IVI is the sum of relative density (RDi), relative frequency (RFi), and relative dominance (RDo), for the pole level and tree level, as well as the sum of RDi and RFi for seedling level, sapling level, undergrowth, shrubs, and herbs (Mueller-Dombois and Ellenberg1974).

$$\text{Density (n/ha)} = \frac{\text{Total individuals of the target species occured}}{\text{Total plot area}} \quad (1)$$

$$\text{Relative density} = \frac{\text{Density of target species}}{\text{Total species density}} \times 100\% \quad (2)$$

$$\text{Frequency} = \frac{\text{Number of plots in which target species occurred}}{\text{Total number of plot}} \quad (3)$$

$$\text{Relative frequency} = \frac{\text{Frequency of target spe}}{\text{cies frequency of all species}} \times 100\% \quad (4)$$

$$\text{Dominance} = \frac{\text{Basal area of target species}}{\text{plot sampling area}} \quad (5)$$

$$\text{Relative dominance (\%)} = \frac{\text{Basal area of target species}}{\text{Basal area of all species}} \times 100\% \quad (6)$$

$$\text{IVI of Tree} = \text{RDi} + \text{RFi} + \text{RDo} \quad (7)$$

$$\text{IVI of Sapling or Seedling} = \text{RDi} + \text{RFi} \quad (8)$$

Where,
IVI : important value index
RDi : relative density
RFi : relative frequency
RDo : relative dominance

Species Diversity Index (H’). The type of diversity used here is α- diversity which is the diversity of species within a community or habitat. The diversity index was calculated by using the Shannon-Wiener diversity index.

$$H' = -\sum_{i=1}^{n} (Pi) \ln (Pi) \quad (9)$$

$$Pi = \frac{ni}{N} \quad (10)$$

Where,
H’ : species diversity index
ni : number of individuals species-i
N : the total of species number

Magurran (1988) states that if H' <1 indicates a low level of diversity, 1< H' <3 indicates a moderate level of diversity, and H' > 3 indicates a high level of diversity.

Evenness index (E). For calculating the evenness of species, the Pielou’s Evenness Index (e) was used:

$$E = \frac{H'}{\ln S} \quad (11)$$

Where,
E : evenness index
H' : shannon-wiener index
Ln : natural logarithm
S : total number of species in the sample

Simpson's index of diversity (D). This index is used to fit large sample communities. The Simpson index represents the probability that any two individuals randomly selected from an infinite community belong to the same species. If all species are represented equally in the sample.

$$D = 1 - \lambda, \text{ with } \lambda = \sum_{i=1}^{5} \frac{ni(ni-1)}{n(n-1)} \quad (12)$$

Where,
D : simpson's index of diversity
ni : number of individuals of ith species
n : total number of individuals of all species at the site

Margalef Index (R). Margalef's index was used as a simple measure of species richness:

$$R = \frac{S-1}{\ln N} \quad (13)$$

Where,
R : margalef's index
S : total number of species in the sample
Ln : natural logarithm
N : total number of individuals in the sample

2.5. Geospatial Analysis
2.5.1. Pre-Processing

Colour composites are intended to combine all bands belonging to satellite images with the same spatial resolution to obtain the colour combinations needed to analyze objects or identify mangrove vegetation object in the satellite imagery. Geometric correction is the process of correcting the position of the image at the proper coordinates depending on the projection system used. Geometric errors are affected by distortions that occur during recording. This is influenced by the rotation of the earth or the shape of the earth's surface. Some of these errors are sometimes corrected by the satellite image provider.

The spectral reflection values of objects in satellite images do not match the actual ones, so this condition requires improvement through radiometric correction by considering atmospheric disturbance factors as the main error correction. Radiometric is carried out in 3 stages related to the sensitivity level of the sensor on the earth's surface. The spectral radiation recorded by the sensor should theoretically have the same value as the reflected value on the earth's surface. However, the spectral reflections in the visible and partially near-infrared (0.36-0.9 μm) are biased due to scattering, reflection, and absorption by the atmosphere, especially by aerosol particles, water vapour and dust. The error correction is carried out to restore the spectral value of the image according to conditions on the earth's surface or close to it.

2.5.2. Mangrove Classification

Mangrove data confusion including in Indonesia is due to the lack of consensus regarding the definition of mangroves (Gandhi and Jones 2019; Mukherjee *et al.* 2014). According to (Blasco *et al.* 1998; Rahadian *et al.* 2019b) the term "mangrove" has five definitions, including:

a. Mangrove ecosystem: The term mangrove ecosystem includes forest and open water surface communities, such as rivers, creeks and canals, as well as sand or mud sediments without forests.
b. Mangrove forest: The term mangrove forest includes tree communities growing naturally or planted in tidal areas.
c. Mangrove land: The term mangrove land includes all halophytic woody and non-woody plant communities included in the tidal zones deemed as mangrove potential areas, even though the land is almost barren, sometimes it is flooding for several days a year.
d. Mangrove area: The term mangrove area includes back-mangrove communities, including salt plains and arrangement of expanded land units resulting from mangrove conversion to other functions, such as ponds and agricultural lands.
e. Mangrove vegetation: The term mangrove vegetation includes all plant communities growing in the tidal areas or botanically included in the mangrove taxa.

For this study, the mangrove vegetation definition was adopted, in which all plant communities growing in the tidal areas were classified as mangrove, meanwhile, waterbody/river, ponds and barren land were excluded in the classification. The identification of mangrove vegetation objects was carried out using the radiometric enhancement technique with contextual histogram specification to obtain a more contrasting appearance of mangrove vegetation. The visual interpretation was performed based on key interpretation elements, such as tone, colour, size, shape, texture, pattern, site, and association (Kelly *et al.* 1999). The delineation of mangroves was carried out by on-screen digitation on a consistent scale. Quality control was carried out by re-interpreting the mangrove object by tracing the delineation results across the coastline with rapid appraisal technique. During this process, the product was visually examined with Sentinel-2A sensors and assisted with high-resolution SPOT imagery.

2.5.3. Mangrove Cover Density

Mangrove Vegetation density is represented by normalized difference vegetation index (NDVI), NDVI is commonly used as an indicator of vegetation status and condition as well as for canopy cover measurements (Rosenqvist *et al.* 2003). The value of this index ranges from -1 to 1. The general range for green vegetation is 0.2-0.8 (Rouse *et al.* 1973). To ensure that the mangrove map analyzed has a high level of accuracy, we carried out field validation which was carried out in parallel with the measurement of biophysical parameters in the field.

2.5.4. Physical Parameters Analysis

The physical parameters of the mangrove ecosystem observed in this study were water quality (salinity) and soil properties. Salinity was measured in situ in the study area representing each vegetation density class in mangrove land systems. The coordinates of all salinity measurement points are recorded using GPS. In addition, other measurements carried out in the field include information on inundation classes, as well as other relevant information to be recorded. The interpolation procedure is designed to take advantage of the types of input data commonly available and the known characteristics of the parameter. Interpolation technique using local interpolation methods, such as inverse distance weighted (IDW) interpolation. Water salinity data from field measurements interpolated to all potential mangrove areas to obtain a salinity distribution map.

2.5.5.Shoreline Changes Analysis

We used Landsat time-series availability of a long-term sequence of continuous data from 1970-2020. Statistical analysis to determine the rate of shoreline change or the level of coastal abrasion was carried out using ArcGIS software with the extension DSAS (Digital Shoreline Analysis System). The analysis using the DSAS consists of three main stages, namely: making a baseline parallel to the shoreline, making a transect line perpendicular to the baseline that divides the shoreline, and calculating the rate of shoreline change. The rate of shoreline change was analyzed using the statistical approach of End-Point Rate (EPR), Linear Regression Rates (LRR), Least Median of Squares (LMS), and Net Shoreline Movement (NSM). EPR, LMS, and LRR are used to quantify the rate of abrasion and accretion per year, negative values indicate abrasion and positive values indicate accretion. NSM is used to quantify the wide range of erosion and accretion.

2.5.6. Rehabilitation Plan Design

The rehabilitation plan is synthesized from quantitative and qualitative approaches from the results of the integration of field observations, measurements of biophysical parameters in the field, and data from geospatial data analysis such as mangrove distribution, mangrove density, water salinity, soil characteristics, coastal vulnerability, land status and other secondary data.

3. Results

3.1. Mangrove Composition and Structure

The study found 9 families and 16 species, consisting of 8 mangrove mayor species and 8 associated mangrove species (Table 2). The mangrove families were Avicenniaceae, Rhizophoraceae, Sonneratiaceae, Rubiaceae, Combretaceae, Malvaceae, Asclepiandaceae, Convolvulaceae, and Aizoaceae.

Plant density at the tree, saplings, and seedlings were 333.33, 4,308.33, and 239.58 ind/ha respectively (Figure 3). Furthermore, the average basal area for tree stages was 4.47 m^2/ha. Only 3 species were found in all sample plots, namely, namely *Avicennia marina, Rhizopora mucronata*, and *Rhizophora apiculata* (Table 3). *Avicennia marina* showed the highest important value index (IVI) at the stage of tree and sapling, it is indicating that the stands density, frequency, and dominance were high (Table 4).

3.2. Mangrove Distribution and Potential Mangrove Area

Almost 97% of the mangrove ecosystem has been converted into ponds, the mangrove vegetation is partially dispersed by forming small patches associated with the surrounding ponds (Figure 4). Aquaculture areas in the Karawang Regency are potential mangrove areas. The area of intertidal wetland (mangrove ecosystem) was quantified 19,139.53 ha, consisting of 421.95 ha (2.2%) of mangrove vegetation and 18,717.58 ha (97.8%) of potential mangrove area with land use as aquaculture (See Table 5). The extent of mangroves in the protected area was lower than non-protected area, which shows that an expansion of aquaculture pond in the protected area (Figure 5).

Table 2. Mangrove plant species were identified in study areas

Family	Family	Ma/Mi/As	Habitus	Abundance
Avicenniaceae	*Avicennia marina*	*Ma*	Tree	+++
	Avicennia alba	*Ma*	Tree	+
Rhizophoraceae	*Rhizophora apiculata*	*Ma*	Tree	++
	Rhizophora stylosa	*Ma*	Tree	++
	Rhizophora mucronata	*Ma*	Tree	+
	Bruguiera cylindrica	*Ma*	Tree	+
Sonneratiaceae	*Sonneratia alba*	*Ma*	Tree	++
	Sonneratia caseolaris	*Ma*	Tree	+
Rubiaceae	*Morinda citrifolia*	*As*	Tree	+
Combretaceae	*Terminalia catappa*	*As*	Tree	+
Malvaceae	*Thespesia populnea*	*As*	Tree	+
	Hibiscus tiliaceus	*As*	Tree	+
Asclepiadaceae	*Calotropis gigantea*	*As*	Herbs	+
Convolvulaceae	*Ipomoea gracilis*	*As*	Herbs	+
	Ipomoea pes-caprae	*As*	Herbs	+
Aizoaceae	*Sesuvium portulacastrum*	*As*	Herbs	+

Ma: mayor, Mi: minor, As: association. +++: high, ++: medium, +: low

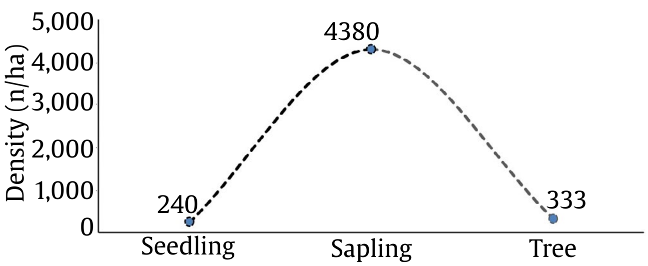

Figure 3. The density of each life stages vegetation

Table 3. Quantitative value of mangrove vegetation parameters

Life stage/species	Di (ind/ha)	Fi	Do (m²/ha)
Tree			
Avicennia marina	127.08	0.33	1.52
Rhizophora apiculata	147.92	0.17	2.19
Rhizophora mucronata	58.33	0.17	0.76
Total of Tree	333.33	0.67	4.47
Sapling			
Avicennia marina	3391.67	0.42	-
Rhizophora apiculata	916.67	0.33	-
Total of Sapling	4308.33	0.75	-
Seedling			
Avicennia marina	18.75	0.42	-
Rhizophora apiculata	220.83	0.33	-
Rhizophora mucronata	25.00	0.25	-
Total of Seedling	239.58	0.75	-

3.3. Environmental Physical Characterization

Based on field measurement salinity treshold at each observation location in the coastal mangrove forest of Karawang Regency from 0-45 ppt (Figure 6). The tolerance of each type of mangrove plant to salinity is different, Average tolerance for mangrove plants is estimated at 36 ppt. *Avicennia* spp. has a high tolerance to salt and *Bruguiera gymnorrhiza* is found in areas with a salinity of 10-20 ppt, while *Bruguiera* spp. can grow with a salinity of no more than 37 ppt. Water quality with low salinity is generally found in ponds that are directly connected to canals or large rivers. Areas with high salinity are pond areas where the floodgates do not have good freshwater circulation.

3.4. Coastal Changes Analysis

Multiple shoreline and baseline are the basic requirements for analyzing the digital shoreline analysis system (DSAS). Long-term rates of change were calculated for entire study areas at each transect for 50 years i.e. 1970 to 2020 using 8 datasets, 1970, 1990, 1995, 2000, 2005, 2010, 2015, and 2020. The coast of Karawang Regency fringe typology, which forms a bay in the west and a headland in the middle. Coastal typologies generally have a high level of vulnerability to abrasion compared to estuary deltas. Based on the analysis of shoreline changes, the Karawang area has an abrasion rate on the open coast of 2.87 m/year with a maximum rate of 13.42 m/year, this rate has implications for the loss of an average coastline width of 134 m with a maximum loss of 655.53 m (Table 6). To handle the visualization of the rate of change of the coastline in the district of Karawang, the map was created using a hexagon grid (Figure 7) and Figure 8 is a graphic of the rate of erosion and accretion, where the accretion rate is greater than the erosion rate,

Table 4. Important species in terms of IVI for each life stage and biodiversity indicators

Life stage/species	RDi (%)	RFi (%)	RDo (%)	IVI (%)	H'	E	D	R
Tree								
Avicennia marina	38.13	50	34.06	122.18				
Rhizophora apiculata	44.38	25	48.99	118.37				
Rhizophora mucronata	17.50	25	16.95	59.45				
Total of Tree	100	100	100	300	1.03	0.36	0.37	0.39
Sapling								
Avicennia marina	78.72	55.56	-	134.28				
Rhizophora apiculata	21.28	44.44	-	65.72				
Total of Sapling	100	100	-	200	0.52	0.23	0.66	0.16
Seedling								
Avicennia marina	7.83	55.56	-	63.38				
Rhizophora apiculata	92.17	44.44	-	136.62				
Rhizophora mucronata	10.43	33.33	-	43.77				
Total of Seedling	100	100	-	200	0.27	0.30	0.86	0.21

H': shannon-wiener index, E: evenness index, D: simpson's index, R: margalef's index

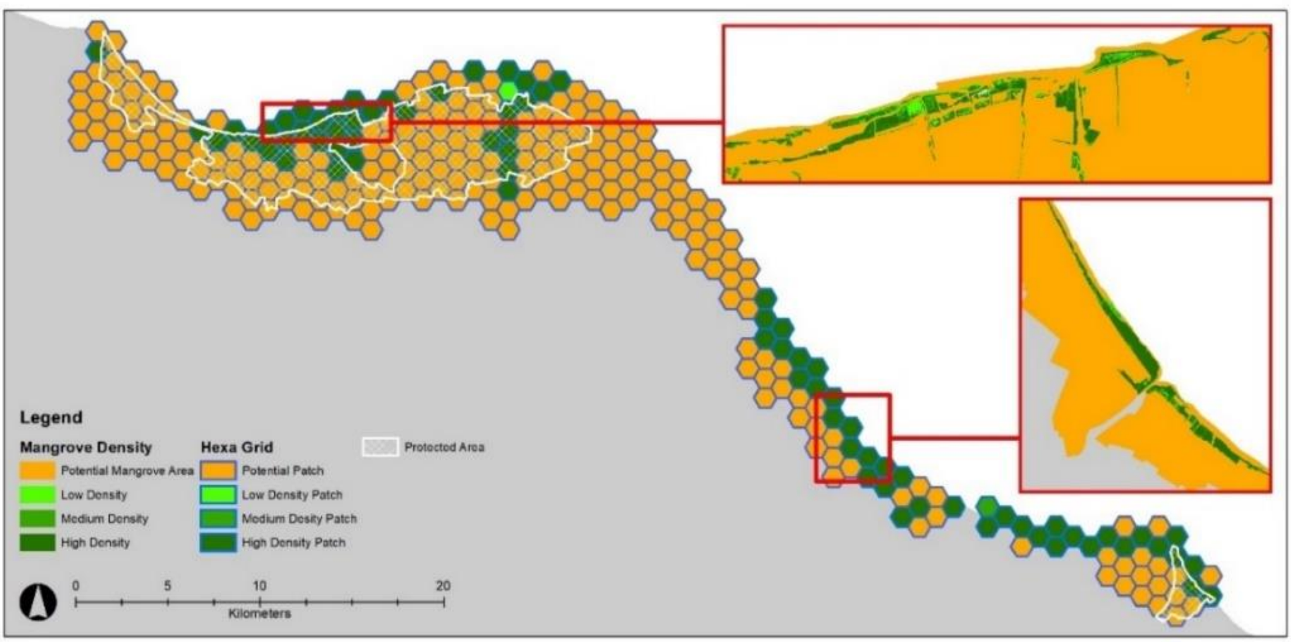

Figure 4. Map of Mangrove vegetation and potential mangrove area distribution

it indicates a positive sediment budget balances. Figure 8 Graphic of the rate of erosion and accretion.

3.5. Rehabilitation Plan Design

The direction of the mangrove rehabilitation plan was built based on a spatial analysis by considering several aspects including the existing mangrove vegetation condition, environmental physical parameters, and the level of vulnerability derived from the history of coastal landform changes. In addition, for the direction of species recommended in rehabilitation efforts, especially in the context of planting, it is analyzed based on the suitability of species to biophysical conditions.

4. Discussion

4.1. Mangrove Composition and Structure

Mangrove ecosystems on Java Island have been systematically exploited since 1,800 especially for the development of shrimp farming (tambak) and for timber extraction, by the end of the 1960s it is estimated that more than 200,000 ha of mangroves have been lost (Kelly *et al.* 1999). This certainly causes

Table 5. Area of vegetated and potential mangrove area

Land status	Sub-district	Veg. canopy cover areas (ha)			Potential Mangrove (ha)	Total
		LD	MD	HD		
Non-protected area	Batujaya	0.93	2.02	3.26	170.05	176.27
	Cibuaya	3.57	5.20	13.36	3,776.82	3,798.95
	Cilamaya Kulon	1.83	4.15	10.34	46.88	63.20
	Cilamaya Wetan	6.88	11.86	30.42	1,113.69	1,162.85
	Cilebar	6.04	12.51	37.01	876.52	932.07
	Cimalaya Kulon	0.08	0.19	0.18	-	0.45
	Pakisjaya	0.51	2.08	1.79	1,614.89	1,619.26
	Pedes	-	-	-	529.94	529.94
	Tempuran	5.03	11.05	49.02	837.54	902.64
	Tirtajaya	12.87	18.20	27.19	1038.21	1,096.47
Total non-protected area		37.74	67.26	172.57	10,004.54	10,282.10
Protected area	Batujaya	2.41	6.00	4.37	1,200.62	1,213.40
	Cibuaya	11.42	20.89	29.10	2,523.78	2,585.19
	Cilamaya Wetan	1.45	1.60	7.64	305.47	316.16
	Pakisjaya	0.62	1.13	1.72	1,289.24	1,292.71
	Tirtajaya	12.20	15.89	27.94	3,393.94	3,449.98
Total protected area		28.10	45.51	70.77	8,713.05	8,857.44
Total		65.85	112.77	243.34	18,717.58	19,139.53

LD: low density, MD: medium density, HD: high density

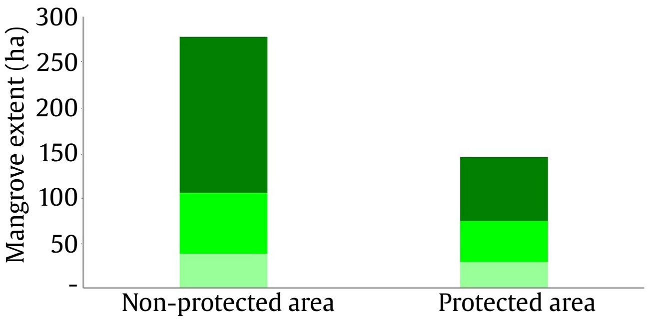

Figure 5. Histogram of vegetation mangrove density area by land status

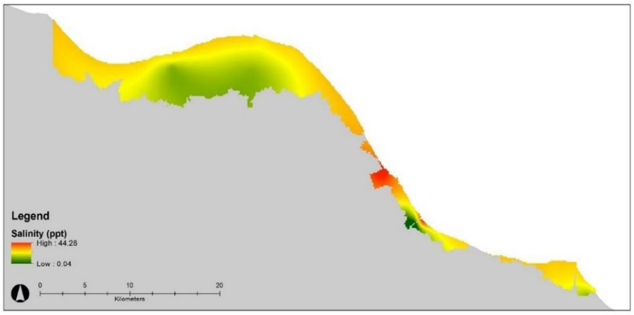

Figure 6. Water salinity level exposure

Table 6. The suitability of several types of mangroves species with environmental factors

Jenis	Salinity (ppt)	Waves and wind tolerance	Sand content tolerance	Mud content tolerance	Inundation frequency (day/month)
Rhizophora mucronata	10-30	ST	MD	ST	20
Rhizophora sylosa	10-30	MD	ST	ST	20
Rhizophora apiculata	10-30	MD	MD	ST	20
Bruguiera parviflora	10-30	SV	MD	ST	10-19
Bruguiera sexangula	10-30	SV	MD	ST	10-19
Bruguiera gymnorrhiza	10-30	SV	SV	MD	10-19
Sonneratia alba	10-30	MD	ST	ST	20
Sonneratia caseolaris	10-30	MD	MD	MD	20
Xylocarpus granatum	10-30	SV	MD	MD	9
Heritiera littoralis	10-30	VS	MD	MD	9
Lumnitzera racemosa	10-30	VS	ST	MD	Low
Cerbera manghas	0-10	VS	MD	MD	Seasonal
Nypa fruticans	10-30	VS	SV	ST	Seasonal
Avicennia spp.	10-30	MD	ST	ST	20

ST = Suitable, MD = Moderate, SV = Severe, VS = Very severe

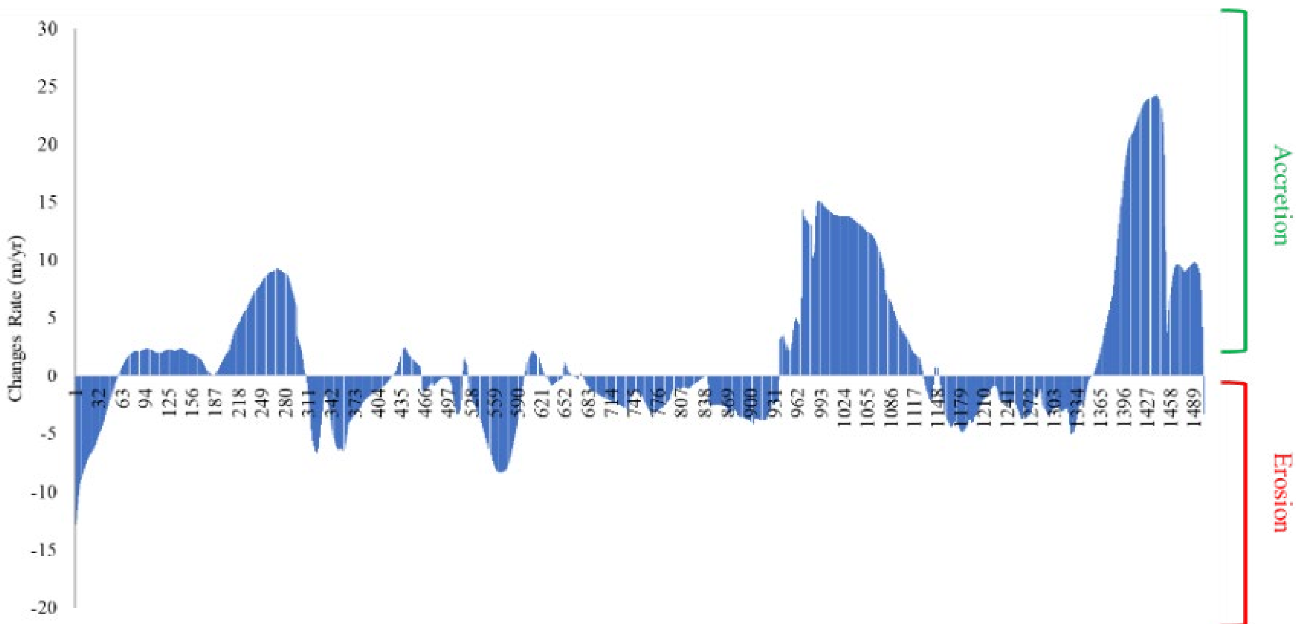

Figure 8. Graphic of the rate of erosion and accretion

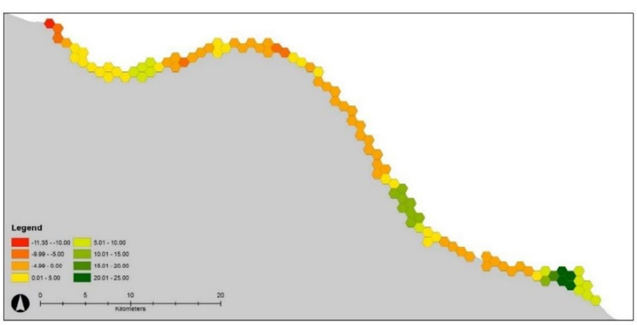

Figure 7. Map of the rate of coastal erosion and accretion

the natural mangrove vegetation species to have decreased and most of the mangroves on the north coast of Java Island are planted mangroves which are mostly dominated by the Rhizophoraceae.

Mangroves species along the Karawang coast are generally dominated by *Avicennia marina* that grows naturally on accretionary land. *Avicennia marina* is a pioneer species that can survive and reproduce naturally well (Hastuti and Hastuti 2018). In aquaculture areas, *Rhizophora mucronata* and *Rhizophora apiculata* are the most common species found and planted. On the riverbank with low salinity, *Sonneratia caseolaris* grows naturally. In addition, it was found that the Mangrove Association plants grow in low-salinity soils.

Species density indicates land suitability toward mangrove species, frequency values indicate the level of adaptation of species in various conditions of different land characteristics, and dominance at the stage of the tree showed that species is high spatial control with sufficient climax levels to regenerate naturally.

The species diversity index is a very useful parameter to compare two communities, especially to study the effect of biotic disturbances and the level of stability of a community (French *et al.* 1989). The value of the species diversity index found is generally low among all the life stages, However, the comparison between the diversity index values for the life stage level shows a higher at life stage of the tree. The low evenness value in all life stages is due to the concentration of species that dominates, and species richness in the study area showed poor existing species (Table 4). This indicates that there is a need for species enrichment in the area to increase species diversity. *Rhizophora apiculata* showed almost the same response as *Avicennia marina*. The basic difference between *Avicennia marina* and *Rhizophora apiculata* in the study area is mostly growing on accretion land and growing naturally and at the sapling and seedling level showing very high numbers. while *Rhizophora apiculata* grows in the backward zone and aquaculture areas.

4.2. Mangrove Distribution and Potential Mangrove Area

Mangrove vegetations are partially distributed in the study area with a small area. Mangrove potential areas are unvegetated lands whose biophysical conditions are suitable for places to mangrove growth. In the context of mapping, these areas refer to open lands whose substrate and hydrological conditions meet the prerequisites for rehabilitation activities. These areas certainly need to be rehabilitated by considering the land use spatial plan.

4.3. Environmental Physical Characterization

Salinity and soil properties were environmental factors that were used as key parameters in analyzing the suitability of the place where mangrove species grow for rehabilitation activities. Salinity has an important role as a determining factor in regulating the growth and sustainability of mangrove vegetation. Salinity is the level of salt contained in the water in the mangrove ecosystem (Kusmana *et al.* 2003). Salinity is influenced by several factors, including tidal inundation, topography, rainfall, freshwater input from rivers, land run-off and evaporation. (Aksornkoae 1989) stated that salinity is an environmental factor that greatly determines the development of mangrove forests, especially for the growth rate, endurance and zoning of mangrove species. Most of the intertidal wetlands in the study area are relatively suitable for growing mangroves considering the high adaptability of mangroves to salinity and supported by diverse physical properties of soil.

The physical properties of the soil analyzed are soil texture. The results of soil analysis showed that the soil (sediment) in the mangrove forest of Karawang Regency consisted of three texture classes, namely: clay, sandy, and loam. Aquaculture systems affect soil texture (Hastuti *et al.* 2015), In traditional pond systems, the soil texture is dominated by clay, in semi-intensive ponds, the texture was very fine clay, Intensive ponds were textured with clay loam, and in mangroves were textured with sandy clay loam.

4.4. Coastal Changes Analysis

The rate of shoreline change that occurs in the study area, will be one of the references for the design of mangrove rehabilitation planning, where areas with a high rate of shoreline change will be the priority areas to be rehabilitated. This is inseparable from the importance of adapting the dynamics of changing coastal environments.

4.5. Rehabilitation Plan Design

Mangrove rehabilitation is an effort to restore the structure and productivity of mangroves to increase biodiversity to a certain extent and fulfil its original conditions (Ilman *et al.* 2016). In this case, mangrove rehabilitation is carried out to restore the ecological function of mangrove land and enrich mangrove species. Planning is an early stage that has an important role in the implementation of mangrove rehabilitation programs/activities. The planning referred to in this study is a technical design process for land rehabilitation based on realistic data and information from the inventory results, assessment of the biophysical condition of the mangrove ecosystem in the field. Spatially, we integrate mangrove typology, mangrove stand density, physical parameters, and land use as the basis for determining the direction of rehabilitation planning.

In the estuarine deltaic mangrove typology, we aim at protecting with natural regeneration considering that the land growth (accession) is gradually accompanied by the natural growth of mangroves. To avoid planting failure in fringe areas, we recommend constructing natural coastal structures or integrating with the engineering approach before planting due to there are several areas that are vulnerable to coastal erosion (Figure 7). On the backward area (100-300 m) which is protected by a fringe area, it is recommended for intensive planting. Furthermore, mangroves with low density, medium density, and high density are recommended for planting, species enrichment, and protecting respectively (Table 7 and Figure 9). Aquaculture has an exceptionally long history in Indonesia (Brown and Prayitno 1987), The dependence of the Karawang community on aquaculture was difficult to avoid, it takes a long time in efforts to raise environmental awareness, social capital, and make ponds in protected areas reforested, a mixed mangrove-aquaculture system is an alternative approach that can be done to improve mangrove ecosystems and provide a bridge between rehabilitation and economic needs of coastal communities. Proper pond management is the key to successful mangrove rehabilitation. The benefit of the Mix mangrove-aquaculture system ware restoring the riparian green belt to protect the riverbank from erosion, sediment capture by mangroves to strengthen pond dikes, and mangroves on the edge of the pond act as a water filter to enhance water quality that enters the pond.

Planting may be beneficial in the following conditions: Planting is necessary when the supply of natural seeds and propagules is very limited due to unavailability of parent trees or hydrologically unconnected (inhibits dispersal of seedlings and propagules). This can happen in coastal areas that are experiencing extensive mangrove degradation. Plantings may also be undertaken for the re-introduction of certain values and lost species from the area referred to as 'enrichment plantings'. Planting is also useful as a vehicle for educational and cultural purposes. As a symbol of life, planting trees can create a long-lasting commitment and sense of belonging among those involved. In sites that have experienced severe erosion, planting mangroves in the remaining bunds can create short-term recovery and slow erosion in those bunds. Tidal mudflats, sand beds, coral reefs and seagrass beds are often found in locations where mangroves can grow and are often targeted and victims of programs or activities for mangrove planting. While

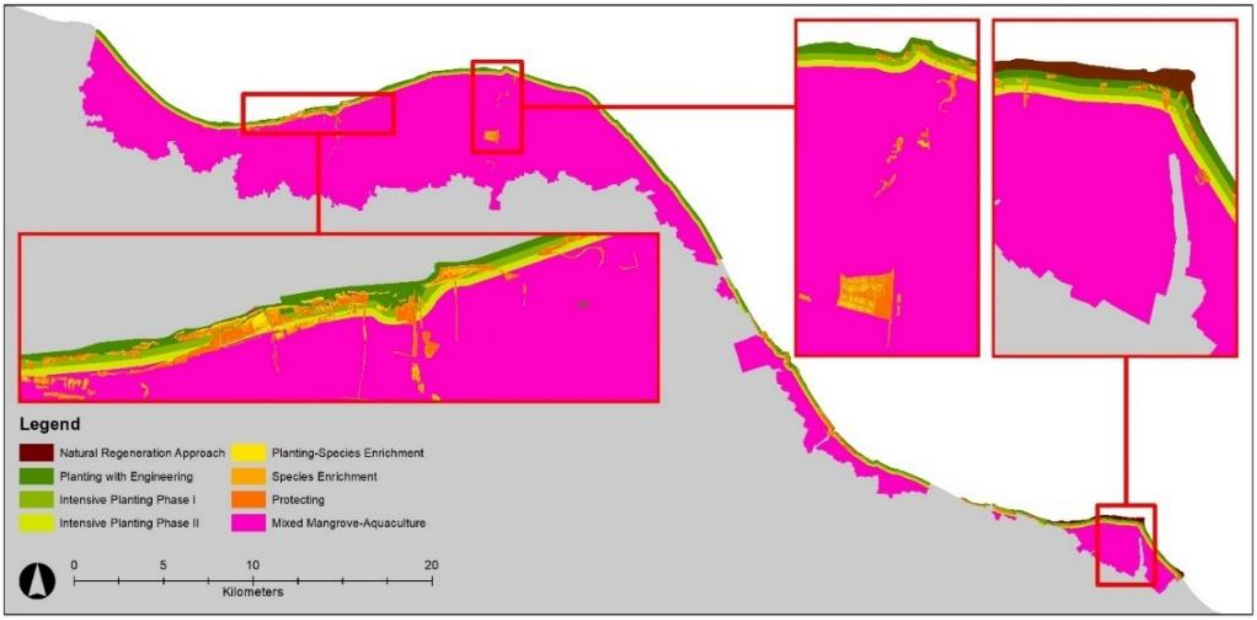

Figure 9. Map of mangrove rehabilitation plan design

Table 7. Rate coastal erosion/accretion and net shoreline movement based on typology

Typology	Movement	Ave	Min	Max
Estuarine	Erosion (m/yr)	-	-	-
	Land loss (m)	-	-	-
	Accretion (m/yr)	12.13	5.71	19.10
	Land gain (m)	670.53	397.03	1053.66
Fringe	Erosion (m/yr)	-2.87	-0.01	-13.42
	Land loss (m)	-134.63	-0.01	-655.53
	Accretion (m/yr)	6.79	0.01	24.24
	Land gain (m)	337.21	0.00	1251.62

in essence the habitat also supports a diversity of species of crustaceans, molluscs, corals, birds, mammals and turtles, including the rare, endangered and endemic. These habitats are highly productive and support the very high biomass of benthic invertebrates and other fauna that support the productivity of both inshore and offshore fisheries. The habitat is also an important foraging location for both resident and migratory waterbirds, including geese, ducks, shorebirds and gulls. In several locations along the world's major flight paths, mudflats and surrounding habitats, upon closer inspection, serve as important resting and foraging locations for migratory waterbird species.

Species-site matching is very useful to support the success of planting a land because this activity will determine the suitability of a plant species with environmental conditions. Especially for mangroves, the factors that need to be considered for species-site matching are salinity, frequency of inundation, soil texture (sand and clay/mud content), and wave and wind strength. The suitability of several types of mangroves with environmental factors can be seen in Table 6. The tolerance of seedlings of several species to colonize canopy gaps or newly formed tidal flats to be the most important determinant of the species composition of mangroves surviving in the delta in the future (Sukardjo *et al.* 2014).

The survival rate of *Avicennia marina* mangrove seedlings in ponds is low, this species is not suitable for integration with ponds. Planting *Avicennia marina* in ponds is not recommended due to the high mortality rate and unsuitable environmental conditions, especially the inundation pattern. Forcing the *Avicennia marina* to be integrated into silvofishery ponds can result in high maintenance costs (Hastuti and Hastuti 2018).

The growth rate, photosynthetic rate, and water use efficiency of *Rhizophora mucronata* and *Rhizophora stylosa* seedlings grown under relatively low salinity conditions were higher than seedlings grown under relatively high salinity conditions (Ball *et al.* 1997). This phenomenon is also reinforced by research (Kusmana *et al.* 2016) that *Rhizophora mucronata* seedlings grown at salinity conditions of about 10 ppt showed relatively higher diameter increments and stem height than seedlings grown at salinity conditions of about 28 ppt.

In conclusion, to restore the condition and function of the mangrove ecosystem in the Karawang Regency, rehabilitation of mangrove areas is necessary with the following directions: Potential areas of unvegetated mangroves are prioritized for rehabilitation because they are generally empty and critical lands through planting and enrichment of mangrove species. Rehabilitation activities in areas with mangrove vegetation are prioritized in areas with sparse and moderate density through planting and species enrichment. Protection activities are prioritized in areas with dense mangrove density. In areas with high land loss, it is recommended to start with the developt of coastal engineering structures to obtain land stability, and areas with high accretion rates are recommended for a natural regeneration approach as nature-based solution.

The types of mangroves that are recommended to be planted on lands that need to be rehabilitated are generally *Avicennia* spp. (especially *Avicennia marina* and *Avicennia alba*), *Rhizophora mucronata, Rhizophora apiculata, Sonneratia alba* (on land with high salinity), *Sonneratia caseolaris* (on land with low salinity), and associated mangrove species for areas far from the coast (on land with low salinity). Rehabilitation activities in mangrove areas need to involve various parties, both in a protected area (*Hutan Lindung*) and a non-protected area (APL). In this case, especially the rehabilitation activities in non-forest areas because most of these areas have various uses and ownership. Adaptive mangrove ecosystem rehabilitation plan based on coastal typology and ecological dynamics approach provides options for planning stakeholders in making decisions to plant or not to plant activities to increase the effectiveness and efficiency of financing coastal environment improvements.

Acknowledgements

The authors would like to thank the Environment and Sanitary Office of Karawang Regency who has given supporting facilities and assisted with permitting in carrying out field survey.

References

Aksornkoae, S., 1989. Management and Conservation of Mangrove Resources for Coastal Development in the Southeast Asian Nations Coast. area Manag. Southeast Asia.

Andreas, H., Usriyah, Zainal, Abidin, H., Anggreni, Sarsito, D., 2017. Tidal inundation ("Rob") investigation using time series of high resolution satellite image data and from Institut measurements along northern coast of Java (Pantura). *IOP Conf. Ser.: Earth Environ. Sci.* 71, 012005. https://doi.org/10.1088/1755-1315/71/1/012005

Aye, W.N., Wen, Y., Marin, K., Thapa, S., Tun, A.W., 2019. Contribution of mangrove forest to the livelihood of local communities in Ayeyarwaddy Region, Myanmar. *Forests*. 10, 1–13. https://doi.org/10.3390/f10050414

Ball, M.C., Cochrane, M.J., Rawson, H.M., 1997. Growth and water use of the mangroves *Rhizophora apiculata* and *R. stylosa* in response to salinity and humidity under ambient and elevated concentrations of atmospheric CO_2. *Plant, Cell Environ.* 20, 1158-1166. https://doi.org/10.1046/j.1365-3040.1997.d01-144.x

Blasco, F., Gauquelin, T., Rasolofoharinoro, M., Denis, J., Aizpuru, M., Caldairou, V., 1998. Recent advances in mangrove studies using remote sensing data. *Mar. Freshw. Res.* 49, 287–96. https://doi.org/10.1071/MF97153

Bosire, J.O., Dahdouh-Guebas, F., Walton, M., Crona, B.I., Lewis, R.R., Field, C., Kairo, J.G., Koedam, N., 2008. Functionality of restored mangroves: a review. *Aquat. Bot.* 89, 251–259. https://doi.org/10.1016/j.aquabot.2008.03.010

Brown, J.H., Prayitno, B., 1987. Backyard fish farming in java, Indonesia. *Community Dev. J.* 22, 237–241. https://doi.org/10.1093/cdj/22.3.237

Danielsen, F., Sørensen, M.K., Olwig, M.F., Selvam, V., Parish, F., Burgess, N.D., Hiraishi, T., Karunagaran, V.M., Rasmussen, M.S., Hansen, L.B., Quarto, A., Suryadiputra, N., 2005. The Asian tsunami: a protective role for coastal vegetation. *Science*. 310, 643. https://doi.org/10.1126/science.1118387

Ellison, A.M., Felson, A.J., Friess, D.A., 2020. Mangrove rehabilitation and restoration as experimental adaptive management. *Front. Mar. Sci.* 7, 327. https://doi.org/10.3389/fmars.2020.00327

[FAO] Food and Agriculture Organization, 2007. FAO Forestry Paper: The world's mangroves 1980–2005. FAO, Rome.

French, D.D., Ludwig, J.A., Reynolds, J.F., 1989. Statistical ecology: a primer on methods and computing. *J. Appl. Ecol.* 26, 1099-1100. https://doi.org/10.2307/2403729

Gandhi, S., Jones, T.G., 2019. Identifying mangrove deforestation hotspots in South Asia, Southeast Asia, and Asia-Pacific. *Remote Sens*. 11, 1–27. https://doi.org/10.3390/rs11060728

Giesen, W., Macdonald, E.M., 1993. Indonesia's mangrove: an update on remaining area and main management issues. *In: International Seminar on "Coastal Zone Management of Small Island Ecosystems", Ambon, 7-10 April 1993.* Ambon: Pusat Studi Lingkungan, Universitas Pattimura. pp. 7-10.

Gunawardena, M., Kingdom, U., Rowan, J.S., Systems, E., Kingdom, U., 2005. Economic valuation of a mangrove ecosystem threatened by shrimp aquaculture in Sri Lanka. *Environ. Manage.* 36, 535–550. https://doi.org/10.1007/s00267-003-0286-9

Hamilton, S.E., Friess, D.A., 2018. Global carbon stocks and potential emissions due to mangrove deforestation from 2000 to 2012. *Nat. Clim. Chang.* 8, 240–244. https://doi.org/10.1038/s41558-018-0090-4

Hastuti, Y.P., Novita, L., Widiyanto, T., Rusmana, I., 2015. Profile in various organic soil depth shrimp pond, Tambak Inti Rakyat, Karawang. *J. Akuakultur Indonesia.* 10, 183-191. https://doi.org/10.19027/jai.10.183-191

Hastuti, R.B., Hastuti, E.D., 2018. Adaptability and growth performance of *Avicennia marina* seedling within Silvofishery pond. *J. Phys. Conf. Ser.* 1025, 012050. https://doi.org/10.1088/1742-6596/1025/1/012050

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

Kelly, M., Estes, J.E., Knight, K.A., 1999. Image interyretation keys for validation of global data sets. *Photogramm. Eng. Remote Sens.* 65, 1041–1049.

Kusmana, C., Wilarso, S., Hilwan, I., Pamoengkas, P., Wibowo, C., Tiryana, T., Triswanto, A., Yunasfi, Hamzah, 2003. Teknik Rehabilitasi Mangrove. Fakultas Kehutanan Institut Pertanian Bogor, Bogor.

Kusmana, C., Husnaeni, A., Tiryana, T., 2016. *Rhizophora mucronata* seedling growth model at different spacings. *Int. J. Eng. Sci. Res. Technol* 5, 457-464. https://doi.org/10.5281/zenodo.203845

Lee, J.S.H., Abood, S., Ghazoul, J., Barus, B., Obidzinski, K., Koh, L.P., 2014. Environmental impacts of large-scale oil palm enterprises exceed that of smallholdings in Indonesia. *Conserv. Lett.* 7, 25–33. https://doi.org/10.1111/conl.12039

Magurran, A.E., 1988. Ecological Diversity and Its Measurement. Croom Helm Ltd, London.

Mueller-Dombois, D., Ellenberg, D., 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York.

Mukherjee, N., Sutherland, W.J., Khan, M.N.I., Berger, U., Schmitz, N., Dahdouh-Guebas, F., Koedam, N., 2014. Using expert knowledge and modeling to define mangrove composition, functioning, and threats and estimate time frame for recovery. *Ecol. Evol.* 4, 2247–2262. https://doi.org/10.1002/ece3.1085

Murdiyarso, D., Purbopuspito, J., Kau, J.B., Warren, M.W., Sasmito, S.D., Donato, D.C, Manuri, S., Krisnawati, H., Taberima, S. 2015. The potential of Indonesian mangrove forests for global climate change mitigation. *Nature Climate Change*. 5, 8–11. https://doi.org/10.1038/nclimate2734

Rahadian, A., Leilan, F., Arafat, I.N., Lestari, T.A., 2019. Ecosystem mangrove management in urban area: case study mangrove Kali Adem Jakarta Indonesia. *IOP Conf. Ser.: Earth Environ. Sci.* 399, 012008. https://doi.org/10.1088/1755-1315/399/1/012008

Rahadian, A., Prasetyo, L.B., Setiawan, Y., Wikantika, K., 2019. A historical review of data and information of Indonesian mangroves area. *Media Konserv.* 24, 163-178. https://doi.org/10.29244/medkon.24.2.163-178

Rosenqvist, Å., Milne, A., Lucas, R., Imhoff, M., Dobson, C., 2003. A review of remote sensing technology in support of the Kyoto Protocol. *Environ. Sci. Policy*. 6, 441–455. https://doi.org/10.1016/S1462-9011(03)00070-4

Rouse, J.W., Hass, R.H., Schell, J.A., Deering, D.W., 1973. Monitoring vegetation systems in the great plains with ERTS Third Earth Resour. *Technol. Satell. Symp.* 1, 309–317.

Sandilyan, S., Kathiresan, K., 2012. Mangrove conservation: a global perspective. *Biodivers. Conserv.* 21, 3523–3542. https://doi.org/10.1007/s10531-012-0388-x

Siikamäki, J., Sanchirico, J.N., Jardine, S.L. 2012. Global economic potential for reducing carbon dioxide emissions from mangrove loss. *Proc. Natl. Acad. Sci.* 109, 14369–14374. https://doi.org/10.1073/pnas.1200519109

Sukardjo, S., Alongi, D.M., Ulumuddin, Y.I. 2014. Mangrove community structure and regeneration potential on a rapidly expanding, river delta in java. *Trees - Struct. Funct.* 28, 1105–1113. https://doi.org/10.1007/s00468-014-1021-2

Valiela, I., Bowen, J.L., York, J.K. 2001. Mangrove forests: one of the world's threatened major tropical environments. *Bioscience*. 51, 807. https://doi.org/10.1641/0006-3568(2001)051[0807:MFOOTW]2.0.CO;2

Vermaat, J.E., Thampanya, U., 2006. Mangroves mitigate tsunami damage: A further response Estuar. *Coast. Shelf Sci.* 69, 1–3. https://doi.org/10.1016/j.ecss.2006.04.019

Yusuf, D.N., Prasetyo, L.B., Kusmana, C., Machfud, 2017. Geospatial approach in determining anthropogenic factors contributed to deforestation of mangrove: a case study in Konawe Selatan, Southeast Sulawesi. *IOP Conf. Ser.: Earth Environ. Sci.* 54, 012049. https://doi.org/10.1088/1755-1315/54/1/012049