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Mangrove Conditions Using Drones Along Several Rivers in Bengkalis Island, Riau, Indonesia

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Abstract. Mangroves on Bengkalis Island experienced a decline between 2000 and 2019. This decrease in mangrove forest area was caused by anthropogenic activities and natural factors, such as coastal erosion. The objective of this study is to assess the current condition of mangroves on Bengkalis Island, Riau, Indonesia. The research was conducted in March 2024 across four rivers on Bengkalis Island, with each river containing three research stations: upstream, midstream, and downstream. Data collection involved capturing aerial photos of mangroves using drones over 100 m x 100 m. The photos were analyzed using the supervised image classification method to identify and assess mangrove land cover. A total of 11 mangrove species were identified along the rivers. The most widely distributed species across all locations were *Rhizophora apiculata* and *Xylocarpus granatum*. Canopy cover at all research sites was classified as dense, with coverage exceeding 75%. This study provides crucial information about the condition of mangroves on Bengkalis Island, serving as a guideline for future restoration efforts.

Keywords: Aerial photo; anthropogenic; canopy cover; land cover;supervised image classification.

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INTRODUCTION

Mangroves generally thrive on tidal flats with muddy substrates at river mouths, along coasts, and in inland areas where mud accumulates, with drier soil conditions along the edges of rivers and streams (Isa & Suratman, 2021). Mangrove forests are complex ecosystems comprising diverse coastal flora and fauna. The mangrove forest area in Riau constitutes approximately 6.72% of Indonesia's total mangrove area, making it the second-largest region (Oktorini et al., 2022; Rosmasita et al., 2020). Administratively, mangroves in Bengkalis Regency cover about 25,373.4 ha or 11.22% of Riau's total mangrove area. It is the third-largest mangrove area following Indragiri Hilir, which ranks first, and the Meranti Islands, which rank second. These mangroves are distributed along rivers and coasts. The rate of mangrove loss in Bengkalis Regency exceeds that of Indragiri Hilir Regency, with 9.98% of its mangroves lost between 2016 and 2017, compared to 6.98% in Indragiri Hilir (Oktorini et al., 2022).

The decline in the mangrove forest area in Bengkalis is caused by anthropogenic activities and natural factors. One area with significant mangrove forests in Bengkalis Regency is Jangkang Village, Bantan District. Mangroves along the Jangkang River are widely utilized by the local community, particularly as raw material for charcoal kilns (Hermanto et al., 2023; Muhtady et al., 2021). Research by Muhtady et al. 2019 found an ecological sustainability indicator score of 32.71, indicating a less sustainable status. Field observations and interviews with local fishermen revealed that in addition to being used for charcoal production, mangroves are also harvested for building materials, firewood, and are being cleared for the conversion of land into shrimp ponds.

Monitoring mangrove vegetation through traditional inventory methods requires a significant amount of time, cost, and effort, particularly because of the challenges posed by difficult access to locations. Fortunately, there is a more efficient approach using remote sensing technology to quantify mangrove distribution and cover, temporal gain or lossof cover, and ecological state of mangrove ecosystems (Rondon et al., 2023). However, remote sensing with satellite imagery involves complex procedures and high costs. A simpler and more cost-effective alternative is the use of drones. This method has proven effective in mapping mangrove coverage, distribution, identification, and structure of mangrove communities by interpreting drone imagery (Timisela et al., 2020).

Data on mangrove diversity and distribution are important for management, restoration, and conservation efforts (Gaol et al., 2023; Sinabang et al., 2022). This study aims to assess the condition of mangroves on Bengkalis Island, Riau, Indonesia. The results of this study are expected to serve as valuable information, references, and considerations for mangrove forest management plans, conservation activities, and restoration efforts in Bengkalis Island and other areas.

METHODS

Study area

This research was conducted across four rivers on Bengkalis Island. Three rivers are located in the Bantan Sub-district: Jangkang River, Liong River, and Kembung Luar River. The fourth river, the Sebauk River, is located in the Bengkalis Sub-district (Figure 1).

Procedures

Each river was divided into three sampling stations: upstream, midstream, and downstream. This division was based on a purposive sampling method that considered the distance to settlements and the intensity of community activities. The upstream section of the river is located closer to the tributaries that connect directly to residential areas. The midstream section was defined as the area between stations 1 and 3 and is situational. The downstream part of the river is near the estuary, situated further away from residential areas.

Mangrove vegetation data was collected using a DJI Mavic 2 Pro drone at an altitude of 50 m. The resulting pixel resolution, or ground sample distance (GSD) is 1.81 cm/pixel. An overlap of 80% was used due to varying vegetation relief (Bayyan, 2019). The shooting area measures 100 m x 100 m (1 Ha). Flight lines were created using the Pix4D Capture application. Flight time estimation is based on calculations of area, altitude, speed, camera angle, and overlap (Bayyan, 2019). Photo capture occurred between 08:00 a.m. and 04:30 p.m., assuming sunny weather and moderate wind conditions.

Data processing

The images were selected by removing blurred or tilted images (those not upright at 90°). The selected images were then processed using Agisoft software to combine them into a single unit called an orthomosaic. This process, known as mosaicking, is based on merging the aerial photo coordinates (Nadzirah et al., 2022).

The mosaicking process was carried out by grouping drone imagery photos based on the sampling stations. This approach was chosen to increase efficiency, as processing all the photos at once would take a significant amount of time. Agisoft software was used, and a chunk or worksheet for 12 observation stations was created. Next, the photos were imported into the workflow section. Points with aligned photos were identified and matched. The quality setting for pair selection was set to 'generic'. The reconstruction quality was selected, and then build orthomosaic in the workflow was used to merge the photos based on coordinates and pixels. The coordinate reference system was left as default, and the orthomosaic was exported in TIFF format.

Figure 1. Map of locations and research stations in Bengkalis Island, Riau, Indonesia.

A spatial approach was applied to large-scale or high-resolution imagery. In this approach, the appearance of the canopy and the location of mangroves were the primary criteria. This process, called image classification, involves sorting or grouping pixels into several classes based on specific criteria or categories of objects. The classification is used to obtain data on mangrove cover and species diversity.

Mangrove identification

Mangrove species identification was conducted by observing the color in images of mangrove leaves or canopies. The technique used for species recognition involved on-screen digitizing based on the interpreter's expertise, with reference to eight image interpretation standards (Panjaitan et al., 2019). Validation of the aerial photo interpretation results was performed visually. This visual observation involved photographing various structures of mangrove trees, including leaves, crown shape, flowers, and roots, within a 10 m x 10 m observation transect (Bayyan, 2019).

Mangrove cover analysis

The analysis of mangrove conditions based on land cover was conducted using the Supervised Image Classification method in ArcGIS software. Drone photos that were taken were processed with ArcGIS to produce two classes: mangrove and non-mangrove land (Nadzirah et al., 2022). This method involves digitizing area objects to create polygons that can be calculated and converted into percentages, allowing for the classification of mangrove cover according to the Indonesian National Standard (SNI) 7717-2020 regarding Mangrove Geospatial Information Specifications. The canopy cover classes are divided into three categories: 1. dense mangrove (70-90%); 2. moderate mangrove (30-70%); and 3. sparse mangrove (0-30%) (Uhib, 2022).

Analysis of water quality parameters

The physical and chemical factors of the river were assessed by categorizing the substrate as either mud or sandy mud. Water quality measurements included temperature, current, salinity, pH, and dissolved oxygen (DO). The collected physical and chemical parameters were tabulated and analyzed using descriptive qualitative methods (Akamaking et al., 2022).

RESULTS AND DISCUSSION

Species composition

A total of 11 mangrove species were found throughout the study site. We identified ten species from drone photos, however ground check (validation) confirmed 11 mangrove species (Table 1). The amount of species in this study is equal to the number of species found in the coastal area of the Mandalika International Circuit, Central Lombok with the most abundant species from the genus *Rhizophora*(Jayadi et al., 2024). The number of species identified in this study exceeds that found in research conducted by Hakim (2003) in the northern part of Bengkalis Island, which identified a total of 9 mangrove species. In that study, the dominant genera were *Avicennia*, *Rhizophora*, and *Bruguiera*. The higher number of species identified in this study is due to its wider coverage of Bengkalis Island, including the western part, specifically Sebauk Village. Additionally, the methods used differ, as the use of drones allows for easier sampling of a wider area.

The number of species identified during ground checks was higher because we failed to distinguish between *Rhizophora apiculata* and *Rhizophora mucronata* in drone imagery. Their similar color tones, leaf shapes, and crown structures make identification difficult. However, during ground checks, *Rhizophora apiculata* was observed to have a reddish underside of the leaves, while *Rhizophora mucronata* displayed a greenish hue. Additionally, *Rhizophora apiculata* has reddish leaves, white-brown stems, and easily peeled scales, whereas *Rhizophora mucronata* has greenish leaf veins, brownish stems, and rough bark (Irawan et al., 2021; Shamin-Shazwan et al., 2021). The ground check area is only 10 m x 10 m, or 100 m², while drones can cover much larger areas. In this study, the drone flying at an altitude of 50 m could reach an area of 100 m x 100 m, or 10,000 m². The larger sampling area allows for the detection of species that may not be present in a 10 m x 10 m plot but can be identified in drone imagery. This is a significant advantage of using drones for vegetation analysis compared to ground checks. The implementation of the mangrove ecosystem assessment method using drones is highly effective.The use of drone technology in forest inventory activities to assess forest characteristics such as canopy density, canopy diameter, canopy height, and tree diameter is more advantageous than conducting direct surveys, particularly in terms of time and cost efficiency

(Hematang et al., 2022). Mangrove forests are more elongated than terrestrial forests, making fieldwork more challenging in mangrove habitats. Inventory and monitoring of mangrove ecosystems will be easier and more efficient using remote sensing and Geographic Information Systems (Arfan et al., 2022).

Overall, *Rhizophora* can be found in almost all parts of the river. This genus typically grows in muddy substrates, which are present throughout the river (Cuenca-Ocay et al., 2023). Soft and muddy soil types provide a good carrying capacity for mangrove growth and development. These areas are typically influenced by tidal activity (Ghina et al., 2024). This genus typically has roots that can adapt to extreme conditions, such as unstable muddy substrates, and facilitate breathing for mangroves (Hariyanto et al., 2019). Mangrove species are distributed differently within mangrove ecosystems depending on tidal levels (low, medium, high) and the elevation of each area, as well as the type of substrate they grow in. Most mangrove species are found from midstream (seaward) to inland areas (Primavera et al., 2012, 2014).

Table 1. Mangrove vegetation assessment using drone and ground check in Jangkang River, Liong River, Kembung Luar River, and Sebauk River in March 2024

Species	Drone												Ground Check											
	Jangkang			Liong			Kembung Luar			Sebauk			Jangkang			Liong			Kembung Luar			Sebauk		
	u	m	d	u	m	d	u	m	d	u	m	d	u	m	d	u	m	d	u	m	d	u	m	d
Rhizophora apiculata	√	√	√	√	√	√	√	-	-	√	√	√	√	√	√	√	√	√	√	-	-	-	√	√
Xylocarpus granatum	√	√	√	√	√	√	√	√	√	-	√	√	√	√	√	-	√	√	√	√	√	-	√	√
Nypa fruticans	√	√	√	-	-	√	√	√	-	√	√	-	-	-	-	-	-	-	-	-	-	√	√	-
Sonneratia caseolaris	√	-	√	-	-	-	-	-	-	√	√	√	-	-	√	-	-	-	-	-	-	-	√	-
Avicennia alba	-	-	-	-	√	√	-	-	-	-	-	-	-	-	-	-	√	√	-	-	-	-	-	-
Sonneratia ovata	-	-	-	-	-	√	-	-	-	-	-	-	-	-	-	-	-	√	-	-	-	-	-	-
Excoecaria agallocha	-	-	-	-	-	-	-	√	-	√	-	-	-	-	-	√	-	-	√	√	-	√	-	-
Rhizophora mucronata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	√	-	-	-	-	-	-
Bruguiera parviflora	-	-	-	-	-	-		√	√	-	-	-	-	-	-	-	-	√	√	√	√	-	-	-
Scyphiphora hydrophylacea	-	-	-	-	-	-	-	-	√	-	-	-	-	-	-	-	-	-	-	-	√	-	-	-
Avicennia marina	-	-	-	-	-	-	-	-	-	√	√	-	-	-	-	-	-	-	-	-	-	√	√	-
Number of Species	**4**	**3**	**4**	**2**	**3**	**5**	**3**	**4**	**3**	**5**	**5**	**3**	**2**	**2**	**3**	**2**	**3**	**6**	**4**	**3**	**3**	**3**	**5**	**2**

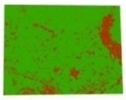
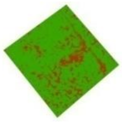
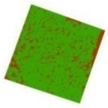
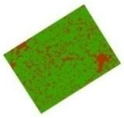
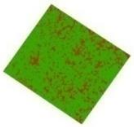
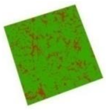
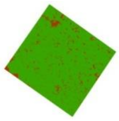
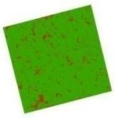
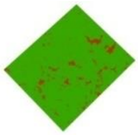
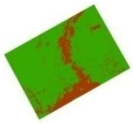
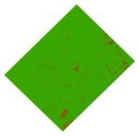
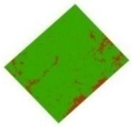
Description: u: upstream, m: midstream, d: downstream

Mangrove cover

Based on the Indonesian National Standard (SNI) 7717-2020 regarding Mangrove Geospatial Information Specifications, all rivers in this study have canopy cover categorized as dense mangroves, with a canopy cover between 70-90%. All rivers have a canopy cover exceeding 0.7 ha of a total sampling area of 1 ha (Table 2).

The mangrove cover in the upstream, middle, and downstream sections of all rivers is in good condition and classified as dense. There is little variation in mangrove cover from upstream to downstream.

Table 2. Mangrove cover conditions using Supervised Image Analysis in Jangkang River, Liong River, Kembung Luar River, and Sebauk River in March 2024

River	Station	Drone Image	Supervised Image Analysis	Covered Area (%)	
				Vegetation	Non-Vegetation
Jangkang	Upstream			0.86	0.14
	Midstream			0.82	0.18
	Downstream			0.81	0.19
Liong	Upstream			0.75	0.15
	Midstream			0.79	0.21
	Downstream			0.82	0.18
Kembung Luar	Upstream			0.92	0.08
	Midstream			0.90	0.10
	Downstream			0.93	0.07
Sebauk	Upstream			0.82	0.18
	Midstream			0.95	0.05
	Downstream			0.89	0.11

The Kembung Luar River has a higher canopy cover compared to other areas because it is part of a mangrove restoration program that began in 2022. This initiative, known as the Mangrove Ecosystem Restoration Alliance (MERA), is a collaboration between Yayasan Konservasi Alam Nusantara (YAKN), HSBC, and the Climate and Land Use Alliance (CLUA). This program is also supported by the Bengkalis Regency government and the NGO Bahtera Melayu Bengkalis Regency. Implementing multi-stakeholder management through close collaboration with local governments, the private sector, NGO facilitators, and international donor agencies is a key step toward optimizing mangrove conservation efforts (Nawari et al., 2021).

Based on field observations, the program appears to be effective, as indicated by the presence of signboards at the research site and interviews with local fishermen, such as Indra from the Kembung Luar River. According to the information gathered, the community has been informed not to cut mangroves along the Kembung Luar River, with certain sanctions or activities that damage the mangroves. In addition to Kembung Luar Village, Teluk Pambang Village is also part of the MERA program(PPID Kab. Bengkalis, 2022).

Typically, the density of mangrove vegetation is affected by various pressures on coastal areas. This leads to changes in the structure and composition of mangrove ecosystems, resulting in habitat loss for flora and fauna, as well as increased levels of sedimentation and abrasion (Kaskoyo et al., 2023). This information indicates that, in allthese research locations, the disturbances encountered have not had a significant impact, largely due to the restoration activities conducted by the restoration group and traditional logging (small productivity). In addition, the practice of illegal logging for household fuel has slightly decreased due to the shift toward using liquefied petroleum gas (Ismail et al., 2021).

Water chemistry and physics

Water quality in a body of water plays a crucial role in supporting and stimulating metabolic processes in mangroves (Hastuti et al., 2020). Therefore, measuring water quality at the research site is essential. The physical and chemical parameters of the water indicate that the water quality is quite good. The water current is slow, with speeds ranging from 0.04 to 0.27 m per second. Almost all the rivers have shallow clarity levels, except for the middle and downstream sections of the Kembung Luar River, which have greater clarity (more than 1 m). The substrate is predominantly mud and sandy mud in the downstream areas. The pH of the water is more alkaline, while the soil pH is generally close to neutral. Dissolved oxygen levels at all locations are slightly below the normal conditions typically found in rivers. Salinity levels varied depending on the location of the measurements, with areas closer to the sea showing higher levels compared to those further inland (Table 3).

Table 3. Physico-chemical parameters of Jangkang River, Liong River, Kembung Luar River, and Sebauk River in March 2024

River	Station	Parameter							
		Physics				Chemistry			
		Temperature (°C)	Velocity (m/s)	Brightness (cm)	Substrate	pH Water	pH Soil	DO (mg/L)	Salinity (ppt)
Jangkang	Upstream	29.0	0.16	26.7	Mud	5.8	6.3	5.3	5
	Midstream	30.0	0.07	39.5	Mud	6.5	6.2	5.4	8
	Downstream	32.3	0.09	68.3	Sandy-mud	6.9	6.9	6.0	18
Kembung Luar	Upstream	35.4	0.04	59.0	Mud	9.0	6.3	5.4	15
	Midstream	35.3	0.04	113.0	Sandy-mud	8.5	6.2	4.5	22
	Downstream	30.1	0.07	117.5	Sandy-mud	7.4	6.9	6.7	25
Liong	Upstream	33.0	0.16	19.2	Mud	5.1	6.9	6.0	0
	Midstream	35.0	0.08	18.5	Mud	6.5	6.9	4.9	3
	Downstream	34.0	0.22	19.5	Sandy-mud	7.8	6.2	5.2	18
Sebauk	Upstream	29.0	0.07	41.0	Mud	8.6	6.0	11.8	24
	Midstream	34.0	0.12	46.5	Sandy-mud	10.5	5.2	13.6	26
	Downstream	35.0	0.27	46.5	Sandy-mud	11.9	5.2	11.0	20

The temperature range at the study site is classified as very good for mangrove growth, as the optimum temperature for mangroves falls between 28ºC and 35ºC (Haya et al., 2016). The temperature in this study ranged from 29ºC to 35.4ºC and was categorized as the optimal temperature. Water temperature is crucial because it regulates biological activity and the solubility of gases in water. In general, surface water temperature is influenced by the intensity of solar radiation, evaporation, freshwater influx, as well as cooling and mixing with the tidal waters of the adjoining ocean (Dattatreya et al., 2018). Changes in water temperature can significantly impact water conditions, as temperature is directly linked to the water cycle. These changes can alter the stratification of the water column and affect the availability of resources, particularly nutrients (Rahmawati et al., 2017).

The velocity of flows in all rivers is nearly the same and does not significantly impact the conditions of the waters at the study site. Because the velocity is relatively slow, it does not substantially affect the condition of the mangroves. However, high tidal velocities determine the level of growth, as they carry organic matter and contribute to sedimentation. Additionally, the velocity affects the dispersal of seeds that are distributed by the flow(Zhang et al., 2020).

In this study, the overall substrate consists of mud and sandy mud, which is highly productive. Substrate texture is a key physical characteristic that influences water flow potential, water holding capacity, and fertility potential. It also affects the biological stability of organic matter by regulating the availability of water and oxygen, as well as the accumulation and isolation of organic matter from decomposers(Dewiyanti et al., 2021).

Salinity is strongly affected by seawater intrusion, driven by tidal processes that create regions of bistability in the saltwater surface. These regions can also be formed by natural disasters, such as storms and tsunamis(Jiang et al., 2015).Individual mangrove species have an optimal salinity range for growth and development: downstream (27% to 28%), midstream (1% to 17%), and upstream (0% to 4%). This variation in salinity affects mangrove distribution. Mangrove species achieve optimal growth rates at elevations with low salinity(Cuenca et al., 2015). Fluctuations in salinity impact the biological characteristics of the ecosystem. High salinity in a body of water lowers its water potential. As a result, roots struggle to absorb water, even as the transpiration rate remains high. This condition leads to physiological drought, which can disrupt the plant's physiological mechanisms (Tobing et al., 2022). Salinity is a key factor that determines the composition of biological components and the distribution of living organisms in the mangrove environment(Dattatreya et al., 2018).

This study utilizes drone technology combined with advanced image analysis to assess mangrove cover in Jangkang River, Liong River, Kembung Luar River, and Sebauk River. The use of drones allows for high-resolution spatial data collection, enabling precise and efficient mapping of mangrove vegetation. Unlike traditional methods, this approach minimizes fieldwork limitations and enhances the accuracy of cover classification. By integrating drone imagery with supervised analysis and ground validation, this research offers a methodology for monitoring mangrove ecosystems, providing valuable insights for conservation and sustainable management strategies.

CONCLUSION

Along the river, eleven mangrove species were identified: 10 species were identified using drones, and one additional species was identified through ground checking. The most common species at all locations were *Rhizophora apiculata* and *Xylocarpus granatum*. The canopy cover in all research locations is classified as dense mangroves, with values exceeding 75%. The supervised image analysis method using drone images is effective for analyzing vegetation, especially mangroves in challenging terrain. This research relies solely on the interpretation skills of the interpreter. For future studies, it is recommended to use the hue value method with Adobe Photoshop software to enhance the identification of mangrove species.

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