Land Cover Changes in Oil-Spill Affected Area: A Case Study in Pulau Rambut Wildlife Sanctuary

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ABSTRACT

An offshore oil spill near Karawang, West Java, in July 2019 caused a considerable impact on the Pulau Rambut Wildlife Sanctuary, a protected area known for its mangrove ecosystems, which provide crucial habitat for waterbirds in Jakarta Bay. The purpose of this study was to map and quantify land cover types on Pulau Rambut, as well as examine land cover changes three years after the spill, with a focus on mangrove dynamics. Land cover categorization was performed using the Maximum Likelihood (ML) method applied to remote sensing data from SPOT-6 and SPOT-7 satellite photos for 2019, 2020, and 2021. Ground truthing and drone imagery were used to validate categorization results, and accuracy was determined using the Kappa statistics. All classes had strong levels of agreement, with Kappa values of 85.66%, 81.40%, and 82% in 2019, 2020, and 2021, respectively. Four types of land covers were identified: mangroves, non-mangrove forests, water bodies, and open spaces. Pulau Rambut has an expected mangrove covering of 18.80 ha in 2019, which increased to 21.15 ha in 2020 before significantly declining to 18.84 ha in 2021. These findings are consistent with field data, in which 12 of 13 MHI (Mangrove Health Index) plots were classed as moderate. This data implies that the 2019 oil spill did not result in a significant or long-term loss in mangrove area on Pulau Rambut.

Keywords: mangrove, maximum likelihood, oil spill, Pulau Rambut, SPOT-6/7

INTRODUCTION

Mangroves are a major vegetation type composed of trees and shrubs that thrive in the intertidal zone of the sea or tropical coasts under harsh, constrained, and dynamic conditions (Duke 1992; Ellison 1994). Pollution is one of the principal causes of mangrove forest destruction, and oil spills are a major contributor (Kusmana *et al*. 2003). Crude oil spilled from offshore drilling by Pertamina Hulu Energi Offshore North-West Java (PHE ONWJ) in July 2019 near Karawang, West Java, could have a substantial impact on coastal ecosystems. Within a few days, the crude oil contamination spread to Pulau Rambut, a nature refuge in the Jakarta Bay area. Pollution caused by oil spills can have negative consequences such as increased stress on mangroves, yellowing leaves (wilting), defoliation of mature trees resulting in reduced crown production and canopy cover, and even tree death and seedling failure depending on the severity of the spill (Mardiastuti *et al*. 2020; Munggaran *et al*. 2021).

Mangrove forests help to mitigate natural events such as waves, storms, and abrasion while also acting as a buffer for marine species (Soraya *et al*. 2012). Mangrove also provides habitat for waterbirds (Mardiastuti *et al*. 2020). Mangroves cover about half of Pulau Rambut and serve as important roosting and nesting grounds for 15 species of waterbirds (Mardiastuti *et al.* 2020), after a field inspection in August 2019. They found no signs of death, near-death, leaf fall, damage, or defects in mature mangrove plants. Seedlings and saplings also looked healthy.

According to research conducted around the world, mangrove responses to oil spills are typically delayed. Significant impacts and symptoms generally appear in the second, third (Lamparelli *et al*. 1997), and even tenth year. However, indicators of mangrove stabilization responses typically develop in the fourth year. The purpose of this work was to evaluate land cover changes over three years after the spill, with a special emphasis on mangrove dynamics.

METHODS

Study Area

The research started in January 2025. The data collection was carried out in March 2025 at the Pulau Rambut Wildlife Sanctuary (SMPR), located between 106°41'14"−106°41'46" E and 5°56'47"−5°56'57" S on Untung Jawa Island, Seribu Islands District, Seribu Islands Administrative Regency, DKI Jakarta Province (Figure 1), for data validation in the form of ground

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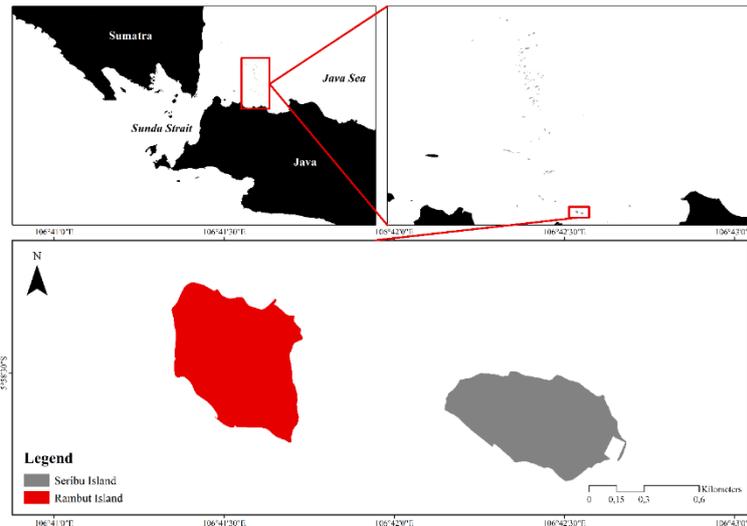* Corresponding Author: Email: lbprastdp@apps.ipb.ac.id

Figure 1 Research locations in Pulau Rambut Wildlife Sanctuary.

checks and vegetation analysis. The Environmental Analysis and Geospatial Modelling Laboratory, Department of Forest Resources Conservation and Ecotourism, Faculty of Forestry and Environment, Bogor Agricultural University, managed and analyzed data from May 2025.

SMPR, as a conservation area, covers approximately 90 ha, with 45 ha of land and 45 ha of water. SMPR contains three types of vegetation: mangrove forests (22.71 ha), lowland forests (16.37 ha), and coastal forests (2.82 ha). Furthermore, the ocean area includes coral reef habitats and seagrass beds (1.79 ha). There are two categories of mangroves in SMPR: primary and secondary. Primary mangroves are always submerged in seawater, whereas secondary mangroves are only submerged when the seawater is high tide (Mardiastuti et al. 2020).

Data Collecting

The data obtained includes both primary and secondary data. Primary data was collected directly from the field, and it included image classification accuracy test data in the form of coordinate points and mangrove data. Additionally, data was gathered through interviews with field officers and the DKI Jakarta BKSDA. Secondary data included information received indirectly, such as SPOT-6 and SPOT-7 imagery data, administrative boundary data, and SMPR shapefiles. It also included information on the distribution of coordinates for oil spill findings made at SMPR in 2019, as well as literatures gathered by searching for publications, journals, or scientific papers from earlier studies.

This study employed Avenza Maps, MonMang 2.0, smartphone cameras, tally sheets, and stationery for field surveys, as well as a laptop with ArcMap software version 10.8, Microsoft Excel, and Microsoft Word for data processing. This study employed SPOT-6 and SPOT-7 satellite imagery to analyze land cover change. The objects observed in this study were mangrove vegetation in areas damaged by the 2019 oil disaster. A ground verification verified the comparability between interpretation results and actual field conditions (Sitanggang et al. 2023).

The ground check location sites were chosen based on the visual interpretation results obtained using the image interpretation elements approach. Ground check operations included documentation, observation of research location conditions and land cover classification, GPS coordinate measurement, and data collection for mangrove vegetation analysis. Purposive sampling was the approach used for collecting sampling points. The ground check coordinate sites were selected based on the presence of mangrove vegetation damaged by the oil spill (primary mangrove), mangrove vegetation unaffected by the oil spill (secondary-associated mangrove), mixed dry secondary forest, coastal forest, and water bodies. Mangrove health was also assessed based on its physical or morphological characteristics.

Classifying Image

Image classification referred to the practice of grouping pixels in a picture into classes that can describe identities with certain features (Sarjani et al. 2017). The method employed was supervised classification using the maximum likelihood algorithm. Supervised digital classification involved categorizing items separately using examples (training area).

Mangrove Health Index (MHI)

This metric is used to assess mangrove health on a spatial scale (Dharmawan & Khoir 2020). Data was collected on three components of mangrove community structure characteristics to calculate the mangrove health index (MHI) using field data.

According to Nurdiansah and Dharmawan (2021), the three components are canopy cover percentage score (Sc), seedling density (Snsp), and tree diameter (Sdbh). Data on the diameters of mangrove trees and stumps were collected in accordance with Minister of Environment Decree No. 201 of 2004, which establishes Standard Criteria and Guidelines for Determining Mangrove Damage.

$$S_c = 0.25C - 13.06$$
$$S_{nsp} = 0.13Nsp + 4.1$$
$$S_{dbh} = 0.45DBH + 1.42$$
$$MHI = \frac{S_C + S_{nsp} + S_{dbh}}{3} \times 10$$

Canopy cover scores (C) were determined for each observation plot, and field-based MHI classification was performed using the MonMang 2.0 application and the hemispherical photography technique. This method involves shooting shots perpendicular to the substrate or vertically towards the sky, capturing the canopy items in the hemisphere photo. According to Dharmawan (2021), MHI values are divided into three categories (Table 1).

RESULTS AND DISCUSSION

Image Classification

The land cover class map is derived from the study of SPOT-6 and SPOT-7 photos classified using the greatest likelihood approach. Field survey data and drone pictures received from the Jakarta BKSDA serve as the primary reference for data training and the identification of mangrove and non-mangrove regions. Land cover classes are classified as mangroves, non-mangrove forests, aquatic bodies, and open regions (Table 2), with the area of each type shown in Table 3.

The overall classifying area for 2019, 2020, and 2021 was 34.96 ha (Figure 2). According to the calculation results, mangroves dominated land cover in 2019, 2020, and 2021, with areas ranging from 18.80 to 21.15 ha (53.78% to 60.52%), while an open area held the smallest land cover area, with an area of 1.01 ha (2.88%). The amount received by the user is less than that obtained by BKSDA Jakarta for the same measurement area. Measurements conducted by BKSDA Jakarta (2024) offer information on the mangrove forest area in SMPR, which is approximately 22.71 ha. Georeferencing accuracy and land cover categorization methods or algorithms can impact differences in land cover area measurements obtained using remote sensing (Doni *et al.* 2021). Furthermore, the image's spatial resolution helps to explain disparities in land cover area.

Mudflats, a type of water body, are a beneficial habitat for aquatic birds. According to Rahayu (11th Apr 2025, pers. comm.), the forest ecosystem controller (PEH) of the Jakarta BKSDA, mudflats are one of the habitat components for water birds that are used as a medium for learning to fly and feeding. This hypothesis is supported by Verheugt's (1987) research, that grey herons (*Mycteria cinerea*) graze in mudflats, fishponds, and rice fields alongside great egrets (*Egretta alba*) and Javanese herons (*Leptoptilos javanicus*). Mudflats are

Table 1 Mangrove Health Index (MHI) value classification

MHI value range (%)	Category
x ≤ 33,33	Poor
33,33 < x ≤ 66,67	Moderate
x > 66,67	Excellent

Table 2 Land cover classes at Pulau Rambut Wildlife Sanctuar (SMPR)

Class types	Color	Information
Mangrove		All types of mangroves including true mangroves and mangrove associations
Non-mangrove forests		Non-mangrove vegetation includes mixed dryland forests and coastal forests.
Water body		Any watery area, such as lagoons, mudflats, swamps, and sea water
Open area		Areas that have no vegetation cover or low vegetation cover

Table 3 Comparison on land cover area in 2019, 2020, and 2021

Land Cover	2019		2020		2021	
	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
Mangrove	18.80	53.78	21.15	60.52	18.84	53.89
Non-mangrove forests	12.15	34.75	10.47	29.94	12.07	34.53
Water body	2.32	6.64	1.50	4.28	3.04	8.70
Open area	1.69	4.83	1.84	5.26	1.01	2.88
Total	34.96	100.00	34.96	100.00	34.96	100.00

classed as bodies of water or open spaces based on their geographical location and are defined as mangrove land cover in the context of the environment.

Accuracy Test

The accuracy test employed an error matrix (confusion matrix) to assess the relationship between field data and classification findings. Accuracy testing was performed on the three image classification results, as each image has a unique image quality and training sample. The accuracy test was evaluated using four criteria: producer accuracy (PA), user accuracy (UA), overall accuracy (OA), and kappa accuracy (KA).

PA represents map producer accuracy, whereas UA represents map user correctness (Wulansari 2017). OA is the percentage of properly identified pixels divided by the total number of pixels used, whereas KA is the percentage of accuracy using all matrix elements (Muhammad *et al*. 2016). The general reference for

Figure 2 Land cover map in Pulau Rambut Wildlife Sanctuar (SMPR) in 2019, 2020, and 2021.

determining the accuracy value of categorization results is KA. Because OA is widely seen as an overestimate, it is rarely utilized as a reliable predictor of success. OA only takes pixels from a contingency matrix's diagonal (Sampurno & Thoriq 2016). The KA coefficient values range from 0 to 1. Muhammad *et al*. (2016) obtained an accuracy value of 80.97% on the research issue of land cover. Thus, the overall KA accuracy score in this study is acceptable.

Field accuracy points were collected up to 120 for the entire land cover, and 200 accuracy evaluation points were utilized to test the classification results' correctness. The accuracy test on the 2019 categorization findings revealed that the non-mangrove forest cover class had the highest UA value (94.60%). The water body class had the smallest value, 83.33%. The open area cover class had the highest PA value in 2019, with 100%, while the non-mangrove forest class had the lowest at 87.50%. The OA value in the 2019 accuracy test results was 91.54%, while the KA value was 85.66%.

An accuracy test of the 2020 classification findings revealed that the non-mangrove forest cover class had the highest value (91.67%), while the mangrove class had the lowest value (88.43%). The water body cover class had the highest PA value in 2020, at 100%, while the non-mangrove forest class had the lowest value, at 79.71%. The OA score for the 2020 accuracy test results was 89.60%, with a KA value of 81.38%. The final accuracy test was performed on the 2021 categorization data, which revealed that the non-mangrove forest cover class had the highest value (91.30%), while the open area had the lowest value (80%). The mangrove cover class had the highest PA value in 2021 at 94.12%, while the non-mangrove forest class had the lowest value at 81.82%. The OA score for the 2019 accuracy test results was 89.22%, with a KA value of 82%. The calculation of the kappa accuracy assessment is provided in Table 4.

Mangrove Land Cover Changes Post-Oil Spills

The results of the examination of land cover changes in SMPR were undertaken in three separate years: 2019, 2020, and 2021. Comparisons were made between two time periods to illustrate changes in land cover classes from 2019 to 2021. The results of the examination of land cover changes can be expressed
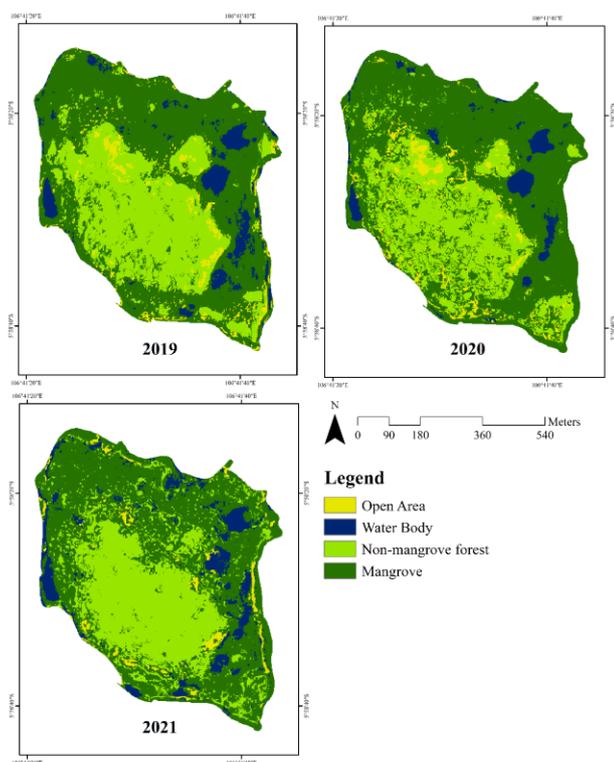
Table 4 Kappa accuracy assessment results

OBJECT ID	Class value	C_1	C_2	C_3	C_4	Total	U_Accuracy	Kappa
−1	C_1	10	1	0	1	12	0.833333	0
−1	C_2	1	94	0	9	104	0.903846	0
−1	C_3	0	1	10	0	11	0.909091	0
−1	C_4	0	4	0	70	74	0.945946	0
−1	Total	11	100	10	80	201	0	0
−1	P_Accuracy	0.909091	0.94	1	0.875	0	0.915423	0
−1	Kappa	0	0	0	0	0	0	0.856663

Remarks: "C_1" = Water body; "C_2" = Mangrove; "C_3" = Open area; and "C_4" = Non–mangrove forest.

as a change in land cover class between two different times (Table 5). Figure 3 also demonstrates the changes in land cover classes between 2019 and 2021. Overall, changes in classes produce minor results, as seen by variations between classes of less than 1 ha. Land cover changed from open areas to mangroves (0.84 ha), water bodies to mangroves (0.52 ha), non-mangrove forests to mangroves (0.45 ha), and mangroves to non-mangrove forests (0.44 ha). Aside from misclassification, changes happened because of environmental influences over two years.

These changes, specifically shifts in growth substrate caused by tidal variations coming through the sluice gate in the northeast of Pulau Rambut, resulted in relatively constant changes in land cover area. However, based on the classification results, patch changes were still visible. The mangrove association area in Figure 3 is dominated by *tengar* mangroves (*Ceriops tagal*). This species is classified as a mangrove species with high salt tolerance at the key early stage of its life cycle (Patel *et al*. 2010). This is consistent with the findings of direct observations reported in Figure 4, which reveal that mature *tengar* individuals have a very high density and that no

physiological condition causing wilting or diseased mangroves were discovered.

Impact of Oil Spill on Mangrove Land Cover

Lamparelli *et al*. (1997) provided information on how mangroves respond to oil spills. The total mangrove community undergoes four phases: initial effects, structural damage, stabilization, and recovery (Figure 5). The sampling site for Lamparelli *et al*.'s (1997) study was on the south bank of the Iriri River, which was extensively impacted by the oil spill from the damaged pipeline on October 14, 1983. The structural parameter in Figure 4 is based on mangrove monitoring data collected four months after the oil spill, monthly for the first year, every three months from 1985 to 1986, every six months from 1987 to 1989, and annually for the following three years (1990−1992).

Generally, the duration of each phase is determined by environmental conditions, as well as the volume and type of oil spill. It has been 5 to 6 years since the Karawang oil spill in July 2019, and it is safe to presume that the mangroves in SMPR have stabilized. The stabilization of changes in the sixth year following the oil spill generally shows that the impacts of the oil spill

Table 1 Land cover changes matrix in 2019 and 2021

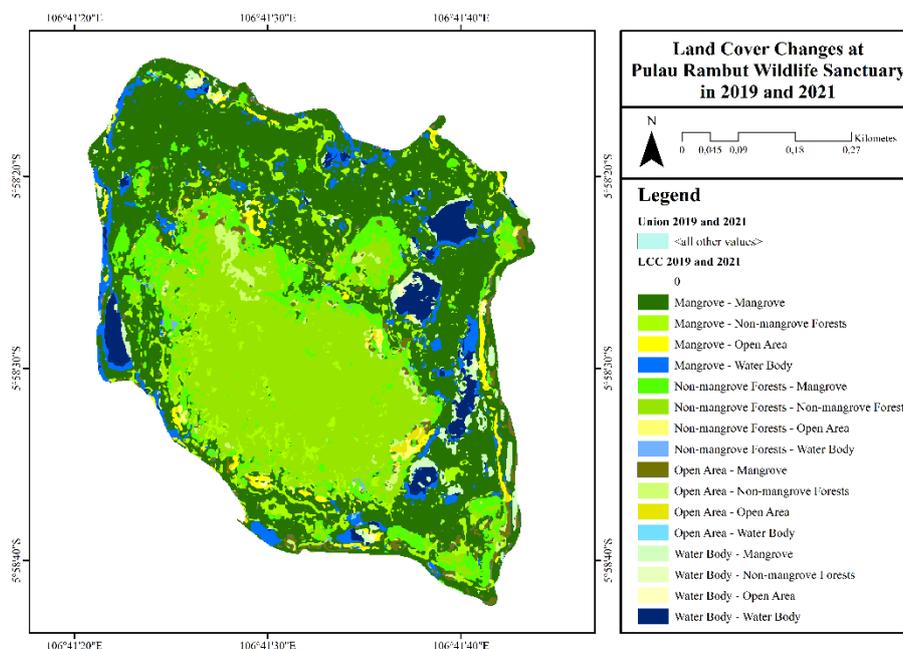| Sum of LCC1921		2019				
		Open area	Water body	Non-mangrove forests	Mangrove	Total
2021	Open area	0.1386	0.1080	0.0709	0.0817	0.3992
	Water body	0.1566	0.3960	0.0882	0.3519	0.9927
	Non-mangrove forests	0.4950	0.1102	0.4158	0.4423	1.4634
	Mangrove	0.8444	0.5206	0.4534	0.0846	1.9031
	Grand total	1.6346	1.1349	1.0282	0.9605	4.7583

Figure 3 Changes in land cover classes in Pulau Rambut Wildlife Sanctuar (SMPR) in 2019 and 2021.

are weakening, signaling the start of the recovery phase in the affected area. The mangrove response during each phase following the oil spill was provided by Mardiastuti *et al*. (2020). During the study, the mangrove ecosystem in SMPR has reached a point of stability, as shown by the spontaneous growth of mangrove seedlings detected during ground checks.

The investigation of land cover changes in SMPR was carried out over three years, namely in 2019, 2020, and 2021. This was done so that the changes in land cover could be seen and classified as good or negative. The land cover change analysis results can be expressed as either an increase or decrease in area.

BKSDA Jakarta's (2024) open area verification and ground check reports were utilized as a reference for presenting data on the amount of land cover changes between 2019 and 2021 (Table 5). Analyses of land cover changes from 2019 to 2021 shows that mangrove land cover in SMPR did not change significantly, as evidenced by field data acquired through interviews with field officers and unbiased accuracy values in 2019 and 2021. The 0.04 ha increase can be attributable to the restoration work done by the Jakarta BKSDA, which included 16,000 individual seedlings received from PHE ONWJ as a form of environmental obligation. The lack of mangrove
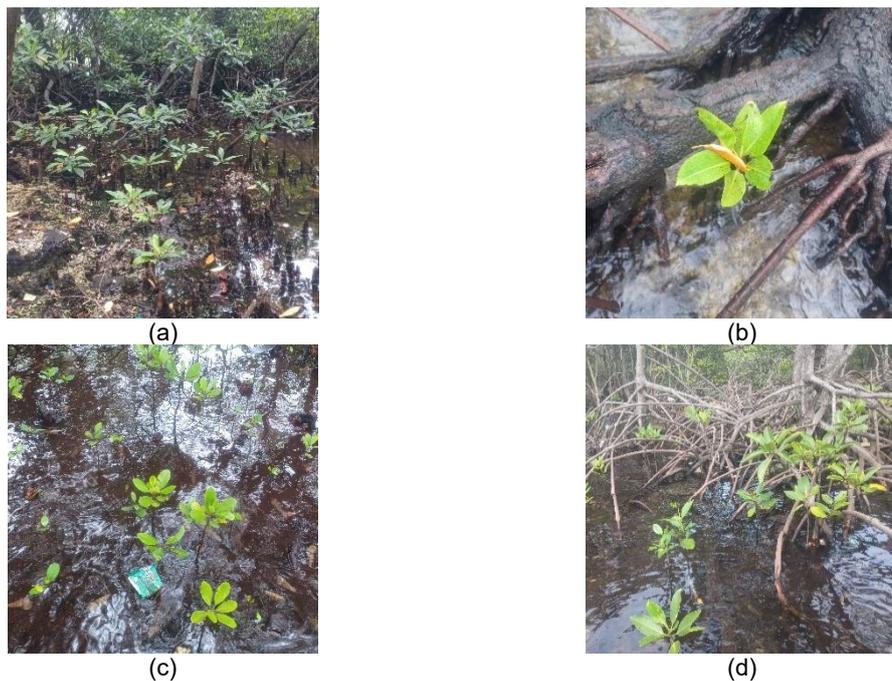

Figure 4 Natural seedlings scattered throughout the observation plot and outside or around the observation plot area (a) *Avicennia* spp., (b and d) *Rhizopora mucronata,* and (c) *Ceriops tagal.*
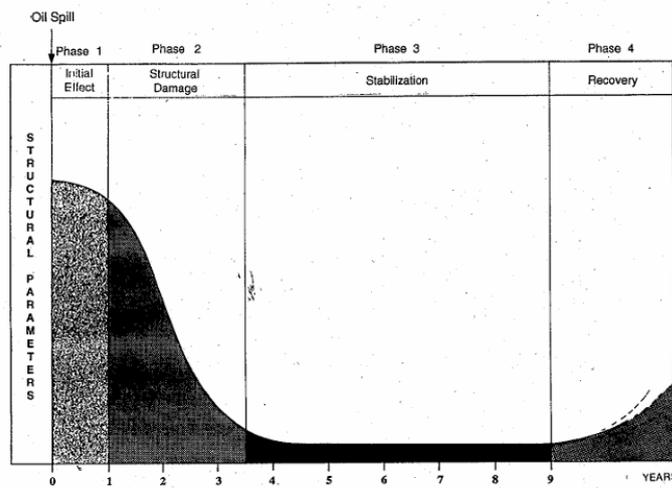

Figure 5 Post-oil spill phase for mangrove structures parameters (Kusmana *et al.* 2003).

mortality after the 2019 oil spill at SMPR indicates the success of teamwork among parties, including Pertamina Patra Niaga Integrated Terminal Jakarta (ITJ), PHE ONWJ, local communities, and other stakeholders, in responding quickly to disaster. This collaboration does not rule out the capabilities of mangrove groups, which are known as adaptive vegetation, due to differences in root morphology between genera, the ability of leaves to excrete excess salt absorbed from their surroundings, and the unique viviparous reproduction strategy in the form of propagules that are released and dispersed in the water before growing on their own in new locations (Duke 1992).

Field-based MHI Analysis

Based on 13 vegetation analysis plots put at four levels of oil spill exposure intensity, 12 of the 13 plots had MHI values in the moderate health range, while one was classified as poor health (Figure 6 and Table 6). The vegetation analysis plots were determined using the oil spill contamination zone map created by Mardiastuti *et al*. (2020). Figure 7 shows four types of affected zones: extremely contaminated, moderately contaminated, lightly contaminated, and uncontaminated.

The percentage of mangrove canopy cover ranged from 13.37% to 88.32%, with an average of 62.02%. plot 1 had the highest canopy cover percentage score, whilst plot 2 had the lowest. The average stem diameter of trees in each vegetation analysis plot ranged from 6.46 cm in plot 2 to 20.04 cm in plot 5, with an overall average of 10.92 cm. The average stem circumference ranged from 5.87 cm to 18.40 cm in plots 1 and 9, with an overall average of 9.03 cm. The plot with the highest seedling density was plot 8, with 26 individuals per area, whereas the plot with the lowest density had no seedlings. Ground checks are critical in remote sensing research to guarantee that data processed using satellite imagery appropriately represents biophysical conditions in the field and to detect any errors in area representation (Congalton & Green 1957). This confirms that the established MHI model can accurately reflect the health of mangroves in the SMPR.

Mangroves in the northeast, north, and northwest are real mangroves with muddy soils. This sort of substrate serves as a reservoir for vital nutrients that promote mangrove growth. Muddy substrates are often nutrient-rich and stable, making them ideal for mangrove life, particularly *Rhizopora mucronata* and *Avicennia alba*. Pulau Rambut's southern mangroves are mangrove associations. The position, which is very

Table 6 Land cover changes matrix in 2019 and 2021

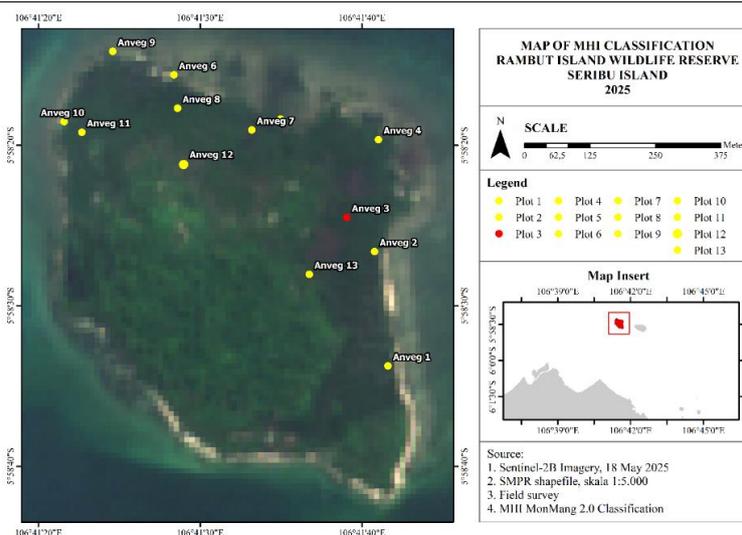| Sum of LCC1921		2019				
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	Grand total	1.6346	1.1349	1.0282	0.9605	4.7583

Figure 6 Field-based Mangrove Health Index (MHI) classification map.

distant from the beach, reduces the risk of damage caused by ocean waves. However, this condition has its own set of issues, including considerable sedimentation, which raises the danger of interrupting mangrove root development (Padmaraga *et al*. 2024).

Natural mangrove seedling growth in SMPR continues to be widespread and evenly distributed throughout the mangrove ecosystem. The seedlings seem to be growing well and thickly. The MHI value based on field data ranges from 29.54% to 65.16%, with an average of 50.72%. The maximum value is found in plot 13, and the lowest value is found in plot 2. Mangrove health information based on field data from 2025 is supplied to enable remote sensing-based categorization results on SPOT-6 and SPOT-7 photos.

An understanding of ecosystem recovery patterns is required to relate Figure 6 to the MHI categorization results in 2025. This is crucial because Figure 6 depicts the immediate impact of the oil spill, whereas conditions in 2025 will be influenced by other, more powerful environmental forces. Furthermore, the ability

of mangroves to withstand environmental changes at this period demonstrates mangroves' flexibility to exogenous substances around the substrate or growing location (Wang *et al*. 2011). According to information acquired from interviews with the Jakarta BKSDA, these elements include water flow patterns and natural sedimentation, which influence the substrate for mangrove growth.

CONCLUSION

The SPOT-6 and SPOT-7 satellite image categorization results show that the area of mangrove land cover in the Pulau Rambut Wildlife Sanctuary was 18.80 ha in 2019, increased to 21.15 ha in 2020, and slightly dropped to 18.84 ha in 2021. This shift indicates that the 2019 oil spill did not cause a large or long-term decrease in mangrove area. The stability and temporary increase in mangrove cover are assumed to temporary increase in mangrove cover are assumed to

Table 6 Comparison of Mangrove Health Index (MHI) results from image classification and field data

| Field plot number	Field MHI value	Health condition	Image MHI value	Health classification	Suitability
1	63.35%	Moderate	53.89%	Moderate	Suitable
2	57.53%	Moderate	53.22%	Moderate	Suitable
3	29.54%	Poor	57.13%	Moderate	Not suitable
4	51.20%	Moderate	63.59%	Moderate	Suitable
5	44.77%	Moderate	45.03%	Moderate	Suitable
6	35.51%	Moderate	50.32%	Moderate	Suitable
7	33.52%	Moderate	28.37%	Poor	Not suitable
8	62.09%	Moderate	58.14%	Moderate	Suitable
9	46.01%	Moderate	32.96%	Poor	Not suitable
10	58.81%	Moderate	43.47%	Moderate	Suitable
11	48.85%	Moderate	54.20%	Moderate	Suitable
12	63.14%	Moderate	38.36%	Moderate	Suitable
13	65.16%	Moderate	51.64%	Moderate	Suitable
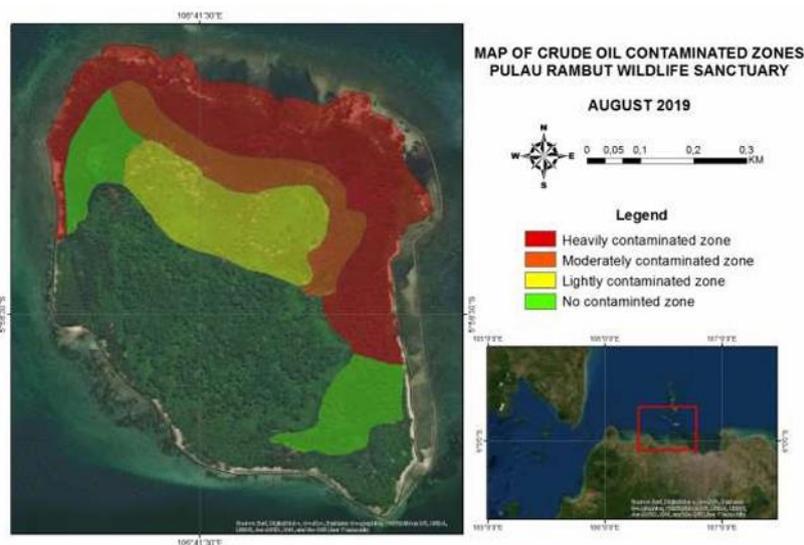
Figure 7 Oil spill contamination zones in Pulau Rambut Wildlife Sanctuar (SMPR) (Mardiastuti *et al.* 2020).

be the outcome of mangroves' natural ecological reaction and recovery efforts by the BKSDA and its collaborators, such as PHE ONWJ, via replanting.

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