Available online at
http://journal.uitm.edu.my/ojs/index.php/BEJ

Built Environment Journal

e-ISSN: 2637-0395

Built Environment Journal 21(1) 2024, 97 – 108.

# Mangrove Dynamics Evaluation at Matang Mangrove Forest Reserved by Multi-temporal Satellite Imageries

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ARTICLE INFO

*Article history:*
Received 31 July 2023
Revised 18 October 2023
Accepted 20 October 2023
Online first
Published 1 January 2024

*Keywords:*
Landsat 8
Mangrove ecosystems
Mangrove dynamics
Matang Mangrove Forest Reserve
RapidEye

*DOI:*
10.24191/bej.v21i1.250

ABSTRACT

Mangrove ecosystems support a wide range of terrestrial and marine organisms by offering sustenance, reproductive habitats, and nurturing environments. The Matang Mangrove Forest Reserve (MMFR), spanning over 40,000 ha, poses challenges in effectively managing and evaluating the entire area. Hence, remote sensing techniques are employed to effectively monitor and map the temporal fluctuations of land use and land cover occurring within mangrove forest areas. In this study, dynamics over nine (9) years (2011 to 2020) of the mangrove ecosystem were evaluated using RapidEye 2011 and Landsat 8 (OLI) 2020 satellite imageries. Change detection was implemented using pixel-by-pixel modelling analysis. The present study revealed the conversion of mangrove area to waterbody at 4625.1 ha (16.7%), dryland forest at 1886.1 ha (6.8%), and oil palm plantations at 186.9 ha (0.7%). The area conversion was attributed to erosion, logging operations, the establishment of aquaculture facilities, and agricultural practices. Hence, the acquisition of data pertaining to the present condition of mangrove forest species, as well as the temporal fluctuations in the study area, holds significant importance for all stakeholders involved in the preservation of this ecosystem.

## INTRODUCTION

The mangrove forest in Malaysia is the third largest mangrove forest in the Asian region after Bangladesh and Papua New Guinea (Gandhi & Jones, 2019). The mangrove forest is a wetland ecosystem influenced by very productive tidal currents along the sheltered coast (Krauss & Osland 2020), which supports ecological and economic chains (Getzner & Islam, 2020). However, compared to mangrove forests in other areas of the world, mangrove forests found in Malaysia have a high structure and species richness and provide a unique habitat for many species, as well as being a major natural resource for humans. Mangrove ecosystems play a crucial role in providing sustenance, reproductive habitats, and nurturing environments

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https://doi.org/10.24191/bej.v21i1.250

for a diverse array of terrestrial and marine organisms, encompassing numerous economically valuable species (Samara et al., 2020) as well as small fish species from coral reef habitats that can be found around mangrove ecosystems (Carugati et al., 2018).

Mangrove forest is a very productive ecosystem because its primary production rate is in line with tropical rainforest, which functions as a carbon sink (Alongi, 2014; Carugati et al., 2018). Most of this carbon stock is lost through decomposition and transferred to adjacent ecosystems (Chen et al., 2018). Mangrove forests possess ecological significance and concurrently assume a pivotal role in fostering sustainability and supporting the livelihoods of the local community (Aye et al., 2019). The resources found in the mangrove forest ecosystem are widely used as food, timber sources, fuel sources, and medicines, especially for the people living in the mangrove forest communities (Hashim et al., 2017). In addition, mangrove forests also protect from disasters such as tsunamis and tropical cyclones and can reduce coastal erosion (Akram et al., 2023).

Mangrove forest reserve areas in Malaysia necessitate significant enforcement and management focus to address the issue effectively. As indicated by Omar et al. (2018), there has been a decrease in land area from 650,311 ha in 1990 to 629,038 ha in 2017. The MMFR spans approximately 40,000 ha, encompassing over 40% of Malaysia's whole mangrove region. As a result, the mangrove ecosystem requires immediate conservation and restoration, as well as planning, management, and access to the most recent data (Maurya et al., 2021). Thus, due to the scenario, time and cost-effective mangrove mapping methods are necessary, which can be obtained using remote sensing (Maurya et al., 2021).

Efficient monitoring of temporal changes in the MMFR area necessitates the adoption of a more streamlined approach. The vast expanse of this area, spanning over 40,000 ha, poses challenges in effectively managing and evaluating the entirety of the region. Therefore, remote sensing techniques are used for monitoring and mapping temporal changes in mangrove forests. With the availability of temporal data on species distribution and surrounding land use conditions, an overview of the status and threats to the MMFR can be determined

## RESEARCH METHODOLOGY

The dynamics of mangrove forest at MMFR were evaluated based on a land use and land cover map of the MMFR area by employing RapidEye 2011 and Landsat 8 (OLI), 2020 satellite imagery using ERDAS Imagine 2014 software. Figure 2 outlines the steps and methods used in this study.

The satellite images underwent pre-processing and were georeferenced using the World Geodetic System 1984 (WGS 84) coordinate system. To assist with the supervised classification, the ground-truth data were utilised in aiding the classification. A supervised classification approach, namely a maximum likelihood classifier, was used to perform image classification. Meanwhile, an accuracy assessment was further adopted to validate the supervised classification.

To determine the dynamics of the distribution of mangrove species in the MMFR, change detection was implemented on the Landsat 8 (OLI) satellite image, 2020 and the RapidEye satellite image, 2011 by utilising the pixel-by-pixel modelling analysis using ERDAS Imagine 2014 software. The detection of changes was used to assess mangrove changes from the two (2) images based on the land use and land cover maps. Change detection consists of comparative analysis through pixel-by-pixel mathematical combinations. Besides, according to Pereira-Pires et al. (2020), employing either pixel-based or object-based methodologies with comparable detection procedures, such as supervised classifications, is likely to yield comparable outcomes.

https://doi.org/10.24191/bej.v21i1.250

To initiate the change detection method, image fusion was further employed due to the utilisation of varying spatial resolutions. The spatial resolution of RapidEye 2011, which was originally 5 m, was resampled to 15 m to match the spatial resolution of the pan-sharpened Landsat 8 (OLI) image from 2020. This resampling was necessary to ensure the accurate execution of the layer-stacking process.

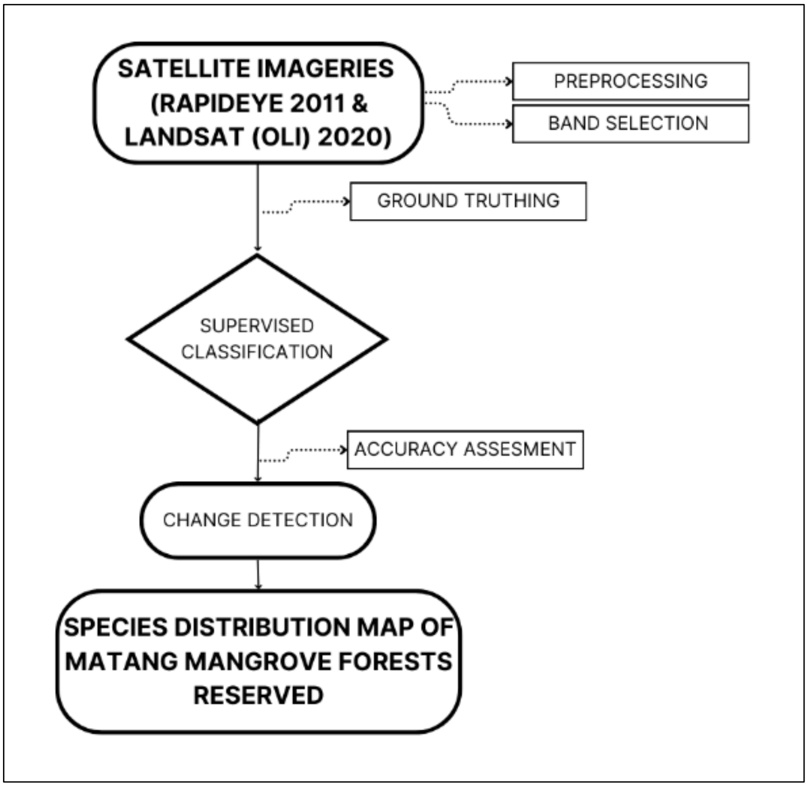


Fig 1. Flowchart of research approach

Source: Author, 2023

## RESULTS AND DISCUSSION

The distribution of land use and land cover map for the years 2011 and 2020 encompasses a total of seven (7) classes for 2011, namely *Rhizophora mucronata, Rhizophora apiculata, Bruguiera parviflora, Bruguiera cylindrica, Avicennia – Sonneratia*, dryland forests, and waterbodies; meanwhile, for 2020, there is one (1) additional class of oil palm plantation area (Figure 1). There are seven (7) classes identified for RapidEye 2011, namely *Rhizophora apiculata, Rhizophora mucronata, Avicennia - Sonneratia, Bruguiera parviflora, and Bruiguiera cylindrica*, dryland forests, and waterbodies; meanwhile, eight (8) classes are identified for Landsat 8 (OLI), namely *Rhizophora apiculata, Rhizophora mucronata, Avicennia - Sonneratia, Bruguiera parviflora, and Bruiguiera cylindrica*, dryland forests, waterbodies, and palm oil plantations.

https://doi.org/10.24191/bej.v21i1.250

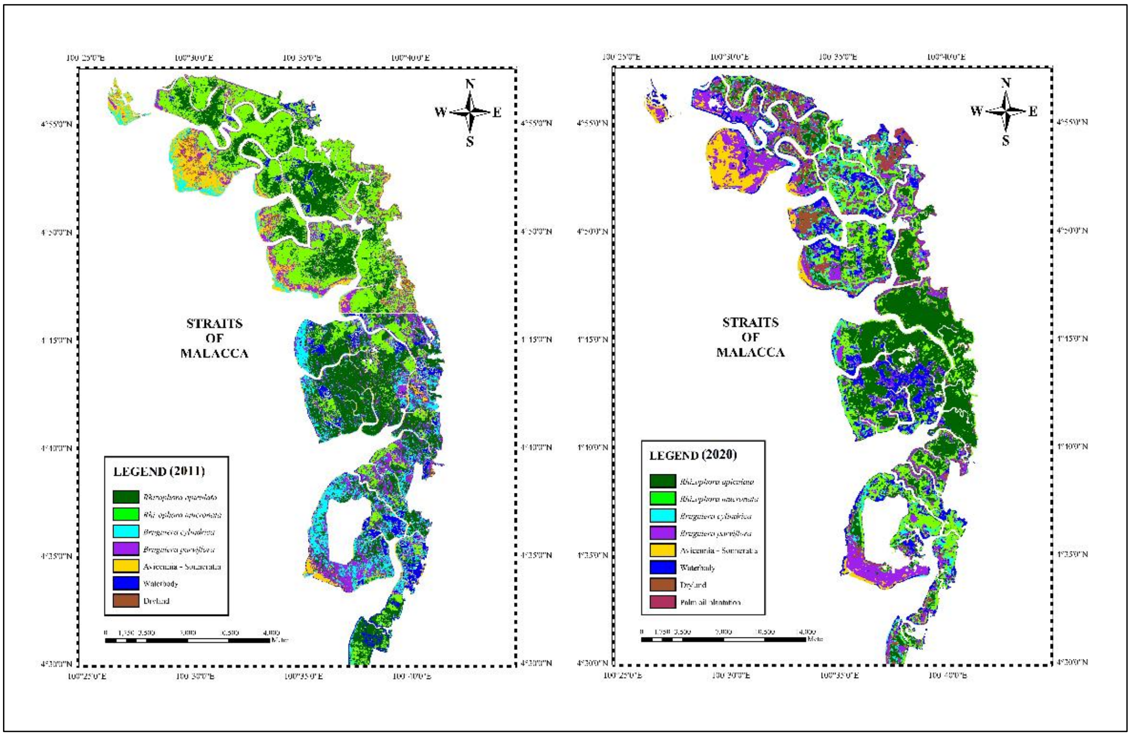


Fig 2. Land use and land cover map of RapidEye 2011 and Landsat 8 (OLI), 2020

Source: Author, 2023

The land use and land cover maps of the 2011 and 2020 image classifications indicated an accuracy assessment of 87.9% and 90.3%, with Kappa statistics of 0.86 and 0.89, respectively. The species distribution map for 2011 found that the total mangrove forest area is 42,730 ha, with the largest area recorded by *Rhizophora apiculata*, which is 13,348 ha, followed by *Rhizophora mucronata*, *Bruguiera parviflora*, *Bruguiera cylindrica*, *Avicennia sonneratia*, and waterbody at 11,809 ha, 6,255 ha, 4,475 ha, 3,313 ha, and 2,614 ha, respectively. The lowest land-use area is dryland forest at 916 ha. Meanwhile, for the species distribution map for 2020, *Rhizophora apiculata* shows the highest coverage area at 11,392.8 ha, followed by *Rhizophora mucronata, Bruguiera parviflora*, water body, *Bruguiera cylindrica*, *Avicennia-Sonneratia*, and dryland forest, respectively, at 8,534.1 ha, 6,793 ha, 5,093 ha, 2,238 ha, 2,082 ha, and 2,077.6 ha. The oil palm plantations exhibited the smallest land area, at 574.4 ha (Table 1).

Table 1. Total area for all land cover and land use categories in the MMFR from 2011 to 2020. (Whereby: AS- *Avicennia Sonneratia*, WB- Water body, BC- *Bruguiera cylindrica*, BP- *Bruguiera parviflora*, DF- Dryland Forest, OP- Oil palm plantation, RA- *Rhizophora apiculata* & RM-*Rhizophora mucronata*)

| Land Use Category | 2011 | | 2020 | |
|---|---|---|---|---|
| | Ha | % | Ha | % |
| RA | 13,348.0 | 31 | 11,392.8 | 29 |
| RM | 11,809.0 | 28 | 8,534.1 | 22 |
| BC | 4,475.0 | 10 | 2,238.0 | 6 |
| BP | 6,255.0 | 15 | 6,793.0 | 18 |
| AS | 3,313.0 | 8 | 2,082.0 | 5 |
| WB | 2,614.0 | 6 | 5,093.0 | 13 |
| DF | 916.0 | 2 | 2,077.6 | 5 |

https://doi.org/10.24191/bej.v21i1.250

| | | | | |
|---|---|---|---|---|
| OP | 0.0 | 0 | 574.4 | 2 |
| TOTAL | 42,730.0 | 100 | 38,784.9 | 100 |

Source: Author, 2023

Mapping the change from mangrove forest to non-mangrove forest area holds significance in elucidating the potential risks posed to the MMFR ecosystem. Each mangrove forest species class exhibits a discernible zoning pattern, characterised by the presence of *Avicennia – Sonneratia* species close to the shoreline, followed by *Bruguiera* and Rhizophora species. Changes from the mangrove forest species class to the non-mangrove forest species class between 2011 and 2020 have been analysed and depicted in Figure 2. Area reduction for the mangrove forest class covers three (3) classes, which are mangrove forest species to waterbody, mangrove forest species to dryland forest, and mangrove forests to oil palm plantations. Nonetheless, the category of "no change" signifies the absence of any alterations in land utilisation.

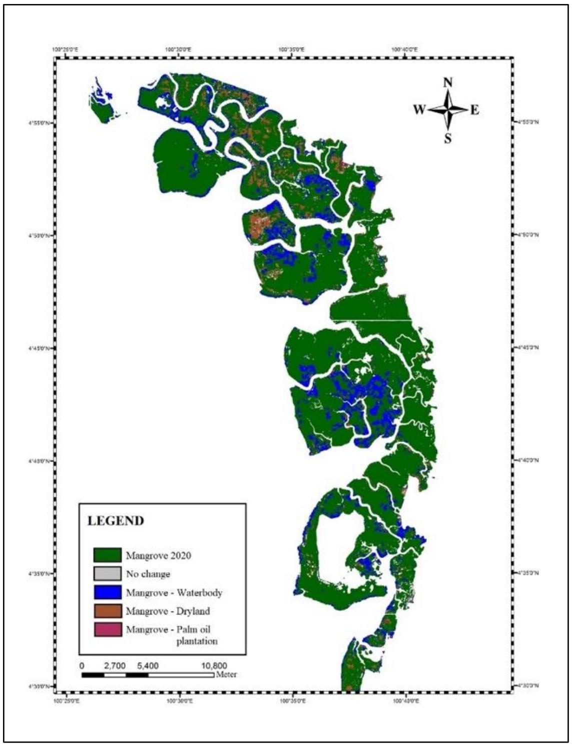


Fig 3. Change of mangrove forest area to different land cover or land use categories in the MMFR from RapidEye 2011 to 2020

Source: Author, 2023

Table 2. Matrix of land cover and land use changes from 2011 to 2020. (Whereby AS- *Avicennia-Sonneratia*, WB- Water body, BC- *Bruguiera cylindrica*, BP- *Bruguiera parviflora*, DF- Dryland Forest, OP- Oil palm plantation, RA- *Rhizophora apiculata* & RM- *Rhizophora mucronata*)

| Species | RA | RM | BC | BP | AS | WB | DF | OP |
|---|---|---|---|---|---|---|---|---|
| RA | 4534.8 | 2581.8 | 656.7 | 1810.1 | 137.5 | 2215.7 | 742.5 | 0.0 |
| RM | 4096.4 | 2388.7 | 719.4 | 1983.8 | 170.4 | 1068.3 | 684.6 | 0.0 |
| BC | 870.7 | 779.2 | 298.1 | 722.7 | 329.2 | 467.2 | 81.4 | 121.8 |
| BP | 1612.7 | 1082.1 | 270.1 | 1169.0 | 202.7 | 519.3 | 218.6 | 0.0 |

https://doi.org/10.24191/bej.v21i1.250

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| AS | 219.6 | 122.8 | 57.7 | 602.1 | 890.6 | 291.9 | 120.1 | 0.0 |
| WB | 501.9 | 551.0 | 155.5 | 222.3 | 34.2 | 210.9 | 39.0 | 41.9 |
| DF | 81.8 | 46.7 | 22.2 | 178.2 | 137.5 | 62.7 | 51.4 | 23.3 |

Source: Author, 2023

The change matrix of land cover and land use classes from 2011 to 2020 is tabulated in Table 2. The change matrix encompasses a total of seven (7) distinct categories that correspond to land cover and land use classes observed in 2011. The result of this algorithm was in the form of a matrix that shows the initial parameter values for the different land cover classes for each class. This approach is the most commonly used approach for change detection studies and has been used by many other studies (Dan et al., 2016).

Eight (8) different land cover and land use classifications from the year 2020 are depicted, with all values expressed in hectares. Changes in land cover and land use occur involving the reclamation of mangrove forest areas to non-mangrove forest classes, as well as changes from one (1) species to another. It is imperative to give due consideration, particularly to changes in the non-mangrove forest category, as these modifications have the potential to impact the long-term sustainability of the mangrove forest ecosystem. This discussion focuses solely on the conversion of mangrove forest areas to non-species mangrove forests, as the transition from one (1) species to another does not currently pose a threat to the sustainability of the mangrove forest ecosystem.

The transition from the mangrove forest species category to the mangrove non-species category encompasses shifts in the water body category, the dryland forest category, and the oil palm plantation category attributed to erosion, logging operations, the establishment of aquaculture facilities, and agricultural practices. The waterbody category has documented a comprehensive alteration in the combined mangrove forest species categories across a total area of 4,625.1 ha. The largest reclaimed is at 2,215.7 ha, which belongs to the *Rhizophora apiculata* class. Conversely, the smallest reclaimed area is 62.7 ha, attributed to the dryland forest class.

Furthermore, there is a total conversion of 1,886.2 ha from all classes of mangrove forest species to the waterbody class and a conversion of 186.9 ha to the oil palm plantation class. In terms of land utilisation within the dryland forest category, the *Rhizophora apiculata* class documented a land area of 742.5 ha allocated for this purpose. The smallest reclamation area identified in the waterbody class at 39.0 ha.

In the study, it was observed that the reclamation of land for oil palm plantations was conducted across different classes. The largest reclamation area, measuring 121.8 ha, was attributed to the *Bruguiera parviflor*a class. Conversely, the smallest reclamation area, spanning 23.3 ha, was associated with the dryland forest class.

The most significant change observed is in the water body class, which experienced a substantial increase in area from 2011 to 2020, amounting to 4,625.1 ha or 16.7%, which is followed by the dryland forest class, which indicated an increase of 1,886.1 ha or 6.8%, and the oil palm plantation class, which experienced a smaller increase of 186.9 ha or 0.7%. The amount of this change is calculated based on the change that has occurred from the mangrove forest species class to the mangrove forest non-species class, excluding land use that has not changed (WB - WB; DF - DF; OP - OP) (Table 2).

Although the most significant change that was detected pertained to the waterbody, it is noticeable that the current condition at the time of image observation exhibited a mid-water amplitude, with the waterbody class experiencing the most significant transformation. The waterbody class exhibits the greatest variation in area within the *Rhizophora apiculata* class, encompassing 2,215.7 ha. Conversely, the smallest change is observed in the dryland forest class, which encompasses an area of 62.7 ha. This is followed by the

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*Rhizophora mucronata*, *Bruguiera parviflora*, *Bruguiera cylindrica*, and *Avicennia – Sonneratia* classes, which cover areas of 1,068.3 ha, 519.3 ha, 467.2 ha, and 291.9 ha, respectively.

In the category of changes in mangrove forest species to dryland forest class, *Rhiophora apiculata* exhibited the most substantial change, with a recorded increase of 742.5 ha. Following this, *Rhizophora mucronata*, *Bruguiera parviflora*, *Avicennia – Sonnerati*a, and *Bruguiera cylindrica* experienced changes of 684.6 ha, 81.4 ha, 218.6 ha, and 120.1 ha, respectively. The water body class exhibited the smallest change, at 39.0 ha. In the domain of modifications to oil palm plantations, three (3) distinct categories have changed. These categories include *Bruguiera cylindrica*, encompassing an area of 121.7 ha, a waterbody spanning 41.9 ha, and a dryland forest covering 23.3 ha.

Results also indicated that the changes occurring along the mangrove forest boundary and its neighbouring area are primarily attributed to the emergence of transitional forests, transitions to a waterbody, and agricultural practices. Changes also take place within the tidal zone due to erosion. In contrast, changes occur within the mangrove forest area due to shifts in species composition resulting from the implementation of the silvicultural system.

Several factors influence the change, which is determined by the location of the change. In the tidal zone between 4.55 °N to 4.56 °N, 4.44 °N and from 4.34 °N to 4.36 °N, the coastline has been eroded by tidal currents has been recorded. Erosion is seen as a contributing factor to the loss of mangrove forest species in tidal zones. Erosion is attributed to specific natural phenomena, such as storms, waves, tidal events, and wind (Bryan-Brown et al., 2020). The majority of mangrove forest species are unable to effectively mitigate coastal erosion in the presence of significant wave action, which disrupts the accretion process and sediment accumulation in the surrounding marine environment. Although mangroves can safeguard coastlines against erosion, storm damage, and wave impact (Tomlinson, 1986), mangroves are vulnerable to erosion caused by natural processes, especially when the soil beneath their root system is undermined primarily owing to severe wave activity, particularly during low tide (Alongi, 2022).

Additionally, various factors, such as soil composition, species characteristics, and soil topography, affect the ability of mangrove forest vegetation to reduce coastal erosion (Koh et al., 2018). Mangrove tree species, specifically those belonging to the genus *Rhizophora*, have demonstrated their efficacy in mitigating erosion due to their possession of extensive and convoluted root systems, which function akin to nets by effectively capturing and retaining soil particles (Das, 2020). The occurrence of erosion in compartment ninety-seven (97) along the tidal zone can be justified by the presence of *Bruguiera* and *Avicennia–Sonneratia* species.

The conversion of mangrove forests to waterbody is attributed not only to erosion but also to the implementation of the silviculture system. The change occurred within the vicinity of the mangrove forest region. Mangrove forests are regions that experience the influence of tidal currents, characterised as shorelines that are submerged by the ebb and flow of tides (Tomlinson, 1986). Hence, mangrove species are known to inhabit not only expansive muddy regions but also the fringes of freshwater rivers, which are likewise subject to aquatic influences. The satellite imagery from 2020 has detected the presence of unpopulated regions that have yet to undergo the process of mangrove species reforestation, which has been a customary practice since 1950 (Goessens et al., 2014).

According to Muda and Shah (2003), certain compartments of the MMFR undergo clear-felling activity once they reach a lifespan of thirty (30) years. The tree harvesting cycle, spanning a period of thirty (30) years, takes place from 2011 to 2020. The application of a silviculture system for commercial production is also observed at the mangrove forest reserve area in Sungai Pulai Johor, Malaysia. The practice of the clear-felling method remains in effect, employing a rotation system spanning twenty (20) years.

https://doi.org/10.24191/bej.v21i1.250

Changes to waterbody in the vicinity of the mangrove forest border were also induced by the process of land reclamation undertaken for aquaculture activities. The 2020 base map reveals the presence of aquaculture areas characterised by the formation of aquaculture ponds within the forest reserve area, specifically in compartment 103. The MMFR plays a crucial role in supporting fisheries and aquaculture production within the state of Perak by providing a range of ecological functions. Furthermore, this particular ecosystem plays a substantial role in the carbon contribution to certain deep-sea fisheries, thereby fostering a heightened level of productivity that sustains both terrestrial and marine food sources (Rahman et al., 2021). Hence, the ecological characteristics of the mangrove forest make it highly conducive for serving as a favourable breeding environment for the aquaculture sector. Aquaculture is a rapidly expanding economic sector on a global scale. Nevertheless, the establishment and expansion of aquaculture operations have been associated with various ecological challenges and social disputes (Kurniawan et al., 2021). Aquaculture commonly leads to the depletion of mangrove forest regions for the establishment of breeding ponds (de Lacerda et al., 2021) since the primary factor attributed to the deforestation of mangroves is the expansion of shrimp ponds in coastal regions (Ahmed et al., 2023).

The dryland forest class has observed the second-highest change, corresponding to 1,886.2 ha. Changes take place in the vicinity of the mangrove forest region, as well as near the pre-existing dryland forest region. The presence of dryland forest areas within the mangrove forest ecosystem can be attributed to the natural process of plant dispersal. The dryland forest within the MMFR is classified as a component of the forest reserve, whereby the extraction of trees is strictly prohibited. The dryland forest has been determined to be situated in proximity to both the mangrove forest region and the Malay reserve area, which is situated within the mangrove forest area. Hence, the transformation from a mangrove forest to a dryland forest classification may transpire due to their adjacency to one (1) another. To mitigate future conversions that may result in the decline of productive forest land, it is essential to establish a broader buffer zone that delineates the boundary between the mangrove forest area and its surrounding vicinity, according to the findings of Akmal et al. (2011), a significant change of 263 ha at Sungai Santi, Malaysia, occurred, resulting in the conversion of these areas into dryland forests. The presence of dryland forest or bushland can be attributed to the conversion of mangrove forests into agricultural land (Biswas & Biswas, 2020).

The transformation of mangrove areas into oil palm plantations constituted the third most significant alteration, encompassing an area of 186.9 ha. The process of conversion takes place in regions that are contiguous to non-mangrove areas, specifically in the Kuala Sepetang sub-area and Kuala Terong sub-area. During the process of the field observation, a shift from mangrove forest to oil palm plantations was observed. The practice of converting land to establish oil palm plantations is a prevalent phenomenon, owing to the adaptability of oil palm trees to a wide range of soil types (Anamulai et al., 2019). This characteristic enables oil palm trees to exhibit tolerance and coexist near the mangrove forest ecosystem. Shevade and Loboda (2019) assert that the primary catalyst for deforestation in Peninsular Malaysia is the expansion of agricultural activities, particularly the establishment of oil palm plantations.

Carugati et al. (2018) argue that the presence of extensive agricultural land has a detrimental impact on the environment, specifically leading to land degradation. This degradation manifests in the reduction of mangrove forest areas, heightened soil acidity, and increased vulnerability of mangrove forests to erosion and water movement, ultimately resulting in elevated sediment flow into adjacent rivers. Anamulai et al. (2019) conducted a study that revealed that the transformation of mangrove forests into oil palm plantations results in the creation of a microclimate characterised by increased temperature and reduced moisture levels. Additionally, this conversion process leads to soil acidification. Hence, the Perak State Forestry Department must allocate significant resources and efforts towards addressing this issue of exploitation. By doing so, the department can effectively curtail such activities and ensure the continued preservation of the forest ecosystem's sustainability.

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## CONCLUSION

Based on the data processing and observation of the difference within nine (9) years, it is demonstrated that the prevalence of mangrove forest plant species within highly productive forest ecosystems accounts for over 80% of the total area designated as a forest reserve. The analysis of the nine (9) years reveals a net decrease in mangrove forest area, with a loss of 6,698.3 ha. However, there were also 1,931.2 ha of newly planted or restored areas observed during this time. The observed reduction in the extent of the mangrove forest area indicates that a portion of this area underwent conversion to a waterbody, encompassing 4,625.1 ha (16.7%) of the total dryland forest, accounting for 1,886.1 ha (6.8%), and oil palm plantations, occupying 186.9 ha (0.7%). The transformation of mangrove forest regions into waterbody areas can be attributed to erosion processes, logging operations, and the establishment of aquaculture facilities. Conversely, the conversion of mangrove forests into dryland forests is primarily driven by the development of dryland forest ecosystems. Meanwhile, the establishment of oil palm plantations can be attributed to agricultural practices.

The MMFR holds significant value for the nation as it serves as a source of diverse renewable commercial products, primarily owing to the sustainable nature of its wood resources. Furthermore, it has been observed that the forest in question has not only contributed to the economic growth of Perak but has also facilitated the emergence of economic prospects within the local community. Hence, the implementation of a comprehensive strategy for the sustainable management of mangrove forests is imperative to preserve the inherent ecological balance of these ecosystems, as any encroachment may result in further land reclamation in subsequent periods. The acquisition of data pertaining to the present condition of every mangrove forest species, as well as the temporal fluctuations in the MMFR, holds significant importance for all stakeholders involved in the preservation of this particular ecosystem. Understanding the dissemination of each species within the MMFR is crucial for comprehending the natural resources, conservation efforts, and management strategies associated with this ecosystem. This knowledge is essential for maintaining a harmonious equilibrium between the productivity of the forest and the ecological diversity it supports.

The information derived from the present condition and overall changes in the extent of the mangrove forest in the MMFR may provide various advantages to stakeholders. The findings, as mentioned earlier, have contributed to the advancement of knowledge regarding the spatial distribution of MMFR. Additionally, they have evaluated the deforestation patterns and identified the underlying factors responsible for such occurrences to inform management strategies. The aforementioned findings demonstrate that the rapid and precise identification of deforestation in protected forest areas can be achieved through the utilisation of remote sensing data. The difficulty in monitoring and managing mangrove forest areas arises from various factors. The utilisation of remote sensing image processing methodology for mapping mangrove forest areas has the potential to enhance the understanding and implementation of comprehensive area management. This is due to the inherent challenges associated with the conventional approach of conducting a land inventory to map mangrove forest areas, which is characterised by its arduous nature, time-intensive requirements, and substantial financial costs. To maintain a sustainable equilibrium between silvicultural practices and natural ecosystems, engaging in collaborative efforts with all relevant stakeholders is imperative. This collaboration should encompass management, monitoring, and law enforcement aspects, given the multifaceted contributions of the MMFR. These contributions include socio-economic benefits and the provision of resources derived from the ecosystem of the mangrove forest itself.

https://doi.org/10.24191/bej.v21i1.250

## ACKNOWLEDGEMENT

The authors would like to acknowledge all the restaurateurs and contributors involved in this study, both directly and indirectly.

## AUTHOR'S CONTRIBUTIONS

None.

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