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Detection and analysis of mangrove cover change in Kepalajerih Island, Batam, Indonesia using Landsat Imagery

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Abstract. *Aunurrahman, Anggoro S, Muskananfola MR, Saputra SW. 2023. Detection and analysis of mangrove cover change in Kepalajerih Island, Batam, Indonesia using Landsat Imagery. Biodiveritas 24: 6126-6133.* For small islands, the mangrove ecosystem is crucial since it offers a variety of goods and services. In this study, we analysed the distribution and coverage of the mangrove ecosystem in Kepalajerih Island, Batam, Indonesia as well as the changes in mangrove ecosystem coverage over time. We also identified the required bands and their value range of Landsat data for mangrove detection. The research was carried out by applying reflectance selection to detect mangrove ecosystems. Landsat Imagery was used in the analysis, including Landsat 5 TM imagery of 1997 and Landsat 8 OLI imagery of 2015 and 2022. The result found that the combination of bands 1 and 5 of Landsat 5 TM or bands 2 and 6 of Landsat 8 OLI are applicable for mangrove detection. Reflectance of B1 or B2 less than 0.0325 indicates vegetation, while reflectance of B5 ranges from 0.0337 to 0.0837 or B6 ranges from 0.0454 to 0.0928, indicating wetland area. Therefore, the combination of both bands makes up for the mangrove area. Based on the analysis result, mangrove coverage in Kepalajerih Island fluctuated from 1,310.27 ha in 1997 to 1,117.29 ha in 2015 and then to 1,188.77 ha in 2022. The fluctuation was caused by a mangrove loss of as much as 262.17 ha and an expansion of 69.18 ha during 1997-2015, and a mangrove loss of 99.39 ha and an increase of 170.88 ha during 2015-2022. The natural drivers likely caused the fluctuation of mangrove coverage.

Keywords: Band combination, fluctuation, mangrove coverage, natural drivers, reflectance

INTRODUCTION

The mangrove ecosystem is crucial for safeguarding coastal areas. In small islands, the significance is even greater. Due to climate change, the small island is vulnerable to increasing sea levels, increased temperatures and rainfall, a loss in freshwater supplies, food poverty, and coral bleaching (Mycoo 2018). In small islands, mangrove is a barrier to various environmental pressures, especially climatic and hydro-oceanic factors such as storm surges and seawater flooding (Soanes et al. 2021). Mangrove forest is expected to protect and maintain the coastline by preventing soil erosion from occurring (Kazemi et al. 2021; Pennings et al. 2021). Mangroves, through their roots, provide sediment stability in the coastal area. Thus, sediment transport driven by tidal and shore currents is controlled (Pennings et al. 2021).

Mangrove is the habitat of various aquatic and terrestrial species (Rog et al. 2017). Mangrove also acts as a sink at carbon and source of nutrient, ensuring the long-term availability of nutrients and reducing coastal pollution (Kaiser et al. 2015). The ecological function of mangroves also includes their ability to prevent seawater intrusion (Hilmi et al. 2017). Mangrove is a dynamic ecosystem in the coastal area where tidal activities occur. Normally, the mangrove ecosystem would expand due to the sediment settlement in the coastal areas, which promotes the establishment of new dunes as growing areas for mangroves (Saintilan et al. 2014; Hoppe-Speer et al. 2015). But because mangroves are found in storm-prone coastal locations, the establishment of a mangrove ecosystem may be disrupted, changing its extent and coverage over time (Balke et al. 2015; de Jong et al. 2021). For the purpose of managing mangroves, information about their distribution on small islands is crucial (Cameron et al. 2021). The condition of the mangrove ecosystem on a small peninsula indicates its vulnerability to coastal disturbances (Moschetto et al. 2021). Additionally, monitoring changes in the mangrove ecosystem's coverage is crucial for identifying potential causes and their potential effects (Cameron et al. 2021).

Batam City is an area in the province of Kepulauan Riau, Indonesia that undergoes intense environmental pressure due to massive industrial activity. The activity is mainly concentrated in Batam Island. However, the surrounding islands uphold an essential role in supporting the livelihood of Batam City, especially related to the provision of natural resources such as food. Kepalajerih Island is one of the islands surrounding Batam Island. Kepalajerih Island has an area of 25.80 km^2 with a coastline length of 36.51 km. Referring to the spatial planning of Batam City, Kepalajerih island acts as a supporting area. The spatial land area utilization includes agriculture, aquaculture, settlement, and mangrove conservation. At the same time, the utilization plan for marine areas includes marine culture and tourism.

Satellite imagery has been used for various mapping purposes, such as land cover change, vegetation/crop health, mineral detection, erosion, accretion, and shoreline change (Liu et al. 2017; Kayet et al. 2019; Kamga et al. 2020; Muskananfola et al. 2020). Satellite imagery is needed to map the distribution and condition of resources with vast area coverage. It's also required to perform historical tracking for past years. Landsat Imagery is a handful of data sources primarily related to earth surface coverage (Fu and Weng 2016). Landsat Imagery data is provided by the United States Geological Survey (USGS) and freely accessible through the portal earthexplorer.usgs.gov. Landsat Imagery has a typical resolution of 30 × 30 m, which could be enhanced to 15 × 15 m by integrating a panchromatic band; it is also frequently used in mangrove coverage mapping and analysis (Son et al. 2015; Umroh et al. 2016; Otero et al. 2019). This research aimed to identify the required bands and their value range of Landsat Imagery for mangrove detection, with example research from Son et al. (2015), Umroh et al. (2016), and Otero et al. (2019), but just different locations. The purpose is similar to analyzing the distribution and coverage of the mangrove ecosystem, and this research aims to analyze the over-time changes in mangrove ecosystem coverage on Kepalajerih Island.

MATERIALS AND METHODS

The area of interest of this research is Kepalajerih Island in Batam City, Province of Riau Islands, Indonesia (Figure 1). As a small island located in Batam waters, oceanographically, the waters of Kepalajerih Island are influenced by the west and east monsoon and transitional seasons that characterize seasons in Indonesian seas (Muskananfola et al. 2021) . The observation was focused on the change in mangrove coverage for the last 25 years. The data used in this research was satellite imagery, including Landsat 5 TM images and Landsat 8 OLI images. The use of Landsat satellite imagery has good resolution for identifying objects in this research. Multi-year detection of mangrove coverage was performed for three sampling periods, including 1997, 2015, and 2022. Satellite imagery data was obtained from USGS (earthexplorer.usgs.gov).

Data analysis was performed using QGIS software. Pre-processing analysis was performed with a Semi-Automatic Classification Plugin (SCP) for radiometric correction, and the method used to detect mangrove coverage was stepwise extraction. Landsat Imagery bands' digital numbers were extracted to identify and distinguish mangrove areas from other ranges, such as sea, non-vegetation, and non-mangrove vegetation. The bands used for the analysis were Bands 1 and 5 for Landsat 5 TM imagery and Bands 2 and 6 for Landsat 8 OLI imagery representing Blue and shortwave infrared bands. The procedure of mangrove identification was as follows: (i) distinguishing land area and sea areas; (ii) distinguishing vegetation and non-vegetation areas; (iii) distinguishing mangroves from other vegetation types. The procedure of mangrove detection and analysis applied in this research is shown in Figure 2.

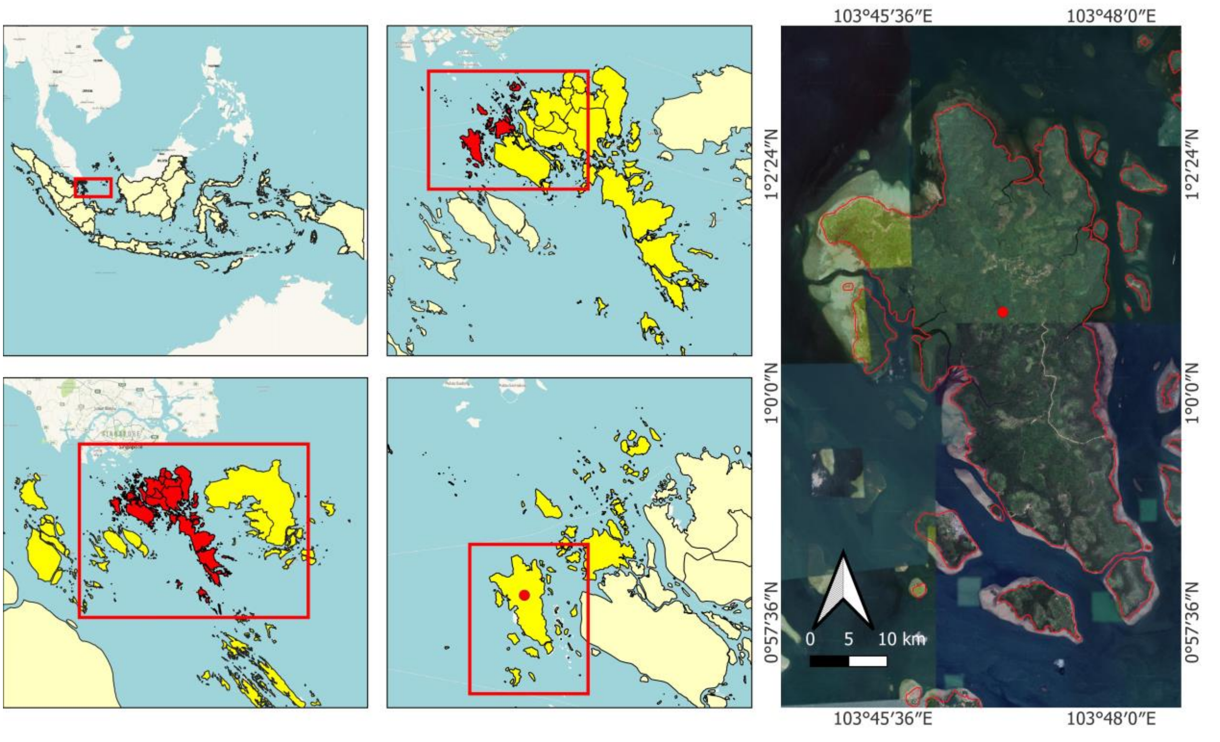


Figure 1. Research location Kepalajerih Island, Batam, Riau Islands, Indonesia

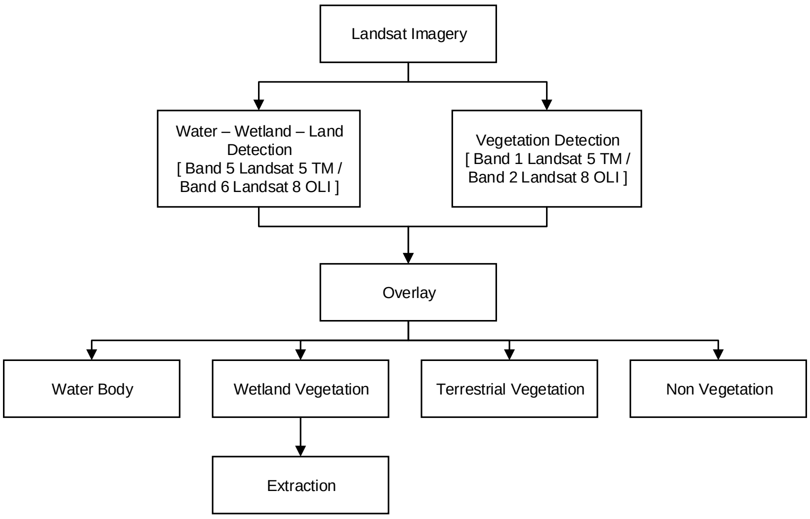


Figure 2. The procedure of mangrove detection and analysis

Validation was performed by comparing the obtained coverage to RGB data visualization. The band combination used for RGB visualization was 321 and 521 for Landsat 5 TM and 432 and 632 for Landsat 8 OLI. The 321/432 band combination was used to visualize true color of the earth surface and to validate identified vegetation areas. The 521/632 combination emphasized the wet vegetation area, distinguishing the mangrove ecosystem from other vegetation. The obtained mangrove coverage and distribution map were then calculated for the extent of the respective year. Further analysis was carried out to detect mangrove coverage and distribution changes. The study was performed through an overlay of mangrove coverage among samples. Later, analysis was performed to calculate the extent of mangrove loss and expansion. Thus, an overlay analysis was performed to identify the changes in mangrove coverage over time.

RESULTS AND DISCUSSION

The study discovered that bands 5 and 6 of Landsat 5 TM and Landsat 8 OLI can be used to discriminate between dry land and wetland areas as well as between land area and water bodies. According to the analysis, the threshold to distinguish between land and water was 0.0325, with digital value of pixels-Digital Number (DN) is shows the summary of band combination and the digital number range for detecting mangrove ecosystems.

Refer to the summary of band combination and digital number ranges; mangrove detection could be formulated in the following algorithm:

Landsat 5 TM: If B5<0.0325, then "water" else if B1<0.0325 then if B5<0.0337 then "other vegetation" else if B5<0.0837 then "mangrove" else "other vegetation" else "non vegetation"

Landsat 8 OLI: If B6<0.0325 then "water" else if B2<0.0325 then if B6<0.0454 then "other vegetation" else if B6<0.0928 then "mangrove" else "other vegetation" else "non vegetation"

0.0325 standing for land area and DN 0.0325 for water body. The analysis result was then used to mask the land area for vegetation coverage analysis. The next step was to identify the vegetation coverage in Kepalajerih Island. This process used band 1 of Landsat 5 TM and band 2 of Landsat 8 OLI. Those bands are applicable to distinguish vegetated and non-vegetated areas. The analysis found that the DN threshold was 0.0325, where DN $<$ 0.0325 represents the vegetated area while DN $\geq$ 0.0325 represents the non-vegetated area. Determination of mangrove coverage was performed based on the distribution of vegetation resulting in this process. Therefore, to identify mangrove coverage from other vegetation, analysis was performed to determine the wetness of the land cover. Mangrove is a wetland ecosystem, which shows that it is supposed to inhabit areas with high moisture or wet areas. This research found that the mangrove ecosystem could be distinguished from non-mangrove vegetation using bands 5 of Landsat 5 TM and 6 of Landsat 8 OLI. The DN range for the wet/moist area in band 5 of Landsat 5 TM was 0.00337 - 0.0837, while in band 6 of Landsat 6 OLI was 0.0454 - 0.0928.

Mangrove ecosystem could be detected by combining Landsat Imagery bands, including Band 1 and Band 5 for Landsat 5 TM and Band 2 and Band 6 for Landsat 8 OLI. By combining those bands, mangrove coverage, and distribution detection could be carried out.

Analysis of mangrove coverage showed that the Kepalajerih Island's ecosystem changes dynamically over time. Based on the analysis, mangrove coverage in Kepalajerih Island was 1,310.27 ha in 1997, decreased to 1,117.29 ha in 2015, and then increased to 1,188.77 ha in 2022. Based on the coverage changes, the mangrove ecosystem in Kepalajerih Island decreased as much as 192.99 ha during 1997 - 2015 and increased as much as 71.48 ha during 2015-2022. Detailed mangrove coverage and distribution in Kepalajerih Island in 1997, 2015, and 2022 are presented in **Error! Reference source not found.**.A-C.

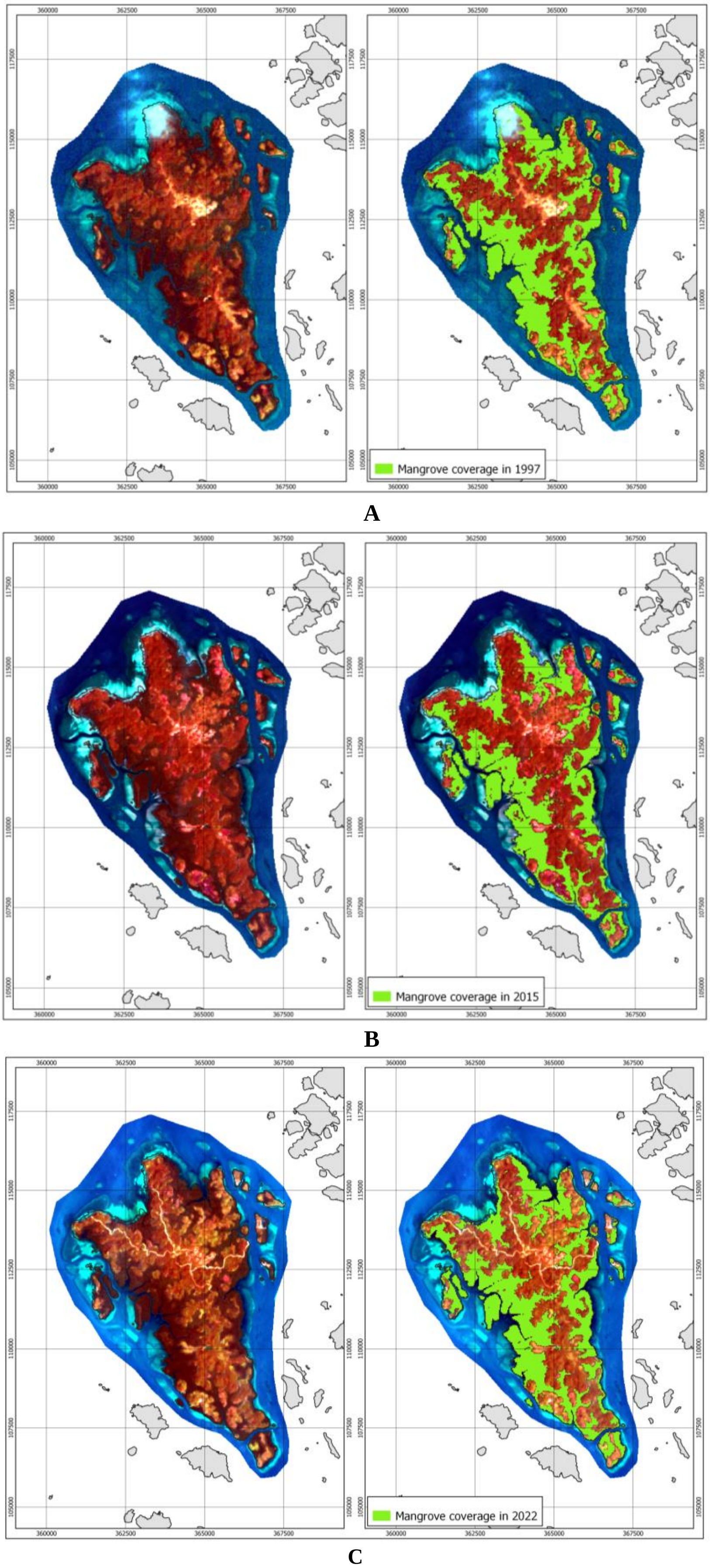


Figure 3. Coverage and distribution of mangrove ecosystem in Kepalajerih Island, Batam, Riau Islands, Indonesia in: A. 1997; B. 2015; C. 2022

Referring to the analysis result, mangrove ecosystem coverage changes over time. This suggests that there should be changes in the fluctuation of the species composition and abundance of the mangrove ecosystem in the study area. The research found that the changes in mangrove coverage in Kepalajerih Island included mangrove loss and expansion. From 1997 to 2015, mangrove loss was detected as much as 262.7 ha, while the growth was 69.18 ha. Later, during 2015-2022, the loss was only 99.39 ha, while the expansion was 170.88 ha. Cumulatively, during 1997-2022, there were 166.56 ha of mangrove loss and 45.05 ha of mangrove expansion. This indicates that some of the lost mangrove coverage was recovered. A detailed analysis of the dynamic of mangrove coverage and distribution is shown in Table 1.

Referring to the coverage changes and time intervals, the average rate of mangrove loss from 1997 to 2015 was approximately 10.72 ha/year. This suggests that about 0.89% of mangrove coverage declined each year. However, from 2015 to 2022, the mangrove ecosystem was expanded with an average annual rate of 10.21 ha/year. This accounts for a 0.89%/year increase in mangrove coverage. Since mangrove coverage declined from 1997 to 2015 and increased again from 2015 to 2022, the cumulative change of mangrove coverage should be lower. Based on the analysis result, the cumulative rate of mangrove coverage decline was 4.86 ha/year or 0.39%/year. Detailed changes in mangrove coverage and distribution in Kepalajerih Island from 1997 to 2022 are shown in Figure 4.A-C.

Figure 3.A demonstrates that mangrove loss most likely happened on the land side, where the mangrove ecosystem interacts with terrestrial regions, between 1997 and 2015. Meanwhile, mangroves have grown along the shoreline. However, Figure 3.B demonstrates that the change in mangrove coverage from 2015 to 2022 followed a paradoxical pattern. Mangrove growth occurred on the land side, while mangrove loss occurred on the beach. Figure 3.C, on the other hand, demonstrated that the loss of mangrove coverage in land and shore areas was likely greater than its expansion.

Discussion

The research shows that Landsat Imagery is applicable for detecting of mangrove coverage and distribution. the combination of bands 1 and 5 in Landsat 5 TM or bands 2 and 6 in Landsat 8 OLI are required to detect mangrove coverage. The band combination is expected to appropriately identify mangrove ecosystems based on the characteristics of mangrove vegetation: wetlands.

Band 1 of Landsat 5 TM and band 2 of Landsat 8 OLI represent the blue band, which is part of visible light. This band is frequently used along with other bands, such as red, green, and near-infrared, to detect land surface coverage (Feng et al. 2015; Xue and Su 2017; Zhang et al. 2019). However, the finding of this research suggests that the blue band alone could not be used in detecting vegetation, especially for trees.

Band 5 of Landsat 5 TM and band 6 of Landsat 8 OLI are applicable for detecting wetlands. The bands are characterized as short-wave infrared. According to Yue et al. (2019), short-wave infrared is applicable for detecting bare soil moisture. Moreover, the applicability of the shortwave infrared band is not limited to soil moisture detection, but also to the detection of water content in vegetation. Sánchez-Ruiz et al. (2014) found that combining shortwave infrared and near-infrared bands could detect vegetation water content. The finding also suggests a novel method for mangrove ecosystem detection. Typically, vegetation detection is carried out through algorithm applications, such as DVI, NDVI, EVI, PVI, GRVI, MGRVI, and NGRVI (Xue and Su 2017; Zhang et al. 2019). However, this research found that reflectance screening is also applicable.

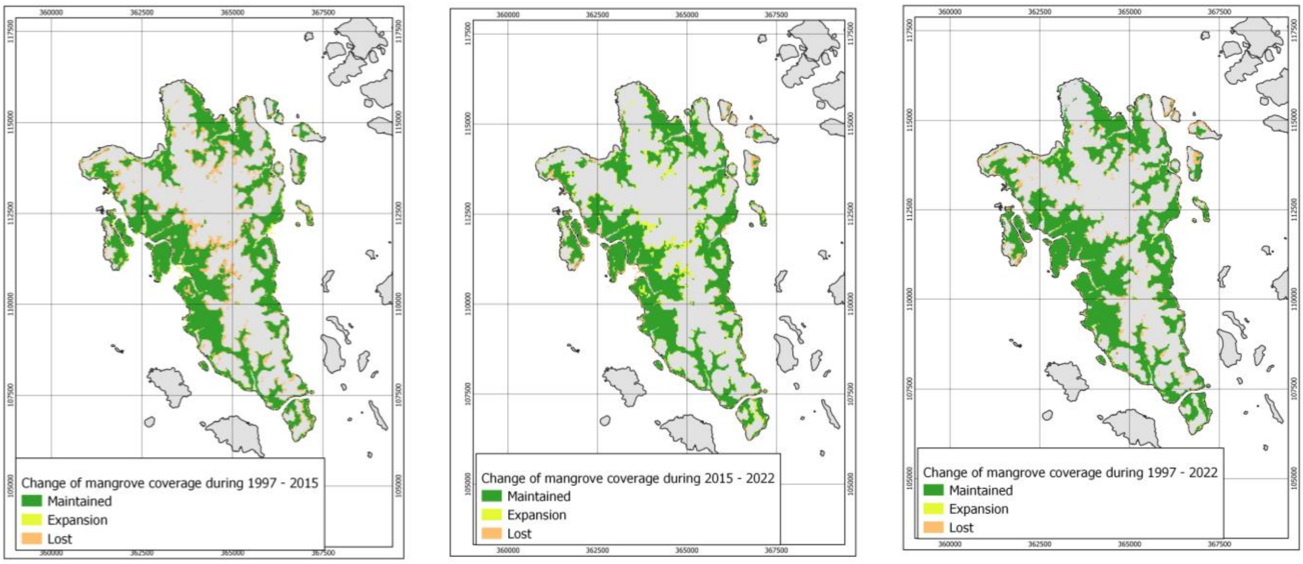
The research suggests that Kepalajerih Island's mangrove ecosystem dynamically changes in terms of coverage and distribution over time. However, the changes were considerably low, with only a 14.73% of coverage decline in 18 years (1997-2015) and a 6.40% of coverage increase in 7 years (2015-2022). The loss and expansion rate shows it could be considered that natural drivers caused the change in mangrove coverage. The research results suggested that from 1997 to 2015, the mangrove ecosystem in the land side undergo ecological succession. Naturally, the mangrove ecosystem would undergo ecosystem succession, and a gradual change in mangrove habitat conditions and species composition (Chen et al. 2018). Typically, after the late stage of the succession, the mangrove ecosystem would enter a transitional phase and finally become terrestrial (Zhang et al. 2019).

Table 1. Change of mangrove coverage in Kepalajerih Island, Batam, Riau Islands, Indonesia

Mangrove Coverage	Periods		
	1997-2015	2015-2022	1997 - 2022
Maintained (ha)	1,048.10	1,017.89	1,143.72
Lost (ha)	262.17	99.39	166.56
Expanded (ha)	69.18	170.88	45.05

Table 2. Summary of band combination and digital number ranges for detection of mangrove ecosystem

Imagery	Band	Reflectance		B1 Landsat 5 TM / B2 Landsat 8 OLI	
				<0.0325	≥0.0325
Landsat 5 TM	B5	< 0.0325		Waterbody	Waterbody
		≥ 0.0325	<0.0337	Other vegetation	Non-vegetation
			0.0337-0.0837	Mangrove	Non-vegetation
			>0.0837	Other vegetation	Non-vegetation
Landsat 8 OLI	B6	< 0.0325		Waterbody	Waterbody
		≥ 0.0325	<0.0454	Other vegetation	Non-vegetation
			0.0454-0.0928	Mangrove	Non-vegetation
			> 0.0928	Other vegetation	Non-vegetation



A B C

Figure 3. Change of mangrove coverage in Kepalajerih Island, Batam, Indonesia: A. 1997-2015; B. 2015-2022; C. 1997-2022

The dynamic distribution of flora is typically related to the availability of suitable habitat. Plants tend to grow while a suitable habitat is available and removed when the habitat becomes unsuitable. In terms of the mangrove ecosystem, the suitable habitat would be wetlands. However, in the coastal area, wetlands coverage could dynamically change. Various drivers such as sedimentation, erosion, elevation change, and sea level rise could cause the dynamics.

The dry-up process typically drives the shift from mangrove ecosystem to the terrestrial ecosystem (Ramakrishnan et al. 2020). The drying-up process in mangrove ecosystems is promoted by sediment and litter accumulation in mangrove floors. The mangrove ecosystem is an ecosystem with a high sedimentation rate. Mangrove roots typically acts as sediment traps in the coastal area (Sarker et al. 2021). Thus, soil elevation within the mangrove ecosystem would gradually alter over time. Research carried out by Hongwiset et al. (2022) showed that the accretion rate within the mangrove ecosystem is higher the farther the distance from the coastline. On the other hand, the inundation frequency also decreases. Therefore, it is relevant to the finding of this research where mangrove ecosystem loss occurred in the landward. The mangrove ecosystem in Kepalajerih Island tended to lose its suitable habitat due to sedimentation, which led to soil stabilization. Over time, terrestrial plants replaced mangrove plants (Chen et al. 2018).

A contrary trend of mangrove coverage change observed from 2015 to 2022 showed the re-establishment of the mangrove ecosystem in the land area. The expansion of the mangrove ecosystem landward could be due to the occurrence of the sea level rise. Sea level rise caused an increase in the sea level, causing the seawater to reach more profound in the land area (Di Nitto et al. 2014). In the case of Kepalajerih Island, the sea level rise promotes the re-habitation of the previous mangrove area. According to Törnqvist et al. (2020) current sea level rise rate ranges from 6 to 9 $mm.year^{-1}$, this rate is considered threatening to mangroves. According to Saintilan et al. (2020), a sea level rise rate of over 6 $mm.year^{-1}$ causes mangroves to be unable to sustain accretion. The loss of mangrove coverage in the shore area was suggested as the impact of the destabilization of mangrove sediment.

Mangrove coverage and distribution dynamics in Kepalajerih Island are considered a natural occurrence. This suggestion is based on the fact that the mangrove coverage decline from 1997 to 2015 was low. Moreover, the lost mangrove coverage was reclaimed from 2015 to 2022, indicating the maintained suitability for mangrove growth. Typically, rapid change in mangrove coverage is the result of anthropogenic impact. According to Moity et al. (2019), mangrove clearing for aquaculture activity is the main cause of rapid mangrove loss, while active reforestation drives rapid expansion. However, such kind of utilization was absent from the area. Referring to the result, the mangrove ecosystem in Kepalajerih Island is under threat of sea level rise rather than anthropogenic factors. There were at least 121.50 ha of mangrove coverage decline in Kepalajerih Island during the past 25 years (1997-2022). Even though most of the coverage is maintained, the possibility of further decline still remains. Therefore, proper management is necessary to ensure the sustainability of the mangrove ecosystem in Kepalajerih Island.

Proper management of the mangrove ecosystem is necessary in order to mitigate the impact of global warming. Participative management could be taken as an option in managing the mangrove ecosystem. Through participative management, mangrove sustainable management could be applied while supporting the local community's economics (Puryono and Suryanti 2019). This could be done by integrating economic activity into the conservation effort; another effort that could be made is mangrove planting. According to Lubis et al. (2018), the shoreline in the Batam area is dominated by sand and mud, which are potential substrates for mangrove growth. Mangrove planting is expected to prevent further withdrawal of the mangrove ecosystem from the shoreline, which would likely happen as the sea level's impact rises.

In conclusion Landsat Imagery is applicable for detecting mangrove coverage and distribution by combining bands 1 and 5 in Landsat 5 TM and bands 2 and 6 in Landsat 8 OLI. The combination includes B1 <0.0325 and $0.0337 \leq B5 \leq 0.0837$ for Landsat 5 TM and B2 <0.0325 and $0.0454 \leq B6 \leq 0.0928$ for Landsat 8 OLI. Mangrove coverage in Kepalajerih Island changed over time, from 1,310.27 ha in 1997, decreased to 1,117.29 ha in 2015, and then increased to 1,188.77 ha in 2022. Loss and expansion of the mangrove ecosystem were identified from the overlay of mangrove coverage, including the loss of 262.17 ha and expansion of 69.18 ha from 1997 to 2015 and loss of 99.39 ha and expansion of 170.88 ha from 2015 to 2022. The natural drivers likely influence mangrove-ecosystem coverage dynamics in Kepalajerih island. Thus, further concern is needed to ensure its sustainability.

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