

FRIM Special Publication No. 60

STATUS OF MANGROVES IN MALAYSIA

Hamdan Omar





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All inquiries should be forwarded to:

Director-General

Forest Research Institute Malaysia

52109 Kepong

Selangor Darul Ehsan

Malaysia

Tel: 603-6279 7000

Fax: 603-6280 4624

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Foreword



The tsunami which hit Malaysia on 26 December 2004 resulted in the government among other things committing itself to enhancing the conservation efforts of mangroves areas. Recognising the destruction caused by the tsunami to life and property caused by the tsunami, it is timely that the government enhance coastal conservation efforts. Hence, the 4th National Biodiversity Council (MBBN) on January 13, 2005 decided that all state governments and Ministry of Natural Resources and Environment (NRE) to take initiative to restore and conserve ecosystems and vegetation of the mangrove forests.

Under the Special Task Force chaired by Secretary General of NRE, now known as Ministry of Natural Resources and Environmental Sustainability (NRES), Director General of Forest Research Institute Malaysia (FRIM) has entrusted to chair of Research and Development Committee (JTRD) to carry out related research and development (R&D) activities. The main objective of JTRD in this regard is to support the implementation of rehabilitation programmes and to strengthen conservation efforts in the mangroves and coastal areas throughout the country .

The JTRD to date has organised seven seminars as platforms to present research findings not only from FRIM but also other agencies, institutions and universities related to forestry R&D. The committee has also produced various types of technical and semi-technical information, guidelines and publications including more than 30 books for reference purposes among relevant stakeholders.

We always encourage and support exchange of knowledge through seminars, publications and other ways of communication. Therefore, publication of this book is welcomed by the JTRD to further enhance our knowledge on scientific information related to mangroves. I believe that the readers will find this book enlightening and useful especially in generating for greater understanding of mangroves in Malaysia. It is also our hope that recommendations provided by authors of the various chapters can be adopted for management purposes of the mangroves which are priceless resources of our country.

DATO' DR. ISMAIL HJ. PARLAN

Director General, Forest Research Institute Malaysia (FRIM)
Chairman of Research and Development Committee (JTRD)

Preface

Status of Mangroves in Malaysia is a collection of reports from research studies and activities related to mangroves and its ecosystem throughout Malaysia. The studies were conducted mostly by Forest Research Institute Malaysia (FRIM), National Water Research Institute of Malaysia (NAHRIM), and Sabah Forestry Department (SFD) that work in fields relevant to mangroves. Chapters that are included in this book were written by experts in their respective disciplines, which encompass, but not limited to the fields of mangroves ecology, geospatial related technology and methods, management, marine and aquatic life, community activities, and hydrodynamics sciences. This book was published under the support of Technical, Research and Development Committee (JTRD), which is chaired by FRIM, where most of the studies related to mangroves are funded by this committee, through the Malaysian Plans funds. The Current edition of Status of Mangroves in Malaysia is also published as a successor to the book with a similar title that was published in 2020. After 4 years, the status of mangroves reported in this book provides updates on the current extents and distribution of mangroves in Malaysia. The concept of this book is similar to the previous one, where varieties of knowledge and information related to mangroves are included and introduced to expose readers about the richness of our priceless, pristine mangroves ecosystem in Malaysia. Thanks to all contributing authors, the JTRD that funded some of the research and to individuals that have been involved directly or indirectly in the production of this book.

Chapter 1

Distribution and Extent of Mangrove changes in Malaysia



Distribution and Extent of Mangrove changes in Malaysia

Muhamad Afizzul Misman*, Sofiya Zulaikha Ruslan & Rodziah Hashim
Forest Research Institute Malaysia, 52109 FRIM, Kepong, Selangor, Malaysia

*Corresponding author: afizzul@frim.gov.my

1. Introduction

Mangrove ecosystems are tropical coastal forests which are adapted to saltwater-based environment. Their unique qualities of existing primarily in moist environments at low elevation along shorelines, lack of seasonality, and compact pattern make them relatively easy to identify in satellite images. In this study, a series of automated steps, including water masking, to extract mangroves from an optical data are presented. Furthermore, as global mangrove datasets are readily available in Google Earth Engine (GEE), an approach to automatically extract training data from existing information is introduced, thus saving time and effort for classification. The method can then be adapted in creating maps that show changes in mangrove ecosystems.

Mangroves act as frontiers that protect coasts from being destroyed by ocean waves, tsunamis and storms. They also act as a natural filter and provide habitat for various aquatic life forms and also improve water quality. Mangroves also act as an extremely strong barrier from sea impacts. They shield the land, thereby safeguarding coastal communities and infrastructure, in addition to supporting a healthy food chain, benefiting both land and marine species. Therefore, mangroves contribute to biodiversity by providing habitat for various organisms.

In Malaysia, mangroves also play a crucial role in carbon sequestration. Sediment carbon stocks in these forests range from 0.8 to 352 megagrams of carbon per hectare. They absorb and store carbon, mitigating climate change impacts [1]. Mangroves also serve as a source of livelihood for local communities, providing building materials, medicinal resources, and wood for the charcoal industry. Additionally, mangrove ecotourism has gained research interest, and contribute to economic growth.

Malaysia's mangroves are not merely trees; they are guardians of the coast, providers of essential services, and stewards of our planet's health. However, despite the realisation of the importance of mangroves in pivotal ways, there has been a notable loss of mangroves over the last few decades. Currently, Malaysia has reserved about 93.74%

(549,818 ha)¹ out of the 586,548 total areas of mangroves as Permanent Forest Reserve and State/National Parks. The remaining is under the state-lands and alienated lands. This indicates that Malaysia is very serious to conserve its mangrove ecosystem for the protection of vicinities, sustaining resources and keeping its vital roles and functions for the human and environment.

Remote sensing satellites are widely used to monitor and obtain data and (i) information over large areas, (ii) produce repeated measurement over a place, and (iii) make full use of electromagnetic spectrum for quantitative and qualitative measurements over mangroves [2]. Satellite information on spatial distribution and temporal changes of mangrove forests is crucial. This study is on the state of mangroves in Malaysia.

2. Identifying mangroves from remotely sensed data

2.1 The study area

The study area covers the entire mangrove ecosystem in Malaysia, which can be divided into two regions: Peninsular Malaysia and East Malaysia (i.e. Malay Borneo). Forests in these regions can be divided into three major types, which are inland dipterocarps (dryland), peat swamp and mangrove forests (wetlands). The mangrove forest is a unique ecosystem and the second largest wetland forest type after the peat swamp forest. Ecologically based on elevation, the mangrove forest is located at the lowest elevation, which is equivalent to the sea level. The mangrove forest is generally found along sheltered coasts where it grows abundantly in saline soil and brackish water dominated mainly by trees from the Rhizophoraceae family. Mangroves are fringing the coastlines (up to 5 km landward) and major estuaries of the regions and they reside on wetlands ecosystem of not more than 20 m land elevation.

¹ Data from Forestry Statistics Peninsular Malaysia, 2022; Sabah Forestry Department; and Forest Department of Sarawak

2.2 Classification of Mangroves on GEE

Images from Landsat-8 Operational Land Imager (OLI) and Landsat-9 OLI-2 satellites that were acquired in 2023 were used in this study. Mangroves are particularly recognisable in satellite imagery by their wetness — these ecosystems thrive at the water/land interface, making them easy to distinguish with satellite sensors that are sensitive to vegetation and water. Workflow for analysing Landsat imagery for mangroves with a light graphic user interface is presented as the Google Earth Engine Mangrove Mapping Methodology (GEMMM) in [3]. The advantages of this approach are the evaluation of the shoreline buffer areas, high- and low-tide imagery, user-friendly interface, and the freely available and well-explained code.

Mangroves are found close to shores, which tend to be at low elevations. The next steps involved automatic water masking to delineate land from sea; then the existing dataset were used to buffer the area of interest so that only mangroves are mapped.

Canny edge detector and Otsu thresholding [4] approach was used to automatically detect water. Next, the land mask was created by inverting the water mask, and removing any areas with elevation greater than 40 m above sea level using the NASADEM (Digital Elevation Model from NASA) data collection. This will ensure the mangroves are mapped accordingly, where they occur.

Mangrove and non-mangrove areas were automatically selected as training data based on the previous datasets [5]. Only three thresholds were used in a training layer, which are: mangroves=1, non-mangroves=2, and everything else=0. The training accuracy was over 99%, which is very good. According to the substitution matrix, only a few training points seem to be confused when randomly replaced.

The Random Forest classification technique was employed to classify the images [6]. The tuning of Random Forest parameters was carried out to identify the best configuration for achieving the highest classification accuracy. This study investigated three tuning parameters: the number of trees (numberOfTrees), the number of variables per split (variablesPerSplit), and the minimum leaf population (minLeafPopulation), utilizing a k-fold cross-validation approach. Fifty combinations of tuning parameters were evaluated, and the one yielding the highest accuracy was chosen for image classification.

All images are classified in order to distinguish mangroves from other land uses. The classification results were transformed into vector shapefile for further refinement and editing. The accuracy of the classification results was assessed using a number of ground-truth points.

3. Distribution of Mangroves in Malaysia

The study indicated that the suitable spectral bands for species discrimination varied with scale. However, near-infrared (700–1327 nm) bands were consistently important spectrum across all scales and the visible bands (437–700 nm) were more important at pixel and crown scales. By using the RandomForest algorithm, the most important bands in the classification were represented by a mean decrease Gini values. The most important bands in mangroves discrimination, from most to least, were; MidIR, NIR-2, NIR, Green, Blue, Red.

The image classification approach used in this study was found to be effective only at large coverage of mangroves. The overall accuracy for the classification was attained at 94%. Mangroves normally appear dark on any combination of spectral bands of multispectral image. This is due to the natural ecosystem of mangroves, which is covered by swamps and sometimes inundated by tidal water. The chlorophyll content of the mangrove leaves, which is higher than those of trees and crops, tends to make them appear darker on satellite images. Each mangrove species has a unique configuration of trunks, prop roots and pneumatophores that works as a different drag force resulting in a different reduction rate of sea waves (**Figure 1**). Additionally, the wet floor of the forest gives special spectral characteristics on satellites images that can be differentiated easily from other features. Further validations were conducted using higher resolutions images, i.e. from SPOT-6, Pléiades, and WorldView-3 images, acquired from e-Pesisir² platform that was developed locally to monitor mangroves, example as shown in **Figures 2 – 5**.

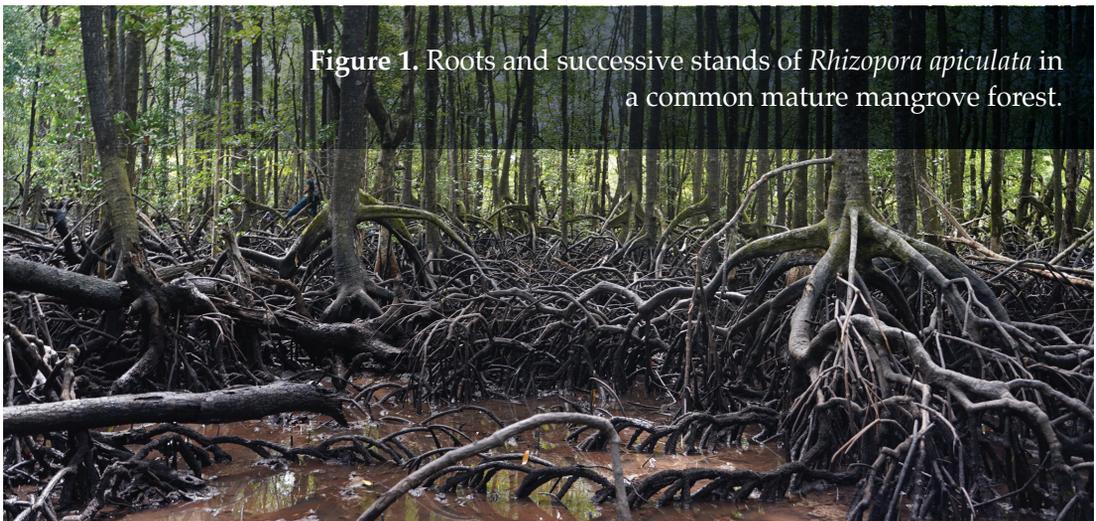


Figure 1. Roots and successive stands of *Rhizophora apiculata* in a common mature mangrove forest.

² <https://epesisir.mysa.gov.my/>



Figure 2. Mangroves as appear on WorldView-3 images over, Kuala Selangor, Selangor.



Figure 3. Mangroves as appear on Pléiades image over Daro, Sarawak.



Figure 4. Mangroves as appear on SPOT-6 image over Beaufort, Sabah.



Figure 5. Mangroves as appear on Pléades over Tuaran, Sabah.

3.1 Spatial distribution of mangroves mapping

The classification results were edited manually to refine both the shape and accuracy. This process was conducted on the vector shapefile by visual interpretation on geographical information system (GIS) platform. The spatial distribution of mangroves was mapped properly (**Figure 6**). The mangroves in Malaysia were mostly found in Sabah (58.6%), followed by Sarawak (21.7%) and Peninsular Malaysia (19.7%). **Table 1** summarises the total extent of mangroves in the respective regions that have been produced from the classification. It is notable that the total extent of mangroves have been decreasing between years 2017 and 2023, from 629,038 ha [5] to 586,548 ha. The total mangroves lost within this six years was 42,490 ha. These mainly occurred in Sabah and Sarawak, and selected states in Peninsular Malaysia. However, in Peninsular Malaysia there was a notable increase of 4,364 ha. Deforestation occurred mainly in stateland areas (outside the Reserved Areas). **Table 2** shows the statistics of Reserved Areas under mangrove forest, indicating that almost all the mangroves in Malaysia, or 94%, are legally protected.

Table 1. Extent changes of mangroves in Malaysia.

Region	Mangroves 2017 (ha)	Mangroves 2023 (ha)	Changes 2017-2023 (ha)
Perlis	49	88	39
Kedah	7,725	8,511	786
Penang	1,967	2,091	124
Perak	44,990	45,048	58
Selangor	20,853	20,874	21
Negeri Sembilan	1,557	1,457	-101
Melaka	1,241	1,103	-138
Johor	26,818	26,105	-713
Pahang	3,759	4,881	1,122
Terengganu	1,571	3,078	1,507
Kelantan	422	2,081	1,659
Sub Total: Peninsular Malaysia	110,953	115,317	4,364
Labuan	313	346	33
Sabah	377,882	343,470	-34,413
Sarawak	139,890	127,416	-12,474
Total	629,038	586,548	-42,490

Table 2. Extents of gazetted mangroves as Reserved Forest in Malaysia as of year 2023.

Region	Mangroves Cover 2023 (ha)	Percentage of Mangrove Cover (%)	Reserved Areas* (ha)	Percentage of Reserved Areas (%)
Perlis	88	0.02	13	0.00
Kedah	8,511	1.45	6,714	1.22
Penang	2,091	0.36	1,058	0.19
Perak	45,048	7.68	42,411	7.71
Selangor	20,874	3.56	18,998	3.46
Negeri Sembilan	1,457	0.25	99	0.02
Melaka	1,103	0.19	238	0.04
Johor	26,105	4.45	18,076	3.29
Pahang	4,881	0.83	1,822	0.33
Terengganu	3,078	0.52	1,037	0.19
Kelantan	2,081	0.35	-	-
Sub Total: Peninsular Malaysia	115,317	19.70	90,466	16.45
Labuan	346	0.06	199	0.04
Sabah	343,470	58.60	322,990	58.74
Sarawak	127,416	21.70	45,697	8.31
Total	586,548	100.00	549,818	100.00

*Reserved Areas include all categories of protections within mangroves, i.e., Forest Reserve, State Parks, National Parks, Totally Protected Area, Mangrove Reserve, Wildlife Sanctuary and National Parks.

Figure 6 shows distribution of mangroves in Malaysia in 2023. Mangroves are found mainly along the west coast of Peninsular Malaysia, west coast of Sarawak and the east coast of Sabah. **Figures 7 – 29** show the distribution of mangroves for each state in Malaysia on a larger scale.



Figure 6. Distribution of mangroves in Malaysia in 2023.

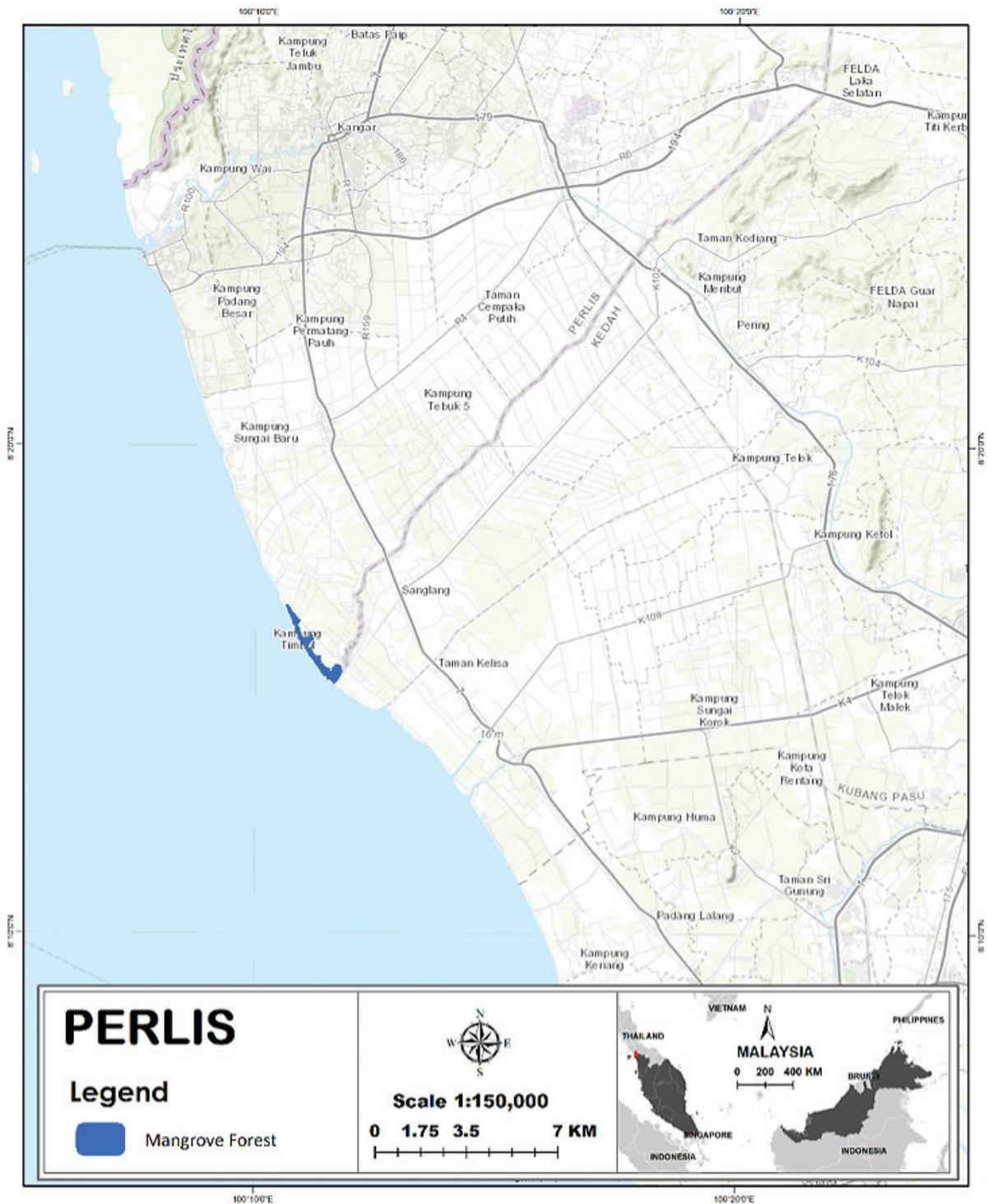


Figure 7. Distribution of mangroves in Perlis.

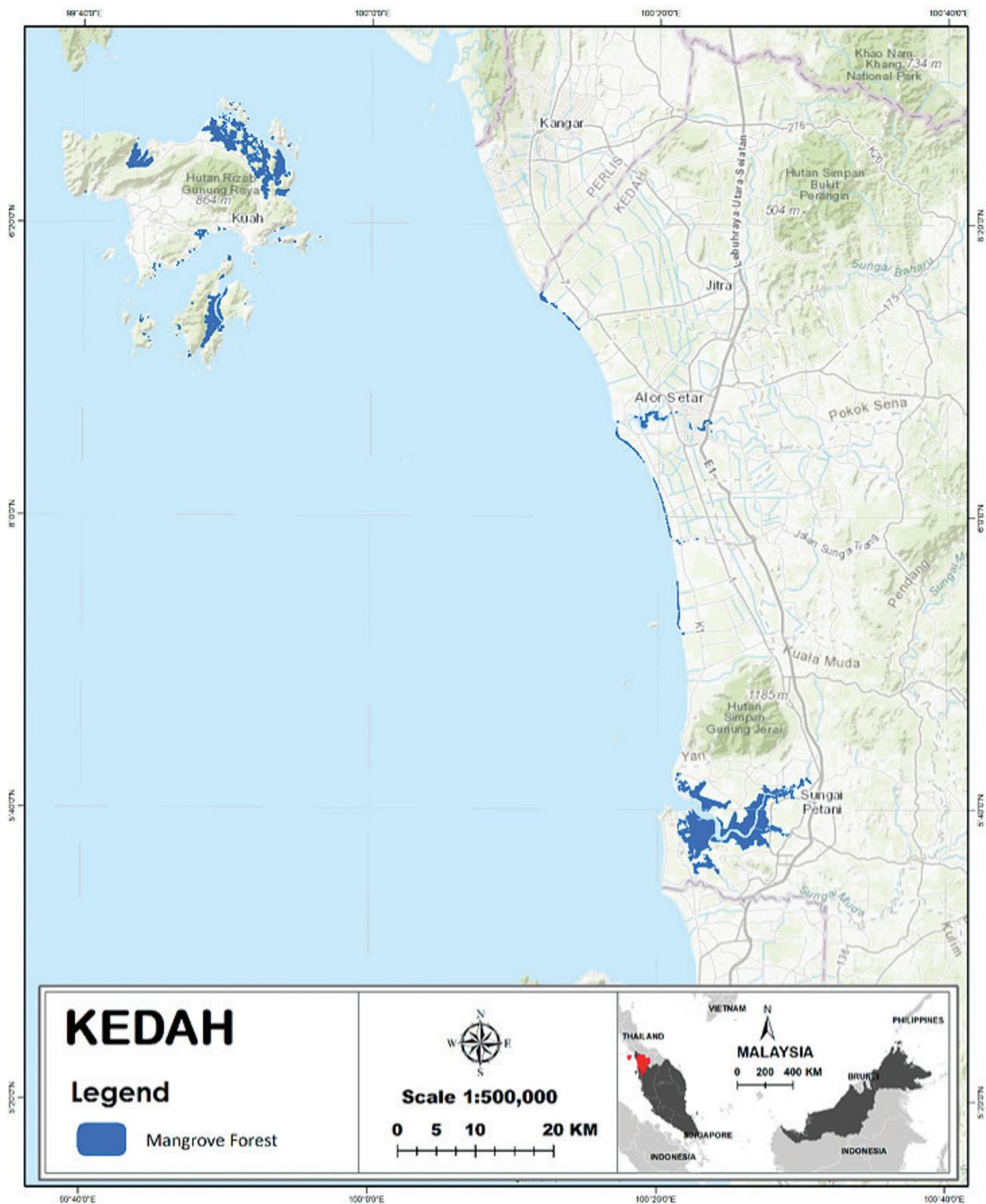


Figure 8. Distribution of mangroves in Kedah.

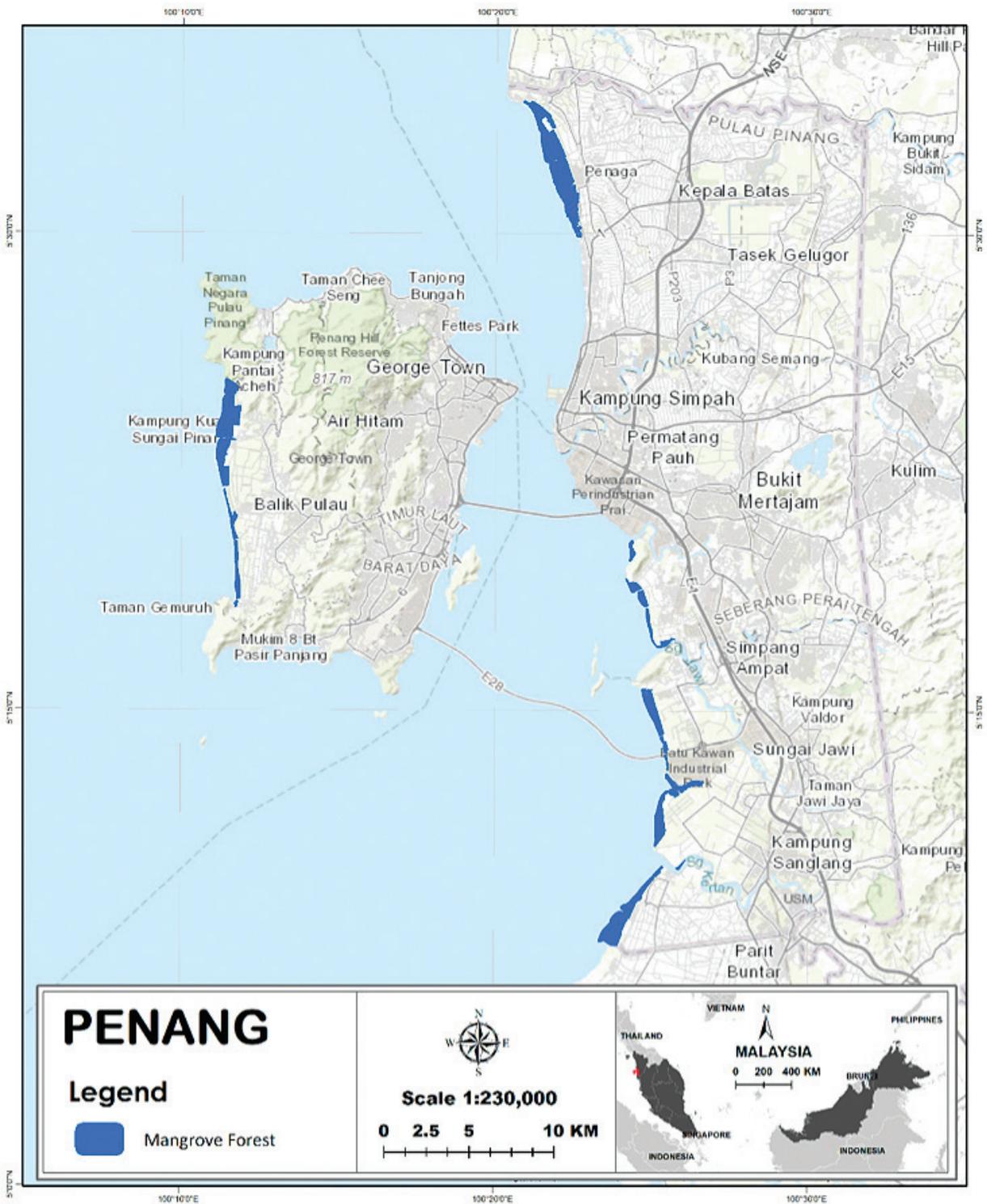


Figure 9. Distribution of mangroves in Penang.



Figure 12. Distribution of mangroves in Negeri Sembilan.

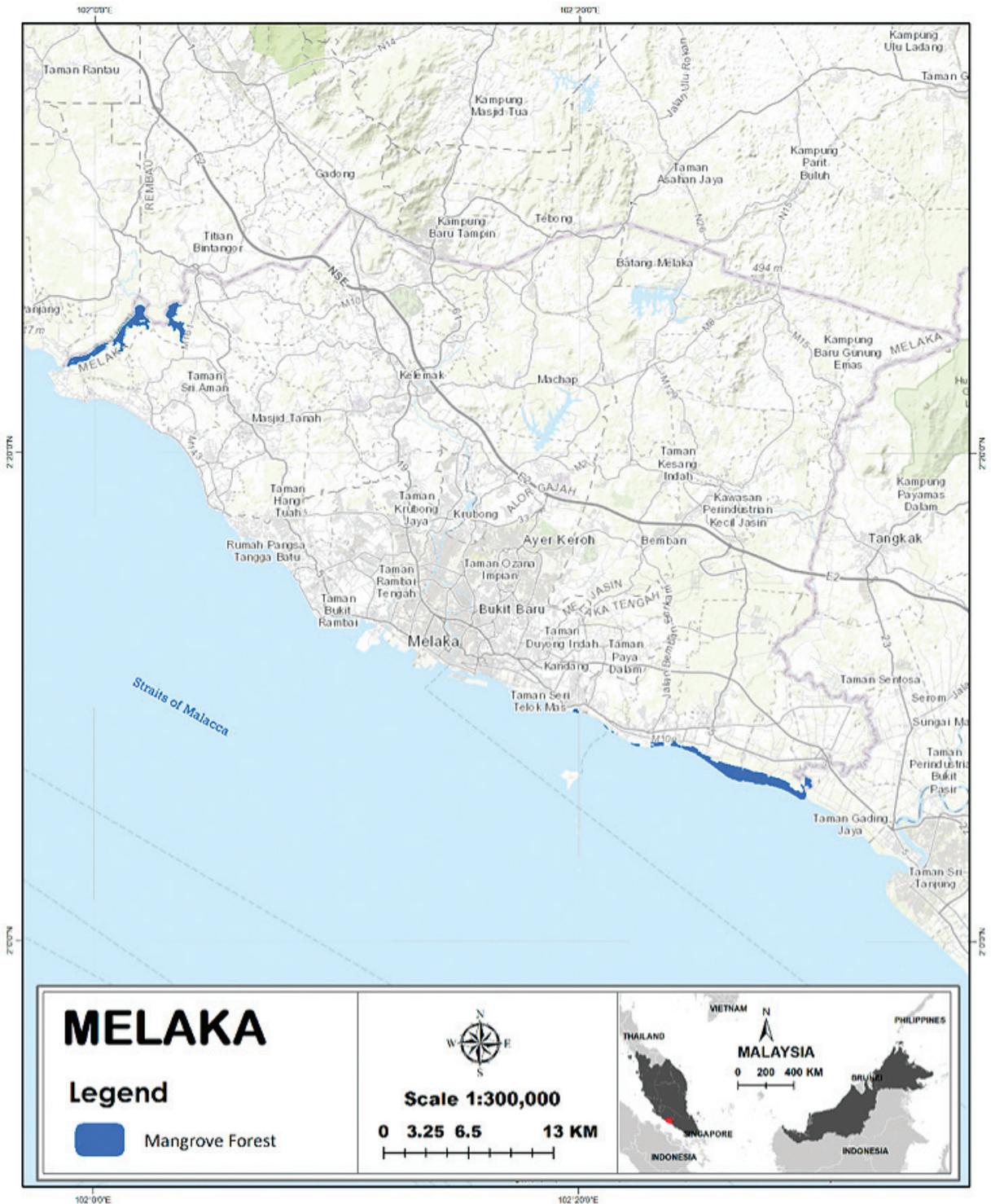


Figure 13. Distribution of mangroves in Melaka.

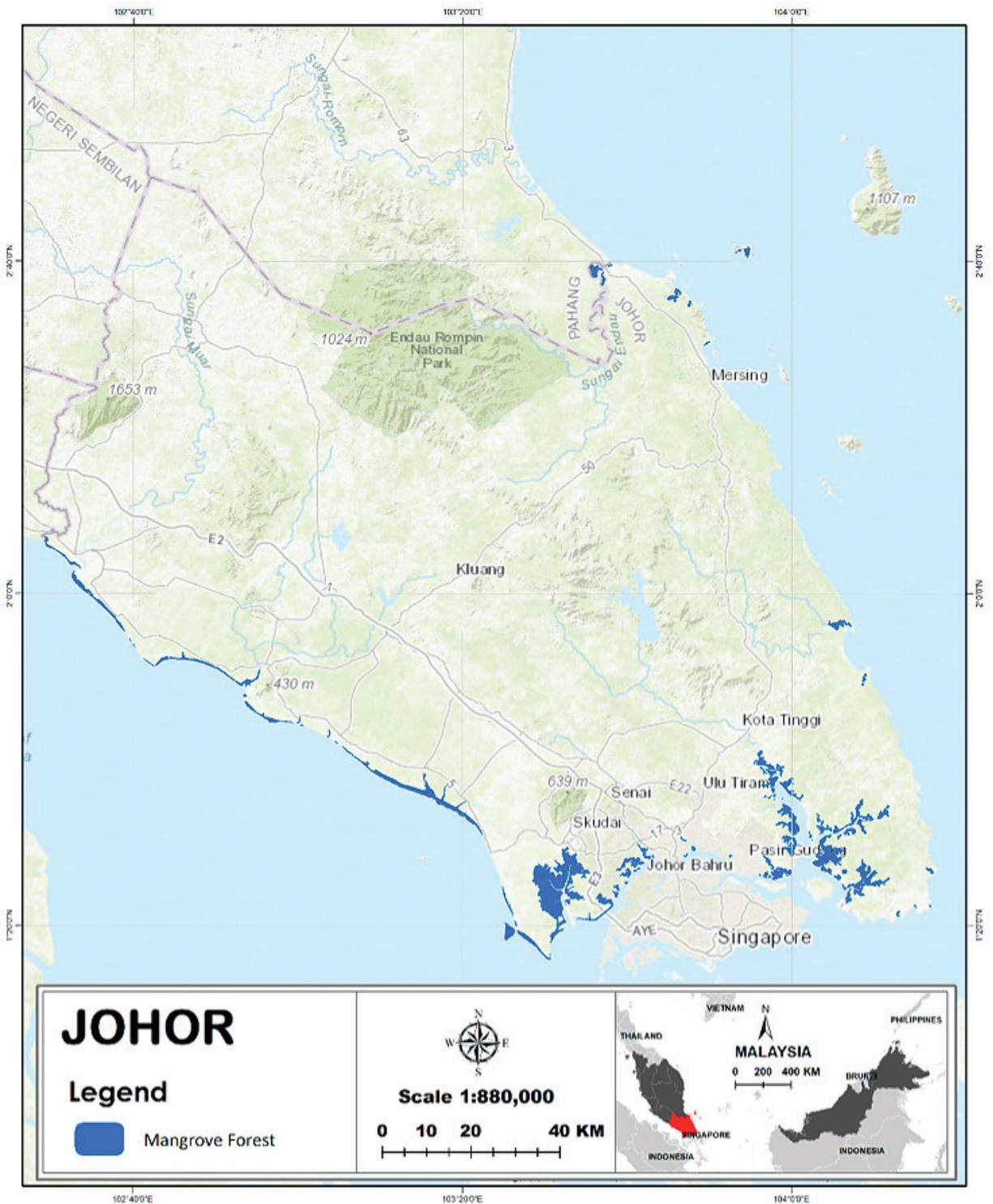


Figure 14. Distribution of mangroves in Johor.

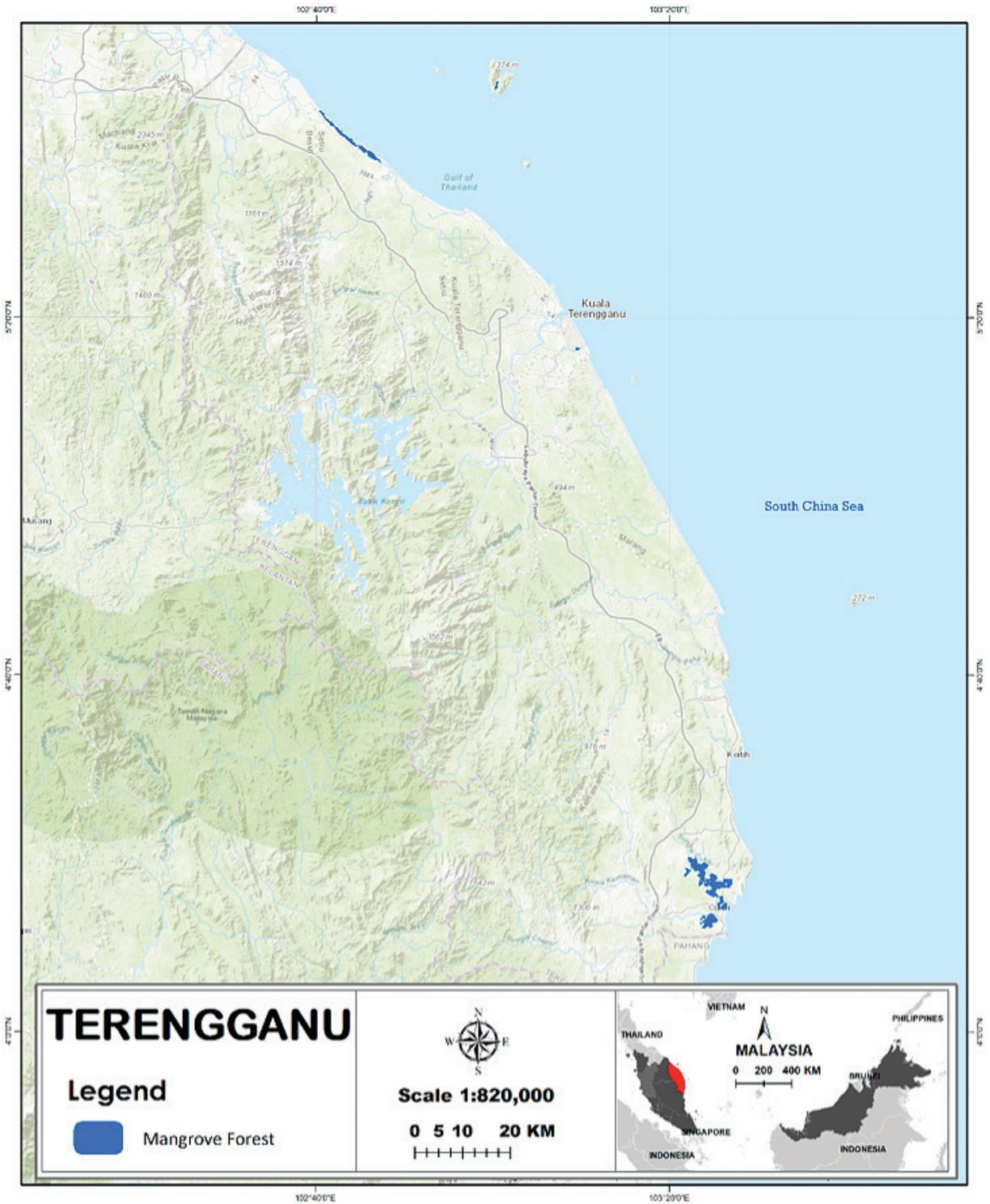


Figure 16. Distribution of mangroves in Terengganu.

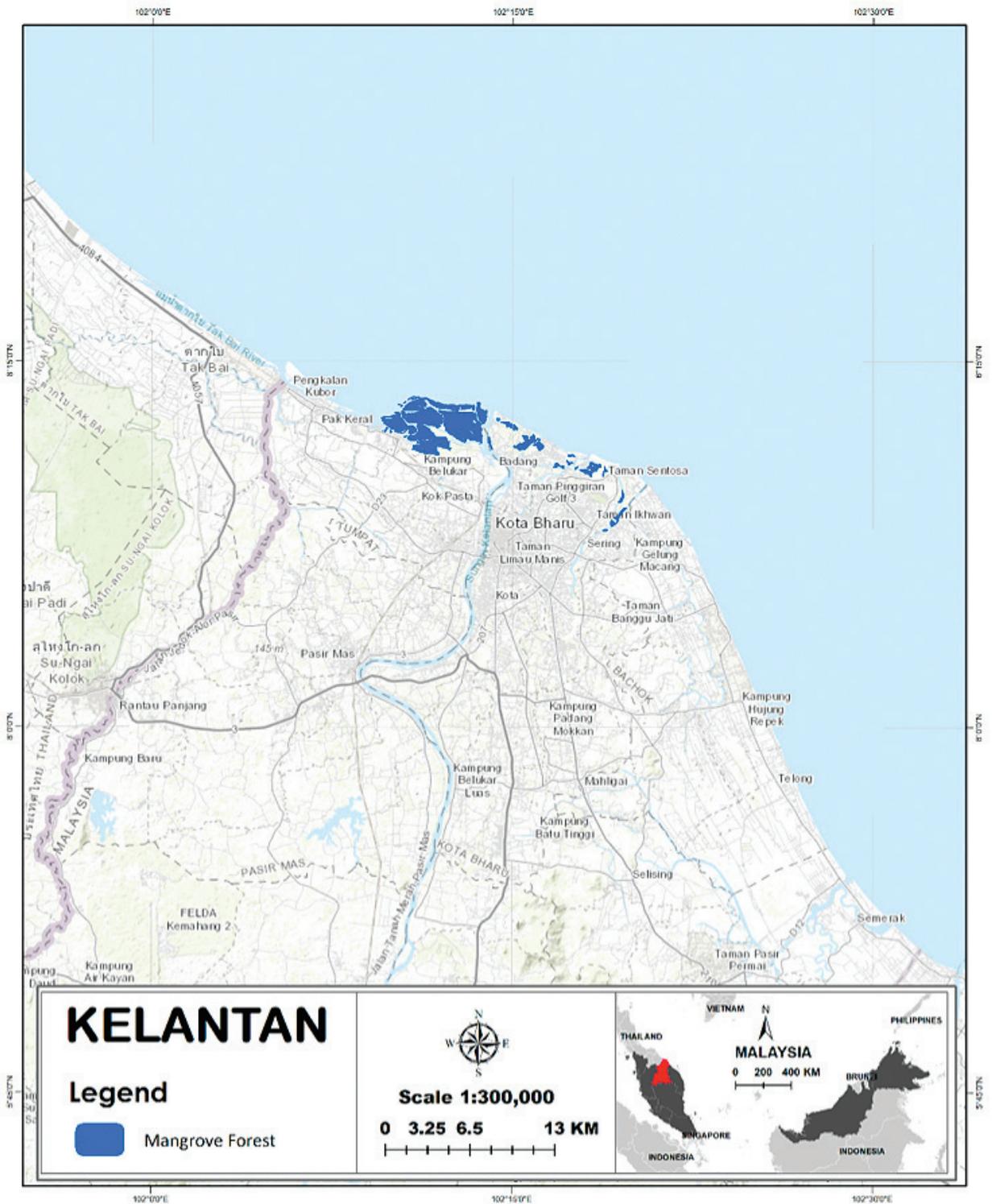


Figure 17. Distribution of mangroves in Kelantan.

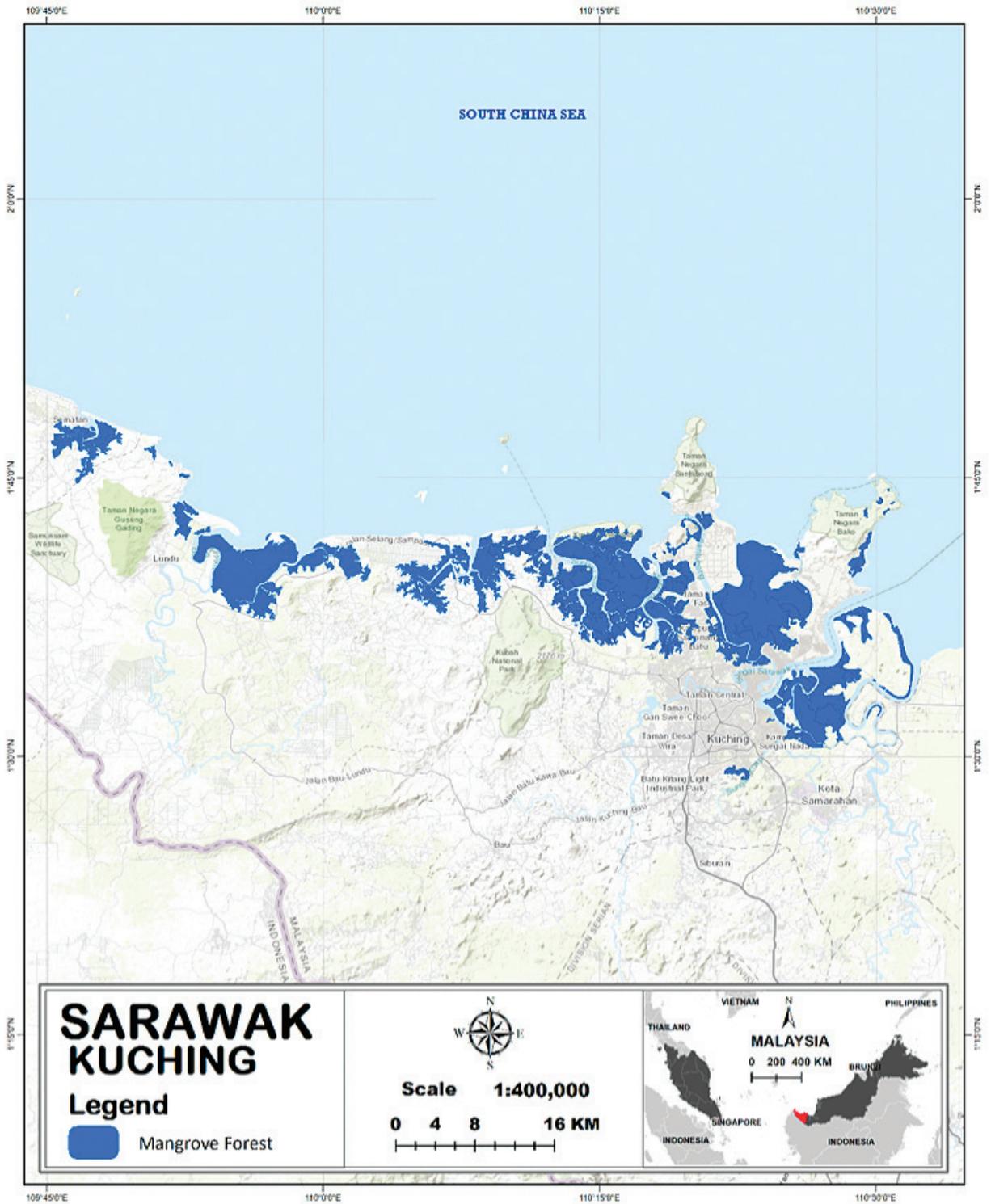


Figure 18. Distribution of mangroves in Kuching, Sarawak.

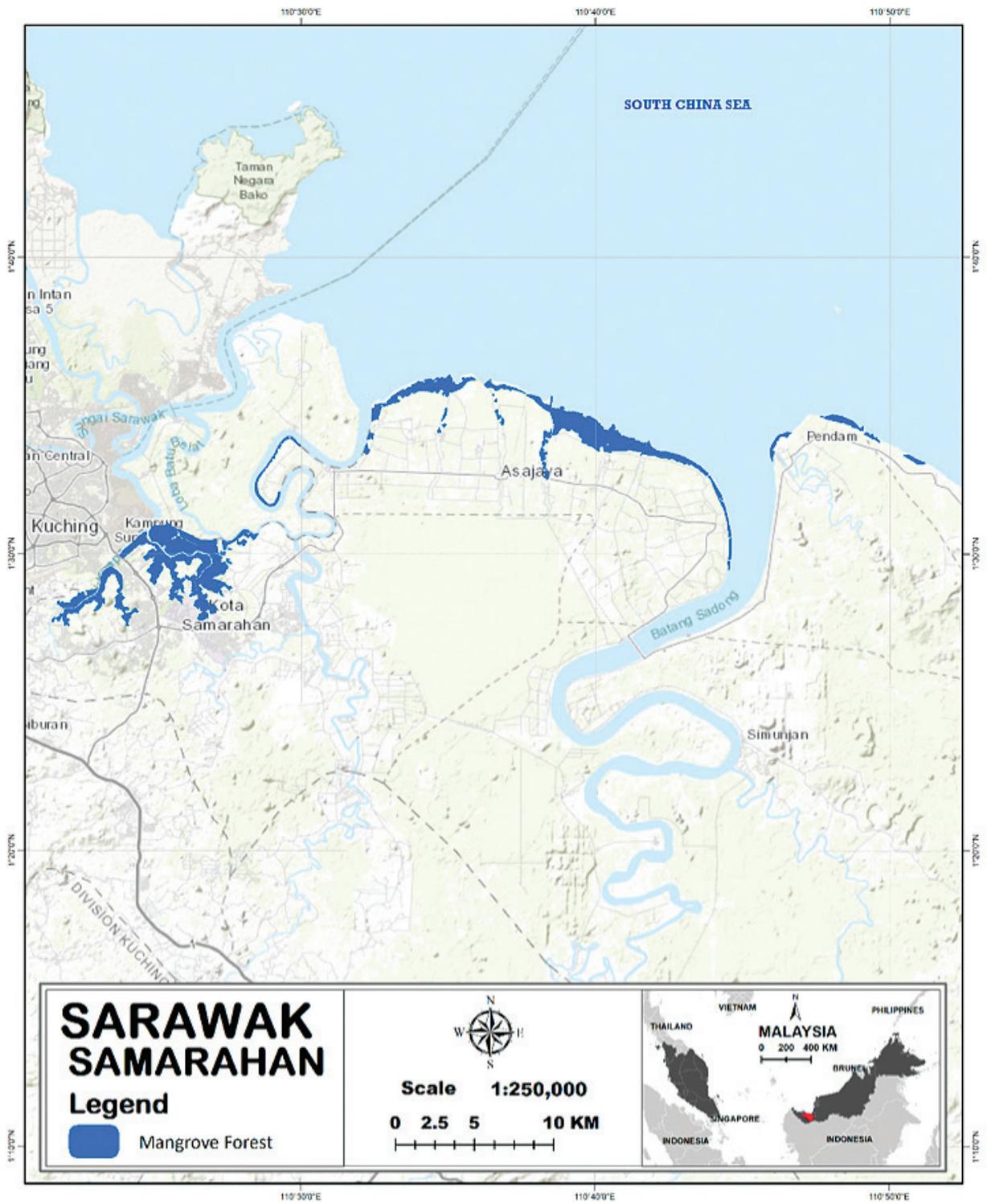


Figure 19. Distribution of mangroves in Samarahan, Sarawak.

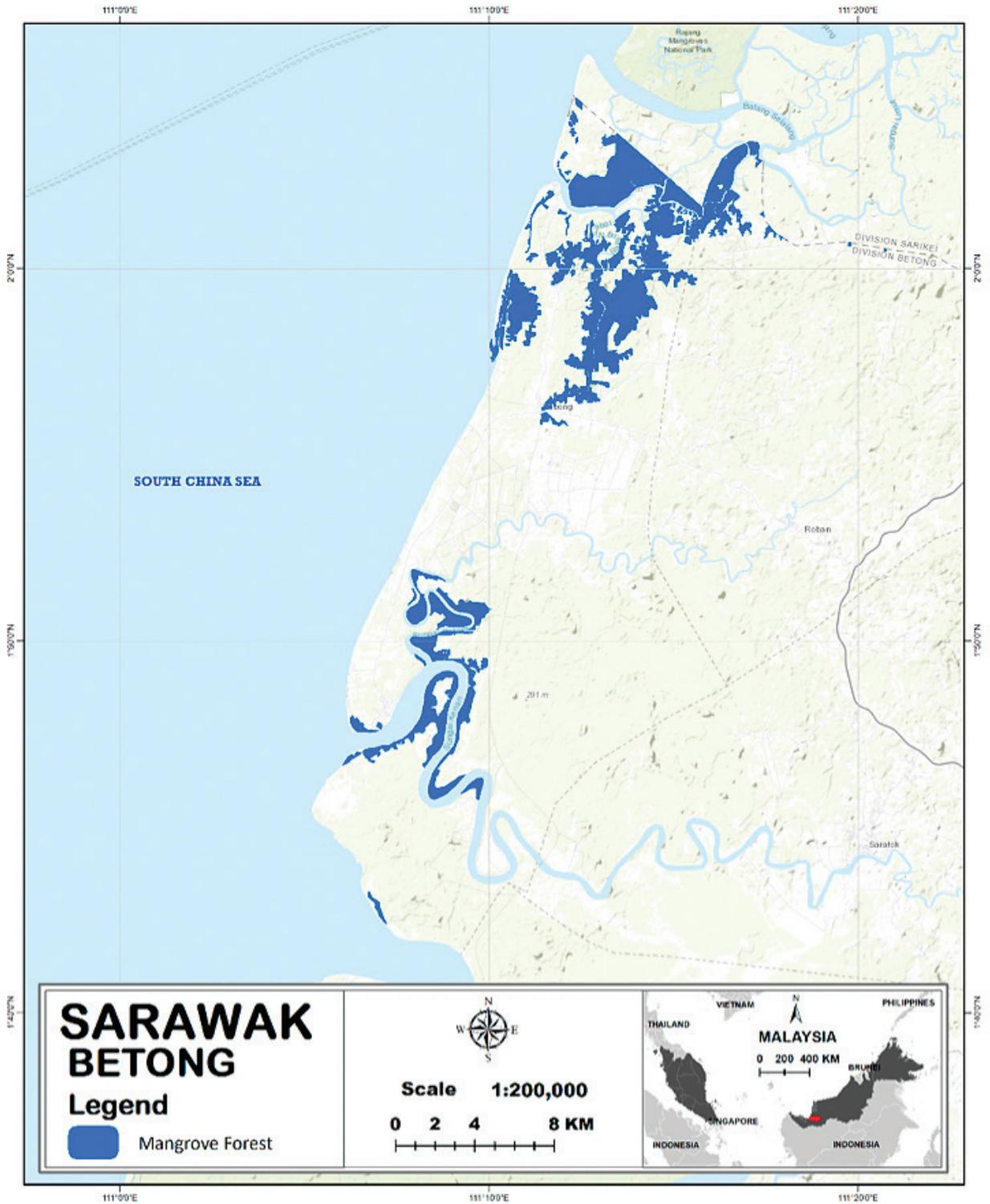


Figure 20. Distribution of mangroves in Bentong, Sarawak.

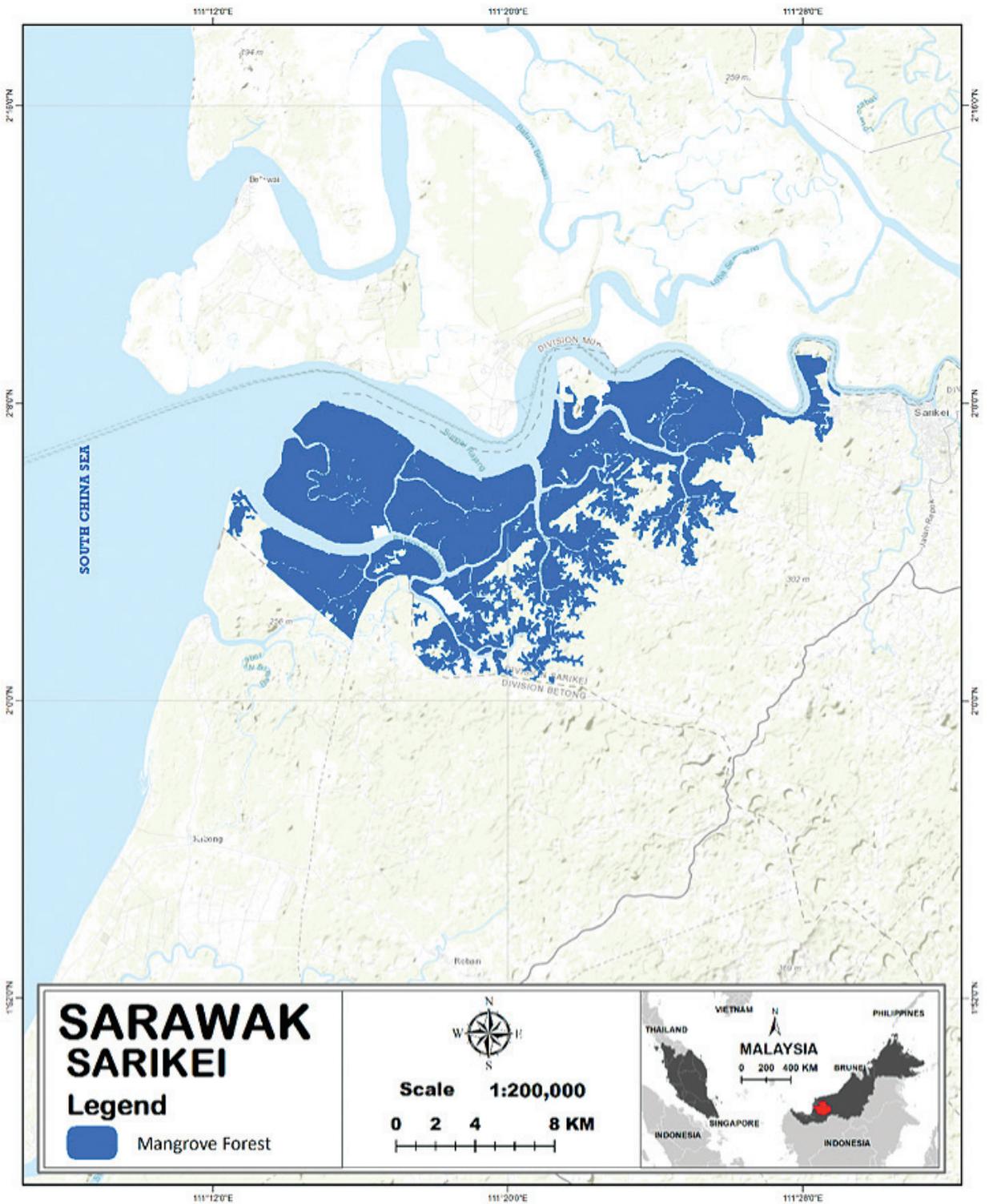


Figure 21. Distribution of mangroves in Sarikei, Sarawak.

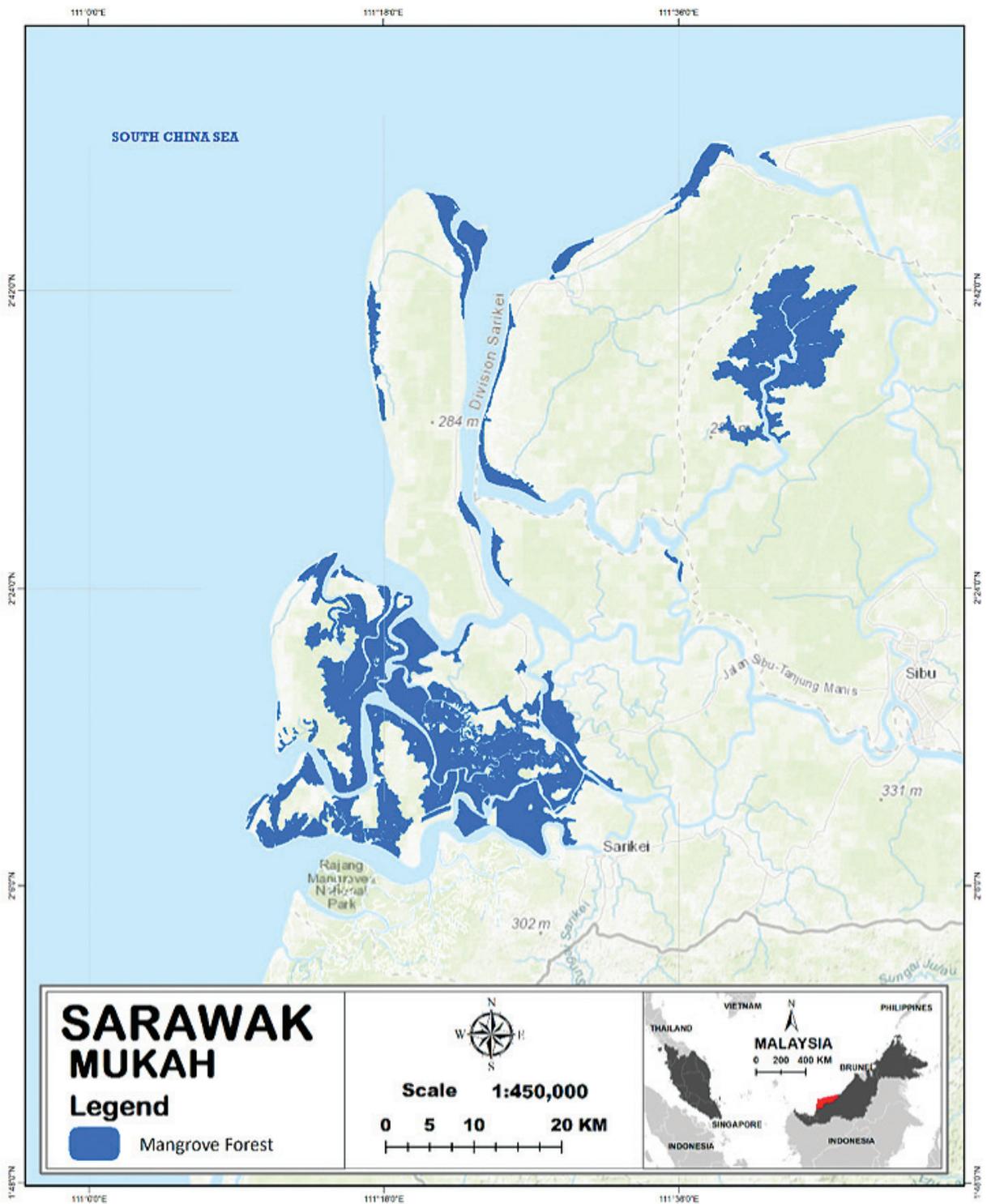


Figure 22. Distribution of mangroves in Mukah, Sarawak.

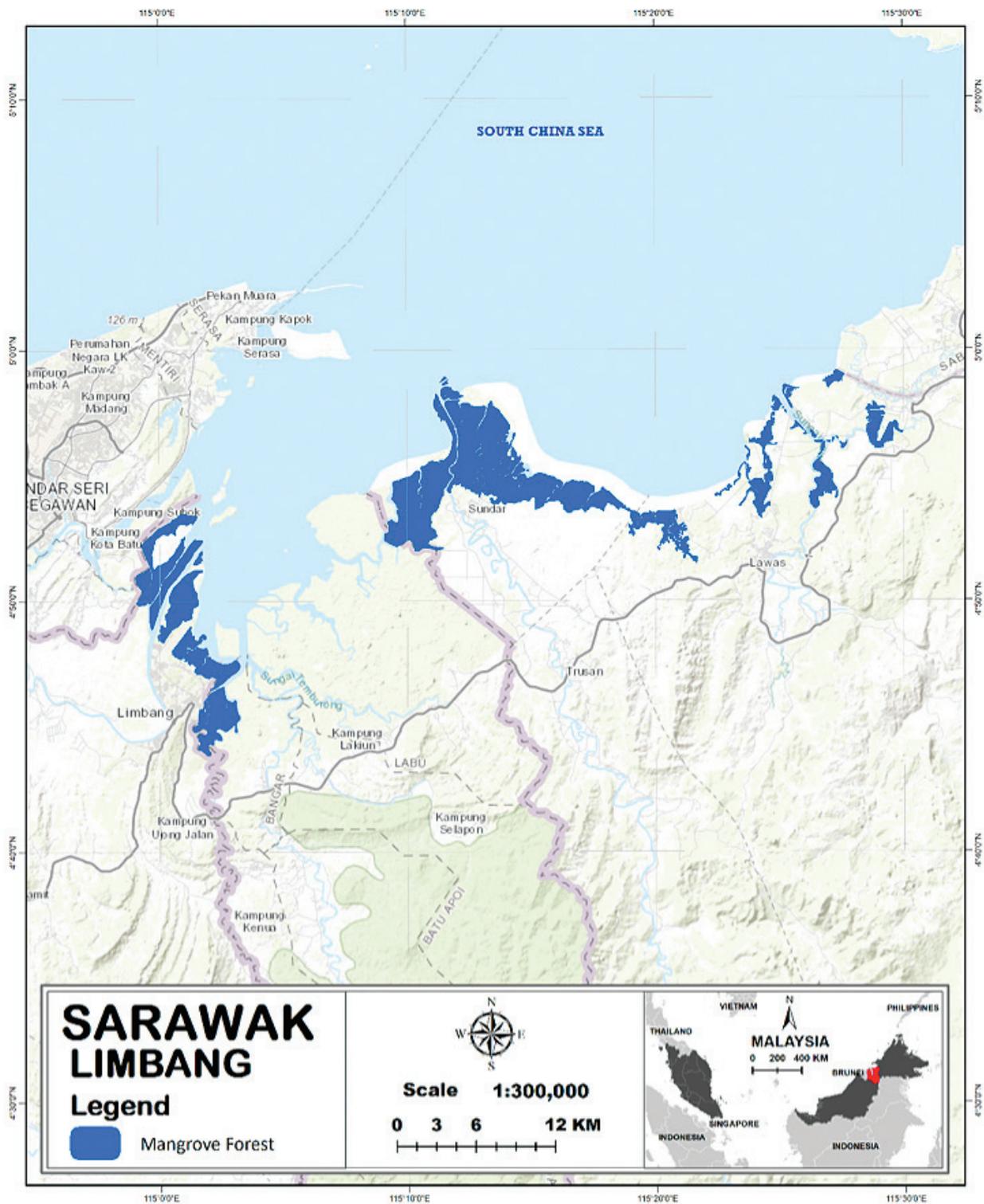


Figure 23. Distribution of mangroves in Limbang, Sarawak.

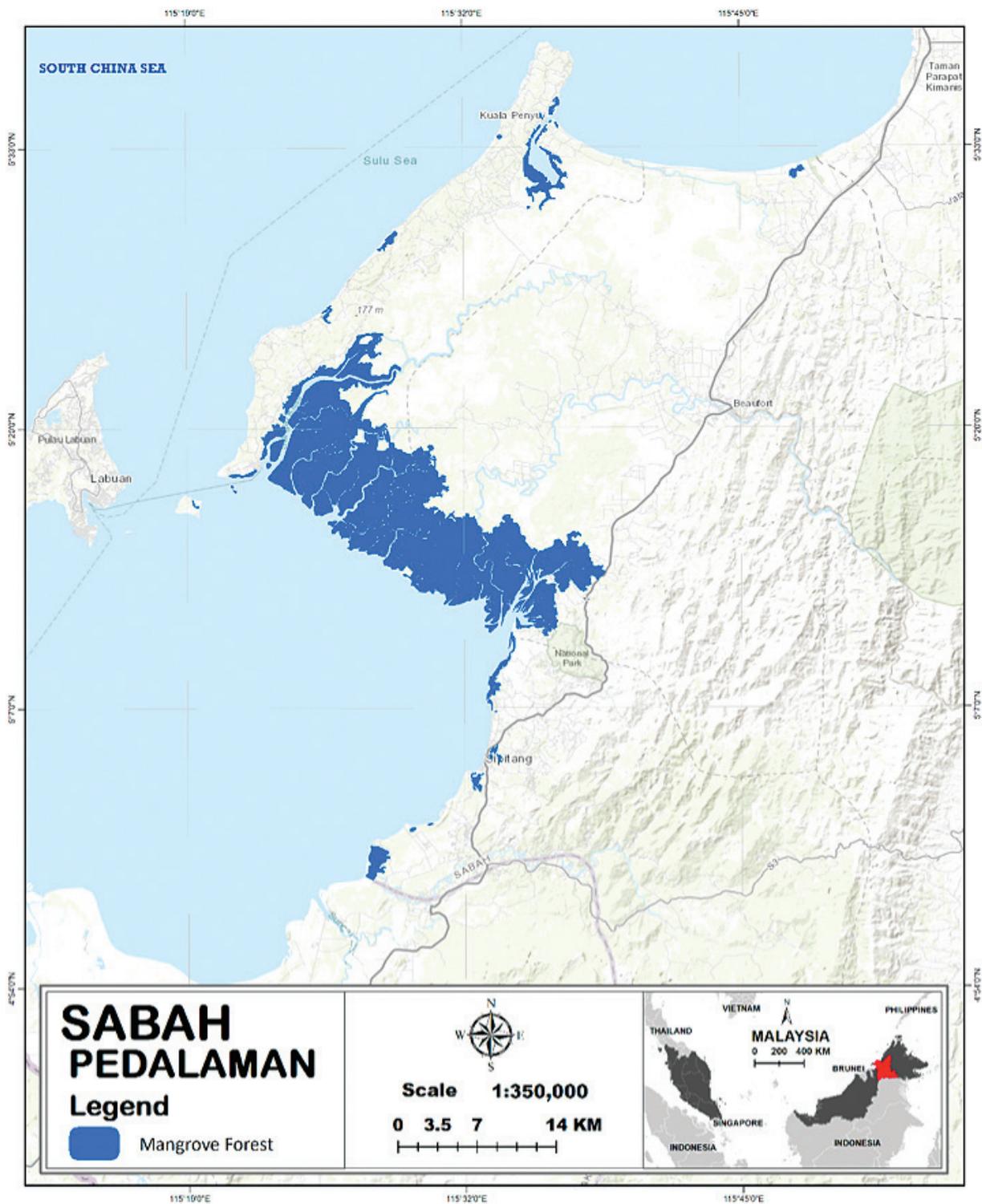


Figure 24. Distribution of mangroves in Pedalaman, Sabah.

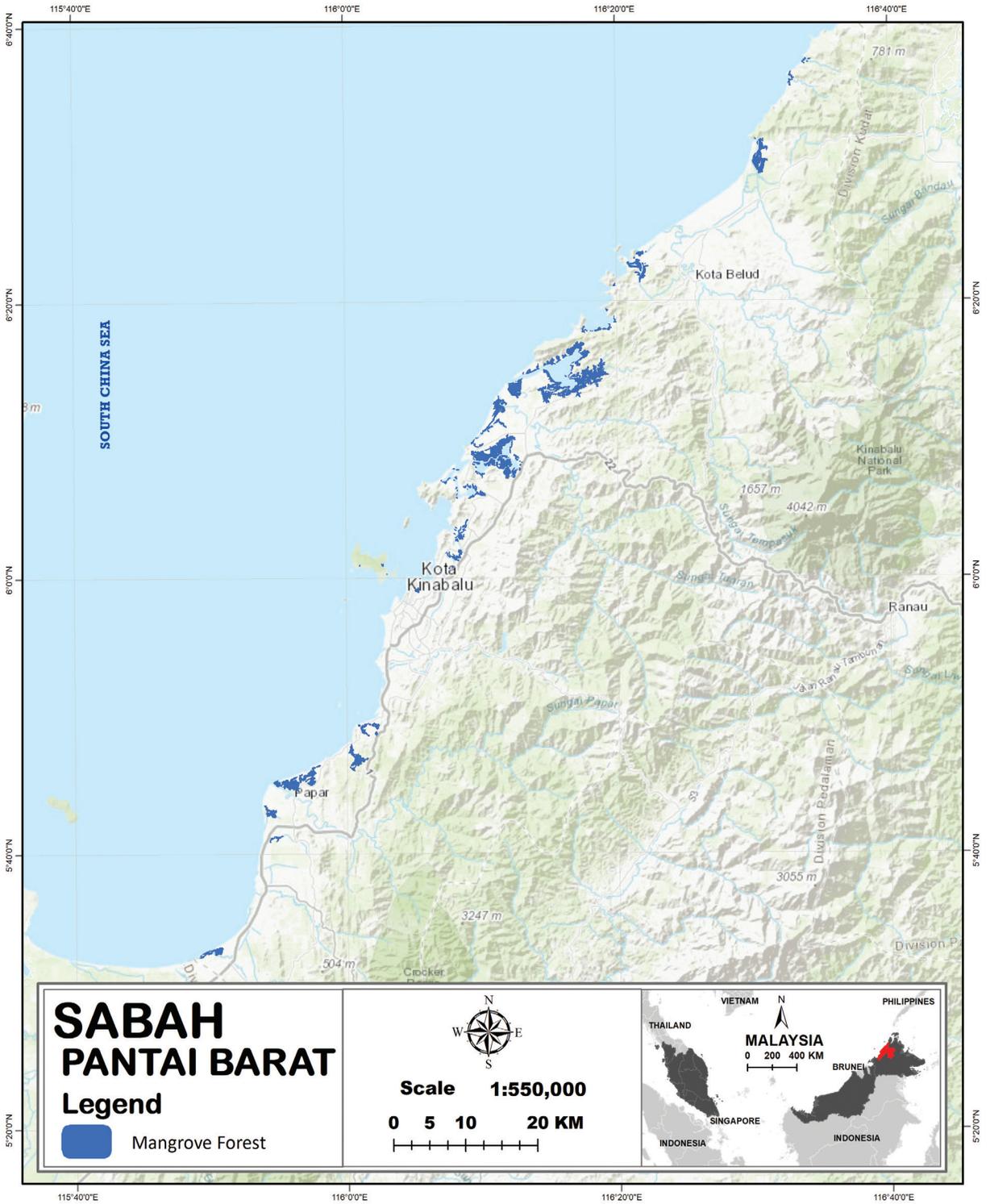


Figure 25. Distribution of mangroves in Pantai Barat, Sabah.

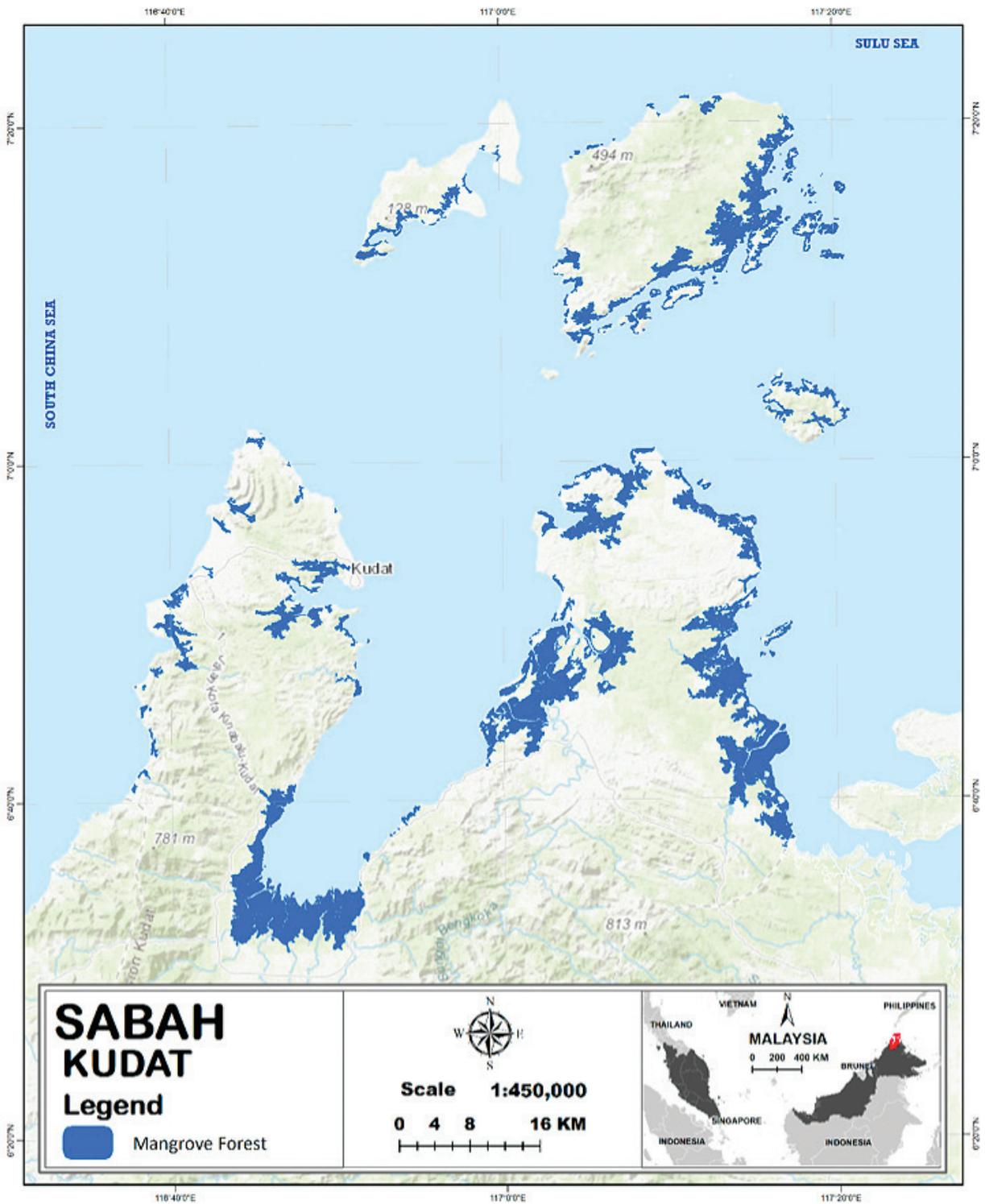


Figure 26. Distribution of mangroves in Kudat, Sabah.

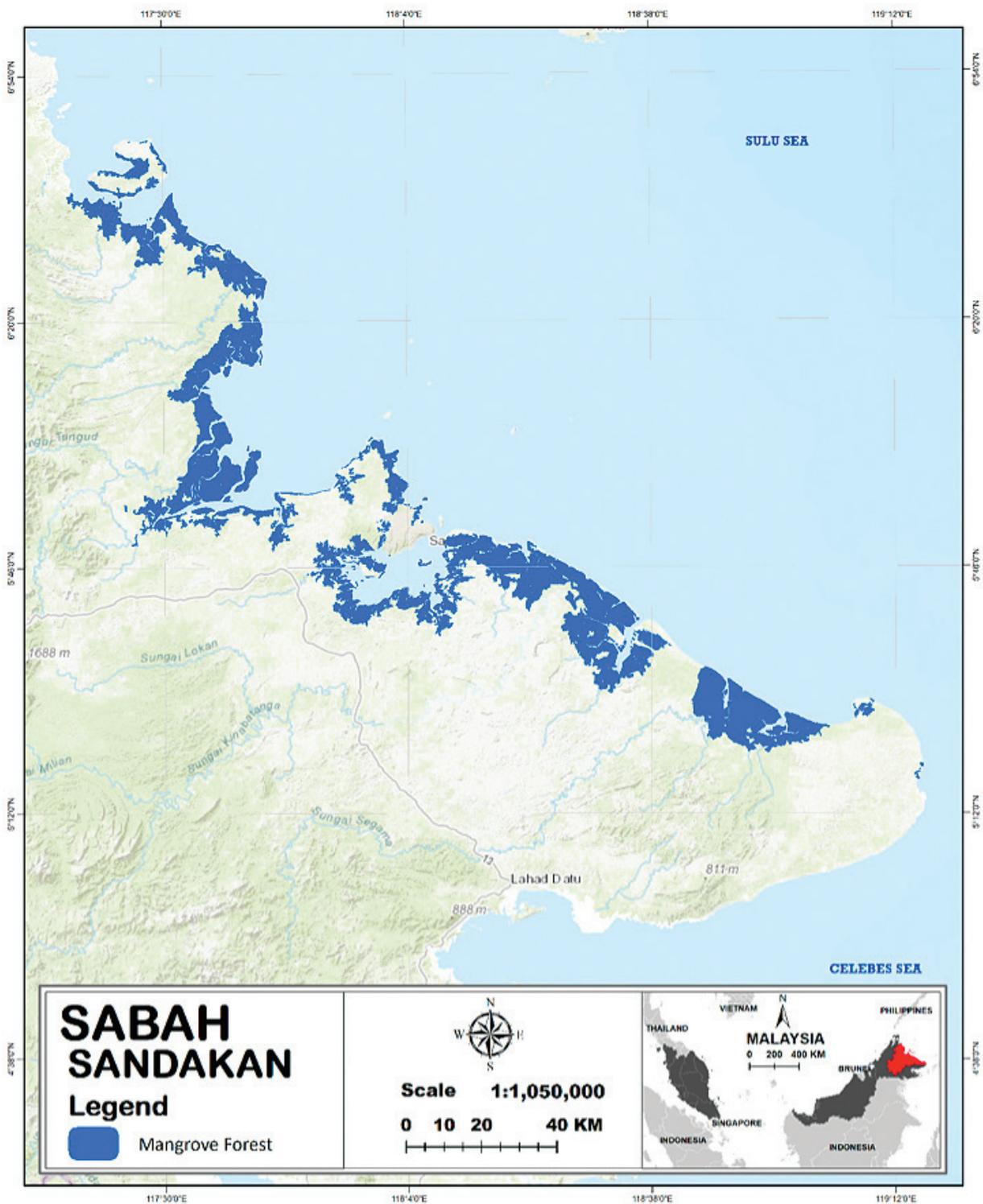


Figure 27. Distribution of mangroves in Sandakan, Sabah.

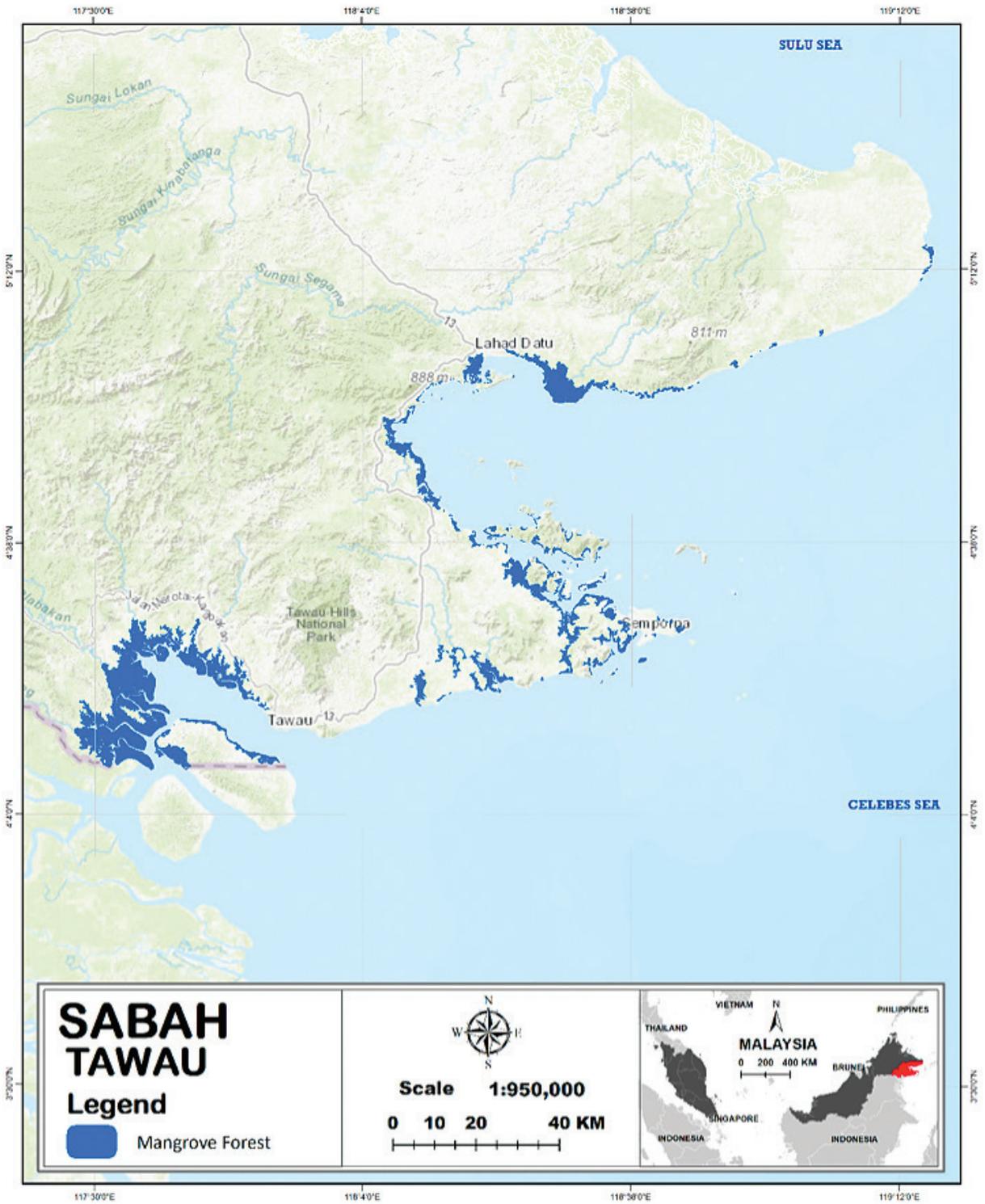


Figure 28. Distribution of mangroves in Tawau, Sabah.

4. Conclusion

This study has assessed the present state of mangroves and its rate of loss in Malaysia between 2017 and 2023. Mangrove coverage in Malaysia decreased from 629,038 to 586,548 ha. Total deforestation was 42,490 ha or 6.8% with the annual rate of deforestation at 7,082 ha yr⁻¹ or 1.13% yr⁻¹ in the same period.

The study found that the Landsat-based mapping and monitoring of mangroves was very practical. It provides a reliable information on mangrove distribution, both qualitatively and quantitatively. Landsat missions also provide a very useful RS tool to monitor changes over time. The study suggests that appropriate actions should be taken by the Government of Malaysia to protect the mangroves and keep their ecosystem intact forever. The most effective way to conserve the mangroves is to gazette the remaining stateland forest as Permanent Reserved Forests (PRFs). These PRFs should then be maintained for current and future generations, while contributing to the mitigation of climate change impacts at the local level. Any development in PRFs should be prohibited or implemented with caution.

Mangroves are dynamic ecosystems which can increase over time and can decrease too because of natural and anthropogenic factors. The power of GEE lies in the cloud-based, lightning-fast, automated approach to workflows, particularly with automated training data collection. This process would usually take days when performed offline in traditional remote sensing software, especially over large areas. The GEE approach is not only fast but also consistent allowing it to be applied to images from different dates to assess mangrove changes over time - both gain and loss.

Acknowledgments

This work was carried out by Research and Development Committee on Mangroves (JTRD) led by FRIM. Special thanks to Forestry Department Peninsular Malaysia (JPSM), Sabah Forestry Department (SFD), and Forest Department Sarawak (FDS) for their support in terms of facilitating ground data collection activities.

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Chapter 2

Detecting Changes in Mangrove Cover in Malaysia



Detecting Changes in Mangrove Cover in Malaysia

Sofiya Zulaikha Ruslan*, Muhamad Afizzul Misman & Rodziah Hashim
Forest Research Institute Malaysia, 52109 FRIM, Kepong, Selangor, Malaysia

*Corresponding author: sofiya@frim.gov.my

Abstract

Malaysia is one of the countries in Southeast Asia with the largest distribution of mangrove forests with 650,000 hectares in 1990. Unfortunately, over the past few decades, there has been a loss of about 20% - 30% of mangrove forests due to various anthropogenic activity and natural disasters. Monitoring and detecting changes in mangrove growth is essential due to their accessibility and the extensive scale of research studies. Many previous studies encountered limitations when analysing mangrove forests, often mitigating them by focusing on specific critical areas. By using remote sensing technologies in conjunction with Geographic Information System (GIS) techniques, these limitations can be addressed. High-resolution SPOT 6 satellite imagery serves as a base-map, complemented by land-use change techniques, enabling visualisation and mapping of mangrove changes between 2017 and 2023. This chapter explores the application of remote sensing and GIS for monitoring and change detection in forestry, specifically mangrove ecosystems in Malaysia. It also emphasises the importance of incorporating this knowledge into a forestry management plan, serving as a baseline for designing protocols and principles to manage mangrove forests effectively, ensuring conservation, restoration, and protection for future generations and preventing extinction.

1. Introduction

Mangrove forests, mostly found in the intertidal zone that are sheltered by the seacoast, are regarded as the most biologically diverse and productive ecosystems compared with the other types of forest [1,2]. They contain high rates of primary production that are equal to tropical humid evergreen forests [3,4] contributing to both coastal and marine systems in addition to supplying goods and services to the local communities [5-7]. The roots of mangrove trees function as wave breakers in preventing flood disasters in the coastal area, especially in the area facing the sea [8-10]. Strong waves and storm can destroy the structure of the coast line and lead to soil erosion that can cause falling trees. Changes in mangrove accretion and reduction are a dynamic process along with the country's growth and development process when urbanisation and land conversion happen from time to time [11-14] thereby destroying the soil conditions to decrease the size of mangrove forests. The mangrove ecosystem is essential as it contributes to sustainability and is a source of (food income) to the local communities and ultimately the economy [3,15-17]. However, the function of

the mangrove ecosystem tends to be overlooked until a major decline happens and the economy rapidly decreases. Mangrove forests are fertile breeding grounds of marine species and previous studies have suggested that the loss of mangroves is typically associated with the loss of biodiversity and marine habitat [4,28].

Mangroves have experienced accretion too in the past but the reduction phase has overshadowed it when an accretion in mangrove forest happens in a small area compared with the area of reduction. Over 30% of the mangroves in the world have disappeared due to natural disasters, such as hurricanes, tropical storms, and tsunamis, especially over the last few decades [6,20]. Without exception, anthropogenic activities, such as logging, forestry, mining, urban expansion, aquaculture, and agriculture have contributed to the six million hectares of mangrove changes worldwide enhancing the potential for forest destruction and deforestation phenomena that have currently become major issues in forestry management [13,21]. Growth in demand for agriculture and aquaculture has encouraged to vanishing mangrove ecosystem in the urban borderline (between an urban area and mangrove forest). This land transformation not only caused the disappearance of forests but also led to the decline in soil fertility [1,18,19]. However, the changes in soil condition may attract the growth of new species that are more suited to such soil conditions, even though only small studies have been conducted on this topic [22-24]. An earlier study reported that there is a change in precipitation that may cause alteration in soil water content and salinity, and which can lead to variations in mangrove species and their growth [17].

From the above, it can be seen monitoring and mapping of mangrove changes are compulsory for future development, sustainability, and government preservation management policies. Anthropogenic activities proved to have played a key role in threatening the mangrove ecosystem and triggered the growth of mangrove species over the last few decades. The preservation and conservation of mangrove forests is challenging due to inaccessible areas and large-scale forest areas which make it time inefficient and costly. Yet, not much ground sample and field data for large-scale mangrove sites are available to map those areas together with their dynamics; the solution to which is found by using remote sensing technology and digital imaging like satellite images. [5,7]. Satellite images employing various sensors, including Landsat TM/ETM, SPOT, ASTER, IKONOS, and Hyperion are used in large-scale research sites [7,29-37]. The near-infrared (NIR) signals can record the internal leaf structure and discrimination of mangroves and facilitate the ecosystem characterisation detection purpose from its different reactions [6,7]. Optical remote sensing where the real image is captured over a large coverage area is widely used in forest classification and mangrove species detection [7,38]. Globally, these techniques have been used in various studies, especially in forestry, worldwide. Even though remote sensing advanced technologies come with limitations from data availability upon specific sites and technical experts for handling procedures, this latest technology can solve issues related to labour cost, especially for mangrove forestry monitoring, restoration, and conservation studies.

Malaysia is one of the countries with the largest extent of mangroves in Southeast Asia. They are however, exposed to various threats, such as anthropogenic activities and natural disasters. Previous studies have suggested in 1990, approximately 2% (650,000 ha) of the total land area in Malaysia was mangrove forests [10,39]. However, it gradually declined over the last decades to 580,000 ha approximately [10,40]. The loss has been noted globally between 1980 and 2005 due to intensive harvesting, natural wave actions, and land use conversion [10,40-43]. Therefore, it is clear that the major threats to mangrove forests are, (i) land use conversion, (ii) overharvesting, (iii) agriculture, and (iv) aquaculture, along with nature phenomena such (i) soil erosion, (ii) rise of sea level, (iii) tropical storm and (iv) tsunami. The major transformation in land uses may cause a change in soil conditions and lead to unhealthy mangrove forests. Some species are unable to grow healthily in this poor soil condition. The mangrove ecosystem works in full cycle loops where each component of flora and fauna contributes to the health of the forest. All the compartments including soil, roots, dead matter, trees, and fauna in mangrove forests have faced major threats continuously for the past decades. Nevertheless, thanks to increased forestry education and awareness, local communities are now more conscious of the importance of forest conservation and management. As a result, numerous new mangrove tree plots have been planted along the coastline, primarily due to reforestation efforts. It is crucial for government departments and social sectors to support these initiatives, especially in regenerating our mangrove ecosystems. Notably, significant growth in mangroves can be attributed to the replanted educational plots.

This chapter discusses the convergence of advanced remote sensing technology and appropriate GIS techniques for detecting mangrove changes in Malaysia over a six-year observation period. By monitoring mangrove ecosystems between 2017 and 2023, patterns of reduction and accretion are visualised, revealing changing phenomena. The final output highlights trends in mangrove alterations and identifies factors driving these transformations throughout the year. Covering 13 states across Peninsular Malaysia and Borneo, the analysis allows easy visualisation of growth and losses in specific areas with significant changes. Understanding the drivers of mangrove forest changes is essential for policy design and effective management. Based on these findings, areas experiencing major changes warrant focused attention, and further analysis using GIS tools can uncover contributing phenomena or activity. Notably, most mangrove changes have occurred outside forest reserve gazette areas, often coinciding with development zones outlined in state development plans. Detailed statistical analysis accompanies this chapter.

2. Changes Analysis

Data on mangrove distribution in Malaysia in 2017 suggested there was over 629,038 hectares. However, by 2023, it rapidly decreased to 586,548 hectares. **Table 1** contains the statistics related to these changes. Over 42,490 hectares of reduction occurred during the observation period. In **Table 1**, the recorded reduction in mangrove distribution across Malaysia indicates a loss of 58,123 hectares of mangrove forest over a six-year period. Conversely, 38,497 hectares of dedicated mangrove areas experienced growth or expansion. However, the extent of mangrove loss surpassed the gains, resulting in an overall reduction. This implies that despite accretion in some areas, it does not fully compensate for the decline. Notably, statistical analysis reveals that the remaining mangrove forest remained unchanged.

Table 1 shows that in Peninsular Malaysia, positive changes have been observed, with an accretion of 4,364 hectares in total mangrove distribution over the six-year observation period. Peninsular Malaysia has experienced both decrement and increment, covering 12,361 hectares and 18,148 hectares respectively. Notably, the decrement involved a smaller forest area than the increment. The growth of mangrove forests managed to offset their loss during 2017 to 2023. Identifying the factors driving mangrove growth in Peninsular Malaysia is crucial as this knowledge can serve as a baseline for effective mangrove management planning across other regions in Malaysia, especially in areas with significant mangrove loss. The total mangrove distribution area in Peninsular Malaysia in 2023 stands at 115,317 hectares.

Borneo on the other hand presents a distinct narrative in mangrove change detection in 2023. In Malaysia, the Borneo state of Sarawak has the largest mangrove coverage of 37.7% while Sabah is the second largest with 22.3%. In 2017, Sabah boasted the largest mangrove forest distribution in Malaysia, spanning 378,195 hectares. However, statistical data on mangrove changes revealed a decline to 343,816 hectares by 2023. The total decrement in mangrove area, as indicated in **Table 1**, amounts to 34,379 hectares. This reduction occurred because the loss of mangrove forest covered a larger area than the increment in mangrove distribution. Specifically, in 2023, Sabah faced a potential loss of 28,190 hectares, while only 12,202 hectares experienced growth over the past six years. Unfortunately, this increase is insufficient to offset the deforestation observed in Sabah during 2023.

In the past six years of monitoring mangrove changes, the state of Sarawak - the largest state in Malaysia - experienced a significant decline. According to the statistics in **Table 1**, Sarawak's mangrove area decreased by 12,474 hectares, which is smaller than the decrement observed in Sabah. In 2017, Sarawak had 139,890 hectares of mangrove forest, but by 2023, this declined to 127,416 hectares. It's important to note that Sarawak didn't only record mangrove loss during this period; there was also an increment of 8,147 hectares. However, the overall reduction in mangrove forest area outweighed the gains, resulting in a net decline of 12,474 hectares over the six-year monitoring period. This contributes to the overall changes in mangrove distribution across Malaysia.

Malaysia, as a developing country, faces changes in land use driven by economic growth and development. Urbanisation, industrialisation, and residential expansion are anthropogenic activities that pose threats to ecosystems, including mangroves. To address this, the government has declared Permanent Reserve Forests (PRFs) for most forested areas, aiming to conserve, protect, and restore these regions. However, further research is needed to identify the specific factors driving mangrove changes in Malaysia. The statistics from **Table 1** serve as a valuable reference for understanding the rate of changes, losses, and gains over the years. By identifying these factors early, the government and forestry departments can take effective action to mitigate issues and prevent further deterioration.

Table 1. Rate of changes in mangrove distribution in Malaysia.

Year 2017 - 2023	Mangrove Loss	Mangrove Gain	Mangrove Changes
<i>Peninsular Malaysia</i>	12,361	18,148	4,364
<i>Sabah</i>	28,190	12,202	-34,379
<i>Sarawak</i>	17,572	8,147	-12,474
Total	58,123	38,497	-42,490

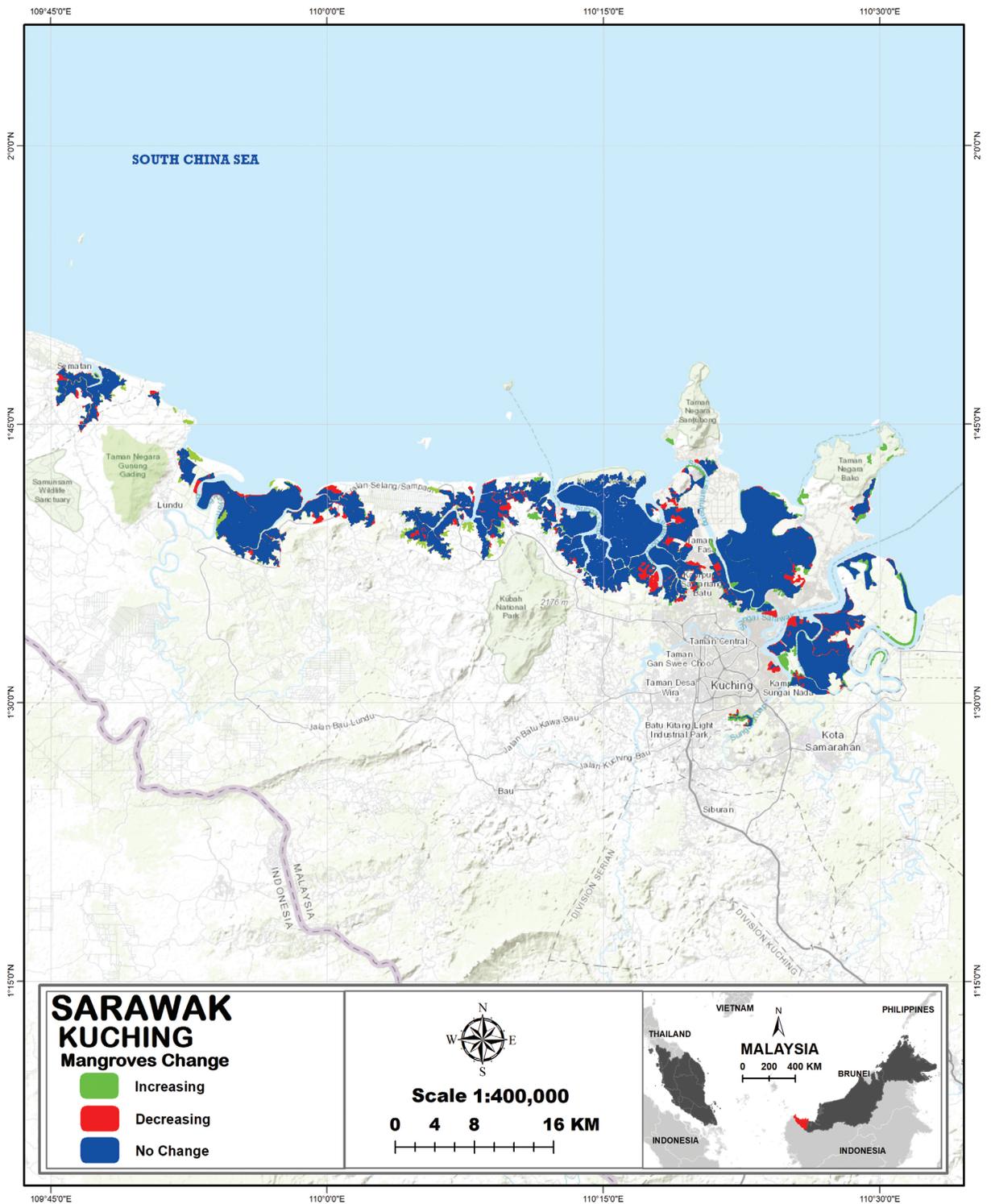


Figure 1. Detection in mangrove changes occurred between 2017 to 2023 in Division of Kuching, Sarawak.

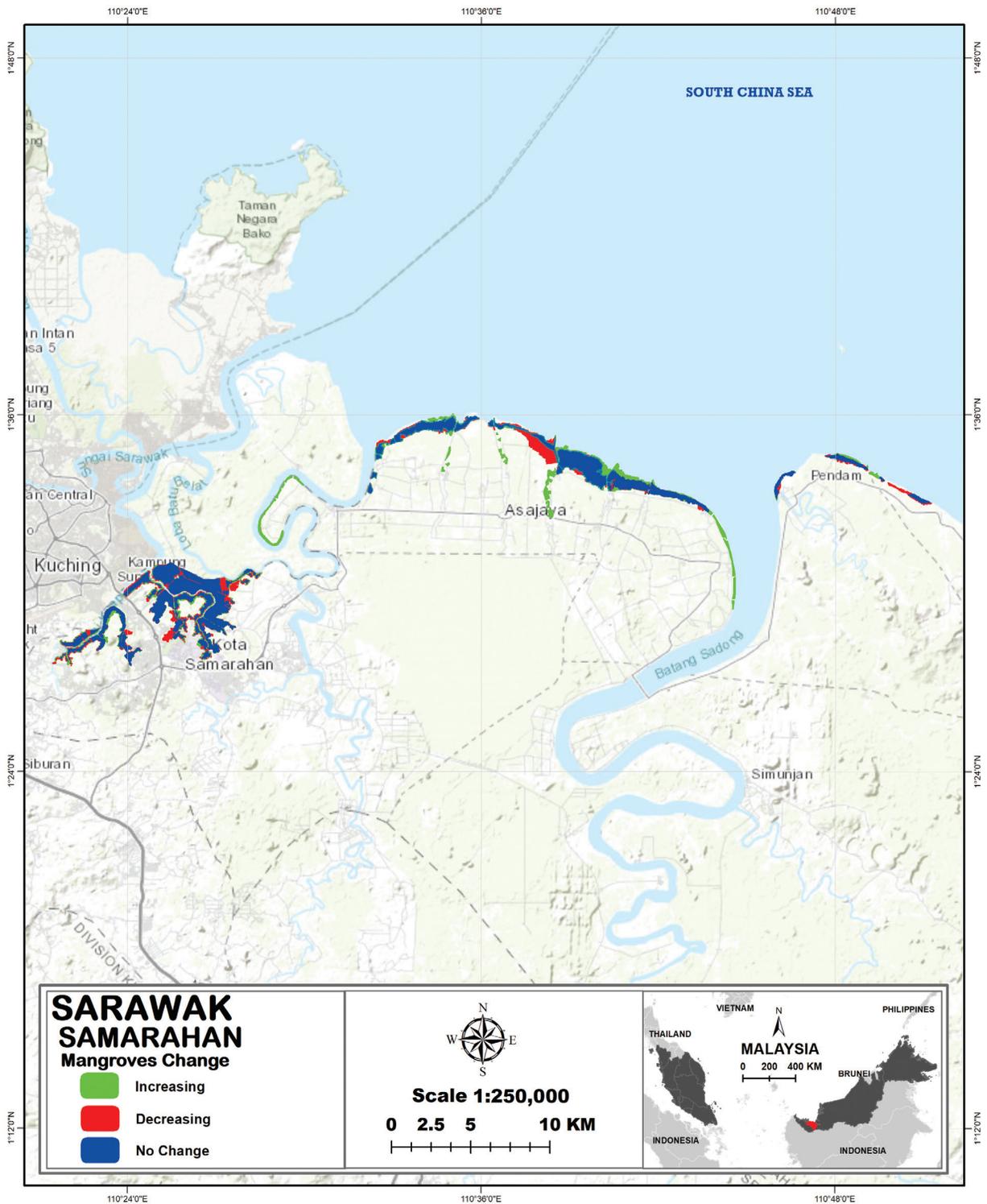


Figure 2. Detection in mangrove changes occurred between 2017 to 2023 in Division of Samarahan, Sarawak.

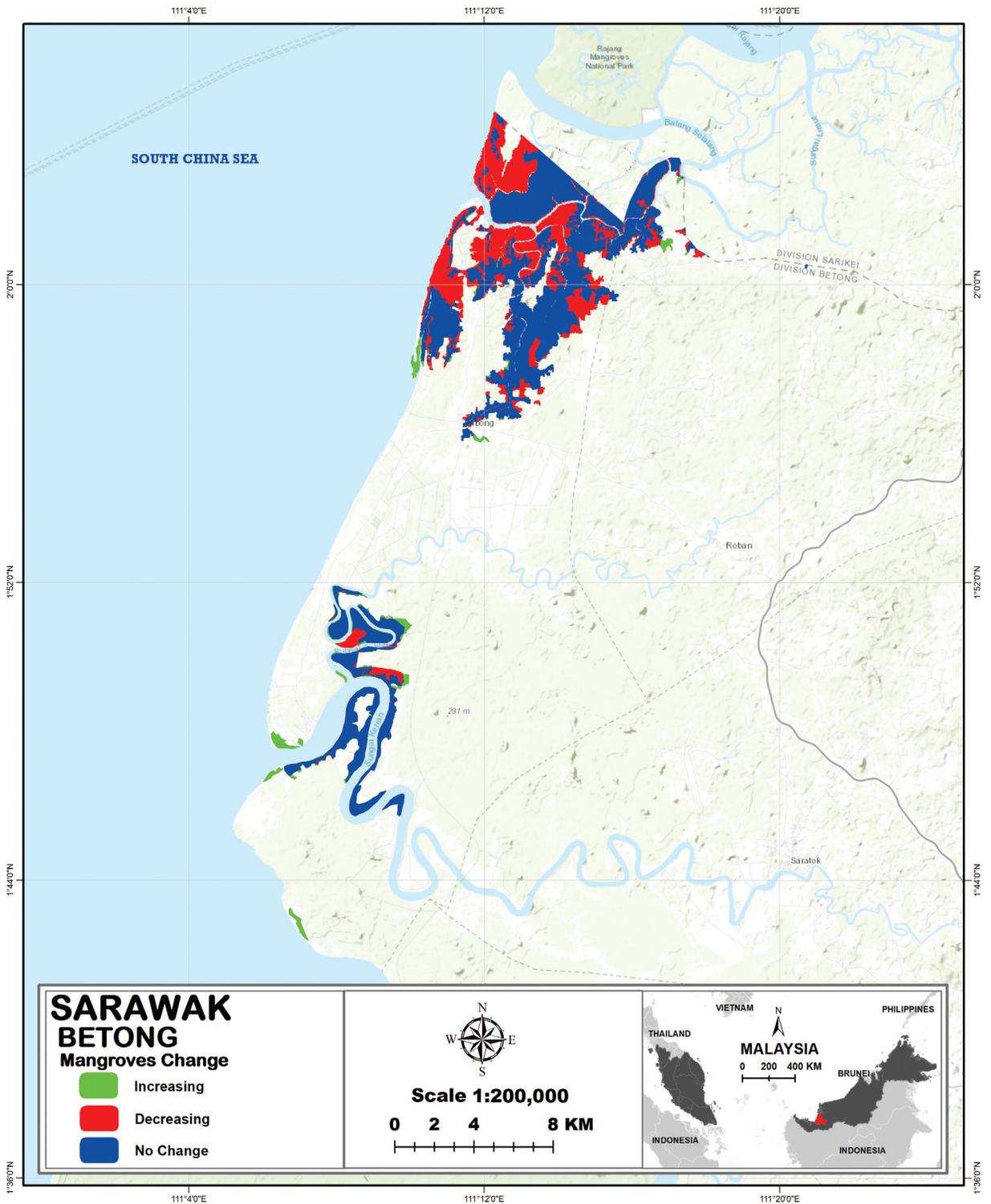


Figure 3. Detection in mangrove changes occurred between 2017 to 2023 in Division of Betong, Sarawak.

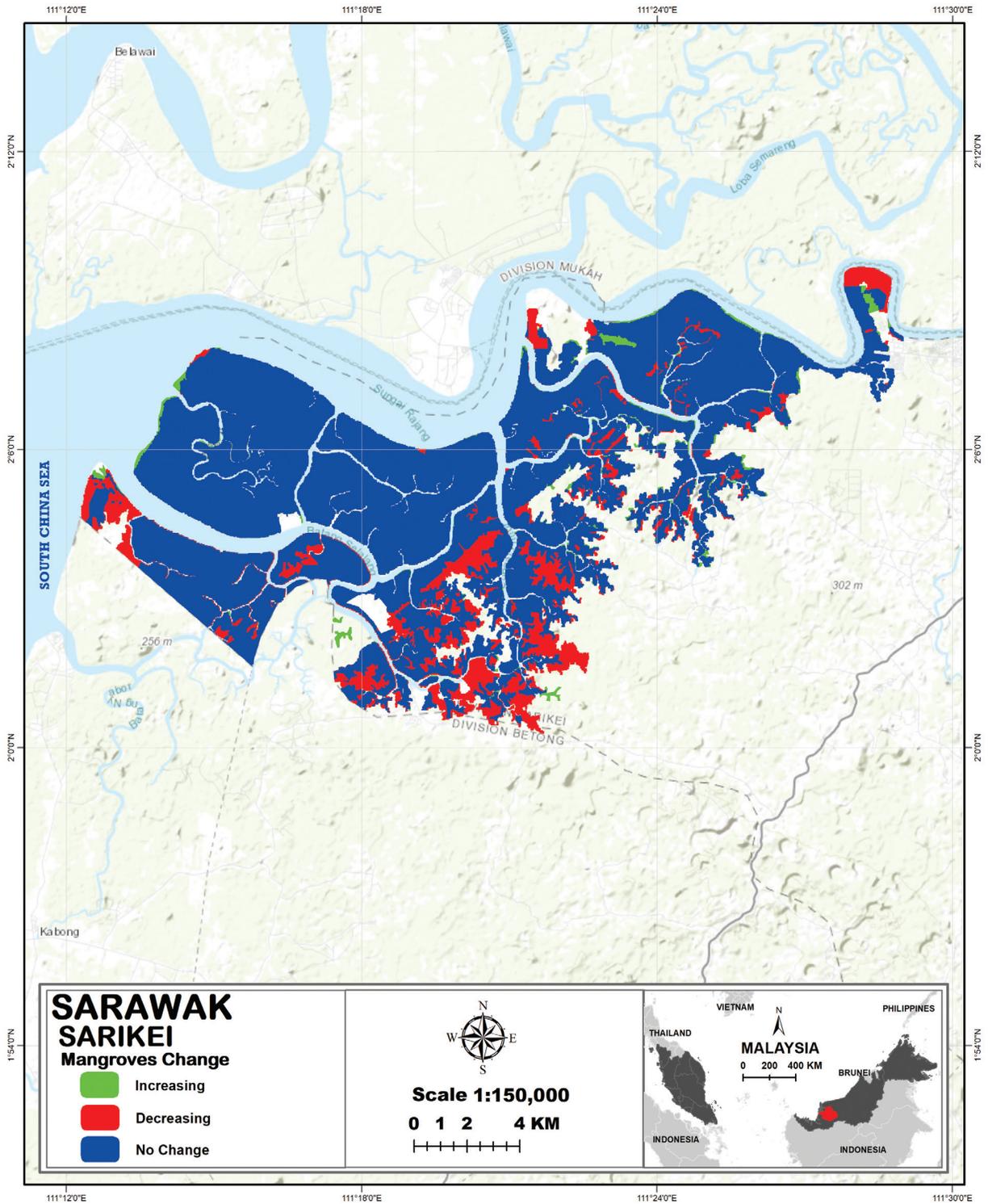


Figure 4. Detection in mangrove changes occurred between 2017 to 2023 in Division of Sarikei, Sarawak.

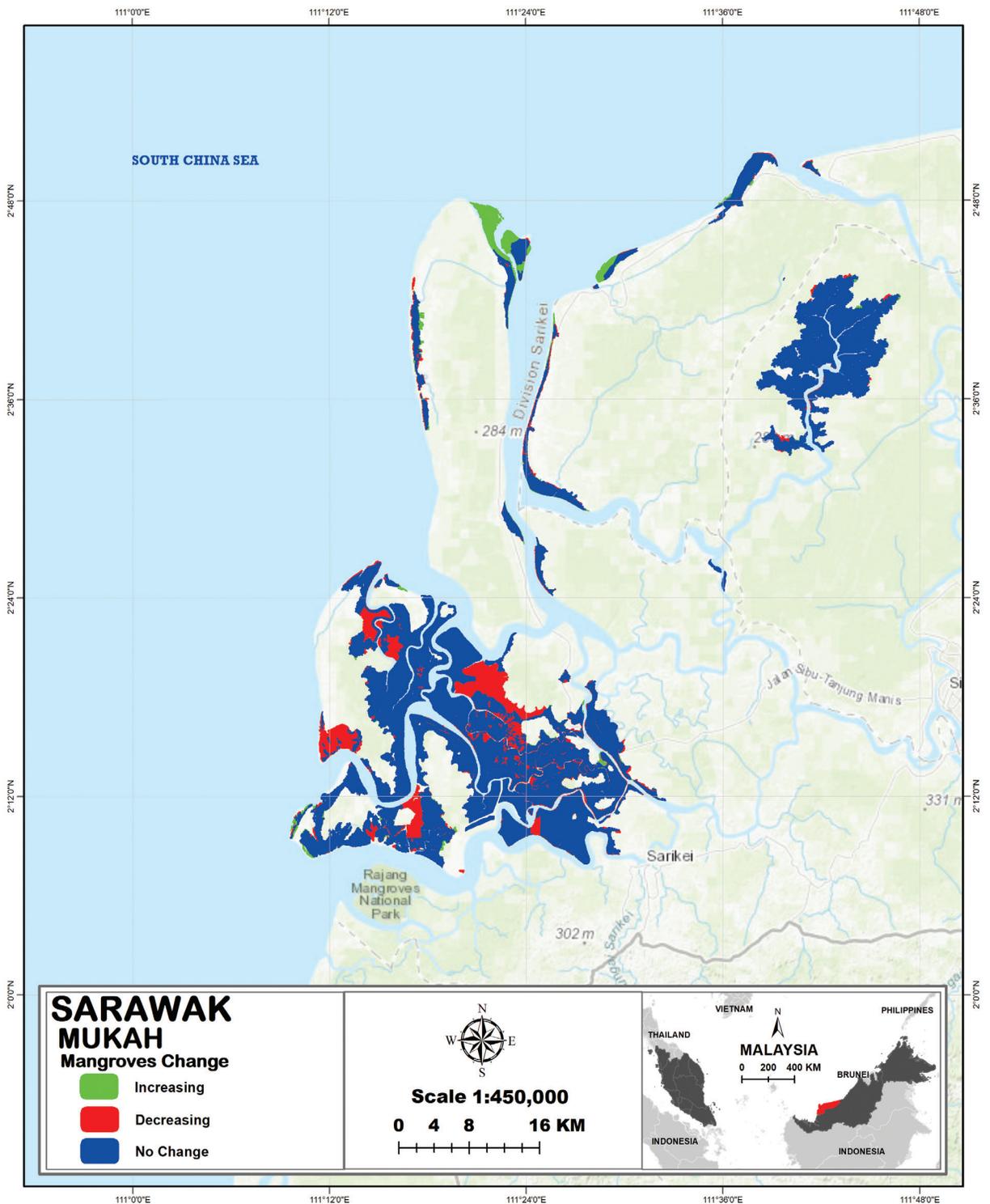


Figure 5. Detection in mangrove changes occurred between 2017 to 2023 in Division of Mukah, Sarawak.

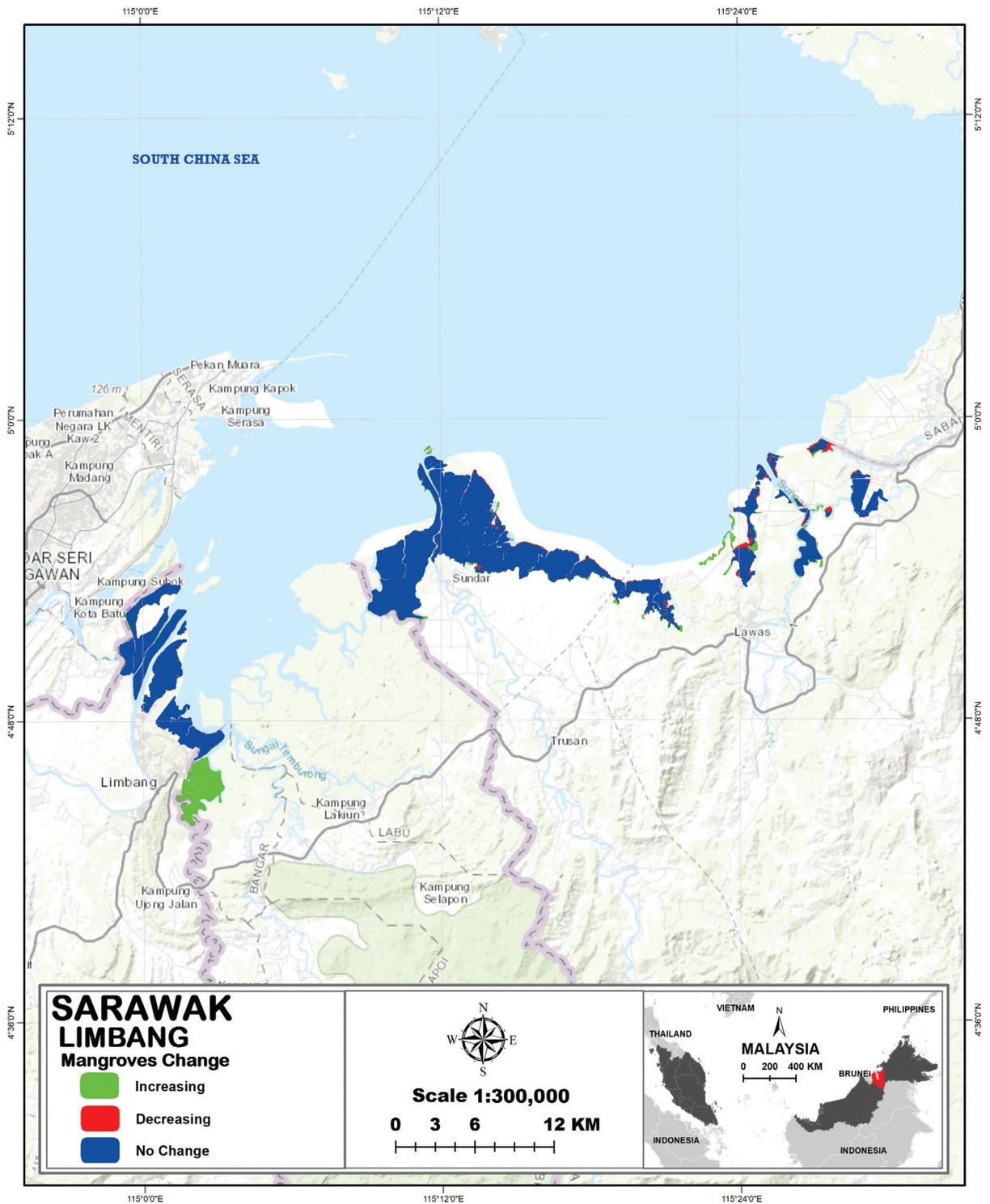


Figure 6. Detection in mangrove changes occurred between 2017 to 2023 in Division of Limbang, Sarawak.

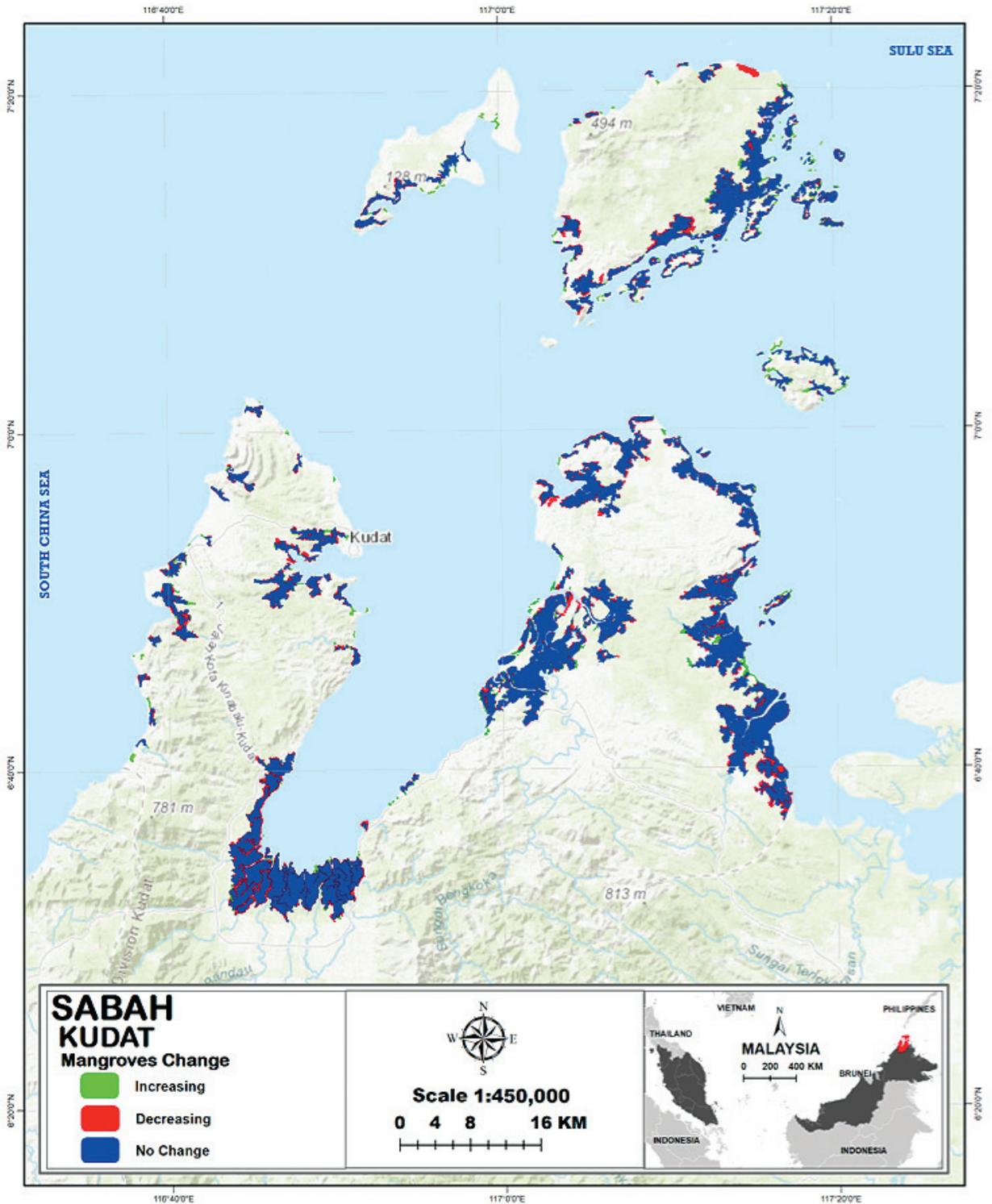


Figure 7. Detection in mangrove changes occurred between 2017 to 2023 in Division of Kudat, Sabah.

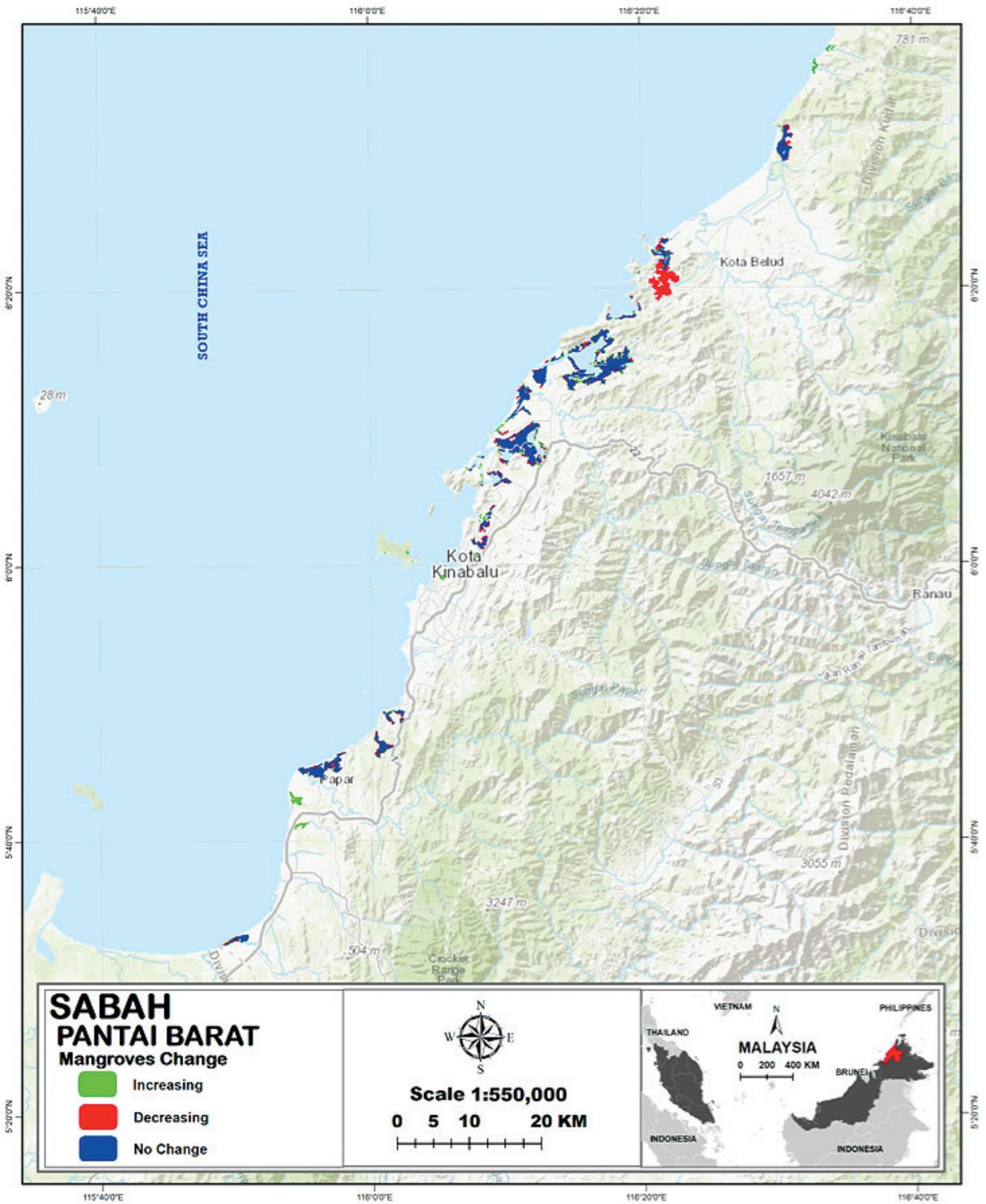


Figure 8. Detection in mangrove changes occurred between 2017 to 2023 in Division of Pantai Barat, Sabah.

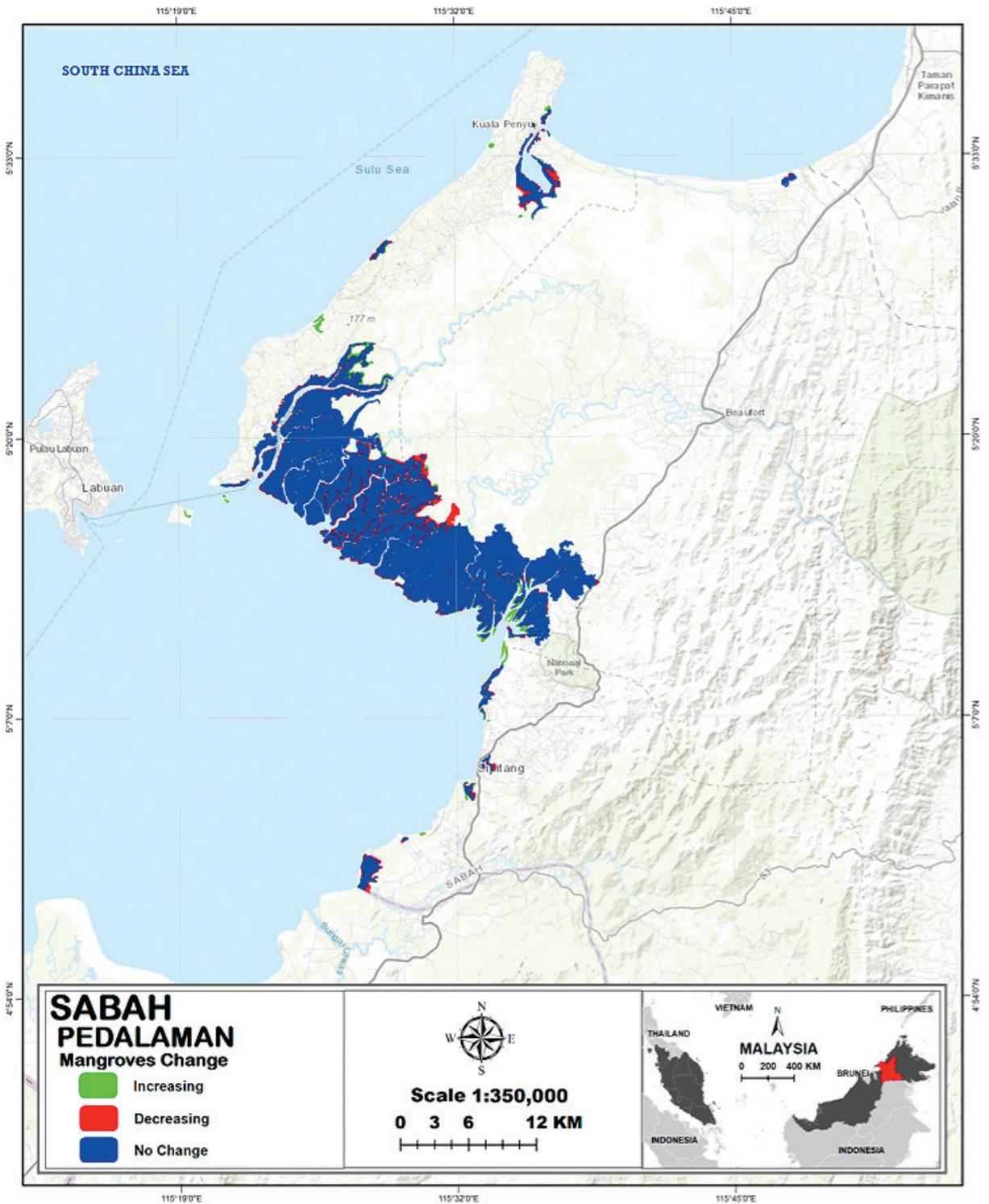


Figure 9. Detection in mangrove changes occurred between 2017 to 2023 in Division of Pedalaman, Sabah.

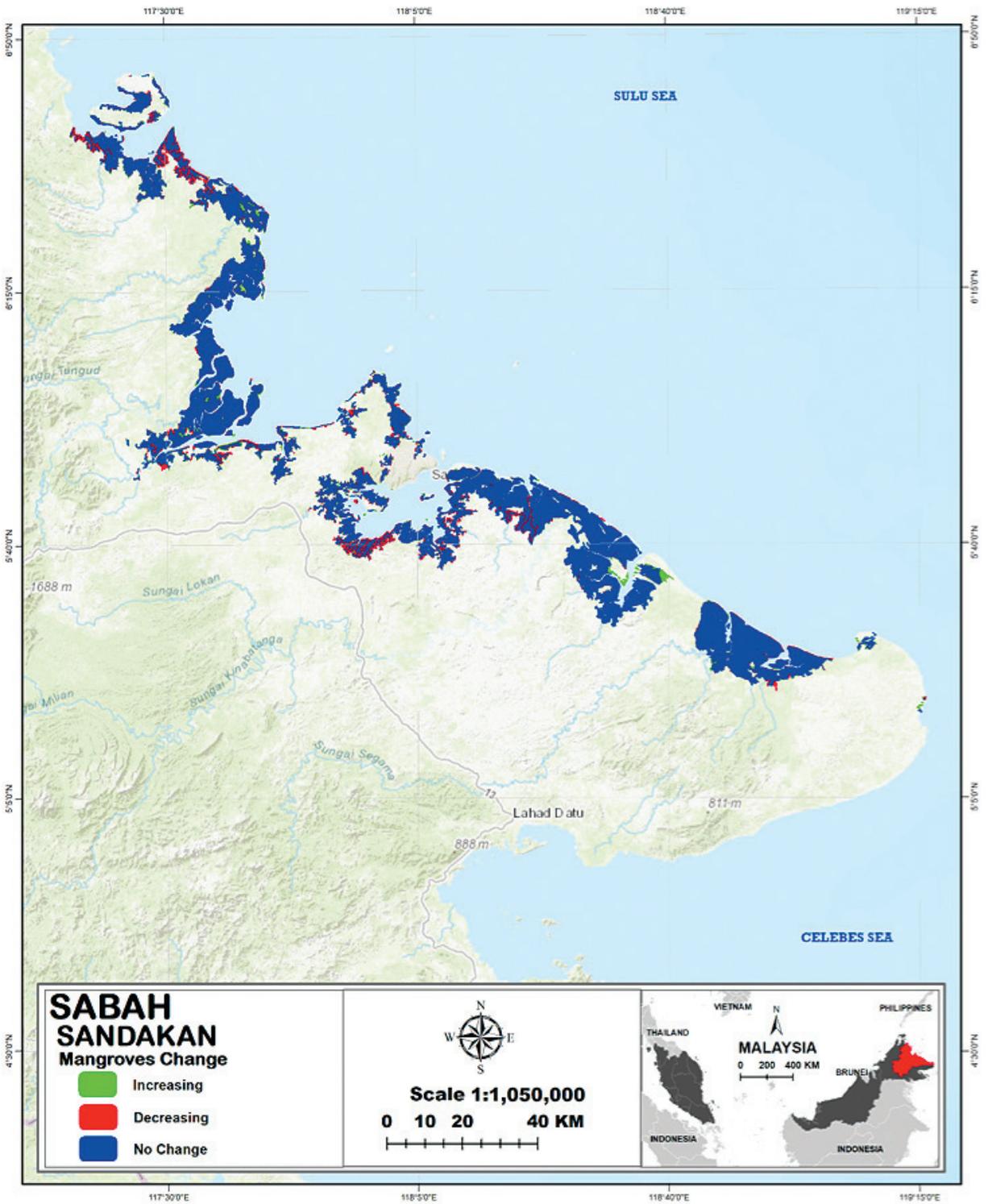


Figure 10. Detection in mangrove changes occurred between 2017 to 2023 in Division of Sandakan, Sabah.

Table 2 provides a detailed breakdown by state. We'll examine each state's contribution to the reduction of mangrove ecosystems. Malaysia's states vary in mangrove forest size and are managed by local authorities. Notably, different factors may drive changes, influenced by each state's development trajectory. Johor Bahru, the capital city of Johor, experiences rapid development projects aligned with economic growth that have the potential of affecting land use.

Pahang, Terengganu, and Kelantan underwent significant mangrove changes over a six-year observation period. These states recorded increments of 1,122 hectares, 1,659 hectares, and 1,507 hectares respectively. These figures reflect the dynamic shifts within the mangrove ecosystems from 2017 to 2023. While these changes result from a combination of anthropogenic activities and natural processes, the positive increments signal resilience against the numerous threats faced by mangroves in these regions.

Kelantan stands out for its remarkable mangrove growth, gaining 1,718 hectares while losing only 3 hectares. Notably, this impressive gain, despite minimal loss, contributes to the overall increment in Kelantan's mangrove forest. These changes are visible at Aur Island, Semut Api village, Cahaya Bulan beach, and Raja Gali River.

Terengganu shares a similar story, gaining approximately 2,826 hectares - an increment that effectively compensates for a 104-hectare loss. Setiu, Redang Island, and Chukai in Terengganu exhibit positive mangrove change.

Pahang, too, demonstrates positive growth, with an increment of 2,771 hectares in its mangrove ecosystem. This gain sufficiently covers the 1,629-hectare loss observed during the six-year monitoring period. Notably, the areas contributing to this increment face the South China Sea, including Kuantan, Pekan, and Rompin. These changes serve as valuable baselines for other states, emphasising the importance of conserving and protecting mangrove forests across Malaysia.

Additionally, the states of Perlis, Kedah, Penang, Perak, Selangor, and the Federal Territory of Labuan exhibit increasing mangrove distribution in 2023. Despite its small mangrove ecosystem (approximately 88 hectares in 2023), Perlis experienced a net growth of 39 hectares. This positive trend is noteworthy given the limited size of the forest. The Federal Territory of Labuan, with a mangrove area of 346 hectares, saw an increment of about 33 hectares. Notably, this gain outweighs the 52-hectare loss, emphasising the importance of protecting even small forested areas. Kedah, Penang, Perak, and Selangor: These states also contributed to mangrove growth over the six-year monitoring period, with increments of approximately 786 hectares, 124 hectares, 58 hectares, and 21 hectares respectively. While the increments may appear modest, they collectively support the overall expansion of mangrove ecosystems. In summary,

encouraging these incremental trends can contribute to the long-term growth of mangrove forests, regardless of their initial size.

In the context of mangrove ecosystems, some states in Malaysia experienced both growth and decline between 2017 and 2023. Negeri Sembilan, Melaka, and Johor faced reductions in their mangrove areas, with the statistics on decrement outweighing the increments. Despite recording a net growth of 3,695 hectares, Johor lost a substantial 713 hectares of mangrove ecosystems. Notable areas of decline include Sedili Kechil, Sedili Besar River, Pulau River, Lebam River, and Johor River. Melaka and Negeri Sembilan encountered mangrove decreases. Melaka lost 225 hectares while Negeri Sembilan lost 533 hectares. In contrast, the increments were smaller (122 hectares and 442 hectares respectively). Overall, Melaka and Negeri Sembilan saw declines of 138 hectares and 101 hectares respectively over the six-year period. Major reductions occurred along the Linggi and Merbau Rivers, as well as the coastline at Merlimau in Melaka. In Johor, the Linggi River, Sepang River, and Chuah coastline in Negeri Sembilan were identified as areas experiencing mangrove ecosystem decline. In order to understand these changes better, additional research is vital to identify the factors driving mangrove alterations during this monitoring period.

Mangrove distribution across each state in Malaysia indicates some regions experienced increments, others faced decrements, while certain mangrove forests remained stable over the six-year period.

Table 2 describes the size of forest areas affected by these changes. This data serves as a baseline for identifying areas of most concern and least concern. Tailoring forestry management plans based on threat levels allows targeted actions for conservation, restoration, and protection of mangrove ecosystems. Given the unique distribution of mangroves, state-level efforts are crucial to prevent further disturbances and preserve these valuable ecosystems.

Table 2. Rate of changes in the distribution of mangrove forests in each state in Malaysia.

Year 2017 - 2023	Mangrove Losses	Mangrove Gain	Mangrove Changes
<i>Perlis</i>	10	48	39
<i>Kedah</i>	831	1,560	786
<i>Penang</i>	413	568	124
<i>Perak</i>	2,706	2,737	58
<i>Selangor</i>	1,646	1,661	21
<i>Negeri Sembilan</i>	533	442	-101
<i>Melaka</i>	225	122	-138
<i>Johor</i>	4,263	3,695	-713
<i>Pahang</i>	1,629	2,771	1,122
<i>Terengganu</i>	104	2,826	1,507
<i>Kelantan</i>	3	1,718	1,659
Peninsular Malaysia	12,361	18,148	4,364
<i>WP Labuan</i>	52	99	33
Total	12,413	18,247	4,398

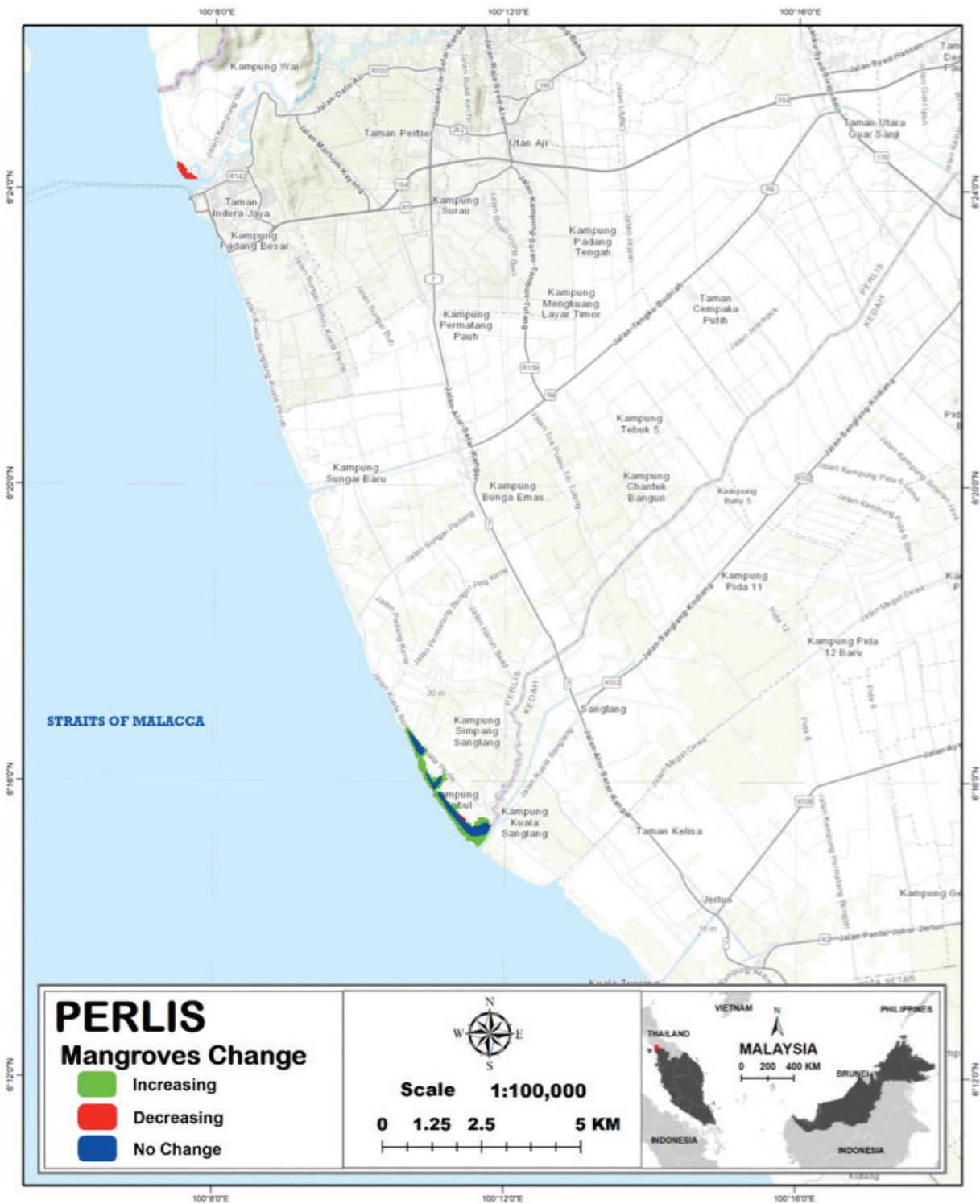


Figure 12. Detection in mangrove changes occurred between 2017 to 2023 in State of Perlis.

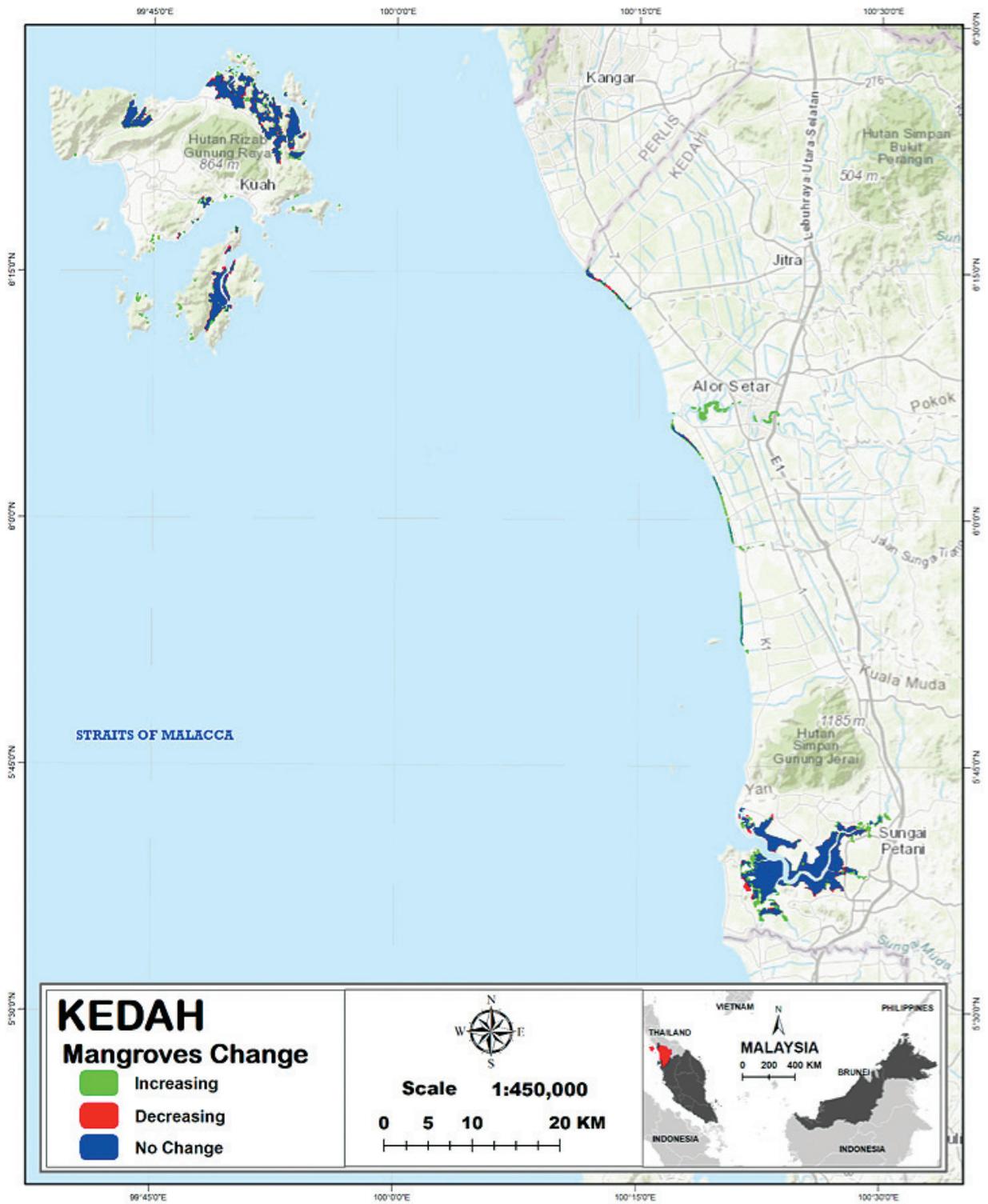


Figure 13. Detection in mangrove changes occurred between 2017 to 2023 in State of Kedah.

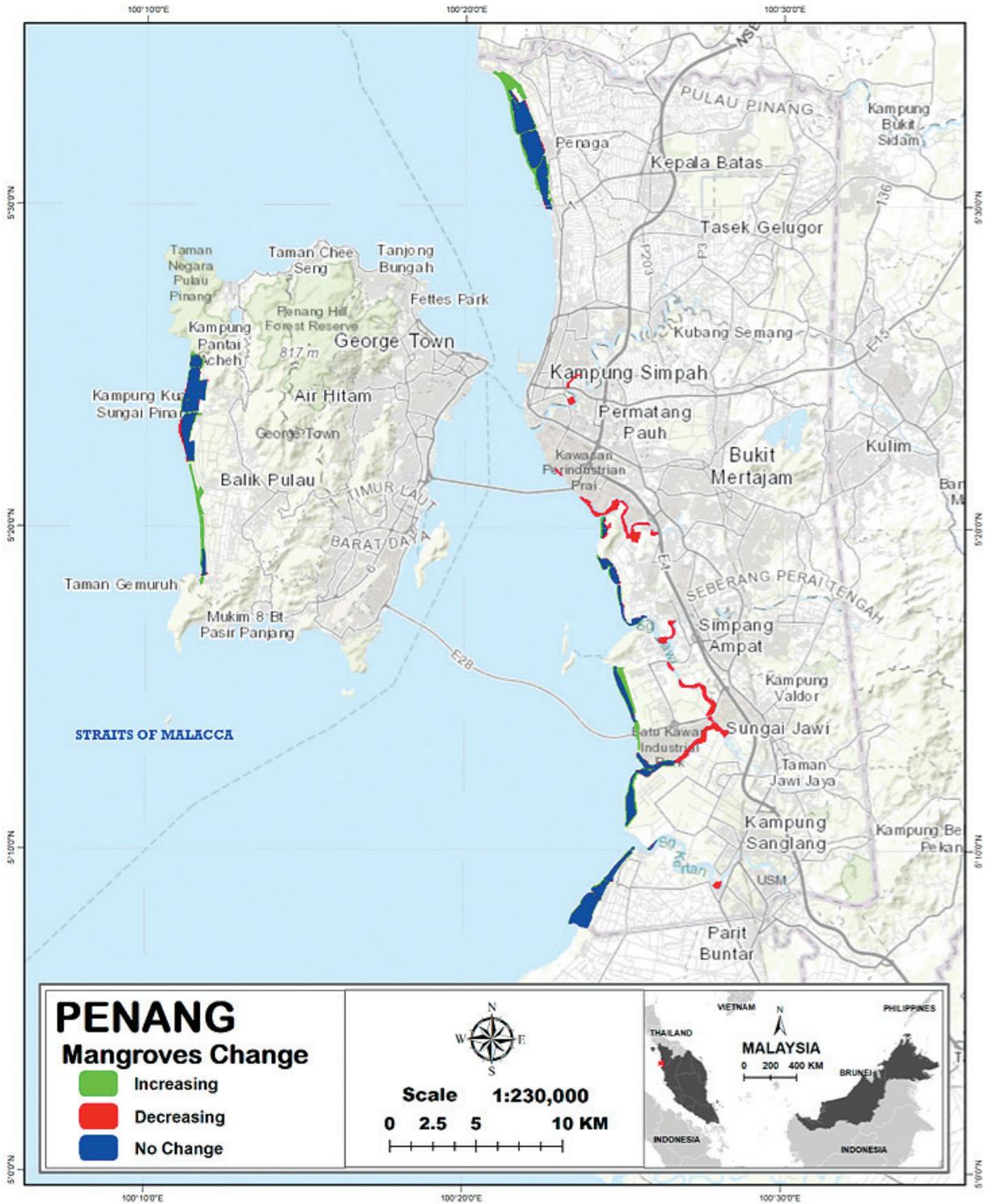


Figure 14. Detection in mangrove changes occurred between 2017 to 2023 in State of Penang.

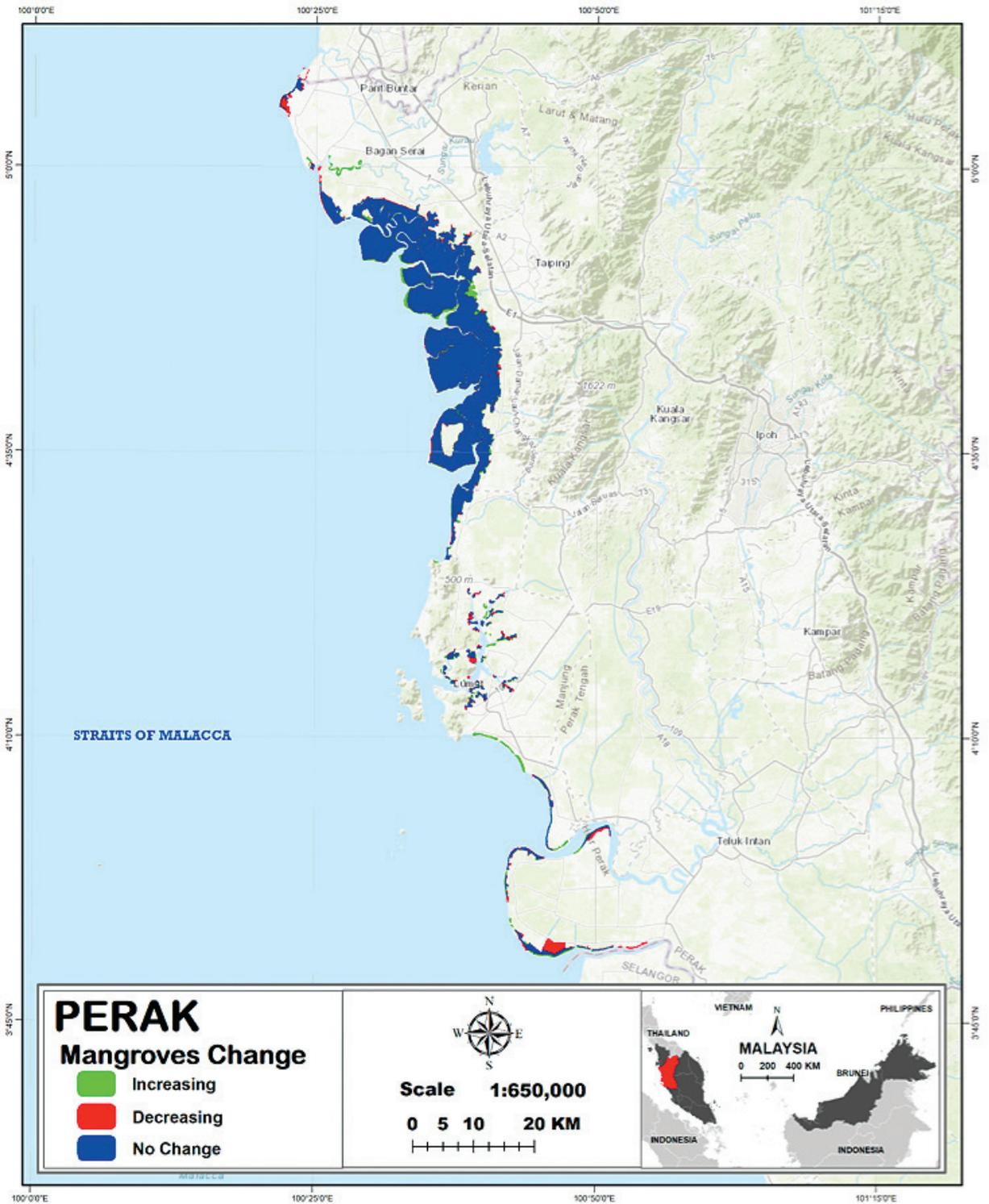


Figure 15. Detection in mangrove changes occurred between 2017 to 2023 in State of Perak.

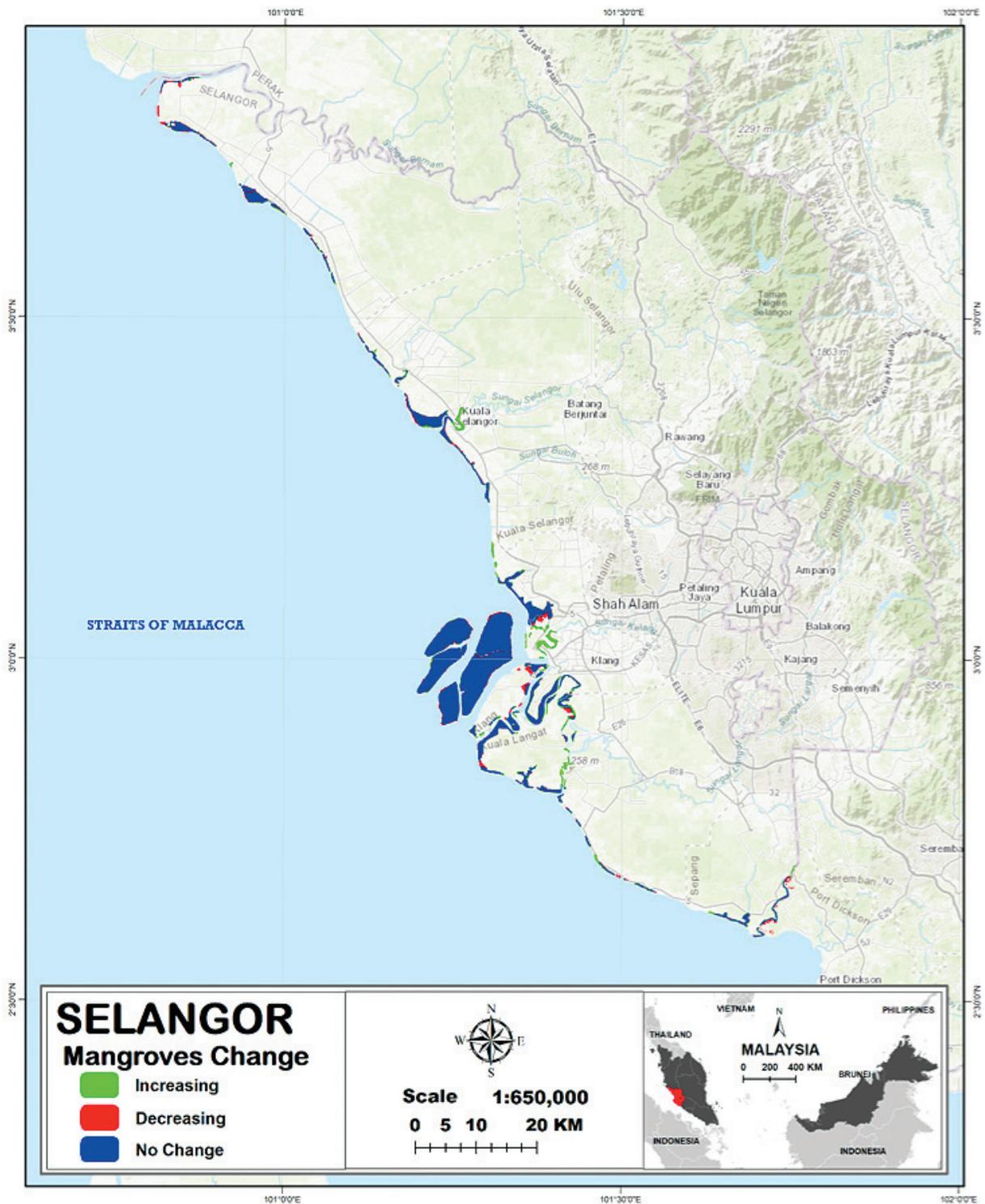
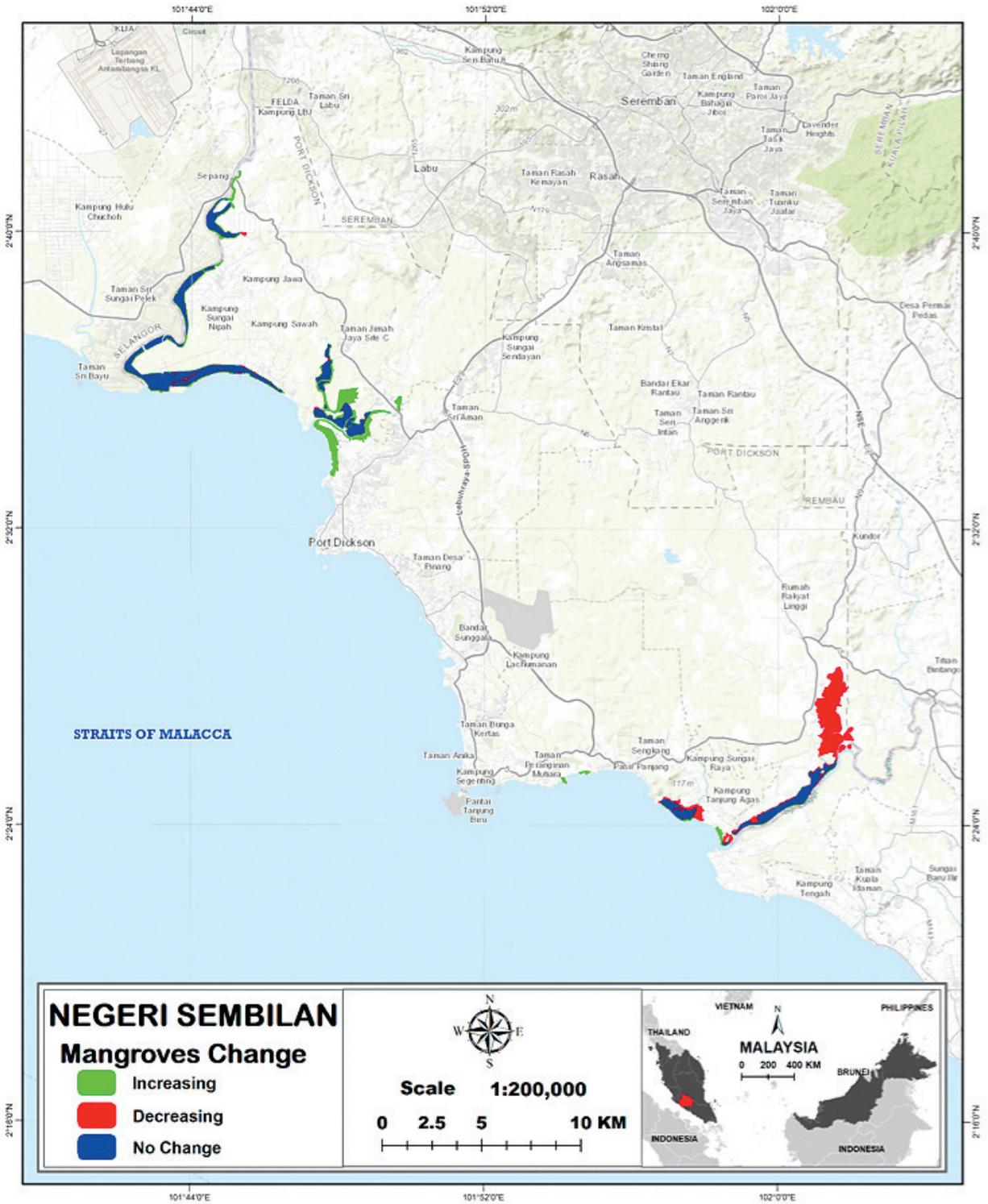


Figure 16. Detection in mangrove changes occurred between 2017 to 2023 in State of Selangor.



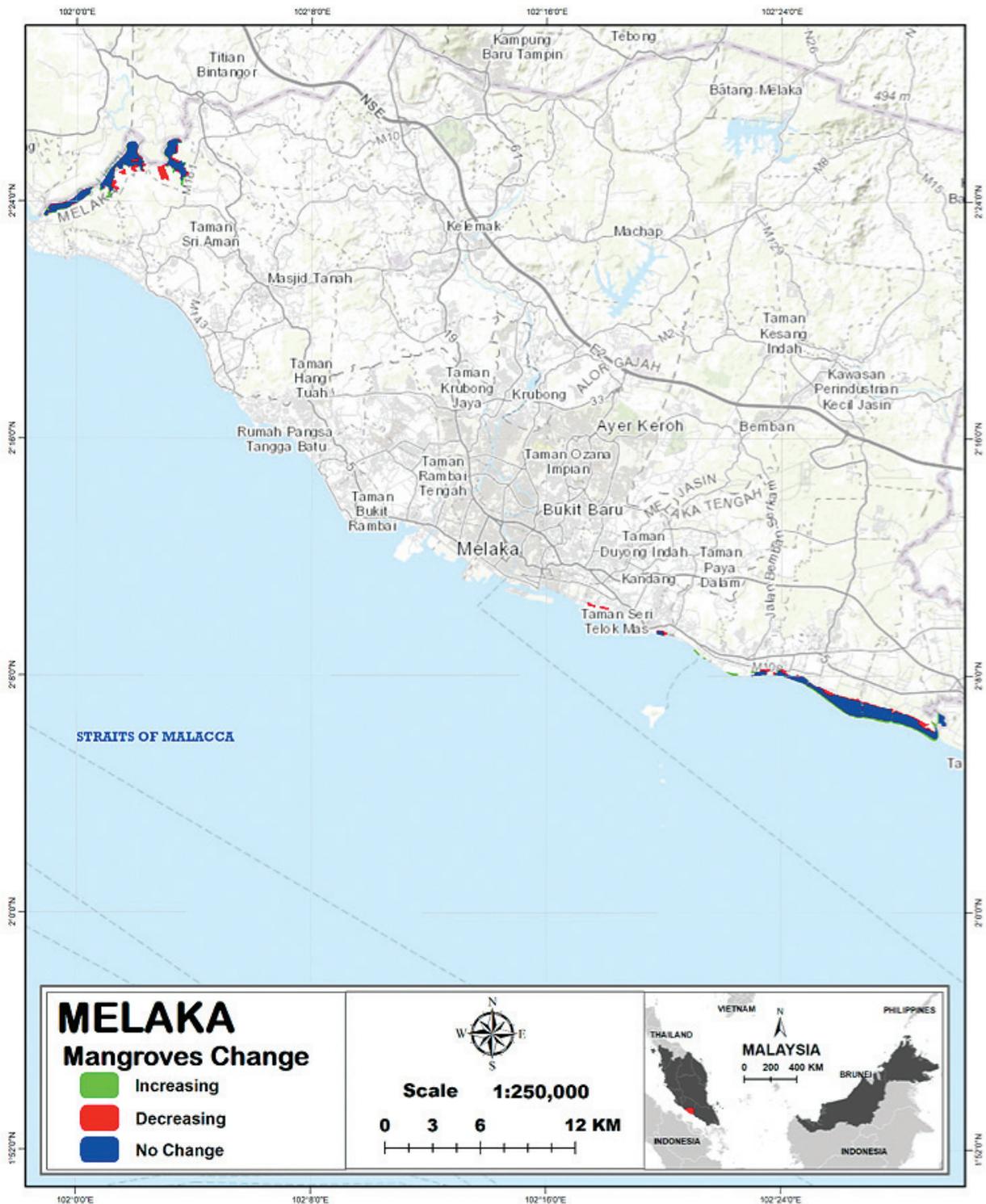


Figure 18. Detection in mangrove changes occurred between 2017 to 2023 in State of Melaka.

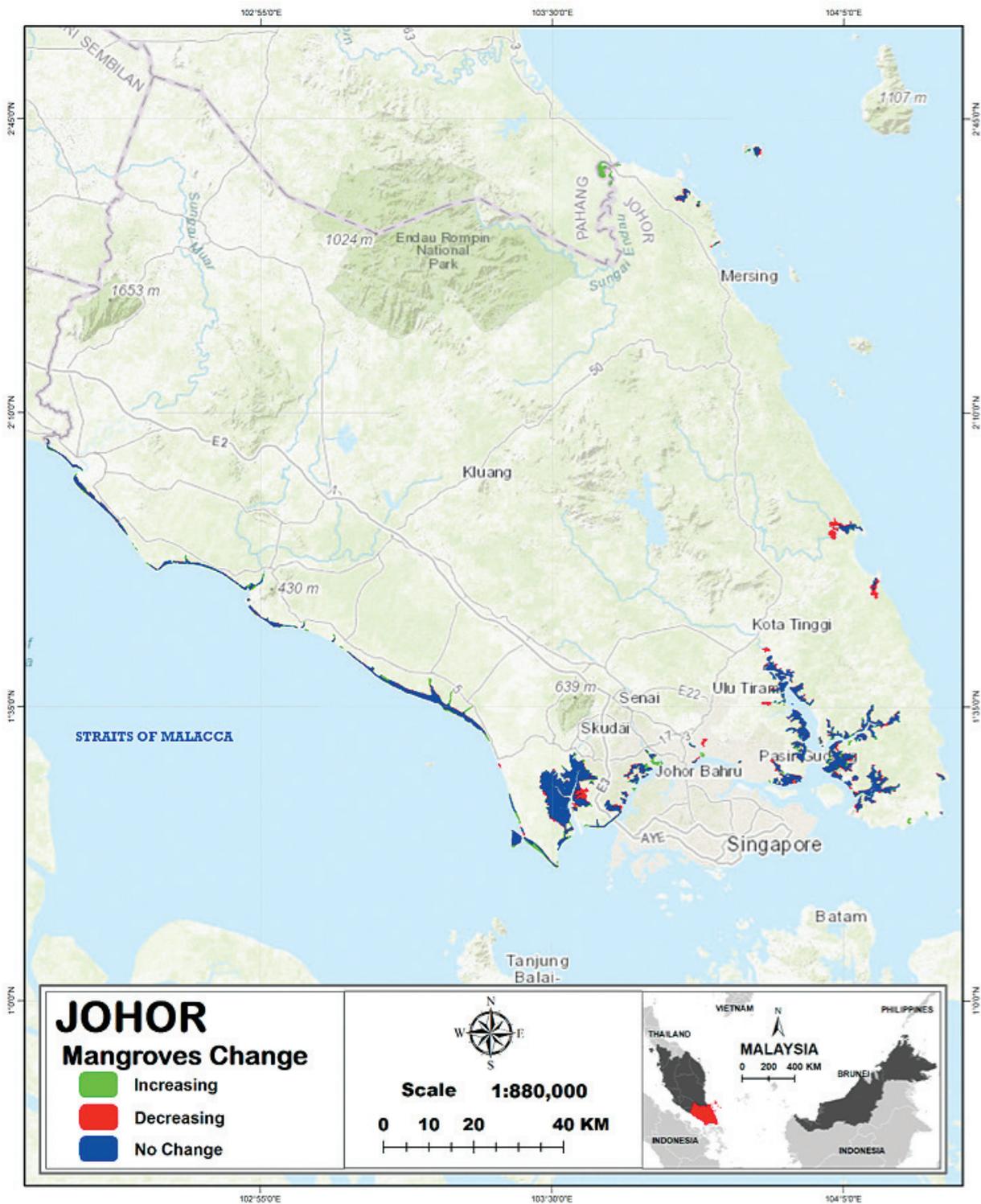


Figure 19. Detection in mangrove changes occurred between 2017 to 2023 in State of Johor.

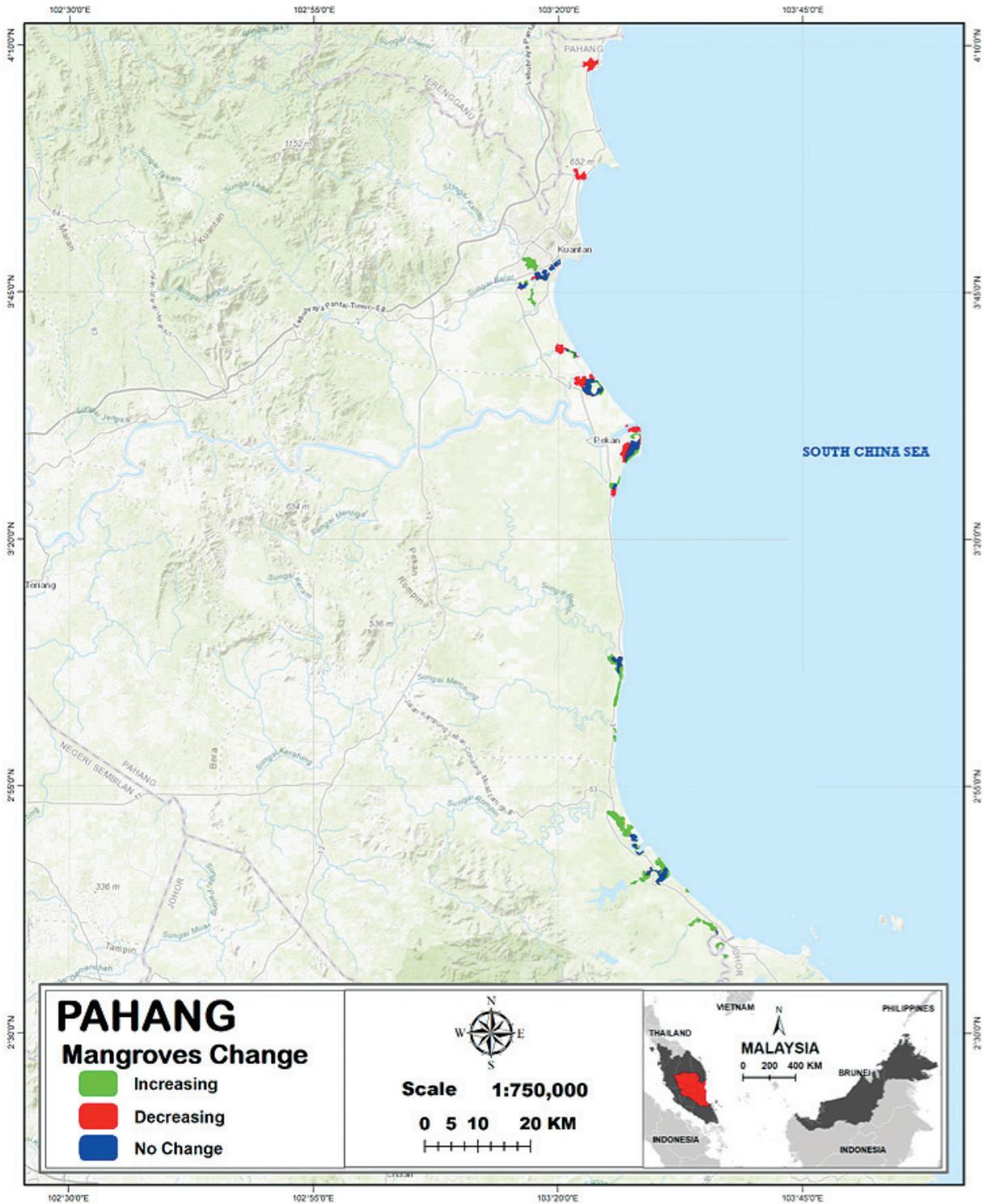


Figure 20. Detection in mangrove changes occurred between 2017 to 2023 in State of Pahang.

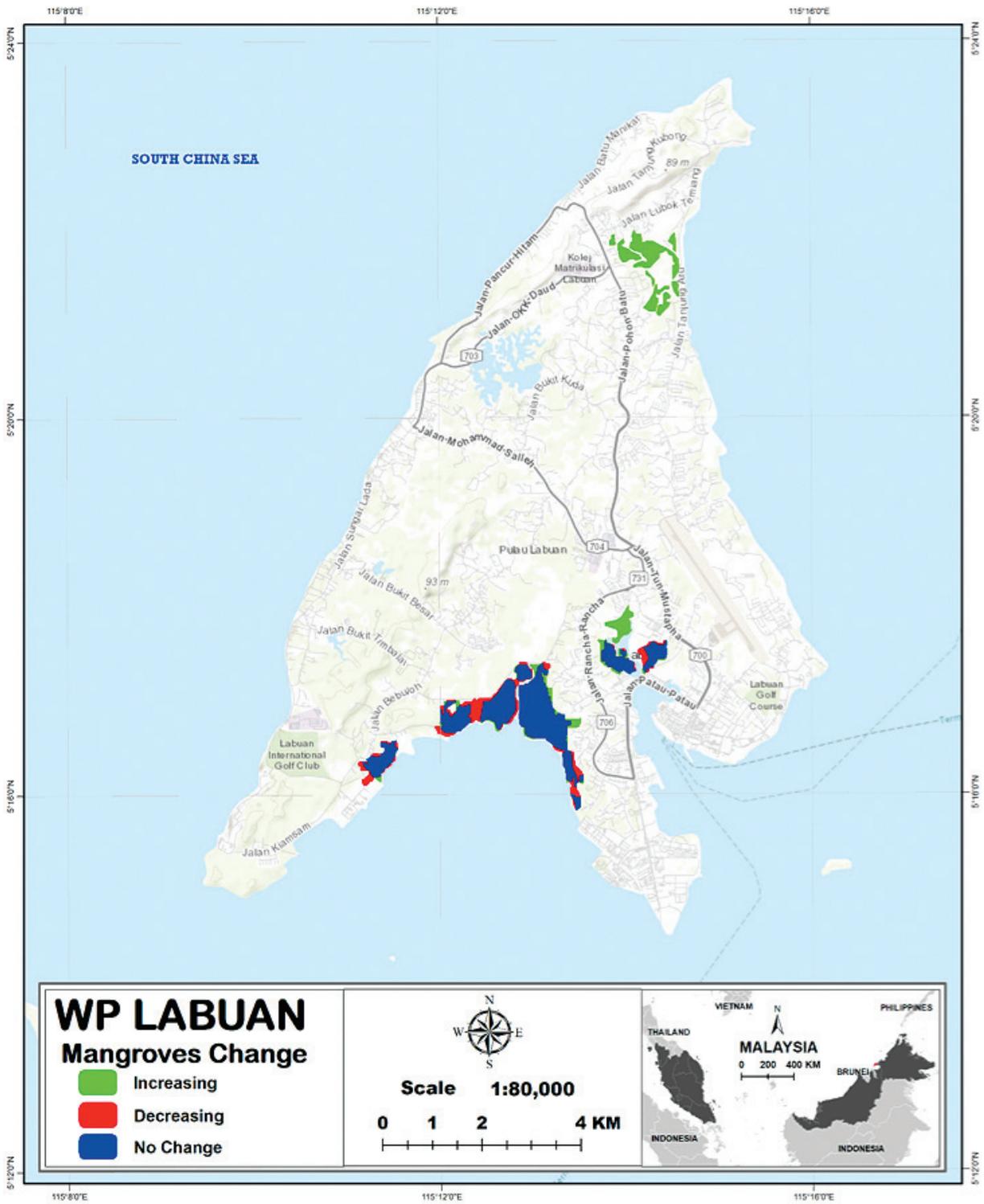


Figure 23. Detection in mangrove changes occurred between 2017 to 2023 in Federal Territory of Labuan.

Changes in mangrove forests in Malaysia has been closely monitored since 1990. These forests comprise four distinct layers: mangrove, peat swamp, lowland, and montane forests, each occupying different elevations. Malaysia stands out as one of Southeast Asia's mangrove-rich countries, emphasising the need for protection.

Research on change detection was conducted from 1990 to 2023 to monitor mangrove growth over time and identify threats to this vital ecosystem. Mangroves play a crucial role, providing goods such as food, income, marine biodiversity, and carbon storage. However, without protective policies, these benefits may diminish over time.

Previous studies have reveal that Malaysia has lost approximately a quarter of its mangrove forests since 1990 [8]. Such reductions can have far-reaching consequences, including climate changes, flood risks, global warming, and rising sea levels.

Trends on mangrove in Malaysia are reflected in **Figure 24** and **Table 2**. Between 1990 and 2017, consistent mangrove loss has been observed in Peninsular Malaysia, Sabah, and Sarawak. However, the line graph reveals an interesting shift in 2023: Peninsular Malaysia experienced an increment in mangrove ecosystems, while Sabah and Sarawak faced a decline. The magnitude of decline is significant, especially for Sabah and Sarawak, which boast the largest mangrove forest cover compared with Peninsular Malaysia. Sabah lost 34,379 hectares out of a total area of 343,816 hectares, while Sarawak declined by 12,474 hectares within a total area of 127,416 hectares in 2023. This translates to an annual loss of approximately 1.63% and 1.67% respectively over the past six years.

In contrast, Peninsular Malaysia recorded an increment of about 4,364 hectares during the same period, representing approximately 0.63% annual mangrove changes. Despite protection, restoration, and conservation efforts, mangrove ecosystems remain vulnerable to threats. Forest owners must consider long-term protection strategies to address potential risks. By understanding these trends, both the government and private sector can foster growth in Malaysian forestry, discovering new plots and species within these vital ecosystems.

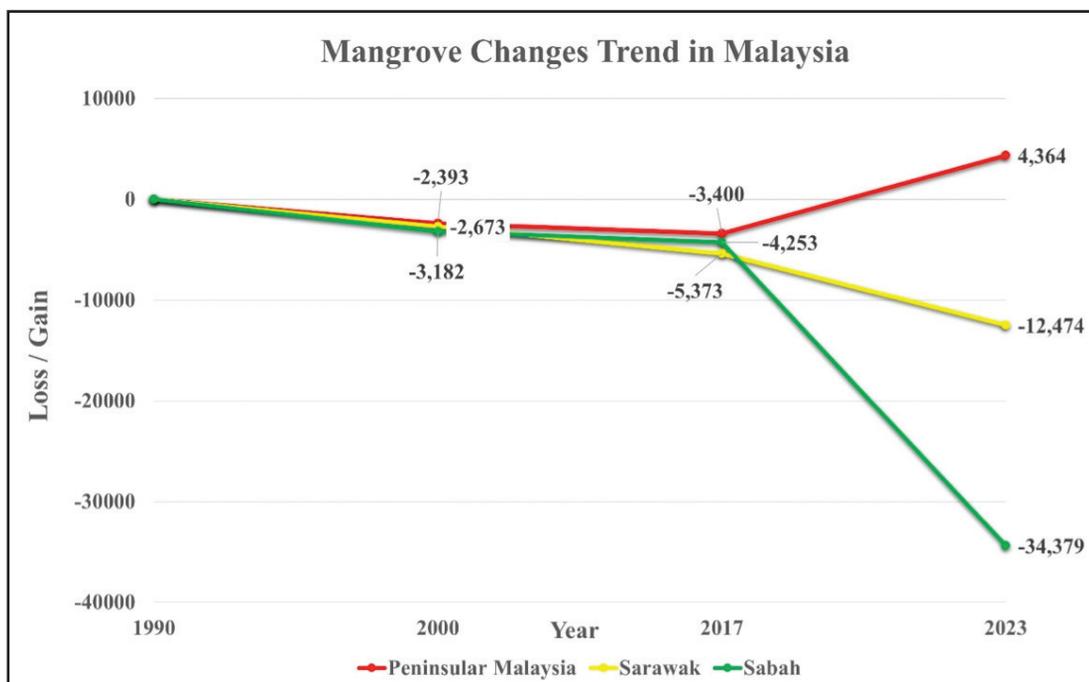


Figure 24. Trend analysis of mangrove changes in Malaysia.

Between 1990 and 2000, mangrove forests in Malaysia experienced an annual change rate of approximately 0.13%, equivalent to 823 hectares. From 2000 to 2017, this rate decreased to 0.12%, corresponding to 776 hectares over the monitoring period. Unfortunately, between 2017 and 2023, the rate surged to 1.2%, resulting in 7,083 hectares of mangrove changes within six years. These fluctuations raise concerns on the condition of mangrove forests, which face threats impacting their size over the decades. Statistical analysis reveals that a total of 0.33% of mangroves have been affected by ecosystem changes from 1990 to 2023. On average, this translates to 639 hectares of mangrove forest alterations during these 33 years of monitoring in Malaysia.

Table 3. Factors of changes in mangrove Malaysia.

Region	Mangrove loss 1990 – 2000 (ha)	Mangrove loss 2000 - 2017 (ha)	Mangrove loss 2017 - 2023 (ha)	Rate of changes 1990 – 2000 (ha yr ⁻¹) / (% yr ⁻¹)	Rate of changes 2000 - 2017 (ha yr ⁻¹) / (% yr ⁻¹)	Rate of changes 2017 - 2023 (ha yr ⁻¹) / (% yr ⁻¹)	Average rate of changes 1990 – 2023 (ha yr ⁻¹) / (% yr ⁻¹)
Peninsular Malaysia	-2,393	-3,400	4,364	239 / 0.20	200 / 0.17	727 / 0.63	308 / 0.27
Sabah	-3,182	-4,253	-34,379	318 / 0.08	250 / 0.07	5730 / 1.67	816 / 0.37
Sarawak	-2,673	-5,373	-12,474	267 / 0.18	316 / 0.22	2079 / 1.63	134 / 0.49
Total	-8,227	-13,190	-42,490	823 / 0.13	776 / 0.12	7082 / 1.20	639 / 0.33

3. Conclusion

This research leveraged remote sensing technology, specifically high-resolution satellite imagery from SPOT 6 with a spatial resolution of 1.5 meters (panchromatic and multispectral), combined with GIS techniques. It aimed to detect changes in mangrove ecosystems across Malaysia. By capturing real-time images of mangrove forests using SPOT 6 imagery, the research successfully identified growth and changes in mangrove distribution from 2017 to 2023.

Notably, it builds upon previous research conducted between 1990 and 2017. The application of different decision-making and analytical techniques demonstrated improved precision and high accuracy. Our findings revealed a reduction in mangrove distribution, totalling 586,548 hectares in 2023 compared to 629,038 hectares in 2017. This decline amounted to approximately 42,490 hectares, with an average annual change rate of 1.2%, equivalent to 7,082 hectares over the last six years in Malaysia.

Specifically, mangrove forests experienced consistent decline in Peninsular Malaysia (from 2,393 hectares to 3,400 hectares), Sabah (from 3,182 hectares to 4,253 hectares), and Sarawak (from 2,673 hectares to 5,373 hectares) between 1990 and 2017. However, in recent studies published between 2017 and 2023, Peninsular Malaysia saw rapid growth (4,364 hectares), while Sabah and Sarawak declined by 34,379 hectares and 12,474 hectares respectively.

The overall potential lies in effectively detecting and mapping changes in Malaysia's mangrove ecosystems using SPOT 6 satellite imagery and GIS techniques. Future monitoring efforts can identify growth and address threats to mitigate mangrove reduction. The accuracy and precision of our findings depend on research priorities. Furthermore, this study underscores the concurrent deforestation of mangroves, affirming the need for conservation, protection, and reforestation efforts to prevent further loss and ensure their survival.

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Chapter 3

Mangrove Flora and Conservation Efforts in Malaysia

Mangrove Flora and Conservation Efforts in Malaysia

Tariq Mubarak Husin*, Mohd Rizuwan Mamat, Hyrul Izwan Mohd Husin.,
Syaierah Abdullah & Nur Ainaa Nabilah Mohamad Bahtiar
Forest Research Institute Malaysia, 52109 FRIM, Kepong, Selangor
*Corresponding author: tariq@frim.gov.my

Abstract

Mangrove forests are a vital component of coastal ecosystems, serving as a protective barrier against erosion, supporting diverse marine life, and providing invaluable ecosystem services. A mangrove forest is characterised as a vegetated region predominantly populated by mangrove plants, typically with a minimum patch size of around 0.01 square kilometres (equivalent to 1 hectare) [1]. The distribution of mangroves is mainly influenced by latitude and temperature, with aridity playing a secondary role. As a result, mangrove forests are present in tropical and subtropical regions, being recognised as some of the most productive ecosystems globally. Worldwide, mangrove forests span around 14.7 million hectares, with Malaysia hosting approximately 629,038 hectares, constituting roughly 4.3% of the global mangrove area [2,3]. Although they account for only 3.5% of 18.045 million hectares of the total forested area in Malaysia [4], mangroves are highly productive ecosystems rich in biodiversity. They host a wide variety of plant species that provide important habitats for various fauna, including mammals, birds, reptiles, fish and molluscs. Malaysia, endowed with extensive coastal areas, harbours rich and diverse mangrove flora, yet these ecosystems remain underexplored and underappreciated. The World Atlas of Mangroves Book reports that there are 73 species and hybrids classified as authentic mangroves worldwide, with 40 of them specifically identified in Malaysia. This chapter explore the unique characteristic of mangrove flora, highlighting their adaptability to harsh coastal conditions, intricate root systems, and specialised reproductive strategies. The chapter also discusses the diverse mangrove flora in Malaysia and some of the initiatives taken to conserve and protect the existing mangrove from further decline. Urgent actions are needed to safeguard these critical ecosystems and preserve their invaluable ecological services. Through education, awareness, and conservation initiatives, it could advocate for the protection and sustainable management of Malaysian mangroves, ensuring their survival for generations to come.

1. Introduction

Malaysia is divided between East and Peninsular Malaysia, separated by the South China Sea. The climate in most parts is hot and humid, with plenty of rain, resulting in substantial mangrove vegetation but this coverage has diminished in some locations. Despite its extensive coastline, Peninsular Malaysia accounts for approximately 18% of the country's mangroves, with over 90% of these located along the more protected west coast facing the Straits of Malacca [2]. East Malaysia is host to a significant cover of mangrove in the northern and northwestern Borneo, consisting of Sabah, located to the north, which accounts for 59% of the nation's mangroves while Sarawak, situated to the west, accounts for 23% [2].

Mangrove forests are vital ecosystems found along tropical and subtropical coastlines across the world. In Malaysia, these unique ecosystems are critical to its biodiversity, coastal protection, fisheries, and carbon sequestration. Malaysia's mangrove vegetation is diverse, with numerous species adapted to the extreme conditions of salty water, fluctuating tides, and muddy substrates. The country further boasts a rich diversity of mangrove species, with over 40 different species identified across its coastal regions. These species belong to various families, including Rhizophoraceae, Avicenniaceae, Sonneratiaceae, and Acanthaceae.

Three dominant genera can be found in Malaysia which are *Rhizophora*, *Avicennia*, and *Sonneratia*. *Rhizophora* species, distinguished by their distinctive prop roots, are among the most common and recognisable mangroves in Malaysia [5]. Examples include *Rhizophora apiculata* and *Rhizophora mucronata* (Figures 1 and 2). *Avicennia* species, often referred to as "true mangroves," thrive in saline environments. *Avicennia alba* and *Avicennia officinalis* are prevalent species found along Malaysian coastlines. *Sonneratia* species are known for their unique aerial roots and viviparous seedlings. Species, such as *Sonneratia alba* and *Sonneratia caseolaris* are commonly found in Malaysian mangrove ecosystems (Figures 3 and 4) [18,19].



Figure 1. Dominant species can be found in Malaysia "*Rhizophora apiculata*".



Figure 2. Dominant species can be found in Malaysia "*Rhizophora mucronata*".



Figure 3. Dominant species can be found in Malaysia "*Sonneratia alba*".



Figure 4. Dominant species can be found in Malaysia "*Sonneratia caseolaris*".

Mangrove flora in Malaysia are a critical component of the country's coastal ecosystems, providing numerous ecological, economic, and cultural benefits. Conservation efforts aimed at protecting and restoring these valuable habitats are essential to ensure their long-term sustainability and the well-being of coastal communities and biodiversity.

2. Mangrove Ecological Zone/ Habitat Adaptations

Mangroves host a group of salt-tolerant plant species that thrive in tropical and subtropical intertidal estuarine areas, sheltered coastlines, and creeks. They are characterised by the dominance of partly submerged sclerophyllous plant species, which, taxonomically, are not related. Mangrove forests, comprising just 1% of the total tropical forest area, nonetheless offer invaluable ecosystems along the tropical coastlines [6]. Mangroves provide unique environments linking land and the sea and sustain ecosystems containing a variety of plants, providing habitat for mammals, birds, fish and insects.

Mangrove plants thrive in harsh environmental conditions, including high salinity, oxygen-deficient waterlogged soil, tidal fluctuations, strong winds, and waves. In order to survive in such environments, mangroves have evolved sophisticated morphological and physiological adaptations. They primarily inhabit the intertidal zone, serving as the transition between terrestrial and marine ecosystems (**Figure 5**).

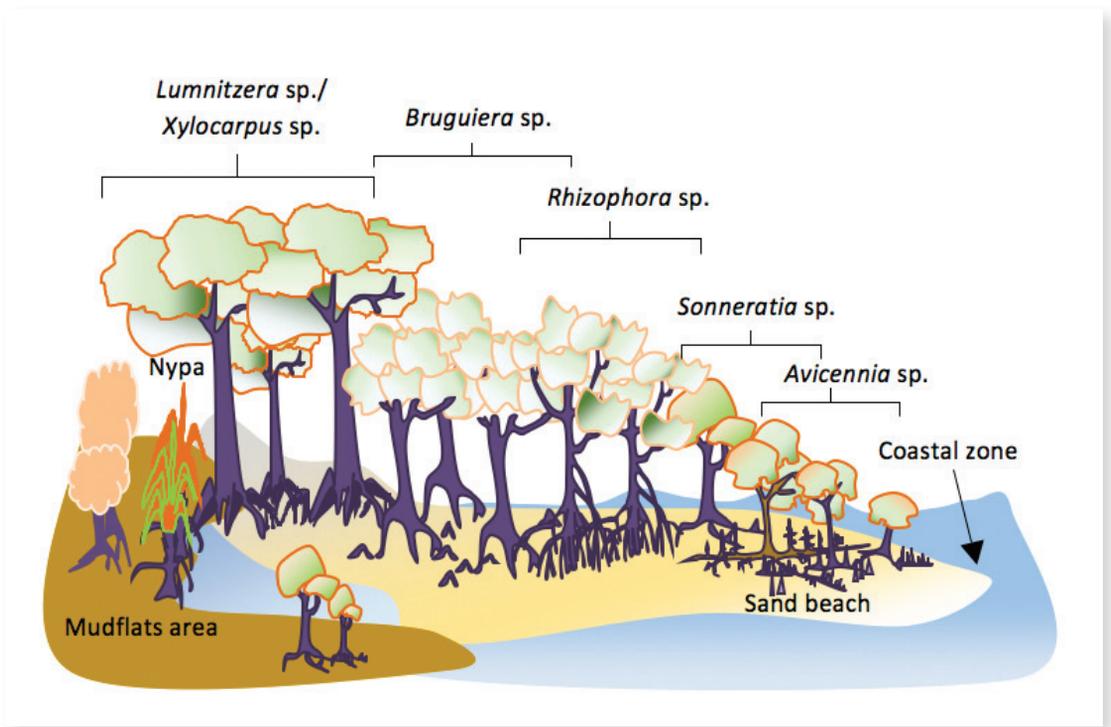


Figure 5. Occurrence of mangroves in the intertidal zones.

True mangroves exhibit various adaptation in order to thrive in saline, waterlogged, and anaerobic conditions, particularly evident in their roots, leaves, and fruits. Roots of mangrove trees often include strut and stilt roots for support and anchorage, aerial prop roots, knee roots, simple curved roots, and buttresses (**Figure 6**). Some species develop specialised root systems, such as pneumatophores, for aeration and gaseous exchange. Leaves of mangroves feature xeromorphic adaptations like cuticles, sunken or chambered stomata, and water storage tissues to reduce transpiration and facilitate salt excretion. Salt glands on leaves aid in salt secretion. Fruits and seeds are adapted for water dispersal, with floating fruits and seeds observed in certain species. Viviparous germination, where seeds germinate while still attached to the parent plant, is common in many species, with variations like apparent vivipary and crypto-vivipary observed in different mangrove families.

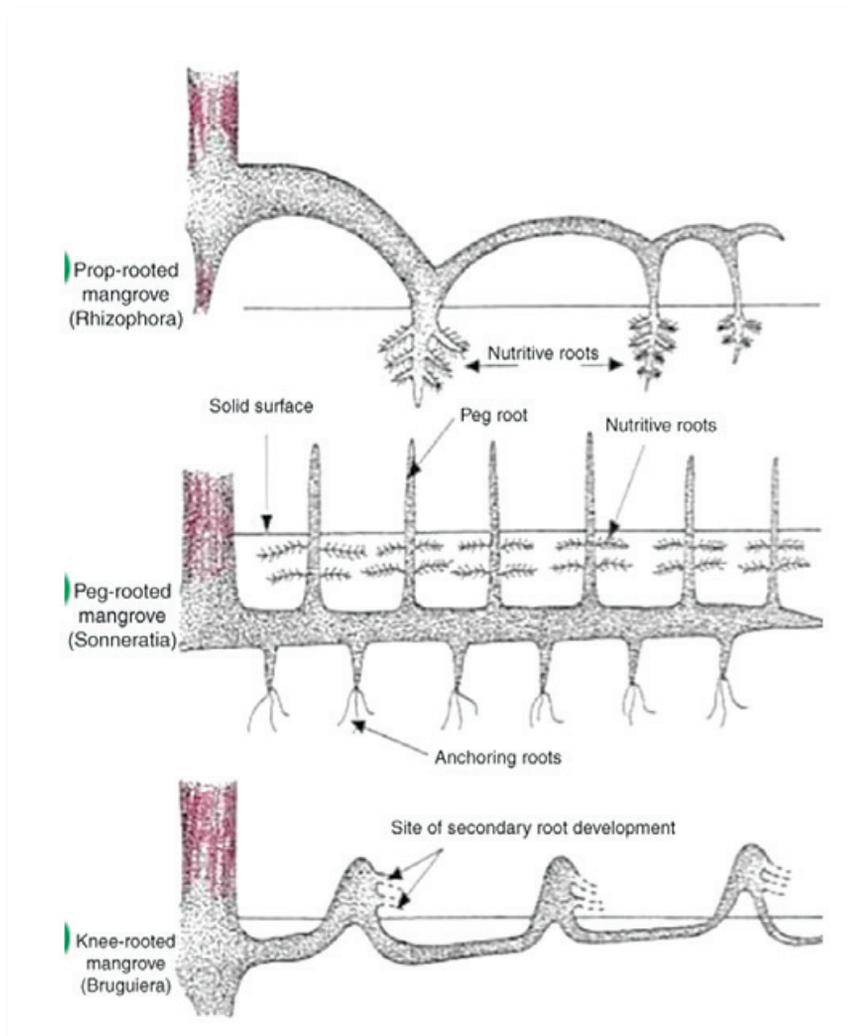
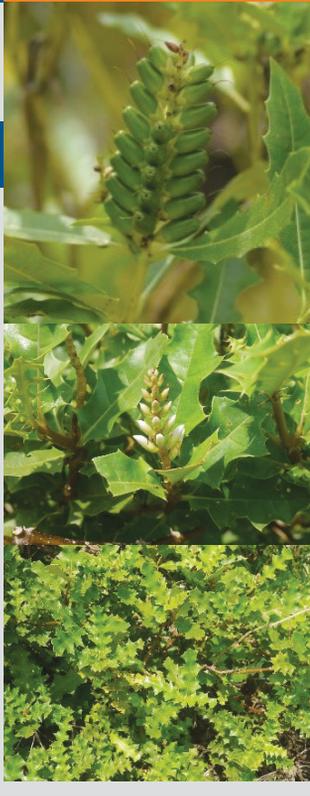


Figure 6. Special adaptation of roots to marshy conditions [6].

3. Mangrove Species in Malaysia

According to World Atlas of Mangroves, there are 40 mangrove species in Malaysia, which is the second most biodiverse country in the Southeast Asia, after Indonesia with 48 species [8]. The list of all mangrove species that can be found in Malaysia are shown in Table 1.

Table 1. Mangrove species in Malaysia [8, 9, 10, 11, 12].

No.	Local Name / (Scientific Name)	Picture
1.	<p data-bbox="492 280 753 349" style="text-align: center;">Jeruju hitam (<i>Acanthus ebracteatus</i>)</p> <p data-bbox="544 388 702 421" style="text-align: center;">Description</p> <p data-bbox="267 465 976 909">A shrub, it can grow up to 2 metres tall, forming dense thickets that can impede movement. Its leaves are oblong to elliptic-oblong, arranged in a decussate pattern with sharp apices, corrugated edges, and sharp needles. The upper surface of the leaves is dark green and shiny, with deeply lobed and spiny margins. Flowers are white to purplish and found in low-lying areas with soft muddy substrate, often inundated by water tide. It prefers low salinity water and may grow on mud lobster mounds. The fruit is an oblong capsule about 2 cm long. Its pinkish stem distinguishes it from Jeruju putih, and the thick thickets it forms can hinder the establishment of Bakau propagules.</p>	
2.	<p data-bbox="511 1076 735 1145" style="text-align: center;">Jeruju putih (<i>Acanthus ilicifolius</i>)</p> <p data-bbox="544 1180 702 1213" style="text-align: center;">Description</p> <p data-bbox="267 1257 976 1734">A shrub growing up to 1.5 m high, spreading and bushy, sometimes forming dense thickets that are challenging to navigate. Its stem is pale yellowish-green, distinguishing it from Jeruju hitam. The leaves are arranged in a decussate pattern, oblong to elliptic-oblong in shape, with acute apices and corrugated margins bearing short spines. The leaf surface is shiny and dark green. The fruit is an oblong capsule, up to 3 cm long, attached to a long stalk, with a smooth, hard, shiny, dark green pericarp. This plant thrives in various tidal inundation levels, typically found on lobster mounds in shaded areas. When exposed to sunlight, it rapidly colonises large areas, creating barriers with its sharp, corrugated leaves and short needles.</p>	

No.	Local Name / (Scientific Name)	Picture
3.	<p data-bbox="455 280 715 349">Piai raya (<i>Acrostichum aureum</i>)</p> <p data-bbox="505 388 665 426">Description</p> <p data-bbox="229 465 939 1025">A mangrove fern growing in erect clumps, reaching up to 3 metres in height, forming dense thickets. Considered a weed, it impedes the distribution of Bakau propagules after logging operations. The fronds are approximately 2 metres long, with the upper surface being scaly and thin towards the leaf margin, while the underside is covered with spores. Young leaflets exhibit a reddish colouration. This fern thrives on mud lobster mounds and avoids high tidal waters. It proliferates rapidly when exposed to direct sunlight, colonising large areas. Manual removal involves chopping the base and overturning the clumps to dry out the roots. Chemical control methods are avoided due to their adverse effects on aquatic life and the environment.</p>	 
4.	<p data-bbox="444 1072 726 1141">Piai lasa (<i>Acrostichum speciosum</i>)</p> <p data-bbox="505 1170 665 1209">Description</p> <p data-bbox="229 1248 939 1731">A smaller fern compared with <i>Acrostichum aureum</i>, with young leaflets exhibiting a reddish colouration. The leaflets are narrow and sharp-pointed towards the apex. It forms thickets and bushy clumps in drier mangrove areas, creating obstacles for walking and hindering Bakau seedling growth. This fern thrives in open spaces in the back mangrove areas, preferring dry places with occasional influence from saline or brackish water.</p>	   

No.	Local Name / (Scientific Name)	Picture
5.	<p data-bbox="479 280 768 349" style="text-align: center;">Kuku helang (<i>Aegiceras corniculatum</i>)</p> <p data-bbox="544 388 704 421" style="text-align: center;">Description</p> <p data-bbox="268 469 976 1068">A bushy shrub, reaching up to 4 metres in height, with simple, spiral, obovate to elliptic leaves that are coriaceous and rounded at the apex. The leaves are pale to dark green, smooth, and shiny on the upper surface, with crystalline salt possibly present. Petioles are up to 1.0 cm long. Flowers are arranged in simple umbels, either terminal or axillary, with 15-20 flowers per stalk. The corolla is white with five petals. The fruit is a curved capsule, reaching up to 8.0cm long, with a sharp-pointed end. Young fruits are green, turning pinkish at maturity. The stem is short and multiple, often forming thick clumps that are difficult to navigate. There are no buttresses or prominent aerial roots. This plant prefers open spaces with sufficient sunlight and is commonly found along mangrove fringes in tidal mud and river estuaries.</p>	
6.	<p data-bbox="521 1141 725 1211" style="text-align: center;">Bekak (<i>Aglaia cucullata</i>)</p> <p data-bbox="544 1242 704 1275" style="text-align: center;">Description</p> <p data-bbox="268 1323 976 1729">A small to medium-sized tree with plank buttresses and pneumatophores. Its bark is smooth, brown or pale orange, and somewhat scaly, while the wood is pale yellowish to orange-brown, emitting white latex. The compound leaves bear 5-9 asymmetrical leaflets. Inflorescences occur in clusters, with numerous small, yellowish flowers featuring three petals and six slightly protruding anthers. Fruits are round with leathery skin and split into three locules, each containing a seed wrapped by a shiny red aril. <i>A. cucullata</i> is a back-mangrove species that thrives in areas with low salinity.</p>	

No.	Local Name / (Scientific Name)	Picture
7.	<p data-bbox="496 278 674 349">Api-api putih (<i>Avicennia alba</i>)</p> <p data-bbox="505 388 665 421">Description</p> <p data-bbox="229 461 939 981">A large tree typically found in mudflats and low-lying areas subject to tidal submergence, reaching heights of up to 15 meters. Its leaves are simple and opposite, lanceolate to elliptical in shape, with acute apexes, measuring 10-18 cm long. The upper surface of the leaf is pale green, while the underside is silver-grey to whitish. Flowers occur in 10-30 flowered spikes, terminal or axillary on distal shoots, with four yellow to orange petals and a five-lobed calyx. The small flowers are approximately 0.5 cm in diameter. Fruits are 1.5-2.0 cm wide and 2.5-4.0 cm long, with hairy, sharp-pointed seed coats and pale green to yellowish coloration. The stem bark is finely fissured and grey to blackish. This tree is among the pioneer species colonising newly developed mangrove areas and may grow alongside other mangrove species such as <i>Sonneratia alba</i>.</p>	  
8.	<p data-bbox="475 1070 695 1141">Api-api jambu (<i>Avicennia marina</i>)</p> <p data-bbox="505 1174 665 1207">Description</p> <p data-bbox="229 1248 939 1734">A small tree, reaching up to 12 metres in height, typically found on mudflats, river banks, and dry areas, exhibiting high tolerance to very saline conditions. Its leaves are simple and opposite, elliptical in shape, with acute to rounded apexes, measuring 5-11 cm long and pale green on the upper surface. Flowers occur in dense spikes with 8-14 small yellow to orange flowers, each with four petals and a five-lobed calyx. Fruits are rounded with sharp-pointed tips, green and velvety pericarp, and a width of 1.5-2.5 cm. The stem bark is smooth, grey to light brownish, and peels in patches resembling the guava tree, hence its name, Api-api jambu. Pneumatophores, pencil-like roots, protrude radially from the tree trunk's undersurface. This tree acts as a pioneer species in newly established mangrove areas.</p>	  

No.	Local Name / (Scientific Name)	Picture
9.	<p data-bbox="531 278 782 349">Api-api ludat (<i>Avicennia officinalis</i>)</p> <p data-bbox="576 378 736 411">Description</p> <p data-bbox="265 448 1051 898">A small tree reaching up to 12 metres in height, widely distributed within mangroves in the country and typically growing in relatively low salinity areas. Its leaves are simple and opposite, obovate to elliptical in shape, with rounded apices. The upper leaf surface is smooth, shiny, and dark green, while the underside is grey with short hair. The fruit is rounded with a sharp pointed end, densely hairy, and wrinkled, resembling a heart shape, with dimensions of 2.0-2.5 cm in width and 2.5-3.0 cm in length. The stem bark is smoothly fissured, grey to brown, sometimes with lenticels. Pneumatophores, pencil-like roots, protrude radially from the trunk base, sometimes accompanied by pseudo-stilt roots. This tree prefers open spaces with sufficient sunlight and is commonly found on mangrove fringes in tidal mud and river estuaries.</p>	
10.	<p data-bbox="524 981 789 1052">Api-api bulu (<i>Avicennia rumphiana</i>)</p> <p data-bbox="576 1081 736 1114">Description</p> <p data-bbox="265 1139 1051 1761">A small to large tree, potentially reaching heights of up to 8 metres, abundant in the East coast of Peninsular Malaysia. Formerly known as <i>Avicennia lanata</i>, it has simple, opposite leaves that are elliptical with rounded to acute apices, measuring 5-9 cm long. The leaf surface is pale green to yellowish, while the underside is hairy and velvety, coppery to grey-white in colour. Flowers occur in dense spikes of 8-14 flowers, with four orange to yellow petals, a five-lobed calyx, and four stamens. Fruits are thick, rounded, and pointed at the tip, hairy, and velvety, with dimensions of 2.0 cm in width and 2.5 cm in length. The pericarp is yellowish green, turning grey at maturity. The stem has a short bole and is branchy, with a dense canopy crown, and the bark is finely fissured and dark brown to black. Pneumatophores and pencil-like roots protrude from the forest floor, spreading radially from the trunk base. While mostly found in the East coast of Peninsular Malaysia, scattered individuals can also be found in the west coast of Johor and a few trees in Bagan Lalang coast of Selangor.</p>	

No.	Local Name / (Scientific Name)	Picture
11.	<p data-bbox="496 282 748 349" style="text-align: center;">Berus-berus (<i>Bruguiera cylindrica</i>)</p> <p data-bbox="539 378 705 413" style="text-align: center;">Description</p> <p data-bbox="229 450 1015 900">A medium to large-sized tree that may grow up to 18 metres high, characterised by a dense crown canopy. While it may resemble <i>B. Parviflora</i>, its dark green canopy distinguishes it. Its leaves are simple and opposite, elliptical in shape, with acuminate apices, measuring 4.0-5.0 cm wide and 10.0-2.0 cm long, with petioles up to 4.0 cm long. Flowers occur in small, 3-flowered cymes, with white petals and a prominent, yellowish-green calyx with 8 lobes spread out from elongated hypocotyls. The fruit consists of hypocotyls up to 15.0 cm long, green to purplish upon maturity, with smooth, slightly curved propagules. The stem has plenty of lenticels and relatively smooth grey bark. It lacks stilt roots but forms small buttresses at the base, with prominent knee roots. This tree prefers higher and drier areas for habitat.</p>	
12.	<p data-bbox="482 987 762 1054" style="text-align: center;">Tumu merah (<i>Bruguiera gymnorrhiza</i>)</p> <p data-bbox="539 1083 705 1118" style="text-align: center;">Description</p> <p data-bbox="229 1145 1015 1763">A large tree that can grow up to 25 metres high, preferring drier mangrove areas typically found in inundation classes III and IV. Its leaves are simple and opposite, elliptic and thick, with acuminate apices, measuring 4.0-8.0 cm in width and 10.0-15.0 cm in length, dark green on the upper surface and pale green on the lower surface. Flowers occur in large, solitary inflorescences, axillary, with white to brown petals and a calyx with 10-14 lobes spreading out and prominently red in colour. The fruit is dark green to purplish tinted brown upon maturity, with a diameter of 2.0-2.5 cm and a length of up to 20.0 cm, bearing cylindrical propagules that may be wavy or ridged, dispersed by water. The stem bark is dark grey, roughly fissured, with lenticels present. While lacking stilt roots, small buttresses form at the base, and knee roots are present. This tree thrives in drier mangrove areas with hardy substrates and can grow abundantly in certain localities.</p>	

No.	Local Name / (Scientific Name)	Picture
13.	<p data-bbox="544 280 768 349">Berus mata buaya (<i>Bruguiera hainesii</i>)</p> <p data-bbox="576 378 735 411">Description</p> <p data-bbox="267 450 1051 896">A medium to large tree with a dense canopy crown, standing out above surrounding species. It is classified as endangered and vulnerable in the IUCN Red List. Its leaves are simple and opposite, with a dark green upper surface and prominent midribs, while the underside is pale green, cuneate at the apex, and wavy along the margin. Flowers occur in inflorescences with 9-12 spreading calyx lobes, very prominent in appearance. The propagules are thick and rounded, reaching up to 10.0-12.0 cm long, smooth with ridges, and dark red and rusty at the tip upon maturity, often nibbled by crabs upon dropping. The stem bark is smoothly fissured for juvenile trees and coarsely fissured for adults, ranging from brown to dark brown in colour. While lacking stilt roots, small buttresses form at the base, and knee-roots are abundant and prominent.</p>	
14.	<p data-bbox="532 981 779 1051">Lenggadai (<i>Bruguiera parviflora</i>)</p> <p data-bbox="576 1081 735 1114">Description</p> <p data-bbox="267 1139 1051 1763">A tall tree with a straight bole reaching up to 20 metres high, characterised by a dense canopy crown that appears pale green to yellowish from a distance. It is easily identified by the presence of slender propagules hanging on the tree. The leaves are simple, coriaceous, elliptic to oblong, with acute or bluntly pointed apices, measuring 7.0-12.0 cm long and 2.5-4.0 cm wide, with petioles up to 2.0 cm long. Flowers occur in cymes with 2-5 small flowers, with a peduncle 2.0-4.0 cm long and a calyx tube 10.0 mm long and 8-lobed. The fruit is a pendulous capsule with a prominent calyx, with hypocotyls reaching up to 15.0 cm long and slender. The stem has a finely fissured bark ranging in colour from grey to light brown. Roots include short, small buttresses and kneed pneumatophores. This plant prefers sandy and hardy substrates, growing abundantly and colonizing blank areas, often rapidly overtaking <i>Rhizophora</i> species.</p>	

No.	Local Name / (Scientific Name)	Picture
15.	<p data-bbox="496 278 748 349" style="text-align: center;">Tumu putih (<i>Bruguiera sexangula</i>)</p> <p data-bbox="539 374 705 413" style="text-align: center;">Description</p> <p data-bbox="229 446 1015 935">This plant has simple, opposite leaves that are elliptical with acuminate apices, measuring 3.0-4.0 cm in width and 8.0-10.0 cm in length, with petioles up to 5.0 cm long. Flowers occur in large, solitary inflorescences, axillary, with white to brown petals and a calyx with 10-14 lobes, greenish to yellow in colour. The fruit is a pendulous capsule with hypocotyls reaching up to 6.0-8.0 cm long, dark green, angular, and blunt at the tip, with smaller propagules compared to <i>B. gymnorhiza</i>. The stem has a short bole with coarsely fissured, dark grey bark. While lacking stilt roots, small buttresses form at the base, and knee roots develop surrounding the base of the tree trunk. This plant is typically found in back mangroves and drier areas.</p> 	
16.	<p data-bbox="515 979 729 1051" style="text-align: center;">Tengar (<i>Ceriops decandra</i>)</p> <p data-bbox="539 1076 705 1114" style="text-align: center;">Description</p> <p data-bbox="229 1141 1015 1624">A small tree or shrub with a bushy habit, reaching up to 3 metres in height, characterised by a dense, pale green canopy. Its leaves are simple and opposite, obovate in shape with rounded apices, measuring 3.0-6.0 cm long. Flowers occur in condensed cymes of 5-10 flowers, axillary, with a green calyx of 5 lobes and short stout peduncles. The fruit or propagule consists of elongated hypocotyls up to 15.0 cm long and 0.8-1.2 cm in diameter, initially green and turning brownish at maturity, with a dark red cotyledonary collar neck. The propagule is smooth with warty features towards the tip, ridges, and cylindrical. The stem has a short, branchy bole with smoothly fissured, grey bark. This plant typically grows in drier mangrove areas.</p> 	

No.	Local Name / (Scientific Name)	Picture
17.	<p data-bbox="568 278 749 349">Tengar Samak (<i>Ceriops tagal</i>)</p> <p data-bbox="576 378 741 411">Description</p> <p data-bbox="265 446 1053 935"><i>Ceriops tagal</i> or commonly known as Tengar samak is a small to medium-sized mangrove tree which usually grows up to 25 m tall with a trunk up to 45 cm in diameter. The bark is grey brown and slightly smooth to flaky. The leaves are yellowish-green, 5–12 cm long and 2–7 cm wide. The flower petals are white and turn brown when decay, the calyxes are green with five lobes and the stamens are 3–5 mm long. This mangrove species is common and widely distributed in Johor, Kedah, Malacca, Negeri Sembilan, Pahang, Perak and Selangor. It is further distinguished from other species by having a ribbed, long and slender hypocotyl that can grow up to 35 cm long [17]. The flowers emit a mild sweet odour to attract pollinators which are most likely to be insects.</p>	
18.	<p data-bbox="508 981 808 1052">Kaju pelok (<i>Dolichandrone spathacea</i>)</p> <p data-bbox="576 1081 741 1114">Description</p> <p data-bbox="265 1141 1053 1734">An evergreen tree with a crooked trunk, featuring leaves with hairy hollow cavities between secondary veins, providing habitat for insects. Its large, trumpet-shaped flowers range from white to greenish-white or yellow and emit a fragrant scent with frilled petal edges. Flowering occurs at dusk, with flowers dropping before sunrise. Fruits are elongated pods resembling horns, containing hard, leathery partitions and numerous dark grey seeds in rows. Typically found along landward mangrove edges, tidal river banks, estuaries, and beach vegetation. Its leaves are used medicinally, brewed into tea to treat mouth infections. Notable for its distinctive large, trumpet-shaped flowers with frilled petal edges and horn-like fruit pods.</p>	

No.	Local Name / (Scientific Name)	Picture
19.	<p style="text-align: center;">Bebuta (<i>Excoecaria agallocha</i>)</p> <p style="text-align: center;">Description</p> <p>A medium-sized tree, occasionally a shrub, reaching up to 15 metres in height and typically found in drier mangrove areas and back mangroves. Its leaves drop annually, with old mature leaves turning red before falling. The tree produces white sap believed to be poisonous, especially if it comes into contact with the eyes. Leaves are simple and alternate, elliptical in shape with acute apexes, measuring 6.0-9.0 cm long. Flowers occur in male spikes resembling catkins, up to 7.0 cm long, and shorter female racemes, with white petals and yellowish-green calyxes. The fruit is three-lobed, similar to a rubber tree, splitting open when ripe. The stem has a finely fissured bark with a grey colouration. While lacking stilt roots or buttresses, it typically grows in higher and drier areas of back mangroves with hardy substrates.</p>	
20.	<p style="text-align: center;">Gurah (<i>Excoecaria indica</i>)</p> <p style="text-align: center;">Description</p> <p>This small tree is characterised by its white latex content, short trunk without buttresses, and bushy crown with upright branches that may have drooping twigs. Its leaves have reddish leaf stalks and finely toothed edges. Green flowers occur in clusters on long spear-like arrangements, and the fruit is round with a woody capsule that starts green and turns almost black when ripe. Both fruits and seeds are poisonous. It can be found in tidal river banks, seashores, freshwater swamp forests, along rivers, and in evergreen lowland forests.</p>	

No.	Local Name / (Scientific Name)	Picture
21.	<p data-bbox="568 278 743 311" style="text-align: center;"><i>Heritiera fomes</i></p> <div data-bbox="244 369 1068 432" style="background-color: #0056b3; color: white; text-align: center; padding: 5px;">Description</div> <p data-bbox="265 450 1051 900"> <i>Heritiera fomes</i>, an evergreen tree reaching heights of up to 25 metres, features a bole with a diameter of 60 cm or more, often with buttresses and pneumatophores (breathing roots) up to 30 cm high. Widely harvested from the wild for local wood use, it's also cultivated in plantations for its valuable timber. This species is primarily found in the landward margin of mangroves in South Asia, a habitat under significant threat from coastal development. Despite being locally common, there has been a substantial decline in its population, particularly in Malaysia, due to mangrove clearing for rice farming, shrimp aquaculture, and coastal development. Classified as 'Endangered' on the IUCN Red List, populations in India and Bangladesh are facing rapid decline, potentially qualifying for 'Critically Endangered' status at a regional level. </p>	
22.	<p data-bbox="554 981 758 1049" style="text-align: center;">Dungun <i>Heritiera littoralis</i></p> <div data-bbox="244 1070 1068 1134" style="background-color: #0056b3; color: white; text-align: center; padding: 5px;">Description</div> <p data-bbox="265 1141 1051 1591"> The medium-sized tree can reach heights of up to 15 metres and is widely distributed within mangrove areas, although its population density is relatively low. It's easily recognisable by its large leaves with a silvery underside and prominent midrib on the upper surface. The leaves are simple, alternate, coriaceous, elliptic, or oblong, with a rounded or acute apex. The flowers form loose panicles up to 10cm long, with purple to brown petals and pinkish calyx lobes. The hard seed coat of the fruit measures 5-7 cm long, starting green and turning brownish when mature, with a smooth surface and ridges on the outer edge. Seed dispersal occurs via water. The stem is branchy, with finely fissured bark bearing white patches along the bole and flaky bark in older trees. This species is typically found in back mangroves. </p>	

No.	Local Name / (Scientific Name)	Picture
23.	<p data-bbox="522 280 722 349">Mempisang (<i>Kandelia candel</i>)</p> <p data-bbox="541 378 701 413">Description</p> <p data-bbox="229 448 918 653">This shrub or small tree, reaching up to 7 metres in height, is sparsely distributed along the banks of tidal rivers among other mangrove plant species. It occupies a narrow niche and is considered rare. Its wood serves as a source of firewood. Notable features include white flowers with numerous stamens and recurved calyx lobes.</p>	 
24.	<p data-bbox="501 743 743 813">Teruntum merah (<i>Lumnitzera littorea</i>)</p> <p data-bbox="541 842 701 877">Description</p> <p data-bbox="229 911 1015 1503">This medium-sized tree, occasionally bushy and shrub-like in its sapling and juvenile stages, can reach heights of up to 20 metres. It typically thrives in back mangroves with harder soil substrates, boasting a branchy canopy crown. Its leaves are simple, spiral, and alternate, with obovate blades and rounded to emarginated apices, appearing thick and dark green on the upper surface, measuring 4-7 cm long. The inflorescence is a raceme, terminal, bearing small, bright red flowers about 1.5 cm long, with green calyx lobes. Its fruits, 2.0-2.5 cm long, are yellowish-green, glossy, vase-shaped, and buoyant, dispersed by water. The stem features coarsely and vertically fissured bark, ranging from grey to dark brown, with small buttresses and developed pneumatophores in the roots. This species primarily inhabits back mangroves but can also be found in sandy beaches.</p>	 

No.	Local Name / (Scientific Name)	Picture
25.	<p data-bbox="525 280 788 349">Teruntum putih (<i>Lumnitzera racemosa</i>)</p> <p data-bbox="576 382 736 413">Description</p> <p data-bbox="267 450 1051 898">Teruntum putih is a shrub or small tree reaching heights of up to 8 metres, less common than <i>L. littorea</i>. Its bushy canopy may form dense thickets in certain areas. It can be distinguished from teruntum merah by its white flowers and smaller leaves. The leaves are simple, spiral, and alternate, with obovate blades and rounded to emarginated apices, measuring 3-7 cm long. The inflorescence is a spike, 1-2 cm long, with small white flowers and green calyx lobes. Its small fruits, up to 0.5 cm in diameter and 1.5 cm long, are yellowish-green and buoyant for water dispersal. The stem is branchy and corky, with coarsely vertically fissured bark ranging from grey to dark brown. Pneumatophores and looping lateral roots may be present. It thrives in back mangroves, tidal swamps, and along coastal belts.</p>	  
26.	<p data-bbox="562 1006 751 1076">Nipah (<i>Nypa fruticans</i>)</p> <p data-bbox="576 1108 736 1139">Description</p> <p data-bbox="267 1164 1051 1584">This palm species thrives along river banks, tolerating a wide range of water salinity from freshwater to high seawater concentrations. Its leaves can grow up to 6 metres long, with erect fronds and glaucous undersides, consisting of up to 30 pairs of leaflets. Female flowers are clustered in globose heads, while male flowers resemble catkins and vary in colour from brick red to yellow. Fruits are borne in heads up to 45cm long, turning dark brown to brick red when ripe, and detach from the fruit bunch. The palm features a rhizome-like stem embedded in the soil, enabling its adaptability to various habitats.</p> 	  

No.	Local Name / (Scientific Name)	Picture
27.	<p data-bbox="501 278 741 311"><i>(Osbornia octodonta)</i></p> <p data-bbox="539 378 701 411">Description</p> <p data-bbox="229 450 1015 726"><i>Osbornia</i> is a genus of mangrove plants belonging to the Myrtaceae family. It consists of only one species, <i>Osbornia octodonta</i>, commonly known as the myrtle mangrove. This species is found in coastal regions of Borneo, the Philippines, the Lesser Sunda Islands, the Northern Territory, Queensland, and northern Western Australia. It was first described by Ferdinand von Mueller in 1862, based on specimens collected in Trinity Bay. The myrtle mangrove typically grows in the inner parts of mangrove forests along coastlines.</p>	
28.	<p data-bbox="491 780 751 848">Bakau minyak <i>(Rhizophora apiculata)</i></p> <p data-bbox="539 877 701 909">Description</p> <p data-bbox="229 938 1015 1524">A prevalent mangrove tree species found throughout mangrove areas in Malaysia, constituting approximately 50% of mangroves in the country. The trees typically grow closely together, forming straight boles and uniform sizes. Their leaves are simple and opposite, narrowly elliptical with apiculate apices, measuring 9-18 cm long, often exhibiting dark black spots beneath the surface. Flowers occur in pairs on stout peduncles, with four white petals and a greenish-yellow, four-lobed calyx. Fruits begin developing after successful fertilisation, initially showing swelling in the central part of the calyx, transitioning from green to pale brown upon maturity, with a reddish-brown elongated hypocotyl developing thereafter. Stilt roots provide support to the dense crown canopy and facilitate mineral, water, and nutrient transport, sometimes reaching heights of up to 2 metres above ground. This species thrives in muddy firm substrates within mangrove areas, particularly in inundation classes II, III, and IV, according to Watson's Inundation Classes.</p> <div data-bbox="372 1541 639 1812">  </div> <div data-bbox="679 1528 1005 1750">  </div>	

No.	Local Name / (Scientific Name)	Picture
29.	<p data-bbox="519 278 796 349">Bakau kurap (<i>Rhizophora mucronata</i>)</p> <p data-bbox="576 378 739 411">Description</p> <p data-bbox="267 450 1056 1039">A mangrove tree species typically reaching a height of 2 metres, commonly found along riverbanks, streams, and creeks in mangrove areas, indicating a preference for freshwater input compared to <i>R. apiculata</i>. The leaves are simple, opposite, and elliptical, larger and broader than those of <i>R. apiculata</i>, with prominent black dots on the underside and short needles at the apex. Flowers form in pendulous clusters of 8-16 dichotomous cymes at leaf axils, with four white petals and hairy stamens, surrounded by a four-lobed creamy yellow to yellowish-green calyx. Young buds are green, maturing to yellowish and creamy colours, and open flowers are often visited by trips, suggesting they are pollinators. Fruits are larger than those of <i>R. apiculata</i>, starting green and turning brownish as they mature, with elongated hypocotyls up to 80 cm long, and hardy, warty propagules. The stem has coarsely fissured, dark grey bark, with a straight bole tapering slightly at the top. Stilt roots can reach heights of up to 1 metre. This species thrives in muddy, soft substrates along riverbanks, and its viviparous propagules are dispersed by water tides.</p>	
30.	<p data-bbox="544 1079 772 1151">Bakau pasir (<i>Rhizophora stylosa</i>)</p> <p data-bbox="576 1180 739 1213">Description</p> <p data-bbox="267 1238 1056 1765">Slightly shorter than <i>R. apiculata</i> and <i>R. mucronata</i>, it can reach up to 18 metres in height, particularly thriving in sandy substrates or rocky islands. Its leaves are simple, opposite, elliptical, with needle-like structures at the apex, measuring 10-18 cm long, often mistaken for <i>R. mucronata</i> due to similar appearance. The presence of black dots underneath the leaf blade distinguishes it. Flowers occur in dichotomous cymes with 4-12 buds, featuring white petals and yellow-green lobed calyxes. Young fruits are green, maturing to a brownish colour, with elongated hypocotyls measuring 10-18 cm long, exhibiting a warty surface. The bark is coarsely fissured, grey to black, resembling that of <i>R. mucronata</i>. Buttresses, reaching up to 1.5 m high, are numerous, with lower branches developing aerial roots for additional support. It predominantly occupies hard sandy substrates or rocky islands, with Pulau Besar, Melaka, being predominantly covered by this species in its mangrove ecosystem.</p>	

No.	Local Name / (Scientific Name)	Picture
31.	<p style="text-align: center;">Bakau hibrid (<i>Rhizophora x lamarckii</i>)</p> <p style="text-align: center;">Description</p> <p><i>R. x lamarckii</i> is a hybrid between <i>R. apiculata</i> and <i>R. stylosa</i>, exhibiting superior traits compared to its parent trees. It grows larger, resembling <i>R. apiculata</i> in trunk and bole morphology, while its leaves resemble those of <i>R. stylosa</i> but are broader and darker green, measuring 9-18 cm long with prominent black dots underneath. Flowers are similar to <i>R. apiculata</i> but with larger buds developing in pairs or sometimes threes or fours on longer peduncles, turning yellowish as they mature. However, fruit production is limited due to its low fertilisation success, with most fruits aborting after the floral stage and failing to develop into propagules. The stem bark is finely fissured like <i>R. apiculata</i>, with a short bole and coarsely fissured dark grey bark. Stilt roots are present, akin to <i>R. apiculata</i>. It thrives in sandy and hardy substrates, notably found in Pulau Tulai in Tioman and Pulau Burung, Port Dickson.</p>	
32.	<p style="text-align: center;">Chengam (<i>Scyphiphora hydrophyllacea</i>)</p> <p style="text-align: center;">Description</p> <p>The plant is a small tree resembling a shrub, growing in dense clumps that are difficult to navigate. It flowers year-round, attracting insects for pollination. Its leaves are simple and opposite, shiny on the upper surface, with obovate blades and rounded apices, measuring 5-7 cm long. The flowers are small, white, arranged in clusters of 3 to 7 on condensed racemes, with 4 petals and a calyx of 4 obscure lobes. The fruits are small and numerous, up to 0.5 cm in diameter and 1.0 cm long, with a globular, ridged, and shiny surface. The stems form multiple branches, contributing to its clump-like appearance. It thrives in muddy substrates and firm soil, often colonising open cleared spaces opportunistically.</p>	

No.	Local Name / (Scientific Name)	Picture
33.	<p data-bbox="558 280 755 349" style="text-align: center;">Perepat (<i>Sonneratia alba</i>)</p> <p data-bbox="576 378 736 413" style="text-align: center;">Description</p> <p data-bbox="265 448 1053 981">This large-sized tree thrives along muddy coastlines, often found alongside <i>Avicennia alba</i>, indicating its role as a pioneer species in mangrove forest formation. It can grow up to 18 meters tall with a dense crown canopy. Its leaves are simple, opposite, oblong to obovate, and 5 to 10 cm long. The white flowers have numerous stamens, with a calyx of 6 to 8 lobes, red in the inner lobes and green in the outer ones, and measure 5 to 8 cm in diameter. Flowers bloom in the late evening and are ephemeral, lasting overnight, attracting trips and bees. The green fruits are smooth-surfaced, 3.5 to 5.0 cm in diameter, with a cup-shaped calyx enclosing the base and spreading or reflexed lobes. The stem is straight with light grey to brownish bark, and pneumatophores protrude above the ground surface. This tree prefers muddy shores and riverbanks and is often inhabited by colonies of fireflies, notably found in specific locations, such as Kampung Kuantan, Kuala Selangor, and Kampung Kak Yah, Kemaman, Terengganu.</p>	
34.	<p data-bbox="529 1035 786 1105" style="text-align: center;">Berembang (<i>Sonneratia caseolaris</i>)</p> <p data-bbox="576 1134 736 1168" style="text-align: center;">Description</p> <p data-bbox="265 1193 1053 1783">This tree is commonly found along river banks, sometimes alongside nipah palms. Its leaves are simple and opposite, with drooping twigs and pinkish petioles. They are oval to oblong, unequal-sided, with rounded apices and prominent recurved tips, measuring 4 to 8 cm long. The flowers form 1 to a few flowered cymes at the terminal, with pinkish petals and a green calyx of 6 to 8 lobes. Numerous stamens are pinkish and white, with flowers opening late evening and lasting overnight, attracting thrips, bees, and nectar-sucking bats. The green fruits are glossy and 6 to 8 cm in diameter, with a flat calyx extended horizontally but not enclosing the fruit. The stem leans towards the river on both sides of river banks, with low branching and smoothly fissured bark. Pneumatophores, conical-shaped roots, protrude from the soil surface. This tree's habitat includes muddy shores and riverbanks, often hosting colonies of fireflies, notably found in specific locations, such as Kampung Kuantan, Kuala Selangor, and Kampung Kak Yah, Kemaman, Terengganu.</p>	

No.	Local Name / (Scientific Name)	Picture
35.	<p data-bbox="496 266 739 340" style="text-align: center;">Pedada (<i>Sonneratia griffithii</i>)</p> <p data-bbox="539 363 696 401" style="text-align: center;">Description</p> <p data-bbox="225 440 1253 1078">The tree has a spreading growth habit, reaching heights of up to 25 metres. Its bark is pale brown, flaky, and smooth when young, becoming fissured as it matures. It produces numerous conical pneumatophores that are stout, elongated, often branching, and have a soft flaky surface, reaching lengths of up to 60 cm. The base of the stem is not buttressed. The leaves are simple, opposite, obovate to suborbicular, dark green, and measure 7-11 cm in length and 6-10 cm in width. They have prominent veins on the upper side, with rounded or emarginated apices and a microdata tip, and cuneate or rounded bases. The petioles are short, less than 0.5 cm long. Inflorescences are solitary cymose on terminal and lateral branches, consisting of 3-5 flowers. Mature flower buds are globose, 2.5-3.0 cm long, with obtuse apices. The calyx tube is 3.0-3.5 cm long, widely bell-shaped, with 6-7 lobes that do not envelop the base of the fruit. The inner side of the calyx is white, and petals are absent. Stamens are numerous, white, and fall off within hours after blooming; anthers are yellow and dorsifixed. The ovary is multi-locular. Mature fruits resemble berries, being globose with a depressed apex, measuring 2.5-3.0 cm in length and 4.0-5.5 cm in width. The pericarp is leathery, the style is less persistent, and persisting calyx lobes spread. The seeds are numerous and angular. The native range of this species is North-East India to West Peninsula Malaysia. It is a tree and grows primarily in the wet tropical biome.</p>	 
36.	<p data-bbox="511 1126 725 1199" style="text-align: center;">Gedabu (<i>Sonneratia ovata</i>)</p> <p data-bbox="539 1222 696 1261" style="text-align: center;">Description</p> <p data-bbox="225 1300 1018 1744">The small tree typically grows up to 6 metres high and is commonly found in back mangroves or higher inundated ground with sturdy substrates. Its leaves are simple, opposite, broadly ovate, and fleshy, with obtuse apices and thick, wavy blades. They are dark green in colour, rounded, and measure 4 to 10 cm long, with petioles up to 6mm long. The flowers are arranged in terminal cymes, usually in groups of 3, with a cup-shaped calyx tube and 6 to 8 lobes. The fruit is a globose berry, smooth and shiny, measuring 2 cm long and 5 cm wide, with a persistent style at the tip. The stem has a short bole and coarse fissures, while numerous conical pneumatophores protrude from the soil surface. The fruit is edible but very sour, and the wood is used for firewood. Additionally, the bark is utilised for tannin and dye, and poultices made from the fruits are used to treat sprains. [17]</p>	  

No.	Local Name / (Scientific Name)
37.	<p data-bbox="482 278 1079 349" style="text-align: center;">Hybrid <i>Sonneratia alba</i> x <i>Sonneratia caseolaris</i> (<i>Sonneratia</i> x <i>gulngai</i>)</p> <p data-bbox="701 378 861 411" style="text-align: center;">Description</p> <p data-bbox="267 448 1289 865">The hybrid of <i>Sonneratia alba</i> and <i>Sonneratia caseolaris</i> is a tall tree up to 25 metres with a dense canopy. It has obovate, dull green leaves with prominent midveins and acuminate tips. Inflorescences usually carry one or two buds, with flowers having red linear petals and numerous stamens. The fruit is erect and globose, measuring 10-20 mm long and 29-48 mm wide, sometimes indented around the style base, with a leathery, smooth, and glossy pericarp without ribs. The persistent calyx measures 41-47 mm from the base of the fruit to the tip of the sepals, with erect lobes 23-28 mm long. Seeds are numerous and angular. Distinguishing features from <i>Sonneratia alba</i> include prominent leaf midveins and typically taller pneumatophores, while contrasts with <i>Sonneratia caseolaris</i> include smooth mature flower bud surfaces and a cup-shaped calyx in mature fruits. Intermediate traits between the parent species include petiole length, style length, and stigma width [18].</p>
38.	<p data-bbox="591 921 968 993" style="text-align: center;">Hybrid <i>S. alba</i> x <i>S. lanceolata</i> (<i>Sonneratia</i> x <i>urama</i>)</p> <p data-bbox="701 1016 861 1049" style="text-align: center;">Description</p> <p data-bbox="272 1074 1289 1491">The hybrid status of <i>S. alba</i> x <i>S. lanceolata</i>. It grows up to 20 metres tall with a dense crown, lacking buttresses, featuring slender pneumatophores. Leaves are elliptic, pale green with a dull upper surface and satin lustre below, prominent midvein, and broadly acute apices with backward-curved mucros. Petioles are mostly decurrent. Inflorescences bear 1 or 2 buds with stems mostly terete. The flowers have a smooth, dull base with calyx lobes about 18-19 mm long. Red linear petals are 25 mm long and 2mm wide. Staminal filaments are around 26 mm long, white with pale yellow anthers. Petals and stamens typically fall off shortly after blooming. The ovary contains about 18 locules, with a 55 mm long style and a 2 mm wide stigma. The fruits are upright and round, measuring 6 mm long and 28 mm wide, often dented near the style base, with a smooth, shiny skin. The calyx remains as a cup measuring 28-30 mm wide, with spreading lobes, each 23 mm long [19].</p>

No.	Local Name / (Scientific Name)	Picture
39.	<p data-bbox="486 278 753 349" style="text-align: center;">Nyireh bunga (<i>Xylocarpus granatum</i>)</p> <p data-bbox="539 378 701 411" style="text-align: center;">Description</p> <p data-bbox="229 446 1015 967">The trees reach heights of 3-8 metres, characterised by long, snaking buttresses. Their bark varies in colour, ranging from light brown to yellowish or greenish, and it is smooth, flaking off over time. The leaves are pinnate, with leaflets that start as bright light green when young and darken to a dark green when mature. The leaflets are narrowly drop-shaped, with rounded tips. Fragrant flowers have white petals and are approximately 8 mm across, while the capsules are woody and range from grapefruit to small pomelo-sized. Typically found in mangroves, particularly estuarine areas, and often co-occurring with <i>Nypa</i> and <i>Sonneratia species</i>. This species can be distinguished from <i>X. moluccensis</i> by its bark characteristics (brown, yellowish, or greenish, smooth, and flaking versus dark grey and non-flaking fissured bark), leaflet tip shape (rounded versus pointed), and fruit size (grapefruit to small pomelo-sized versus orange-sized).</p>	
40.	<p data-bbox="475 1012 765 1083" style="text-align: center;">Nyireh batu (<i>Xylocarous moluccensis</i>)</p> <p data-bbox="539 1112 701 1145" style="text-align: center;">Description</p> <p data-bbox="229 1161 1015 1754">The tree reaches heights ranging from 5 to 20 metres and is characterised by bark with longitudinal fissures. It may have small buttress roots or none at all, with many peg-shaped pneumatophores, which are blunt-tipped and nearly cylindrical. Its compound leaves consist of 2-3 pairs of oblong leaflets, each measuring 4-12 cm long, with more pointed tips and a thin, leathery texture. These compound leaves are arranged spirally and turn vivid yellow before withering, lending an autumnal appearance to the mangrove forest. The tiny white to pinkish flowers occur in clusters on an inflorescence. The fruit is oval-shaped (not globular), with a diameter of 8-12 cm, containing 5-10 seeds. The timber is moderately light and soft yet strong, seasoning well, and is commonly used in house and boat construction. In Java, it is also utilised for making handles for traditional daggers known as 'kris', as well as for firewood. Traditional medicinal applications include using the seeds for treating stomach aches, the fruits to stimulate appetite, and the bark tannin for intestinal ailments. Additionally, the bark is used for tanning fishing nets.</p>	

4. Mangrove Conservation Efforts

Mangrove forest situated within the Permanent Forest Reserve spans an area of 0.09 million hectares, constituting approximately 1.86% of the total Permanent Forest Reserve in Peninsular Malaysia [14]. Despite its relatively modest percentage, this mangrove expanse serves a crucial function, particularly in safeguarding coastal areas against disasters, such as tsunamis and coastal erosion, which have historically resulted in loss of life and property damage, as evidenced by the events of December 26, 2004. In the early days, Malaysia's attention was more centred on planting mangroves to harness economic resources, particularly for charcoal production within the Matang Mangrove Forest Reserve. Overtime, their function has since expanded, transitioning towards conservation and restoration of mangrove throughout the country.

Prior to the first ever recorded tsunami to struck Malaysia in 2004, there had been no comprehensive nationwide planting initiative dedicated for mangroves in Malaysia. Recognising the significance of this ecosystem, the government launched the National Planting Program for Mangroves and Other Suitable Coastal Species, involving multiple states across Malaysia, including collaboration among the Federal and State Governments, forest managers, researchers, local communities, and NGOs. From 2005 to 2023, a total of 3,461.64 hectares of Malaysia's coastline have been planted and treated, involving the cultivation of 7,952,431 seedlings (**Table 2**).

Table 2. Mangroves and other suitable coastal species planting done by the Forestry Department from 2005 to 2023 [15]

Year	Area (Ha)	No. of Trees Planted
2005	189.3	477,802
2006	113.45	539,019
2007	403.19	1,051,023
2008	620.31	1,507,120
2009	526.87	1,357,433
2010	428.86	930,995
2011	85.28	198,203
2012	52.16	54,326
2013	68.6	68,929
2014	59.3	72,428
2015	57.4	66,650
2016	106.32	163,173
2017	92.3	137,818
2018	70.2	116,541
2019	52.35	54,692
2020	56.5	70,786
2021	246.8	235,607
2022	48.6	108,351
2023	183.85	741,535
Total	3,461.64	7,952,431

4.1 Mangrove Planting in High Risk Area Using Innovative Planting Technique in Sungai Haji Dorani

Coastal forests, particularly mangrove ecosystems, play crucial roles in shoreline protection, mitigating coastal erosion, and storm surges. However, there's a concerning rate of the disappearance of natural wetlands, especially mangroves. Over the span of 55 years, about 35% of the world wetlands area have been lost, with Malaysia's mangrove cover declining from 650,311 ha in 1990 to 629,038 ha in 2017 or about 3.3%, with an annual loss rate of 788 ha yr⁻¹ or 0.13% yr⁻¹, primarily occurring outside Permanent Reserved Forest (PRF) areas [3]. This loss significantly impacts CO² emissions, with mangroves serving as vital carbon sinks.

The coastal area of Kuala Bernam Forest Reserve, Selangor, is chosen for mangrove conservation and restoration due to its high-risk wave erosion. Restoration methods include breakwater structures and innovative planting techniques. Located near D'Muara Marine Park Resort, this area has experienced erosion since 2000, altering water and sediment quality. It also experiences high wave, typically ranging from 1.5 to 1.8 metres under normal conditions, and could reach up to 2.36 metres during the peak of the monsoon season. Observations showed the occurrence of mangrove loss due to strong waves and erosion, thinning the forest to 10m in some areas.

On 3 July 2007, 4 geotubes were installed totalling 200-metre long, with a distance of 100 meters from the coast (**Figure 7 & 8**). The installation of these geotubes was due to a successful collaboration with FRIM, JPS, NAHRIM, the Selangor State Forestry Department, and the Sabak Bernam Land and District Office [16]. After the successful installation of the geotubes, restoration and conservation activities have been actively carried out, involving the local community. They assist in the preparation of planting stock, site preparation, and planting in the field. Planting was done using innovative techniques which are Comp-mat (CM), Comp-pillow (CP), Bamboo Encasement Method (BEM) and conventional. Four mangrove species were planted; *Rhizophoran apiculata*, *R. mucronata*, *Avicennia alba*, and *A. marina*.

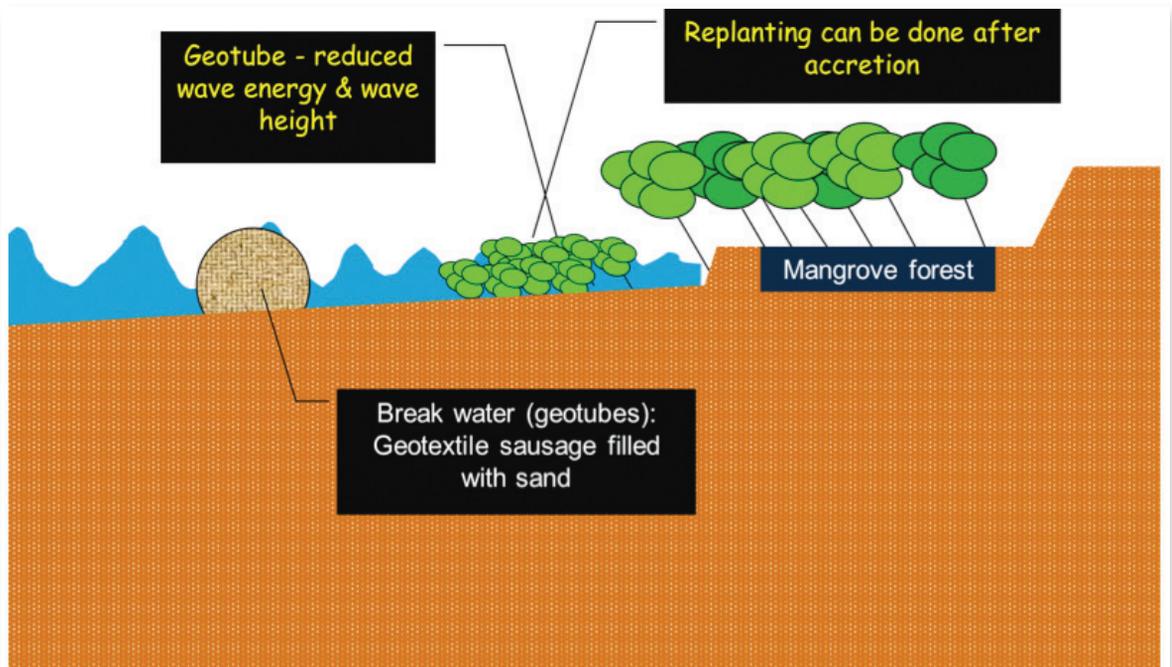


Figure 7. Illustration of Geotube by the engineers of Malaysia's Department of Drainage and Irrigation (DID).



Figure 8. Sea View - Study plot after > 5 years (October 2013).

The planting of mangrove trees in the study plot began in December 2007 using BEM, CM, CP, and conventional techniques. After 8 years, it was observed that the success percentage of the crop technique was as follows: CM > CP > BEM > Conventional, with the CM technique contributing to the highest success percentage. Conventional techniques are not recommended, despite geotube support. **Figure 9** below shows the plot area after 13 years of planting.



Before planting
(17 July 2007)

1 year 3 month
after planting
(14 March 2009)



8 years after
planting (2015)

After 8 Years: Seaward
Mangrove Established
(200 m × 100 m) ~ 2ha



Figure 9. the plot area after 13 years of planting.

Community awareness programmes are pivotal for fostering understanding and engagement with mangrove ecosystems, promoting conservation, and ensuring sustainable management practices. Such initiatives not only garner local support for conservation efforts but also contribute to sustainable livelihoods and enhance the resilience of mangrove ecosystems. Recognising the efficacy of the innovative planting methods, on December 2011, the Malaysia Book of Records acknowledged the pioneering work in mangrove rehabilitation and restoration (Figure 10). The establishment of a mangrove forest model in Kampung Sungai Haji Dorani, Sungai Besar, Selangor, using innovative planting techniques, exemplifies proactive measures taken to address the pressing challenges facing coastal ecosystems.

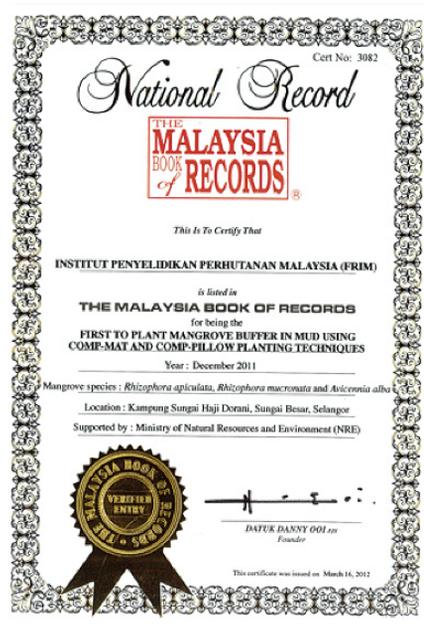


Figure 10. Malaysia Book of Records acknowledged the pioneering work in mangrove rehabilitation.

4.2 Mangrove Poles as Breakwater Structure

Due to sea level rise most coastal areas are inundated and eroded. With existing mangrove in continuous decline due to erosion it has become difficult for mangrove regeneration to take place naturally. In order to increase planting success in high risk areas, breakwater structures are needed to stabilise, reduce wave energy and promote sedimentation. A breakwater structure using mangrove poles were erected in Sg. Hj. Dorani, within the mangrove area of the Kuala Bernam Forest Reserve Selangor adjacent to the geotube breakwater structure from previous mangrove planting research conducted by Dr. Raja Barizan in 2007.

Approximately 1200 mangrove poles were acquired from Matang for the construction of the breakwater structure. These poles were installed along a 60-meter stretch parallel to the coastline, positioned about 30 meters from the shoreline (Figure 11 & 12). The modified comp-pillow technique involves using coconut fibre enclosed in a cylinder-shaped net measuring 1 metre in length and 0.4 metres in width. Each comp-pillow is then filled with three mangrove seedlings, namely *Rhizophora apiculata*, *Rhizophora mucronata*, and *Rhizophora stylosa*. Four 1.5-metre stake are anchored to each side of the comp-pillow to secure it into the mud. Approximately 200 modified comp-pillows were planted using this innovative technique.

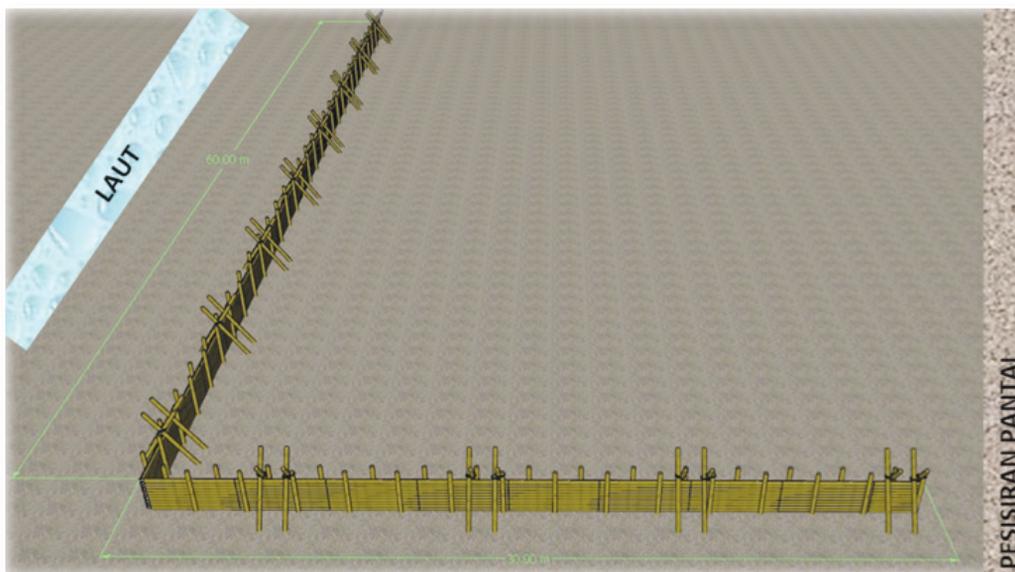


Figure 11. Illustration of a mangrove pole breakwater structure.



Figure 12. Ariel image of the mangrove pole breakwater structure and mangrove seedlings plated using comp-pillow technique in Sg. Hj. Dorani.

5. Conclusion

Mangrove species in Malaysia display a remarkable adaptation to thrive in challenging coastal environments, characterised by saline, waterlogged, and anaerobic conditions. These adaptations, including specialised root systems, xeromorphic leaf features, and unique fruit and seed structures, enable mangroves to survive and propagate in their habitats. Malaysia's mangrove vegetation is diverse, with species adapted to the extreme conditions of salty water, fluctuating tides, and muddy substrates.

Amounting in excess of 40 different species and belonging to various families, including Rhizophoraceae, Avicenniaceae, Sonneratiaceae, and Acanthaceae, Malaysia has a very rich diversity of mangroves. Conservation efforts for mangroves here, therefore are crucial due to their ecological significance and the threats they face from coastal development, pollution, and climate change. Initiatives aimed at protecting and restoring mangrove ecosystems are vital for preserving biodiversity, supporting coastal communities, and mitigating the impacts of natural disasters.

Collaborative efforts involving government agencies, research institutions, NGOs, and local communities are essential for effective mangrove conservation. Strategies include the establishment of protected areas, restoration projects, sustainable management practices, and public awareness campaigns. Safeguarding Malaysia's mangrove flora requires concerted action and long-term commitment to ensure the resilience and sustainability of these invaluable coastal ecosystems for future generations.

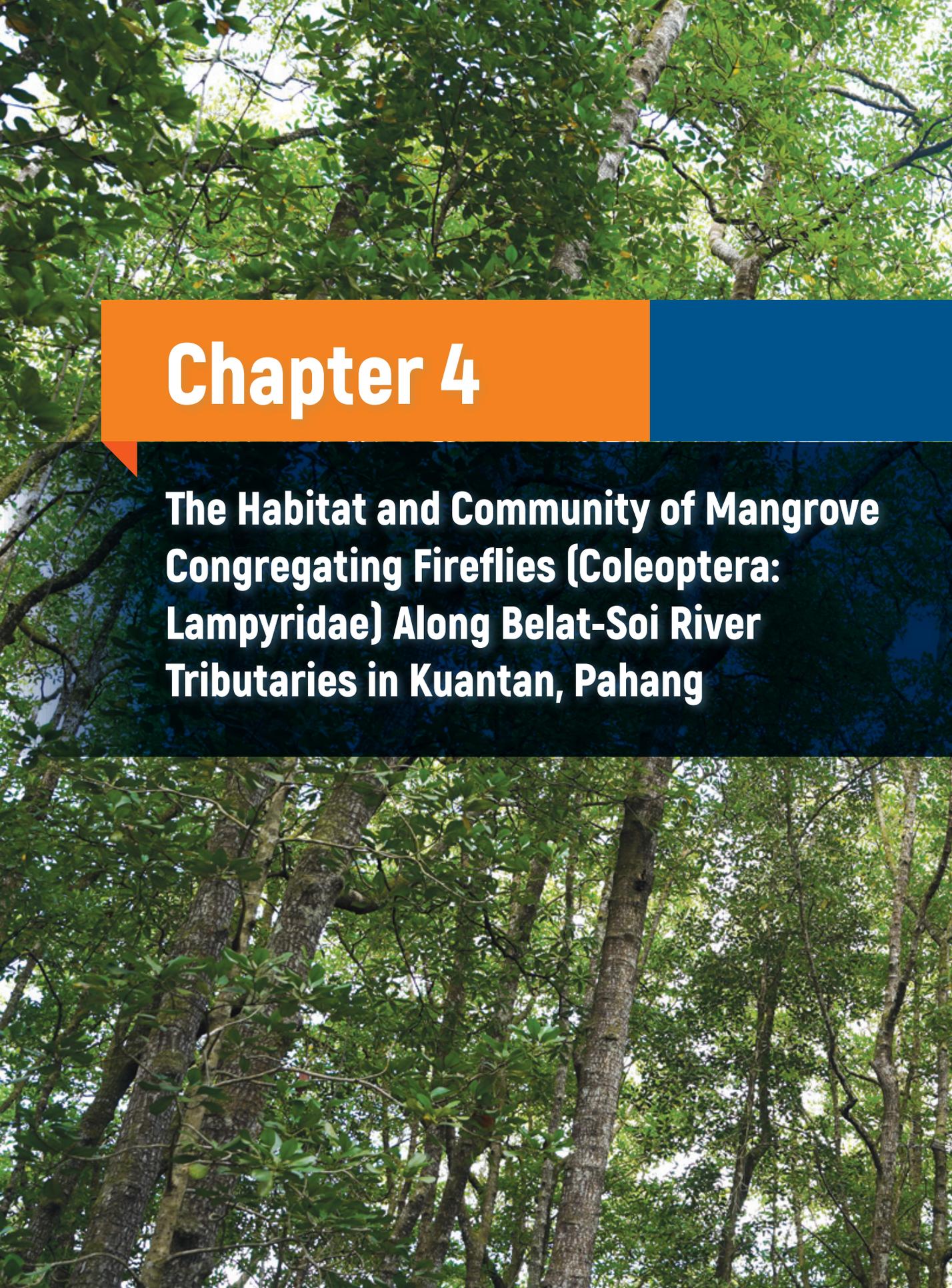
Acknowledgments

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Chapter 4

**The Habitat and Community of Mangrove
Congregating Fireflies (Coleoptera:
Lampyridae) Along Belat-Soi River
Tributaries in Kuantan, Pahang**

The Habitat and Community of Mangrove Congregating Fireflies (Coleoptera: Lampyridae) Along Belat-Soi River Tributaries in Kuantan, Pahang

Nada Badruddin^{1*}, Nurul Ain Johan¹, Deenatul Aiman Ros²,

Nur Diyana Abdul Rahman² & Nursalwa Baharuddin²

¹Forest Research Institute Malaysia, 52109 FRIM, Kepong, Selangor

²Universiti Malaysia Terengganu (UMT), 21030 Kuala Nerus, Terengganu

*Corresponding author: nada@frim.gov.my

1. Introduction

Malaysia is one of a handful of countries where mangrove congregating fireflies can be found. The global distribution of this group of fireflies is centralised in the South East Asian region and limited to between the south of India to Papua New Guinea [1]. In terms of their specific habitat, they are confined to the mangrove areas, including river estuaries experiencing high and low tides [2]. The mangrove congregating fireflies are beetles from the Lampyridae family. They undergo a four-stage lifecycle of between five to seven months [3]. Around 80% of their life is spent in the breeding habitat located inland from the riverbanks, with the larvae being the longest period of their lives. The adult stage is spent on trees growing along the river edges, and termed as the displaying habitat.

The life of a firefly begins when the egg is hatched into a larva. Firefly larvae predate macro-snails living on river beds and mudflats. Upon entering several instars, the mature larvae undergoes pupation underground in a soil chamber. Once the adults are ready to emerge, they break away from the pupal casing and emerge from the ground before flying to nearby trees lining the riverbanks. The fireflies we see flashing their light in large numbers on canopy of trees in mangrove areas are known for their touristic values and many local communities in mangrove areas of Malaysia benefit socio-economically from their presence [4]–[6].

Data on these mangrove congregating fireflies in Malaysia are limited. Most of their habitat are around Selangor River, Selangor and Sepetang River, Perak [7]–[9]. Additionally, not many studies have focused on the salinity conditions of the river in relation to the distribution of congregating firefly species in a particular habitat. Therefore, efforts to increase the knowledge of habitat and population of the

congregating fireflies in other areas continues, particularly as habitat loss is the major threat to firefly survivability [10]; and there is a steady loss in mangrove areas over time [11].

The Kuantan River basin is located along East Coast Range bordering Pahang and Terengganu. One of the tributaries from this river is Belat River, located near Kampung Belukar, Kampung Baharu Batu Empat and Kampung Gudang Rasau. Soi River is a tributary of Belat River. Part of the surrounding areas of Belat River encompass the Kuantan Mangrove Forest Reserve. Belat and Soi Rivers are among the habitats of the mangrove congregating fireflies in Peninsular Malaysia. Local people engage in prawn fishing and harvesting of mud crabs as a source of livelihood. The rivers that join the Kuantan River are also visited by tourists on boat rides to witness natural splendour, such as the birds and the crocodiles. The display of lights at night from the adult fireflies is spectacular especially when seen on boats from Shahbandar Jetty in Kuantan towards Belat River.

2. Methodology

A survey was conducted of the habitat and community of mangrove congregating fireflies in Belat-Soi tributaries between 2019 and 2020 where part of the Belat River enters into the Kuantan Mangrove Forest Reserve and where this river and Soi River are surrounded by housing areas, aquaculture plots and oil palm plantations. The objectives of the survey included the identification of firefly species and their display trees; mapping the spread of the displaying habitats; identifying species of macro-snails present in the breeding habitats; and recording the salinity readings of the river system within the mangrove congregating firefly habitat.

Six kilometres of the Belat River and 2.3 km of Soi River was surveyed for the presence of adult fireflies. Several entry points from the river to breeding habitats were identified. Areas found to have firefly larvae were searched for macro-snails. The search focused on detecting snails that has shells 1cm or less in diameter as these types are likely a food source of the firefly larvae due to its compatible size.

During the day, the researchers visited both rivers via boat to record the general vegetation along them. Representative breeding habitat of fireflies was undertaken in order to record the presence of macro-snails. At night, the survey continued to sample for the adult fireflies on the display trees. Each tree with a group of light flashing fireflies was recorded and GPS coordinates were taken. Specimens of fireflies were collected and preserved for identification. Salinity readings were collected along both rivers using a water parameter reader. The sampling points of the rivers began 3 km upstream of the jetty and sampling points were positioned 1 km apart with 6 sampling points recorded for water salinity readings along Belat River and 2 sampling points along Soi River.

3. Findings

3.1 Species of congregating fireflies of Belat-Soi tributaries

Three (3) species of congregating fireflies were recorded in the area comprising *Pteroptyx bearni*, *P. mallacae* and *P. tener* (**Figure 1**). All three species were recorded along Belat River while two species, i.e. *P. bearni* and *P. mallacae*, were recorded along Soi River. Each species of the congregating fireflies produces distinct light flashing patterns. *P. tener* and *P. mallacae* produce light synchronously, while *P. bearni* produces light at a slower pace and asynchronously (**REF**).

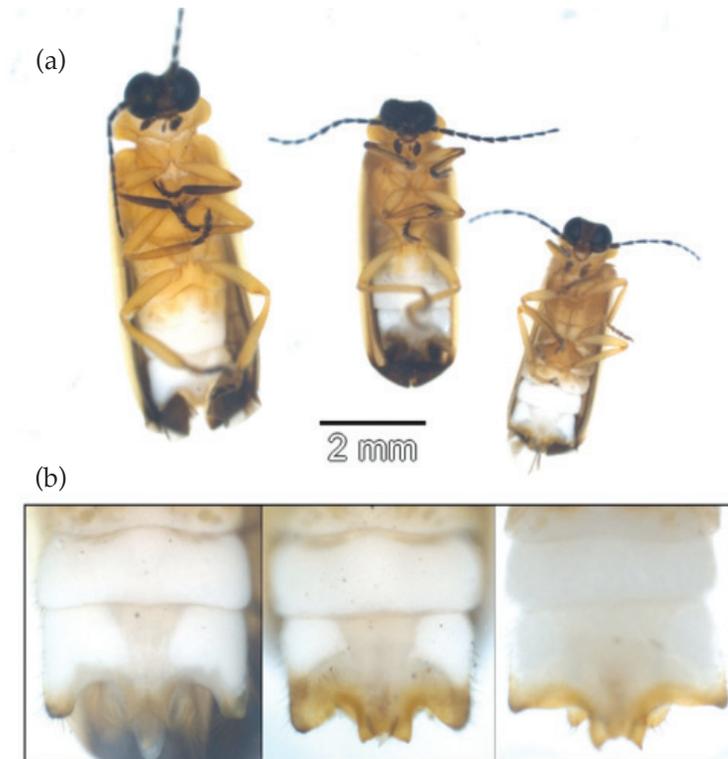


Figure 1. Three species of congregating fireflies recorded in Belat-Soi tributaries comprising (from left to right) *Pteroptyx malaccae*, *P. bearni*, *P. tener*. Comparison of (a) size and (b) the light organ shapes the three species.

3.2 Display trees of fireflies in Belat-Soi tributaries

The adult fireflies were recorded to occupy trees on both sides of the riverbanks. In general, *P. bearni* inhabited the length of the area covered in the survey. *P. mallacae* occupied further downstream of the habitat, as opposed to *P. tener* which was recorded relatively upstream of the rivers. **Figure 2** shows the displaying habitat range of the three species of congregating fireflies recorded in Belat-Soi tributaries.

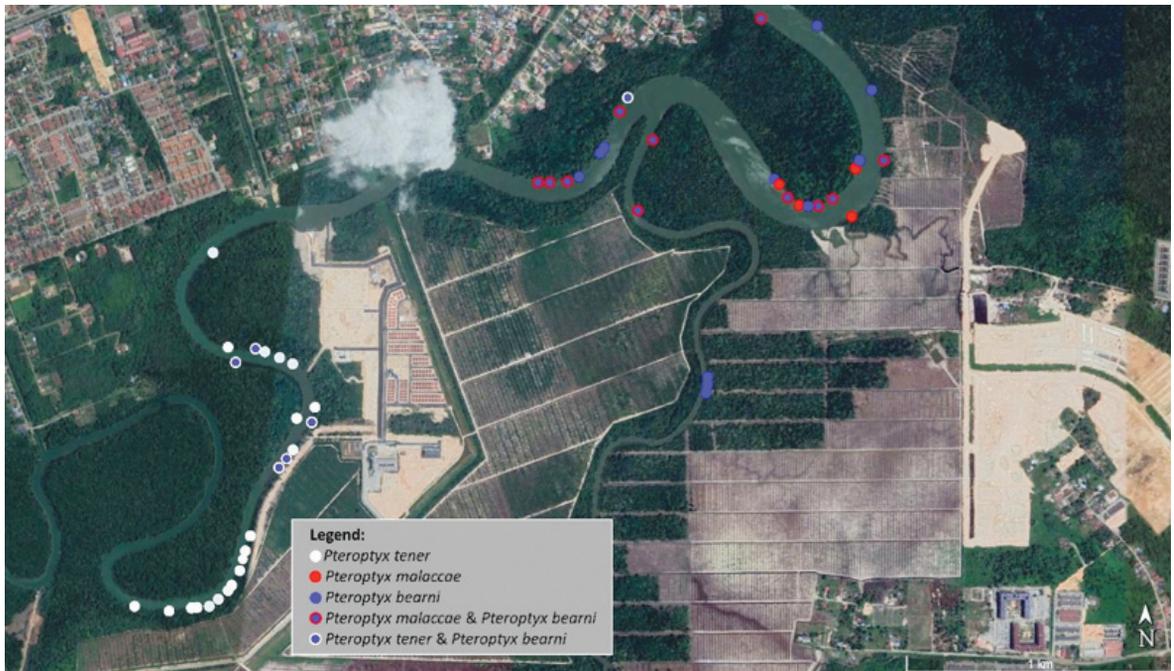


Figure 2. The spread of adult congregating fireflies in the study area. The display trees were occupied by either one species or by two species. Satellite image source: Google Earth dated 17 April 2019.

Certain display trees were recorded to be occupied by two different congregating firefly species. At the upper stream sections of the river, *P. bearni* and *P. tener* were found on a particular tree. Further downstream, the display trees were occupied by *P. bearni* and *P. malaccaae*. They were observed to form separate groups, although two species were occupying a tree — *P. bearni* occupied sections of the canopy that overhangs nearest to the river surface, with either *P. malaccaae* or *P. tener* forming their respective groups relatively at the higher sections of the shared canopies.

The display trees along the two rivers were found to be numerous. Based on the survey conducted, a total of 11 types of display trees was recorded. From the total of 52 individual trees observed with adult congregating fireflies, *Excoecaria agallocha* (Local name: bebuta) dominated the area, followed closely by *Sonneratia caseolaris* (berembang). Belat-Soi tributaries recorded a higher variation of display tree types compared with the congregating firefly habitats in Selangor and Sepetang Rivers [7], [9]. **Figure 3** shows the map of the distribution of display trees while **Figure 4** summarises the types of display tree in percentage of numbers occupied by the adult fireflies in the area.

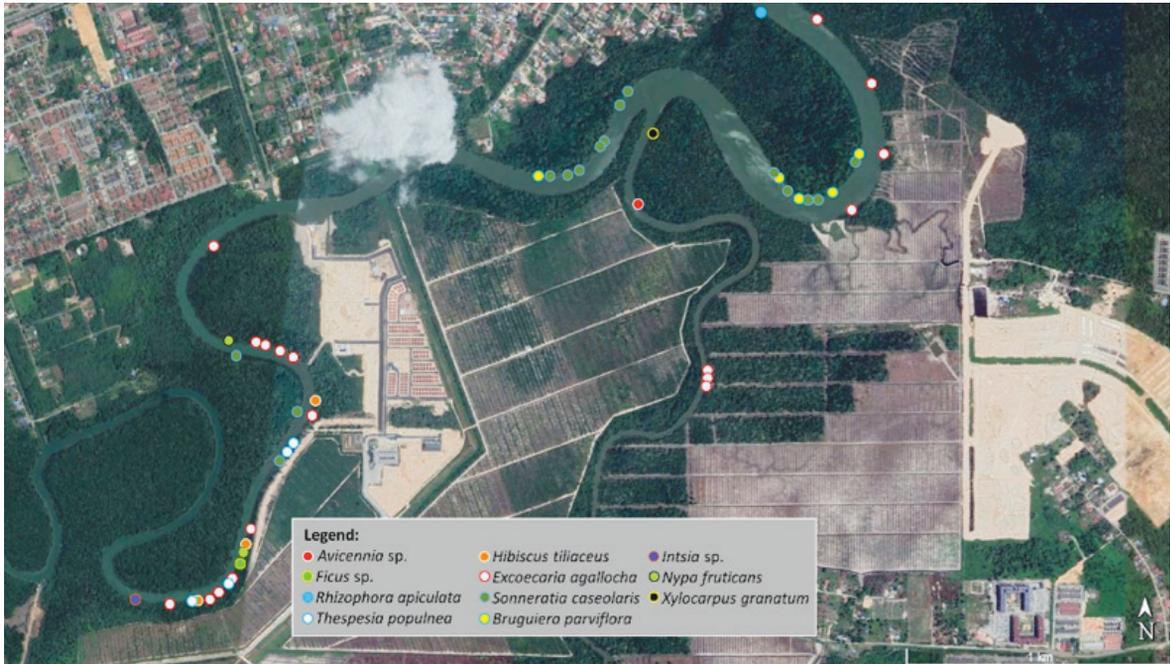


Figure 3. The different types of display trees inhabited by the adult congregating fireflies in the Belat-Soi tributaries. Eleven species of trees were recorded with bebuta, *Excoecaria agallocha* recording the highest number. Satellite image source: Google Earth dated 17 April 2019.

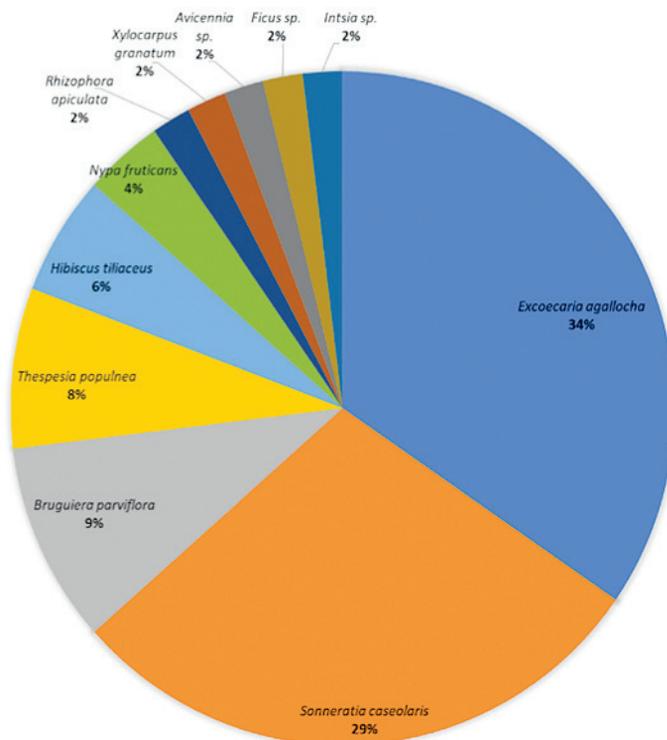


Figure 4. The display trees in Belat-Soi tributaries according to the percentage of numbers. More than half (63%) of the trees with adult congregating fireflies were of bebuta, *Excoecaria agallocha* and berembang, *Sonneratia caseolaris* variants.

3.4 Macro-snails in the congregating firefly breeding habitats of Belat-Soi tributaries

A total of 11 sites were surveyed to assess the presence of macro-snails (Figure 5). The survey aimed to ascertain the presence of macro-snails along the river but was constrained to the downstream area of the jetty utilised for boat access in this study. This restriction was necessitated by the absence of suitable entry points along the river, compounded by ongoing construction activities in the vicinity (for detailed information, see Section 3.6).



Figure 5. Locations along the river entered to locate macro-snails in the area. Sites labelled as green dots are sites where snails were found, while the red dots were otherwise. Satellite image source: Google Earth dated 17 April 2019.

The vegetation in these locations primarily consisted of *Nypa fruticans* and *Rhizophora* spp. Out of the sites surveyed, four yielded no macro-snails, while the remaining seven sites documented a total of nine (9) species from five (5) families and six (6) genera of macro-snails. Each site recorded between two to six species of macro-snails. **Table 1** lists the macro-snail species categorised by site, and **Figure 6** describes the snail species recorded from this survey.

Table 1. List of species of macro-snails recorded in this study based on 11 sampling sites along Belat and Soi Rivers.

Family	Sp. / Site	Belat-River					Soi-River					
		SnB1	SnB2	SnB3	SnB4*	SnB5*	SnB6	SnB7	SnB8	SnS1*	SnS2*	SnS3
Potamididae	<i>Cerithidea obtusa</i>	●										
Ellobiidae	<i>Ellobium aurisjudae</i>						●					
Littorinidae	<i>Littoraria carinifera</i>	●					●					●
	<i>L. scabra</i>											●
	<i>L. strigata</i>		●	●								
Neritidae	<i>Clithon faba</i>	●					●	●				
	<i>Neripteron cornucopia</i>	●										
	<i>N. violceum</i>		●									
Assimineidae	<i>Optediceros breviculum</i>	●	●	●			●	●	●			●

*No macro-snails found

Optediceros breviculum (family Assimineidae), commonly referred to as the ‘red berry snail,’ was identified in all seven sites housing macro-snails. This species characterised by its striking aesthetic, is a commonly encountered species inhabiting the sheltered niches of mangrove ecosystems and the sediment-rich zones in monsoon drainage systems [12]. Predominantly adorned with a vivid red hue, although sporadically observed in black variations, its dietary preference primarily centres around algae consumption. Moreover, fireflies such as *Pteroptyx malacca*, have been documented to consume gastropods, including *Assiminea* snails [13].

Three (3) species of macro-snails from the Littorinidae family were identified across five (5) sampling sites. These molluscs are primarily found in association with mangrove trees, salt-tolerant shrubs, and grasses, and are often classified as ‘obligate mangrove-dwellers’ [14]. Evidence showed that larvae of *Micronapsis* firefly in Brazil feed on small snails, notably *Echinolittorina lineolate* (Gastropoda: Littorinidae) [15]. Although such cases were not observed in Malaysia, there is a high likelihood that larvae exhibit tendency to feed on them, given that fireflies are opportunistic feeders with respect to snail species.

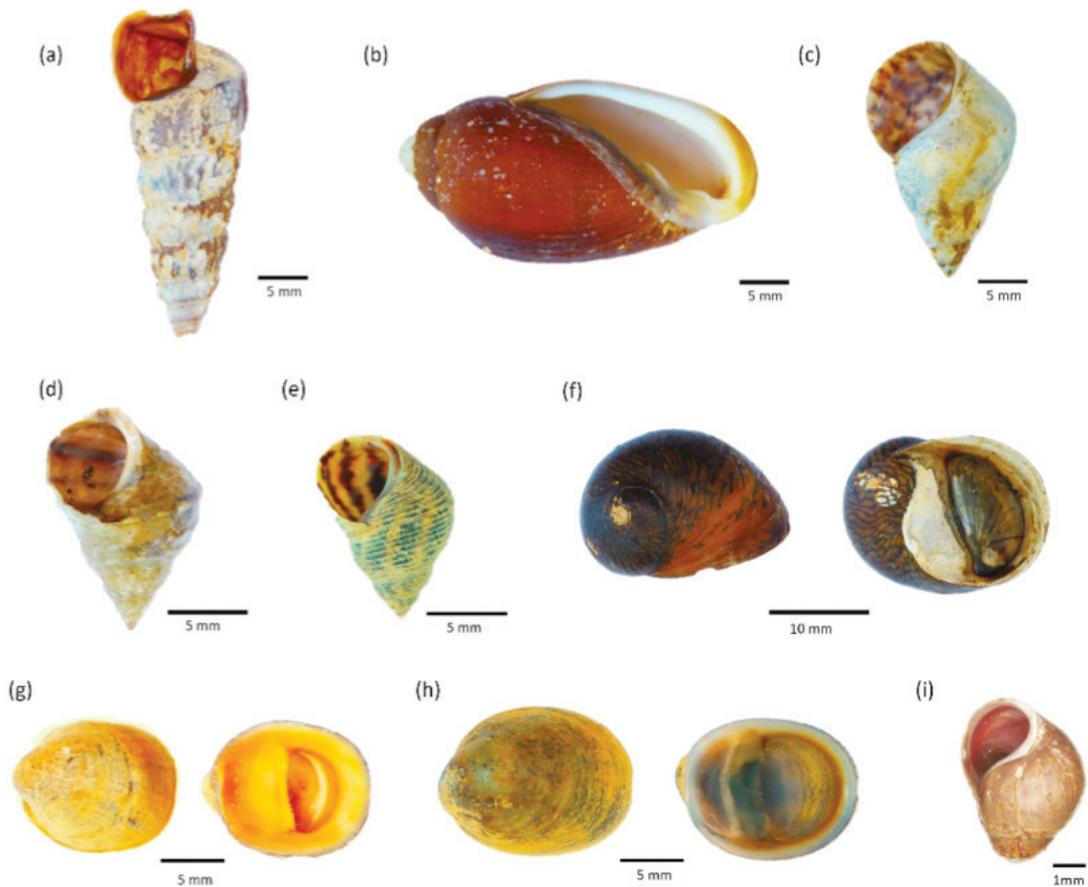


Figure 6. Nine species of snails were recorded from the breeding habitats of the congregating fireflies in Belat-Soi tributaries. The snails were (a) *Cerithidea obtusa*, (b) *Ellobium aurisjudae*, (c) *Littoraria scabra*, (d) *Littoraria carinifera*, (e) *Littoraria strigata*, (f) *Clithon faba*, (g) *Neripteron cornucopia*, (h) *Neripteron violaceum* and (i) *Optediceros breviculum*.

3.5 Water salinity in Belat-Soi congregating firefly habitat

Water parameter readings were taken along the two rivers between 20:35 and 22:55 hrs on 6 July 2020. The 10 readings per sampling point were averaged and presented as a table inset in **Figure 7**. The range of average salinity readings were between 2.22 and 10.02 practical salinity unit (psu). Relating the salinity reading with the distribution of the different congregating firefly species shows the habitat of *Pteroptyx tener* was within the area of the river that has salinity readings between 2.22 and 5.23 psu, while *P. bearni* and *P. mallacae* mainly inhabit sections of the river with higher salinity readings ranging between 6.13 and 10.02 psu. Such observation could be related to the adaptation of these species to a particular assemblage of vegetations influenced by salt intrusion into the river system from the sea.



Figure 7. Locations along the Belat and Soi Rivers where water quality readings were taken in particular of the salinity levels. Table inset showing the average values of salinity readings according to sampling points. Satellite image source: Google Earth dated 17 April 2019.

3.6 Threats to the habitat

Land use changes were happening in the congregating firefly habitat in Belat River which were not detected during the first survey made in 2019. During the second visit to the area in July 2020, inland sections of the riverbanks were found to be cleared-off the original vegetations. According to the locals, the clearing was to make way for the construction of flood mitigation bunds. Observations made from the river showed clearings were made close to the river edges (**Figure 8**).



Figure 8. Clearings of natural vegetations of the riverbanks could be seen from the river during the sampling made in 2020. As the congregating firefly breeding habitats are on the riverbanks, disturbance from construction of bunds is likely to impact the fireflies negatively.

Upon overlaying the display trees geolocations on a satellite image dated 18 June 2020 of the study area, the extend of clearings were made more apparent (**Figure 9**). There is a concern such land changes would impact negatively on the firefly community in the mangrove area as the bunds went through their breeding habitats.

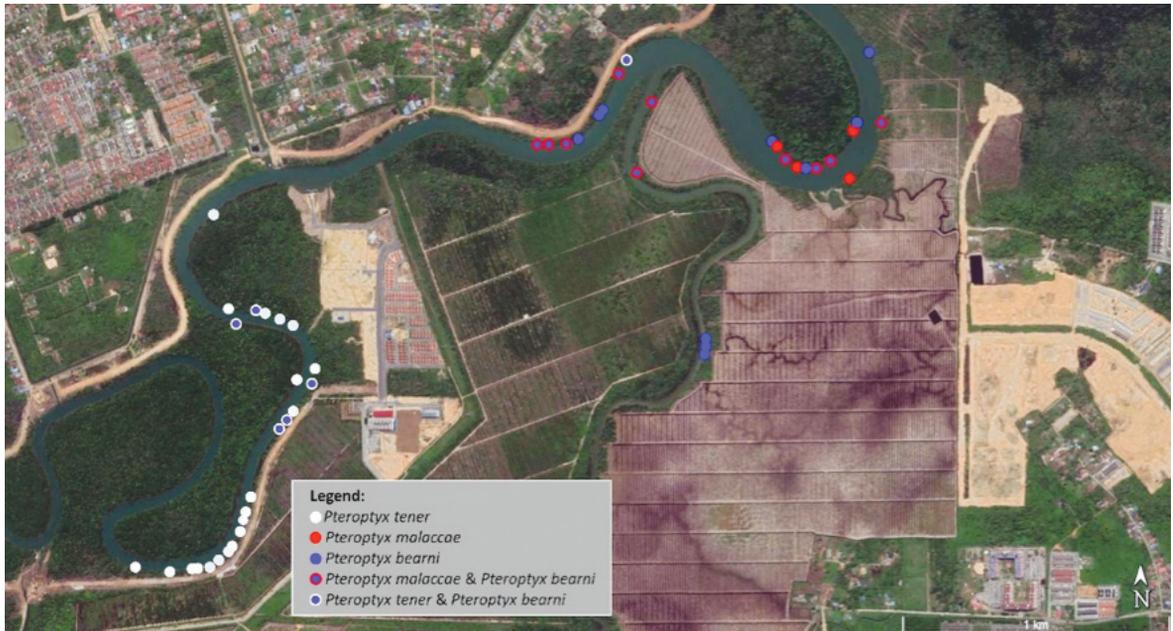


Figure 9. Land cleared for construction of flood mitigation bunds along the Belat River could be seen from the satellite image dated 18 June 2020. Upon completion, the bunds would go through the breeding habitat of the fireflies, posing a threat to the survival of the fireflies in the area. Satellite image source: Google Earth dated 18 June 2020.

5. Conclusion

Three species of congregating fireflies inhabit the mangrove and estuarine areas of Belat-Soi tributaries, namely the *Pteroptyx bearni*, *P. malacca* and *P. tener*. The display trees of the adult fireflies were found to be numerous in comparison to the display trees of the congregating fireflies along Selangor and Sepetang Rivers. This chapter has discussed the distribution of the firefly species with the display trees and identified macro-snails in the breeding habitat that are potential food source for the firefly larvae. Salinity readings of the river water was also examined which were related to the firefly species presence along the river. Habitat loss due to land use changes could impact negatively on the mangrove congregating firefly community in Belat-Soi tributaries.

Acknowledgments

Our thanks to the locals who assisted us in the fieldwork, mainly Aminullah and Mahadi. Our gratitude also to FRIM Entomology Branch's past and present staff, Nor-Azlan MA, Shaiful-Amri MS, Muhaimin M. and Alif-Daniel MMS for assisting the work both in the study site, as well as in the laboratory. This study was funded by the 11th Malaysia Plan (Research & Development), Project title: Documentation and Biodiversity Conservation Towards Prosperity and Sustainability of Natural Resources (Phase 1).

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Chapter 5



Presence of Vertebrates at Selected Mangroves in Perak: Towards Identification of Key Biodiversity Areas (KBA)



Presence of Vertebrates at Selected Mangroves in Perak: Towards Identification of Key Biodiversity Areas (KBA)

Mohammad Shahfiz Azman*, Nor Hazwani Ahmad Ruzman,
Noor Faradiana Md Fauzi, Muhammad Asyraff Azahar, Manoshini Appanan,
Nur Aina Amira Mahyudin, Kaviarasu Munian
& Muhammad Syaridzwan Baharudin
Forest Research Institute Malaysia, 52109 FRIM, Kepong, Selangor
*Corresponding author: shahfiz@frim.gov.my

1. Introduction

A mangrove forest is a vegetation area confined by mangrove plant species with a minimum patch size of about 0.01 km². Low trees dominate this forest, but some species can grow to about 50-60 m, extending a few kilometres inland from the coastline or river estuarine. It lacks shade-tolerant understory plants with many roots, salt water, and mud at the ground level [1].

There are 307 species of mammals, 814 species of birds, 567 species of reptiles, and 242 species of amphibians in Malaysia [2]. Of these, species such as flying fox (*Pteropus vampyrus*), long-tailed macaque (*Macaca fascicularis*), silver-leafed langur (*Trachypithecus cristatus*), javan pipistrelle (*Pipistrellus javanicus*) brown-winged kingfisher (*Pelargopsis amauroptera*), mangrove pitta (*Pitta megarhyncha*), great tit (*Parus major*) and mangrove blue-flycatcher (*Cyornis rufigastra*), saltwater crocodile (*Crocodylus porosus*), mangrove pit viper (*Cryptelytrops purpureornaculatus*) and mangrove snake (*Boiga dendrophila*) are among the vertebrates in Malaysia [3,4].



Figure 1. Island flying fox (*Pteropus hypomelanus*) by Shahfiz, MA.



Figure 2. Common sandpiper (*Actitis hypoleucos*) by Shahfiz, MA.



Figure 3. Saltwater crocodile (*Crocodylus porosus*) by Shahfiz, MA.

Mangroves provide critical ecosystem services to the vertebrates, their habitats as well as being their food sources. Numerous species utilise the plants to nest and nurture their young ones. According to [5], the mangrove nesting tree for Sunda pygmy woodpecker (*Yungipicus moluccensis*) is recorded as low as 2 m up in scrubby mangroves. Still, most nests are 3-18 m above ground or water. The nests can be on the underside of a dead branch. At the same time, vertebrates mutually benefit mangroves by dispersing the seeds and pollinating the plants through flying foxes, bats, and birds.

Figure 4. Sunda pygmy woodpecker (*Yungipicus moluccensis*) and its nest by Shahfiz, MA.



Figure 5. White-bellied sea eagle (*Haliaeetus leucogaster*) and its nest by Shahfiz, MA.

2. Assessments of Vertebrates in Peninsular Malaysia

Numerous studies have been conducted on avifauna in mangroves in Peninsular Malaysia. [6] recorded 47 species of birds in four mangrove forest sites in Selangor. MNS [7] recorded 116 species from 40 families of birds in Bagan Datuk, Perak. Nur-Syuhada et al. [8] mentioned 38 species from 23 bird families in her study of mangroves in Tumpat, Kelantan.

Lim et al. [9] documented 158 species from three taxa (mammals, birds, and herpetofauna). Of these, there were 15 mammals, 119 species of birds and 19 species of herpetofauna at Sepang Mangrove Forest Reserve in Negeri Sembilan. Pillai [10] listed 26 species of mammals, 55 species of birds, seven species of amphibians, and 12 species of reptiles from Sungai Pulai Mangroves in Johor. Talib et al. [11] recorded three amphibian species and eight reptiles at Delta Tumpat Mangrove Forest in Kelantan.

2.1 Presence of Vertebrates in Matang Mangrove Forest, Perak

The Forestry Department of Peninsular Malaysia published *Sustainable Management of Matang Mangroves: 100 years and Beyond* in 2005. This book contained three chapters related to terrestrial vertebrates found in Matang Mangroves. Noramly [12] reported 61 species of resident and migratory birds; Abdul [13] mentioned 162 species of birds with 114 resident birds and 48 migratory species, 28 species of mammals, and seven species of reptiles; Shahrul-Anuar et al. [14] listed 17 species of mammals including two species of otters and seven species of reptiles. Yeap et al. [15] recorded 24 species of waterbirds in Matang mangrove forest.

Report on Status Overview and Recommendations for the Conservation of Milky Stork (*Mycteria cinerea*) in Malaysia was published in 2006 [16]. In this document, the northwest coast of Perak, particularly the Matang mangrove, has been the species' stronghold despite being recorded to be seen down to the west coast south of Johor [5]. In the 1980s, 100-150 individuals of this bird were found in Pulau Kelumpang and Pulau Terong. Not only for the milky stork populations, these two areas were globally significant for other waterbirds such as Lesser adjutant (*Leptoptilos javanicus*) and other migratory shorebirds ranging from 18,500 to 31,500 waterbirds recorded from 1989 to 1992 annually.

Despite attempts by the department to breed the Milky stork at Matang in the late 1980s and early 1990s, the monitoring conducted in the following decade was sporadic and focused only on Pulau Kelumpang. It was found that there was a massive decline (more than 90%) of the population over the last 20 years. There has not been an assessment on the species population at Pulau Terong since 1986 although it is generally perceived to have declined.

Thus, a joint survey was conducted from August 2004 to January 2006 to gain a better understanding of the current population status, assess ecological change in the main habitats, threats to the species, and evaluate their conservation needs. The survey was carried out both on foot and using boats, and an aerial survey was conducted using Cessna 172. A total of eight points were established covering Pulau Kelumpang and Pulau Terong. Based on this survey, it is confirmed that the population is declining severely. There were only 10 individuals in 2004; the highest count was eight birds in 2005, and only four in 2006.

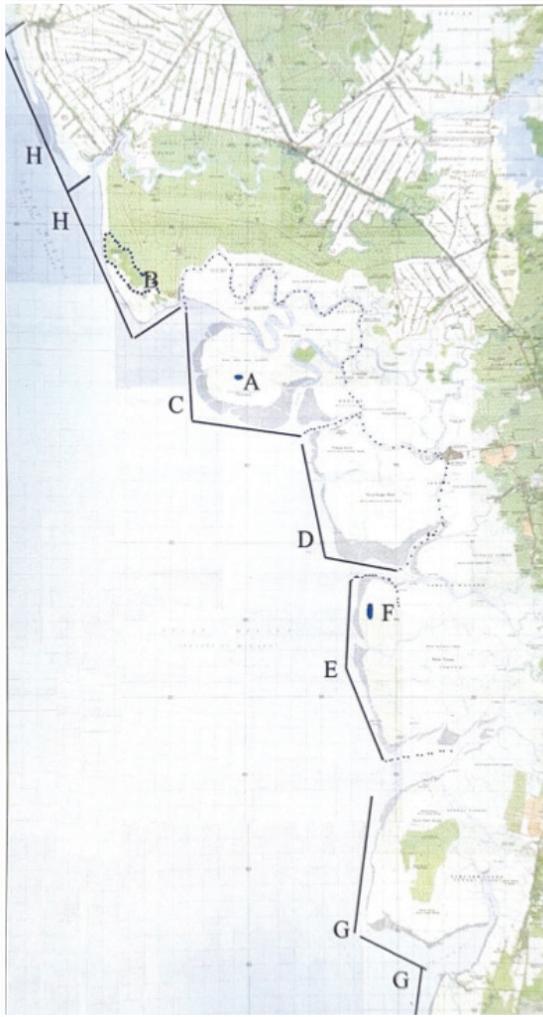


Figure 6. Survey areas in the Matang Mangrove Forest and adjacent coastal areas (Source: Wetlands and DWNP, 2006).

Note: A- Pulau Kelumpang Lake; B – Inter-tidal mudflats at Bang Zhu kao, Kuala Gula; C- Coastal zone and rivers surrounding Pulau Kelumpang; D – Coastal zone and rivers surrounding Pulau Sangga Kechil & Besar; E – Coastal Zone and rivers surrounding Pulau Terong; F – Pulau Terong Lake; G – Pulau Pasir Hitam & South Sg Kerang Coast; and H – Kuala Gula – Kuala Kurau – Tg Piandang coast.

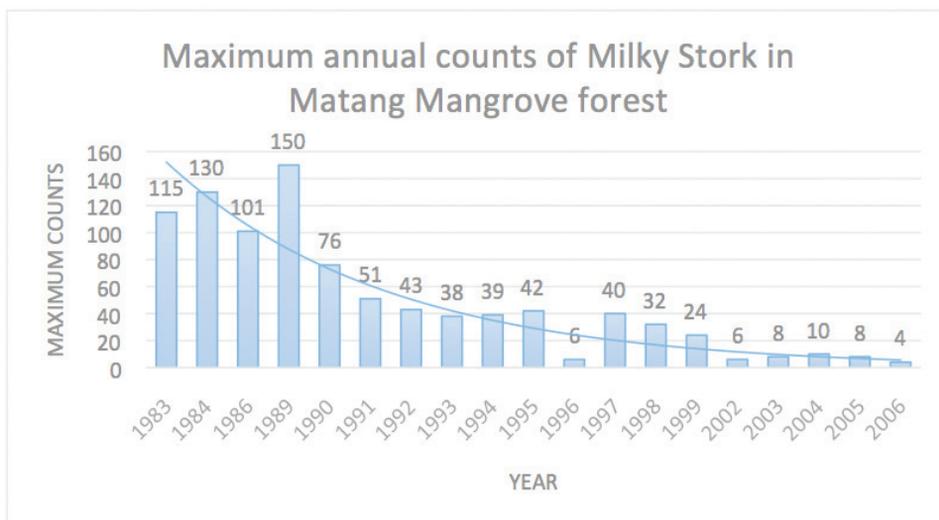


Figure 7. Maximum annual counts of Milky Stork in Matang Mangrove forest from 1983 to 2006 [16].

In summary, although several attempts to breed Milky stork have been recorded at Pulau Kelumpang in 1989, 1990, and 1997, as well as in Kuala Selangor Nature Park in 2003, the success has likely been zero. No juvenile or immature birds have been observed since 1983. The drastic decline is attributed to the erosion cycle along the Matang coastline, resulting in lower densities of benthic bivalves, gastropods and polychaete worm that serve as important waterbird and marine fish prey organisms. On the other hand, populations of egrets and Lesser adjutants appear to have remained stable.

According to Faiq et al. [17], a release programme of captive-bred Milky Storks was initiated in Kuala Gula Bird Sanctuary in 2007 where the team monitored nine survivors out of 40 individuals. The survival rate of the released species was low (22.5%) due to predation, starvation and competition. Risk of being exposed to predator attack was higher among the males since they have larger home range thus, lowering their survival rate and leading to an imbalanced sex ratio.

Azimah [18] conducted a study to identify environmental habitat requirements by migratory birds (Scolopacidae and Charadriidae) in Matang Forest Reserve, Perak, using environmental modelling. Environmental modelling includes information about land use, land cover, and food sources influencing migratory birds' distribution in habitat selection. As a result, areas nearer to the cliffs are the hotspots for migratory birds. This is due to the highest food sources available, including small prawns, fishes, insects, worms, mollusc and grains. These areas are Kuala Gula, Pulau Kelumpang, Pulau Selinsing, and parts of Pulau Sangga Kecil, with at least 1,445 birds within 50 m². However, areas in Sungai Bahru, Sungai Sepetang, Trong, Temerlok, and Sungai Tinggi show the lowest density of migratory birds with 25 individuals per 50 m² due to fewer food sources available as well as being closer to the land.

2.2 Assessment of selected vertebrates at mangroves in Jebong Forest Reserve and Bagan Datuk, Perak

2.2.1 Matang Eco-education Centre in Jebong Forest Reserve, Perak

Matang Mangrove Forest is one of the largest mangrove forests starting at Kuala Gula in the north to Bagan Panchor in the south [12]. Jebong Forest Reserve is a part of Matang Mangrove Forest. Matang Eco-Education Centre, Kuala Sepetang is one of the main attractions of Jebong Forest Reserve that exhibit a true mangrove ecosystem. Visitors can experience a mangrove ecosystem when walking on the plank in this centre. However, not much information has been documented, especially on vertebrates.

Observations and trappings were carried out on non-volant mammals, birds, reptiles and amphibians at this centre between 2021 and 2022. The main objective is to document the vertebrates, especially mammal reptiles and amphibians in this area. Therefore, the efforts was focused to update information related to other vertebrate taxa. A total of 50 cage traps, 50 Sherman traps, 10 mist nets and three harp traps were set. As a result, eight species from six families of mammals, were trapped.

Table 1. Checklist of mammals at Matang Eco-Education Centre.

No.	Family	Common Name	Scientific Name
1	Cercopithecidae	Long-Tailed Macaque	<i>Macaca fascicularis</i>
2	Cercopithecidae	Silvered Langur	<i>Trachypithecus cristatus</i>
3	Muridae	House Rat	<i>Rattus rattus</i>
4	Muridae	Malaysian Field Rat	<i>Rattus tiomanicus</i>
5	Pteropodidae	Long-Tongue Nectar Bat	<i>Macroglossus minimus</i>
6	Rhinolophidae	Trefoil Horseshoe Bat	<i>Rhinolophus trifoliatus</i>
7	Sciuridae	Plantain Squirrel	<i>Callosciurus notatus</i>
8	Tupaiaidae	Common Treeshrew	<i>Tupaia glis</i>

Table 2. Checklist of Birds at Matang.

No.	Family	Common Name	Scientific Name
1	Acanthizidae	Golden-bellied Gerygone	<i>Gerygone sulphurea</i>
2	Accipitridae	Crested Serpent-Eagle	<i>Spilornis cheela</i>
3	Accipitridae	Crested Goshawk	<i>Accipiter trivirgatus</i>
4	Accipitridae	Chinese Sparrowhawk	<i>Accipiter soloensis</i>
5	Accipitridae	White-bellied Sea Eagle	<i>Haliaeetus leucogaster</i>
6	Aegithinidae	Green Iora	<i>Aegithina viridissima</i>
7	Alcedinidae	Blue-eared Kingfisher	<i>Alcedo meninting</i>
8	Alcedinidae	Collared Kingfisher	<i>Todiramphus chloris</i>
9	Ardeidae	Great Egret	<i>Ardea alba</i>
10	Ardeidae	Little Egret	<i>Egretta garzetta</i>
11	Ardeidae	Striated Heron	<i>Butorides striata</i>
12	Bucerotidae	Oriental Pied-Hornbill	<i>Anthracoceros albirostris</i>
13	Campephagidae	Kentish Plover/ Pied Triller	<i>Lalage nigra</i>
14	Cisticolidae	Common Tailorbird	<i>Orthotomus sutorius</i>
15	Cisticolidae	Ashy Tailorbird	<i>Orthotomus ruficeps</i>
16	Columbidae	Pink-necked Green-pigeon	<i>Treron vernans</i>

No.	Family	Common Name	Scientific Name
17	Cuculidae	Chestnut-winged Cuckoo	<i>Clamator coromandus</i>
18	Cuculidae	Chestnut-bellied Malkoha	<i>Phaenicophaeus sumatranus</i>
19	Cuculidae	Lesser Coucal	<i>Centropus bengalensis</i>
20	Dicruridae	Black Drongo	<i>Dicrurus macrocercus</i>
21	Dicruridae	Bronzed Drongo	<i>Dicrurus aeneus</i>
22	Hirundinidae	House swallow	<i>Hirundo javanica</i>
23	Muscicapidae	Asian Brown Flycatcher	<i>Muscicapa dauurica</i>
24	Muscicapidae	Mangrove Blue-Flycatcher	<i>Cyornis rufigastra</i>
25	Nectariniidae	Ruby-cheeked Sunbird	<i>Chalcoparia singalensis</i>
26	Nectariniidae	Copper-throated Sunbird	<i>Leptocoma calcostetha</i>
27	Nectariniidae	Little Spiderhunter	<i>Arachnothera longirostra</i>
28	Oriolidae	Black-naped Oriole	<i>Oriolus chinensis</i>
29	Pachycephalidae	Mangrove Whistler	<i>Pachycephala cinerea</i>
30	Pellorneidae	Short-tailed Babbler	<i>Trichastoma malaccense</i>
31	Pellorneidae	White-chested Babbler	<i>Trichastoma rostratum</i>
32	Phylloscopidae	Two-barred Warbler	<i>Phylloscopus plumbeitarsus</i>
33	Picidae	Sunda Woodpecker/ Sunda Pygmy Woodpecker	<i>Dendrocopos moluccensis/</i> <i>Yungipicus moluccensis</i>
34	Picidae	Banded Woodpecker	<i>Chrysophlegma miniaceum</i>
35	Picidae	Streak-breasted Woodpecker	<i>Picus viridanus</i>
36	Picidae	Laced Woodpecker	<i>Picus vittatus</i>
37	Picidae	Common Flameback	<i>Dinopium javanense</i>
38	Picidae	Greater Flameback	<i>Chrysocolaptes guttacristatus</i>
39	Pycnonotidae	Olive-winged Bulbul	<i>Pycnonotus plumosus</i>
40	Pycnonotidae	Red-eyed Bulbul	<i>Pycnonotus brunneus</i>
41	Rhipiduridae	Malaysia Pied-Fantail	<i>Rhipidura javanica</i>
42	Sittidae	Velvet-fronted Nuthatch	<i>Sitta frontalis</i>
43	Strigidae	Buffy Fish-Owl	<i>Ketupa ketupu</i>
44	Sturnidae	Javan Myna	<i>Acridotheres javanicus</i>
45	Timaliidae	Pin-striped Tit-Babbler	<i>Mixornis gularis</i>

Table 3. Checklist of Herpetofauna at Matang.

No.	Family	Common Name	Scientific Name
1	Agamidae	Green crested lizard	<i>Bronchocela cristatella</i>
2	Agamidae	Forest Garden Lizard	<i>Calotes emma</i>
3	Elapidae	Banded krait	<i>Bungarus fasciatus</i>
4	Gekkonidae	common house gecko	<i>Hemidactylus frenatus</i>
5	Scincidae	East Indian brown mabuya	<i>Eutropis multifasciata</i>
6	Varanidae	common water monitor	<i>Varanus salvator</i>
7	Viperidae	Mangrove pit viper	<i>Trimeresurus purpureomaculatus</i>
8	Dicroglossidae	Asian Brackish Frog	<i>Fejervarya cancrivora</i>
9	Dicroglossidae	Asian Grass Frog	<i>Fejervarya limnocharis</i>
10	Dicroglossidae	Malayan Giant Frog	<i>Limnonectes malesianus</i>

Figure 8. Matang Education Centre by Syaridzwan, MB.



Figure 9. Velvet-fronted nuthatch (*Sitta frontalis*) by Shahfiz, MA.

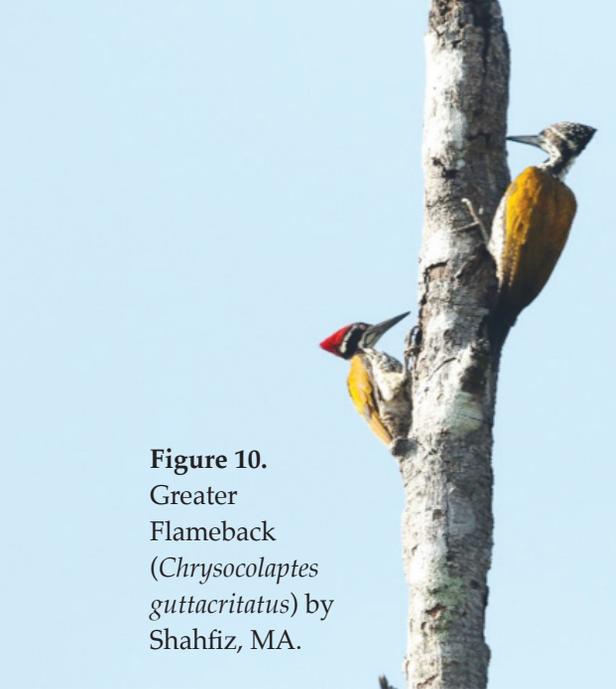


Figure 10.
Greater
Flameback
(*Chrysocolaptes
guttacritatus*) by
Shahfiz, MA.



Figure 11. Brahminy Kite
(*Haliastur indus*) by Faradiana, NMF.

2.2.2 Bagan Datuk, Perak

A team called Perak Bird Group from Malaysia Nature Society carried out a 9-month survey in Bagan Datuk, Perak. The results of the survey which took place in 2018 led to a publication of its book [19] which documented 116 species from 40 families. Later surveys were carried out on mammals, birds, reptiles and amphibians were carried out in 2019, 2021 and 2022. The NGO's main objective was document and update the list of vertebrates in Bagan Datuk, Perak. Collapsible cage traps, mist nets, harp traps, camera traps and bat detectors were used during this survey at the bund of the mangrove towards the coastline. This information is crucial to identify the potential sites for Key Biodiversity Areas in Perak.



Figure 12. Mangroves in Bagan Datuk
by Shahfiz, MA.

A total of 85 species of birds from 33 families, 25 species of mammals from 12 families and seven species from six families of herpetofauna have been identified in addition to 32 species and 5 families of birds (see the below tables). **Table 4** Checklist of Birds in Bagan Datuk Mangroves.

Table 4. Checklist of Birds at Mangroves of Bagan Datuk.

No.	Family	Common Name	Scientific Name	See & Chan 2020	Current Study
1	Phasianidae	Red Junglefowl	<i>Gallus gallus</i>	/	/
2	Columbidae	Spotted Dove	<i>Streptopelia chinensis</i>	/	
3	Columbidae	Asian Emerald Dove	<i>Chalcophaps indica</i>	/	/
4	Columbidae	Zebra Dove	<i>Geopelia striata</i>	/	/
5	Columbidae	Pink-necked Green-pigeon	<i>Treron vernans</i>	/	/
6	Columbidae	Thick-billed Green-pigeon	<i>Treron curvirostra</i>		/*
7	Columbidae	Pied Imperial-pigeon	<i>Ducula bicolor</i>	/	
8	Cuculidae	Greater Coucal	<i>Centropus sinensis</i>	/	/
9	Cuculidae	Chestnut-breasted Malkoha	<i>Phaenicophaeus curvirostris</i>		/*
10	Cuculidae	Chestnut-bellied Malkoha	<i>Phaenicophaeus sumatranus</i>		/*
11	Cuculidae	Green-bellied Malkoha	<i>Phaenicophaeus tristis</i>	/	
12	Cuculidae	Chestnut-winged Cuckoo	<i>Clamator coromandus</i>		/*
13	Cuculidae	Horsfield's Bronze-cuckoo	<i>Chrysococcyx basalis</i>	/	
14	Cuculidae	Little Bronze-cuckoo	<i>Chrysococcyx minutillus</i>	/	
15	Caprimulgidae	Large-tailed Nightjar	<i>Caprimulgus macrurus</i>	/	
16	Apodidae	Germain's Swiftlet	<i>Aerodramus germani</i>	/	
17	Rallidae	White-breasted Waterhen	<i>Amaurornis phoenicurus</i>	/	/
18	Charadriidae	Pacific Golden-plover	<i>Pluvialis fulva</i>	/	
19	Charadriidae	Red-wattled Lapwing	<i>Vanellus indicus</i>	/	
20	Charadriidae	Lesser Sand-plover	<i>Charadrius mongolus</i>	/	
21	Charadriidae	Greater Sand-plover	<i>Charadrius leschenaultii</i>	/	
22	Charadriidae	Kentish Plover	<i>Charadrius alexandrinus</i>	/	
23	Charadriidae	Black-bellied Plover	<i>Pluvialis squatarola</i>	/	

No.	Family	Common Name	Scientific Name	See & Chan 2020	Current Study
24	Charadriidae	White-faced Plover	<i>Charadrius alexandrinus dealbatus</i>	/	
25	Scolopacidae	Whimbrel	<i>Numenius phaeopus</i>	/	
26	Scolopacidae	Eurasian Curlew	<i>Numenius arquata</i>	/	
27	Scolopacidae	Bar-tailed Godwit	<i>Limosa lapponica</i>	/	
28	Scolopacidae	Black-tailed Godwit	<i>Limosa limosa</i>	/	
29	Scolopacidae	Ruddy Turnstone	<i>Arenaria interpres</i>	/	
30	Scolopacidae	Great Knot	<i>Calidris tenuirostris</i>	/	
31	Scolopacidae	Broad-billed Sandpiper	<i>Calidris falcinellus</i>	/	
32	Scolopacidae	Curlew Sandpiper	<i>Calidris ferruginea</i>	/	
33	Scolopacidae	Red-necked Stint	<i>Calidris ruficollis</i>	/	
34	Scolopacidae	Little Stint	<i>Calidris minuta</i>	/	
35	Scolopacidae	Asian Dowitcher	<i>Limnodromus semipalmatus</i>	/	
36	Scolopacidae	Terek Sandpiper	<i>Xenus cinereus</i>	/	
37	Scolopacidae	Common Sandpiper	<i>Actitis hypoleucos</i>	/	/
38	Scolopacidae	Common Greenshank	<i>Tringa nebularia</i>	/	
39	Scolopacidae	Nordmann's Greenshank	<i>Tringa guttifer</i>	/	
40	Scolopacidae	Common Redshank	<i>Tringa totanus</i>	/	
41	Glareolidae	Oriental Pratincole	<i>Glareola maldivarum</i>	/	
42	Laridae	Little Tern	<i>Sternula albifrons</i>	/	
43	Laridae	Gull-billed Tern	<i>Gelocheidon nilotica</i>	/	
44	Laridae	White-winged Tern	<i>Chlidonias leucopterus</i>	/	
45	Laridae	Whiskered Tern	<i>Chlidonias hybrida</i>	/	
46	Laridae	Common Tern	<i>Sterna hirundo</i>	/	
47	Laridae	Great Crested Tern	<i>Thalasseus bergii</i>	/	
48	Laridae	Lesser Crested Tern	<i>Thalasseus bengalensis</i>	/	
49	Ciconiidae	Lesser Adjutant	<i>Leptoptilos javanicus</i>	/	
50	Ardeidae	Cinnamon Bittern	<i>Ixobrychus cinnamomeus</i>		/*
51	Ardeidae	Grey Heron	<i>Ardea cinerea</i>	/	
52	Ardeidae	Purple Heron	<i>Ardea purpurea</i>	/	/
53	Ardeidae	Great Egret	<i>Ardea alba</i>	/	
54	Ardeidae	Intermediate Egret	<i>Ardea intermedia</i>	/	/
55	Ardeidae	Chinese Egret	<i>Egretta eulophotes</i>	/	

No.	Family	Common Name	Scientific Name	See & Chan 2020	Current Study
56	Ardeidae	Little Egret	<i>Egretta garzetta</i>	/	/
57	Ardeidae	Cattle Egret	<i>Bubulcus ibis</i>	/	
58	Ardeidae	Javan Pond-heron	<i>Ardeola speciosa</i>	/	
59	Ardeidae	Striated Heron	<i>Butorides striata</i>	/	
60	Ardeidae	Black-crowned Night-heron	<i>Nycticorax nycticorax</i>	/	/
61	Elanidae	Black-winged Kite	<i>Elanus caeruleus</i>	/	/
62	Accipitridae	Black Baza	<i>Aviceda leuphotes</i>	/	
63	Accipitridae	Crested Serpent-eagle	<i>Spilornis cheela</i>	/	/
64	Accipitridae	Changeable Hawk-eagle	<i>Nisaetus cirrhatu</i>	/	
65	Accipitridae	Crested Goshawk	<i>Accipiter trivirgatus</i>	/	
66	Accipitridae	Chinese Sparrowhawk	<i>Accipiter soloensis</i>		/*
67	Accipitridae	Brahminy Kite	<i>Haliastur indus</i>	/	/
68	Accipitridae	White-bellied Sea-eagle	<i>Haliaeetus leucogaster</i>	/	/
69	Stringidae	Oriental Scops-owl	<i>Otus sunia</i>		/*
70	Stringidae	Buffy Fish-owl	<i>Ketupa ketupu</i>		/*
71	Stringidae	Spotted Wood-owl	<i>Strix seloputo</i>	/	/
72	Bucerotidae	Oriental Pied-hornbill	<i>Anthracoceros albirostris</i>		/*
73	Alcedinidae	Common Kingfisher	<i>Alcedo atthis</i>	/	/
74	Alcedinidae	Blue-banded Kingfisher	<i>Alcedo peninsulae</i>		/*
75	Alcedinidae	Black-backed Dwarf- kingfisher	<i>Ceyx erithaca</i>		/*
76	Alcedinidae	Stork-billed Kingfisher	<i>Pelargopsis capensis</i>	/	/
77	Alcedinidae	Ruddy Kingfisher	<i>Halcyon coromanda</i>		/*
78	Alcedinidae	White-throated Kingfisher	<i>Halcyon smyrnensis</i>	/	/
79	Alcedinidae	Black-capped Kingfisher	<i>Halcyon pileata</i>	/	
80	Alcedinidae	Collared Kingfisher	<i>Todiramphus chloris</i>	/	/
81	Meropidae	Blue-throated Bee-eater	<i>Merops viridis</i>	/	/
82	Meropidae	Blue-tailed Bee-eater	<i>Merops philippinus</i>	/	/
83	Coraciidae	Dollarbird	<i>Eurystomus orientalis</i>	/	/
84	Picidae	Sunda Woodpecker	<i>Yungipicus moluccensis</i>	/	/
85	Picidae	Greater Flameback	<i>Chrysocolaptes guttacristatus</i>	/	/
86	Picidae	Common Flameback	<i>Dinopium javanense</i>	/	/
87	Picidae	Streak-breasted Woodpecker	<i>Picus viridanus</i>		/*

No.	Family	Common Name	Scientific Name	See & Chan 2020	Current Study
88	Picidae	Laced Woodpecker	<i>Picus vittatus</i>	/	/
89	Falconidae	Black-thighed Falconet	<i>Microhierax fringillarius</i>	/	
90	Pittidae	Blue-winged Pitta	<i>Pitta moluccensis</i>		/*
91	Acanthizidae	Golden-bellied Gerygone	<i>Gerygone sulphurea</i>	/	
92	Campephagidae	Pied Triller	<i>Lalage nigra</i>	/	
93	Oriolidae	Black-naped Oriole	<i>Oriolus chinensis</i>	/	
94	Artamidae	White-breasted Woodswallow	<i>Artamus leucorhynchus</i>	/	
95	Aegithinidae	Common Iora	<i>Aegithina tiphia</i>	/	/
96	Aegithinidae	Green iora	<i>Aegithina viridissima</i>		/*
97	Rhipiduridae	Malaysian Pied-fantail	<i>Rhipidura javanica</i>	/	/
98	Dicruridae	Ashy Drongo	<i>Dicrurus leucophaeus</i>	/	
99	Dicruridae	Crow-billed Drongo	<i>Dicrurus annectens</i>		/*
100	Dicruridae	Bronzed Drongo	<i>Dicrurus aeneus</i>		/*
101	Dicruridae	Greater Racket-tailed Drongo	<i>Dicrurus paradiseus</i>		/*
102	Laniidae	Tiger Shrike	<i>Lanius tigrinus</i>	/	/
103	Laniidae	Brown Shrike	<i>Lanius cristatus</i>	/	
104	Corvidae	House Crow	<i>Corvus splendens</i>	/	/
105	Corvidae	Large-billed Crow	<i>Corvus macrorhynchos</i>	/	
106	Stenostiridae	Grey-headed Canary- flycatcher	<i>Culicicapa ceylonensis</i>		/*
107	Paridae	Cinereous Tit	<i>Parus cinereus</i>	/	/
108	Cisticolidae	Common Tailorbird	<i>Orthotomus sutorius</i>	/	/
109	Cisticolidae	Ashy Tailorbird	<i>Orthotomus ruficeps</i>	/	/
110	Cisticolidae	Rufous-tailed Tailorbird	<i>Orthotomus sericeus</i>		/*
111	Cisticolidae	Rufescent Prinia	<i>Prinia rufescens</i>	/	
112	Cisticolidae	Yellow-bellied Prinia	<i>Prinia flaviventris</i>	/	/
113	Cisticolidae	Zitting Cisticola	<i>Cisticola juncidis</i>		/*
114	Hirundinidae	Barn Swallow	<i>Hirundo rustica</i>	/	/
115	Hirundinidae	Pacific Swallow	<i>Hirundo tahitica</i>	/	/
116	Pycnonotidae	Yellow-vented Bulbul	<i>Pycnonotus goiavier</i>	/	/
117	Pycnonotidae	Olive-winged Bulbul	<i>Pycnonotus plumosus</i>	/	/
118	Pycnonotidae	Rey-eyed Bulbul	<i>Pycnonotus brunneus</i>		/*
119	Pycnonotidae	Ochraceous Bulbul	<i>Alophoixus ochraceus</i>		/*

No.	Family	Common Name	Scientific Name	See & Chan 2020	Current Study
120	Zosteropidae	Swinhoe's White-eye	<i>Zosterops simplex</i>	/	/
121	Pellorneidae	Grey-breasted Babbler	<i>Malacopteron albogulare</i>		/*
122	Pellorneidae	Short-tailed Babbler	<i>Pellorneum malaccense</i>		/*
123	Pellorneidae	Abbott's Babbler	<i>Turdinus abboti</i>	/	/
124	Pellorneidae	Horsfield's Babbler	<i>Turdinus sepiarius</i>		/*
125	Sturnidae	Asian Glossy Starling	<i>Aplonis panayensis</i>	/	/
126	Sturnidae	Common Hill Myna	<i>Gracula religiosa</i>	/	
127	Sturnidae	Common Myna	<i>Acridotheres tristis</i>	/	/
128	Sturnidae	Jungle Myna	<i>Acridotheres fuscus</i>		/*
129	Sturnidae	Javan Myna	<i>Acridotheres javanicus</i>	/	/
130	Muscicapidae	Dark-sided Flycatcher	<i>Muscicapa sibirica</i>	/	
131	Muscicapidae	Asian Brown Flycatcher	<i>Muscicapa dauurica</i>	/	/
132	Muscicapidae	Oriental Magpie-robin	<i>Copsychus saularis</i>	/	/
133	Muscicapidae	White-rumped Shama	<i>Copsychus malabaricus</i>		/*
134	Muscicapidae	Mangrove Blue Flycatcher	<i>Cyornis rufigastra</i>	/	/
135	Muscicapidae	Korean Flycatcher	<i>Ficedula zanthopygia</i>	/	
136	Dicaeidae	Crimson-breasted Flowerpecker	<i>Prionochilus percussus</i>		/*
137	Nectariniidae	Brown-throated Sunbird	<i>Anthreptes malacensis</i>	/	/
138	Nectariniidae	Copper-throated Sunbird	<i>Leptocoma calcostetha</i>	/	/
139	Nectariniidae	Olive-backed Sunbird	<i>Cinnyris jugularis</i>	/	
140	Nectariniidae	Little Spiderhunter	<i>Arachnothera longirostra</i>		/*
141	Ploceidae	Baya Weaver	<i>Ploceus philippinus</i>	/	
142	Estrildidae	Pin-tailed Parrotfinch	<i>Erythrura prasina</i>		/*
143	Estrildidae	White-rumped Munia	<i>Lonchura striata</i>	/	
144	Estrildidae	Scaly-breasted Munia	<i>Lonchura punctulata</i>	/	/
145	Estrildidae	Chestnut Munia	<i>Lonchura atricapilla</i>	/	/
146	Estrildidae	White-headed Munia	<i>Lonchura maja</i>	/	/
147	Passeridae	Eurasian Tree Sparrow	<i>Passer montanus</i>	/	
148	Motacilidae	Eastern Yellow Wagtail	<i>Motacilla tschutschensis</i>		/*

* - additional species

Table 5. Checklist of mammals at Mangroves in Bagan Datuk.

No.	Family	Scientific Name	Common Name
1	Cercopithecidae	<i>Trachypithecus cristatus</i>	Silvery Lutung
2	Cercopithecidae	<i>Macaca fascicularis</i>	Long-tailed Macaque
3	Felidae	<i>Prionailurus bengalensis</i>	Leopard Cat
4	Pteropodidae	<i>Macroglossus minimus</i>	Dagger-toothed Long-nosed Fruit Bat
5	Pteropodidae	<i>Eonycteris spelaea</i>	Common Nectar Bat
6	Pteropodidae	<i>Cynopterus brachyotis</i>	Short-nosed fruit bat
7	Pteropodidae	<i>Macroglossus sobrinus</i>	Hill Long-tongued Fruit Bat
8	Rhinolophidae	<i>Rhinolophus trifoliatus</i>	Trefoil Horseshoe Bat
9	Megadermatidae	<i>Megaderma spasma</i>	Lesser False Vampire
10	Vespertilionidae	<i>Myotis hasseltii</i>	Lesser Large-footed Myotis
11	Vespertilionidae	<i>Pipistrellus javanicus</i>	Javan Pipistrelle
12	Vespertilionidae	<i>Kerivoula hardwickii</i>	Common Woolly Bat
13	Vespertilionidae	<i>Kerivoula papillosa</i>	Papillose Woolly Bat
14	Vespertilionidae	<i>Myotis horsfieldii</i>	Lesser Large-tooth Bat
15	Vespertilionidae	<i>Pipistrellus tenuis</i>	Least Pipistrelle
16	Vespertilionidae	<i>Pipistrellus stenopterus</i>	Narrow-winged pipistrelle
17	Vespertilionidae	<i>Philetor brachypterus</i>	Short-winged Pipistrelle
18	Muridae	<i>Rattus tiomanicus</i>	Malaysian Field Rat
19	Muridae	<i>Rattus rattus</i>	House rat
20	Mustelidae	<i>Aonyx cinereus</i>	Asian Small-clawed Otter
21	Sciuridae	<i>Callosciurus notatus</i>	Plantain Squirrel
22	Suidae	<i>Sus scrofa</i>	Wild Boar
23	Tupaiaidae	<i>Tupaia glis</i>	Common Tree Shrew
24	Viverridae	<i>Arctogalidia trivirgata</i>	Small Toothed Palm Civet
25	Viverridae	<i>Paradoxurus musangus</i>	Common Palm Civet

Table 6. Checklist of herpetofauna at mangroves in Bagan Datuk.

No.	Family	Scientific Name	Common Name
1	Dicroglossidae	<i>Fejervarya cancrivora</i>	Crab-eating Frog
2	Scincidae	<i>Eutropis multifasciata</i>	Common Sun Skink
3	Agamidae	<i>Draco melanopogon</i>	Black-bearded Gliding Lizard
4	Agamidae	<i>Calotes versicolor</i>	Oriental garden lizard
5	Elapidae	<i>Bungarus fasciatus</i>	Banded Krait
6	Varanidae	<i>Varanus salvator</i>	Common Water Monitor
7	Viperidae	<i>Trimeresurus purpureomaculatus</i>	Mangrove pit viper



Figure 13. Ruddy Kingfisher
(*Halcyon coromanda*) by Shahfiz, MA.



Figure 15. Mangrove Pit Viper
(*Trimeresurus purpureomaculatus*) by Shahmirul, AS.

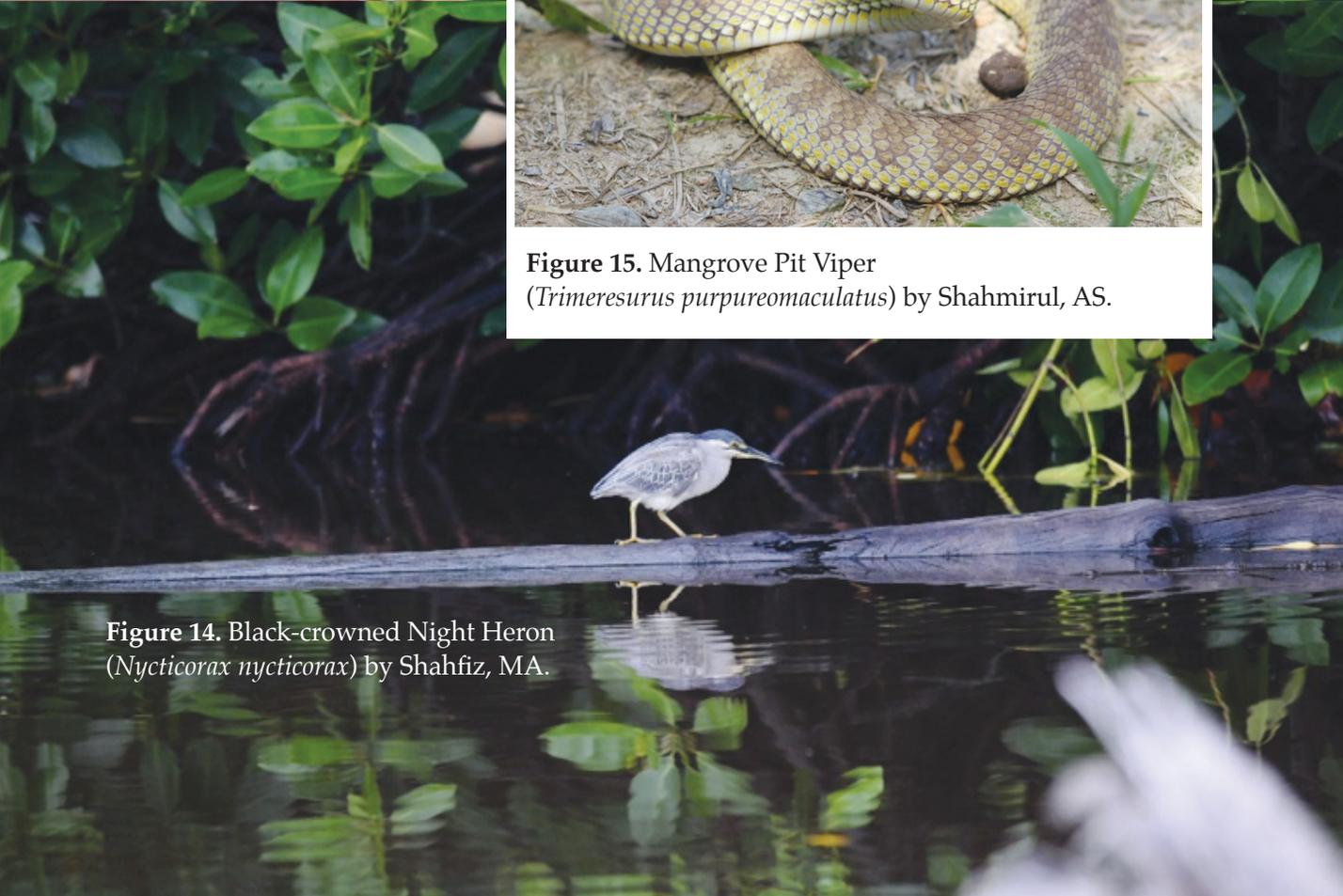


Figure 14. Black-crowned Night Heron
(*Nycticorax nycticorax*) by Shahfiz, MA.



Figure 16. Egret and Herons by Shahfiz, MA.



Figure 17. Black-shouldered kite (*Elanus caeruleus*) by Shahfiz, MA.



Figure 18. Wild Boars (*Sus scrofa*).



Figure 19. Long-tailed Macaque (*Macaca fascicularis*).

3. Conclusion and Recommendations

Numerous studies focused on Matang mangroves have indicated the Milky stork, population in the country have drastically declined, although the more recent researches show otherwise. According to Amir [20], mangroves are fragmented due to habitat loss, a direct result of land conversion for agriculture, aquaculture, and urban development. Moreover, they are affected by severe erosion, aggravated by anthropogenic disturbances and rising sea levels. Baseline information on vertebrates is scarce, and not much-standardised monitoring has been carried out for long-term studies.

Therefore, baseline information needs to be gathered, updated, and published, and where it is available, they must be monitored regularly. The dynamics of vertebrate populations are vital to model viable ecosystems supporting communities. Action plans have to be formulated and strategised. Practicality is among the keywords that must be emphasised in the action plans. Many action plans have been formulated but are complex and cannot be implemented due to certain constraints. Synergy between agencies (federal and state) must be strengthened and harmonised.

In the National Policy on Biological Diversity 2022-2030 [2], the need for ecosystem conservation was emphasised. First, Target 3 - By 2030, terrestrial and marine spatial planning fully incorporate elements of biodiversity conservation. Second, Target 8 - By 2030, at least 20% of terrestrial areas, inland waters, and 10% of coastal and marine areas are conserved through effectively managed and ecologically representative protected areas and other effective area-based conservation measures (OECMs). Globally, an initiative called Key Biodiversity Areas (KBA) defined the conservation of species, genetic and ecosystem levels beyond protected areas, supporting the national target on OECM.

Geographically there is an Important Bird and Biodiversity Area (IBA) known as Teluk Ayer Tawar Bird Area in Penang [21]. The southern part of the IBA site is known as North Selangor Coast Bird Area. Therefore, it is crucial to complete this mosaic by recognising Matang mangroves as a key biodiversity area for Bagan Datuk to emerge as a main connectivity for KBA and IBA for the country.

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Chapter 6

Unravelling the Socioeconomic Aspects of Mangrove Livelihood: A case study of selected areas in Pahang



Unravelling the Socioeconomic Aspects of Mangrove Livelihood: A case study of selected areas in Pahang

Mukrimah Abdullah*, Mohd Parid Mamat & Norliyana Adnan
Forest Research Institute Malaysia (FRIM), 52109 Kepong, Selangor

*Corresponding author: mukrimah@frim.gov.my

1. Introduction

Malaysia's coastline is estimated to be 4,810 km, extending across the West Coast and East Coast of Peninsular Malaysia, as well as Sabah and Sarawak [1]. The Malaysian coastline features diverse ecosystems, including the mangrove forest ecosystem. Mangrove forests are among the most important types of forest in Malaysia, accounting for 3.7% of global coverage of mangrove forests [2]. Mangroves play a crucial role in sustaining the well-being and prosperity of local communities through their multifaceted benefits.

Mangrove forests act as frontiers that protect the coastal land and act as buffer zones against strong winds and coastal erosion, safeguarding coastal communities and economies [3]. Mangroves also serve as corridors for biological diversity enriching coastal resources, provide habitat for various marine life, function as natural filter that improves the quality of water and also play an important role as carbon sink in coastal environment [4]. Mangroves store significant amounts of carbon, contributing to climate change mitigation efforts and potentially offering economic opportunities through carbon trading or payment for ecosystem services programmes [5]. The mangrove ecosystem also serves as a spawning and nursery ground for various species of shrimp and fish which will enhance the resilience of local fisheries. Therefore, mangrove forests are among the most naturally fertile and productive area as it serves as nesting and feeding ground for biodiversity [6].

Mangrove resources also contribute to the socio-economic development of the country, especially the surrounding community (who live near the mangrove forest ecosystem and benefit from it)[7,8]. This is because mangroves are a fertile breeding ground for mud crab, variety of shrimp species, gastropods and also cockles. This forms an ecosystem that serves as a crucial food and economic source benefitting the surrounding community. Additionally, it improves the environmental quality and aesthetic value as tourist attractions. Mangroves are one of the potential sites for sustainable tourism development that can produce tourism-based communities [9,10]. Mangroves attract tourists interested in ecotourism and recreational activities, such as birdwatching,

kayaking, and nature trails, providing opportunities for local businesses to thrive which also benefits the local government.

Therefore, maintaining and conserving mangrove ecosystem is crucial not only for the mangroves but also for well-being and livelihood of local community. This chapter will unravel the socio economics of mangroves livelihood, focusing on two areas, namely Sungai Kuantan Mangroves and Delta Kelantan Mangrove.



Figure 1. Fishing activity at mangroves.

2. Sungai Kuantan Mangrove Forest: A jewel of Kuantan City

Generally, there is estimated about 1.55 million hectares of forest reserve in Pahang, in which 3,889 hectares are mangroves. They are located along the east coast of Pahang, specifically in the districts of Kuantan, Pekan and Rompin. Among these, 853 hectares of mangroves are located at Sungai Kuantan, Pahang. About 621 hectares of mangroves are located at Sungai Cherating and Sungai Ular, Gebeng. This green little pocket of Kuantan, provide various of ecosystem goods and services which contribute to the well-being and livelihood of local community in addition to serving as an ecotourism spot. The strategic location of the Sungai Kuantan Mangrove Forest, in the midst of the city centre of Kuantan, attracts both domestic and international tourists to witness its well-preserved uniqueness.

Among the activities available here are recreational fishing, boat cruises along Sungai Kuantan, firefly watching at night, boardwalk and observation tower in the 1.86-hectare mangrove forest area and visits to the fishing village. The existence of mangrove forests in Sungai Kuantan is also important as a source of income for the locals and in protecting the coast from erosion, waves, strong winds, and other factors. Among the marine life that can be found here are nipah crab, shrimp, clam, and various types of fish such as barramundi and grouper. They not only serve as a source of daily food but also as a source of income generation.

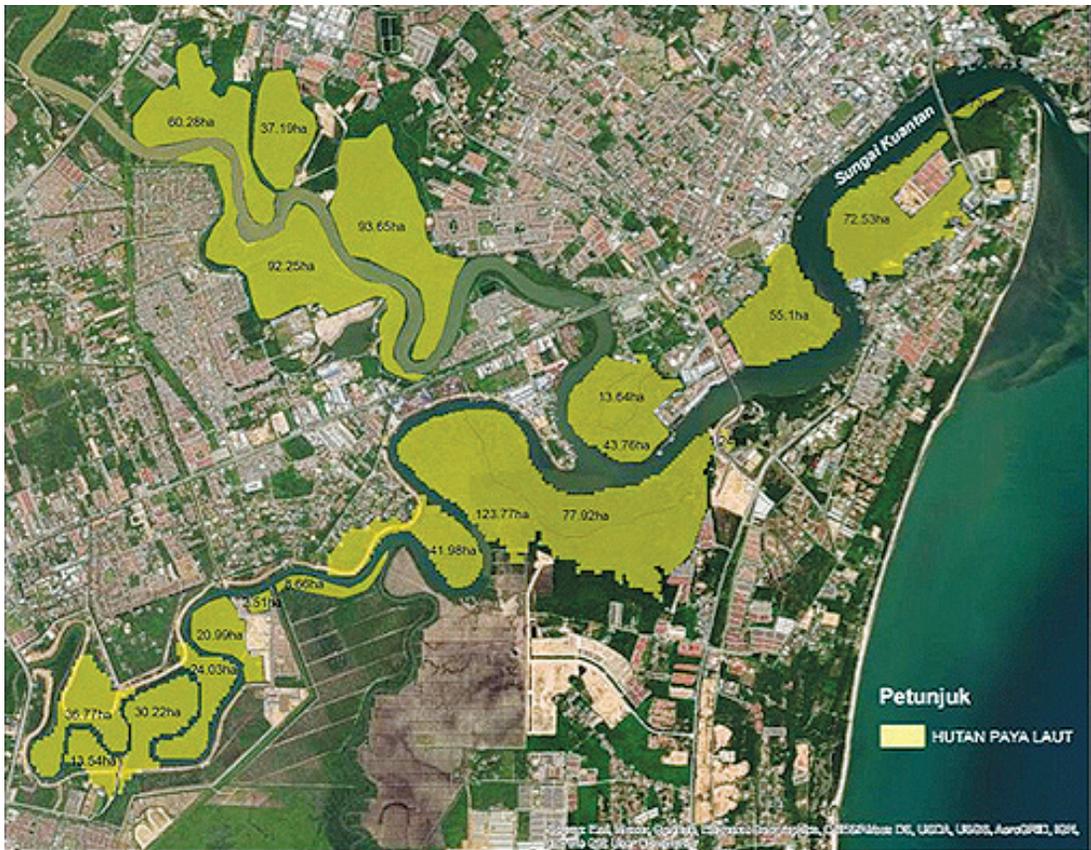


Figure 2. Distribution of Sungai Kuantan Mangroves.



Figure 3. Recreational fishing activity in mangroves.



Figure 4. Tourist attractions at Sungai Kuantan Mangroves.

2.1 Mangrove community

The community in Sungai Kuantan has a close relationship with the mangrove forest environment. The community's dependence on the products and resources of the mangrove forest and coastal areas in Kuantan is for self-sustainability to support daily life and as a leisure activity. A total of nine (9) fishing villages were selected to document socio-economic activities related to the mangroves in Sungai Kuantan (Table 1)

Table 1. Households information.

Villages	Households	Sampled Households	Percentage (%)
Kampung Anak Air	150	21	5.5
Kampung Belukar	400	70	18.2
Kampung Kempadang	150	44	11.5
Kampung Peramu	900	80	20.8
Kampung Permatang Badak	60	20	5.2
Kampung Sungai Isap	120	43	11.2
Kampung Tanah Putih	150	41	10.7
Kampung Tanjung Api	180	35	9.1
Kampung Tanjung Lumpur	80	30	7.8
Total	2,190	384	100.0

(Source: Actual survey, 2020)



Figure 5. Socio economic survey.



Figure 6. Community village jetty.



Figure 7. Fishing tools to catch crab.

Interviews were conducted with 384 households (there were 1,689 members living in the households) from 9 village; majority of the respondents, 53%, were females (Table 2). This percentage is close to the gender ratio in Malaysia, which is 53% who identify as male and the rest female (Department of Statistics Malaysia, 2023). In terms of marital status, 40% of household members were married, while the rest were single. Their average age was 29.4 years old. About 50.4% of the respondents have received education only up to the secondary school while 26.6% had primary level education. The rest had a Diploma and Degree qualification.

They were employed in the public and private sector, while some worked in the factory and as contract workers, self-employed (such as fisherman, entrepreneur, grocery stores, food and beverages business), and as farmers. Employed categories contributes the highest percentage at 34.8%, followed by self-employed and agriculture categories with 26% and 7.5% respectively.

Table 2. Demographic background.

Socio demographic information		Frequency	Percentage
Gender	Female	896	53.0
	Male	793	47.0
Marital status	Single	1014	60.0
	Married	675	40.0
Age	Mean	29.4 years old	
	<15 years old	448	26.5
	15 - 40 years old	772	45.7
	15 - 64 years old	382	22.6
	> 65 years old	87	5.2
Education	No formal education	210	12.4
	Primary school	449	26.6
	Secondary school	852	50.4
	Professional cert./Diploma	23	1.4
	University	155	9.2
Profession / Occupation /Job (n = 1046)	Employed	364	34.8
	Self-employed	272	26.0
	Agriculture	78	7.5
	Unemployed	332	31.7

2.2 Utilisation of Sungai Kuantan Mangroves

Purposes of utilisation

The study revealed that 36% of the participants utilised the mangrove forest area in Sungai Kuantan, Pahang. The purposes for which respondents use the mangrove forest area can be categorised into three: for personal consumption, for income generation (such as fishing for fishermen or selling fish locally), or simply as a leisure activity, primarily indulging in fishing. The results showed mangroves are mainly utilised for recreational fishing, followed by for own use and consumption and lastly for income generation (Table 3). This proved that the mangroves are a source of livelihood and recreation which offer good value for the local community. This finding suggested that conserving and maintaining mangroves are crucial for their benefits to the community.

Table 3. The uses of mangrove forest by local community.

Uses	N	Number of households uses mangroves area	Percentage of households uses mangroves area
For own used/ consumption	384	51	13%
For income generation, such as fisherman, local fish monger	384	38	10%
Recreational fishing during free/ leisure time	384	94	25%



Figure 8. Local community fishing at Sungai Kuantan.

Mangrove forest resources

The utilisation of mangrove forest resources by communities can vary depending on cultural, economic, and environmental factors. It is an important source of economic provision such as fishing, harvesting of non-timber forest products like fruits (such as ‘berembang’ and ‘nipah’), materials for handcraft and medicinal plants. The most common fish species harvest by the villagers are *Macrobrachium rosenbergii* (Udang galah), *Scylla serrata* (mud crab or locally known as ketam nipah), *Polymesoda expansa* (lokan), *Cerithidea obtusa* (siput sedut/ Belitung) variety of fishes, such as grouper (kerapu), sea bass (siakap), croaker (gelama) and many more.



Figure 9. Nipa palm fruits.



Figure 10. Lokan.

Table 4 shows the mangroves resources that are often harvested by locals. Among the important catch in the Kuantan River is Udang galah, which can fetch a hefty price between RM 40 and RM 90 per kilogram. It is estimated that the total catch per trip is 4 kg during the season. There are also various fish species such as grouper, sea bass and thorn fish. Most respondents stated they do not sell molluscs, such as lokan and siput Belitung which are for personal consumption and as offering to others. Therefore, it is clear mangroves offer good livelihood for the community.

Table 4. Mangroves resources.

Mangrove resources	N	Percentage of households harvest	Uses
Udang Galah	384	41%	Commercial and own use
Mud crab / ketam nipah	384	36%	Commercial and own use
Fishes	384	11%	Commercial and own use
Mollusca / seashell	384	8%	Commercial and own use
Others	384	3%	Commercial and own use

Figure 11. Among the catches in mangroves.



2.3 Community perception of Mangroves

The Likert's scale ranging from 1 (not important) to 5 (very important) was employed to assess the community ratings of the mangroves. The findings suggested that the majority agree that the preservation and conservation of mangrove forests in Sungai Kuantan are highly important as habitats for flora and fauna, as well as a heritage source and attraction for tourists engaging in recreational activities. The community disagreed that the mangrove forests in Sungai Kuantan is a source of disruption and restricting their living space as they by and large view it as a source of livelihoods – mainly farming and agriculture purposes. **Figure 12** shows the perception of community on the importance of mangroves. The majority support the conservation of the mangrove ecosystem seeing it as highly valuable and as a habitat for various species of flora and fauna, (a score of 4.68). The local community also agreed that this area is important as a natural heritage source, based on the same high score of 4.68. Additionally, the community conceded that this area is one of the attractions for tourists engaging in recreational activities, as well as serving as a buffer against strong waves and as a breeding and spawning ground for various animal species, with average scores of 4.54, 4.53, and 4.45 respectively.

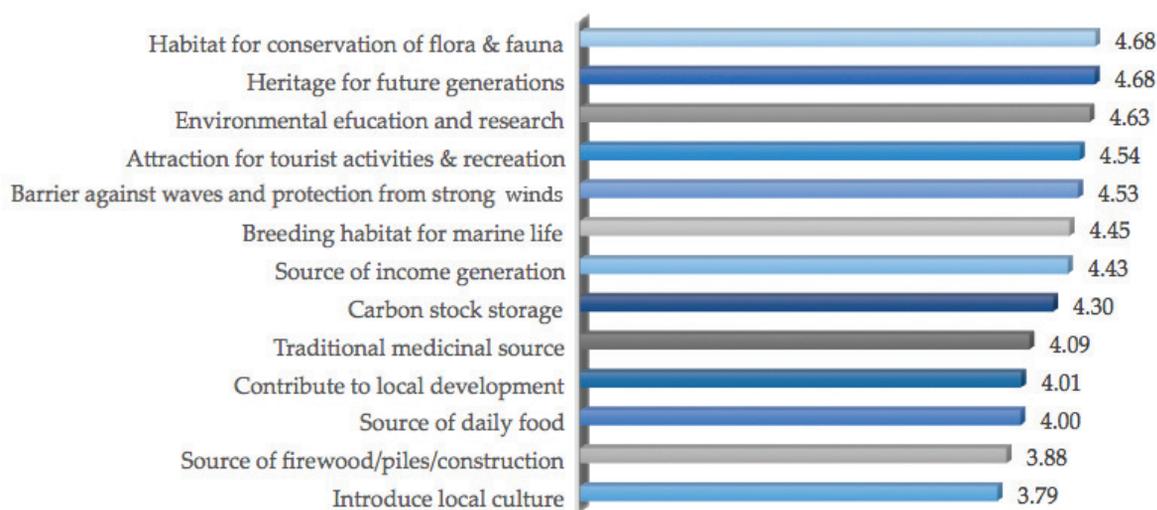


Figure 12. Perception of community on the important of mangroves.

2.4 Contribution of mangrove to livelihood

There are two types of income which are either in form of cash or in-kind. The findings revealed that the average monthly household income was RM 2,882 (Table 5), in which 92% of the household incomes within this community were in the form of cash, while the rest derived from in-kind sources.

Table 5. Households' monthly income.

Types of income	RM / month	Percentage (%)
Cash income	2,652	92
In-kind income	230	8
Average households' monthly income	2,882	100



Figure 13. View of Sungai Kuantan community jetty area.

The community derive an income by selling fresh fish and crab or processed foods, such as fish ball, dried fish (ikan kering), and shrimp paste (belacan). The results showed 31% of household income was generated from the mangroves and its related sources (Table 6). This is an important finding suggesting mangrove resources are an important source of livelihood for the community.

Table 6. Income generated from mangroves.

Average income generated from mangroves and its related sources	
Average monthly income generated	RM 862
Percentage income generated	31%

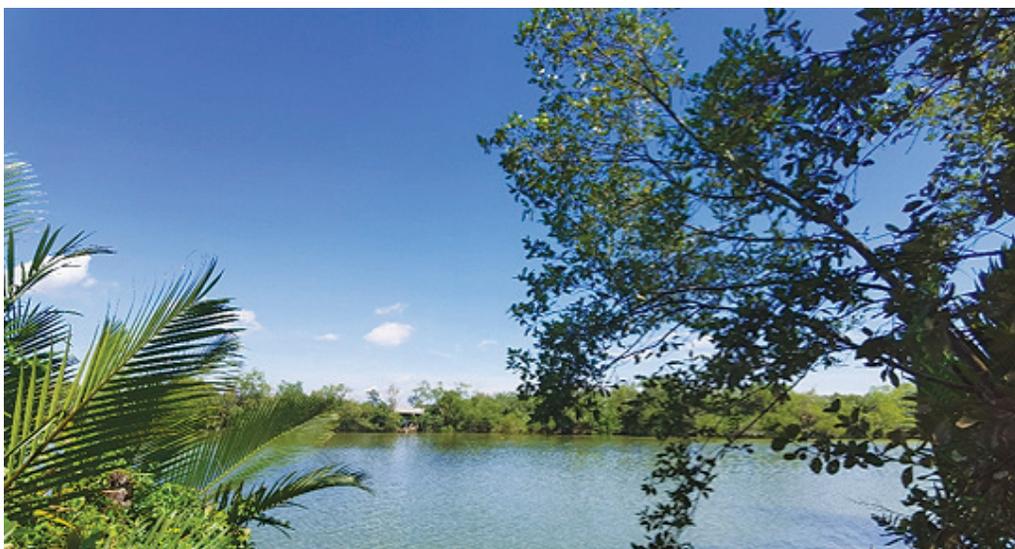


Figure 14. View of Sungai Kuantan mangroves area.

The Household Income Survey (HIS) is one of the surveys conducted by Department of Statistics Malaysia. The main objective of HIS is to measure the economic well-being of the population; collect information on the income distribution patterns of households according to various socio-economic characteristics, and provide basic data for calculating Poverty Line Income (PLI). Household income and poverty statistics are used for formulating policies and development plans, especially for poverty eradication strategies. Based on the survey conducted, a total of 180 households are below this PLI, accounting for poverty rate of 46.9%. If there is no income generated from the mangroves, the poverty rate may increase up to 52.3%.

3. Delta Kelantan Mangrove Forest: From Barren Land into Forest

Delta Kelantan Mangrove Forest (DKMF) is in Tumpat, the northern part of Kelantan. This area is part of the floodplain that covers Kuala Besar in the East until Kuala Sungai Golok (bordering Thailand) in the West. The delta area covers around 13,000 hectares covering 17 islands. The uniqueness of the area is that it is formed by sedimentation from “Red Flood” event in 1971, transforming the once barren land into its current state. In 2000, Forestry Department of Kelantan and Forestry Department of Peninsular Malaysia jointly embarked on an initiative to plant mangroves on several islands within the Kelantan Delta, including Pulau Tujuh, Pulau Kambing, Pulau Layang-Layang, Pulau Bedal, and Pulau Mas. A total of 113,969 mangrove trees were planted for the purpose of biodiversity conservation. Among the mangrove species planted were *Rhizophora mucronata* and *Rhizophora apiculata*.

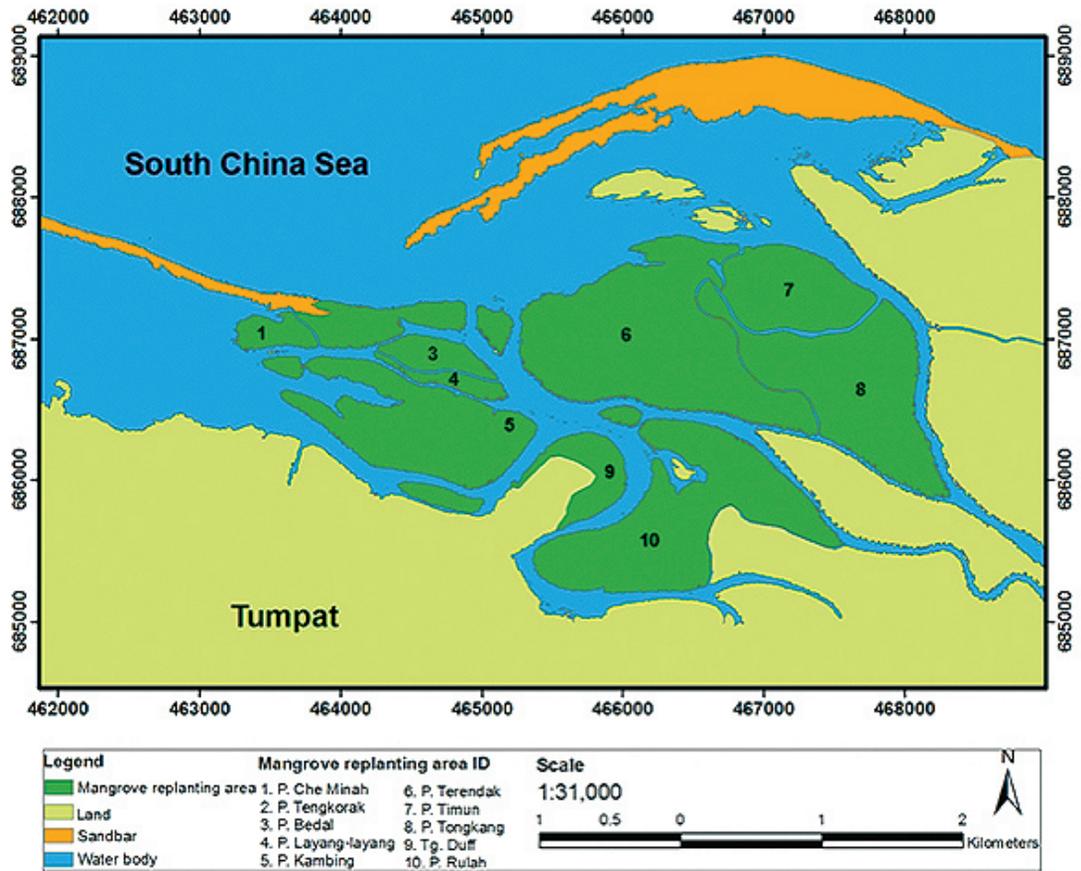


Figure 15. Mangrove replanting area at DKMF.



Figure 16. DKMF during early planting programme.

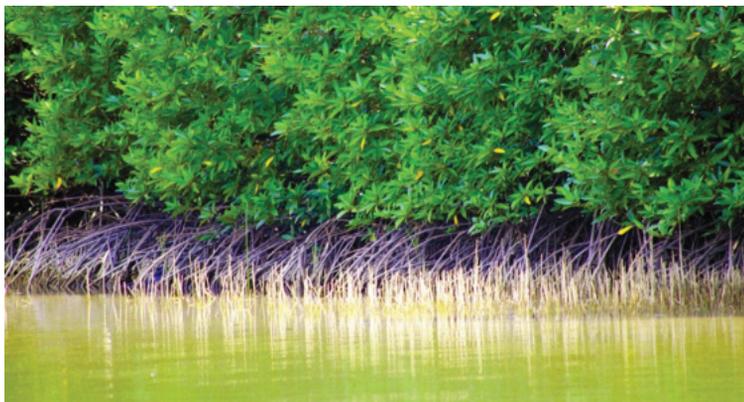


Figure 17. Current state of mangroves at DKMF.

The DKMF serves as a significant economic resource for the local population, particularly through its marine life, alongside its vital function in protecting the coastal areas from erosion, strong winds, and other environmental factors. The people in this area directly benefit from mangrove resources and coastal protection.

3.1 Demography

Two types of villages, coastal and island villages, were included in the study (Table 7). A total of 12 villages were sampled with five villages located along coastal areas and seven in the island areas. Out of the 2,379 households in the delta area, 21.1% or 501 households (an average of five family members per household) were interviewed for this research. A total of 2,327 individuals took part in the study

Table 7. Number of Households interviewed.

Villages	Name	Total household in village	Head of households interviewed	Household members
Coastal Village	Kg. Baru Nelayan	600	70	322
	Kg. Tanjung Kuala	500	81	362
	Kg. Besut	500	60	301
	Kg. Pak Jah	120	30	150
	Kg. Kelong	220	42	174
Island Village	Kg. Pulau Cendol	30	16	63
	Kg. Pulau Suri	166	58	299
	Kg. Pulau Besar	68	55	278
	Kg. Pulau Che Soh	10	8	45
	Kg. Pulau Seratus	53	23	95
	Kg. Pulau Beluru	36	22	89
	Kg. Pulau Tongkang	76	36	149
Total		2,379	501 (21.1%)	2,327

(Source: Actual survey, 2021)



Figure 18. Household survey.



Figure 19. Location of coastal and island villages involved in the household survey.

Table 8 presented the demographic background for 2,327 household members. The number of males and females were equally represented, with males accounting for 50.7%. The age range and its percentage are as follows: age 11 to 20 years old (20.7%), followed by 21 to 30 years old (16.9%), above 60 years old (13.5%), 31 to 40 years old (11.2%) and 51 to 60 years old (10.3%), 41- 50 years old (9.3%), 6 to 10 years (9%) and below 5 years old (8.9%). Those who have secondary education formed the majority (47.3%) followed by primary level education (26.2%). Higher education whereby upper secondary school (form 6) and tertiary education accounted for only 2.4% and 6.0% respectively. In term of marital status, half of the household members were single (53.8%), followed by married ones (42.1%).

Table 8. Demographic profiles.

Uses	N	Frequency	Percentage
Gender	Men	1,179	50.7
	Women	1,148	49.3
Marital status	<5 years old	208	8.9
	6 to 10 years old	210	9.0
	11 to 20 years old	481	20.7
	21 to 30 years old	394	16.9
	31 to 40 years old	260	11.2
	41 to 50 years old	219	9.4
	51 to 60 years old	240	10.3
	> 60 years old	315	13.5
Education	No formal education	419	18.0
	Primary school	610	26.2
	Secondary school	1,101	47.3
	Upper secondary school	56	2.4
	Tertiary education	140	6.0
Marital Status	Single	1,253	53.8
	Married	980	42.1
	Other (widowed)	93	4.0
	Total	2,327	100.0

(Source: Actual survey, 2021)

3.2 Utilisation of DKMF mangrove

Most of the locals, about 88% were aware on the mangrove plantation programme by Forestry Department at the DKMF. The results showed that about 47.7% who visited DKMF were attracted by its activities whereby 68.9% were interested in fishing, or to acquire mangrove produce, such as fish, crabs and clams. About 12.2% visited DKMF for recreational activities, while the rest operated boats along this route. A total 5.4% of the locals were involved in tree planting while about 1.4% were working there or visited to obtain nipah. **Table 9** shows the results on the use of DKMF.

Table 9. Visitation and activities in DKMF.

Types of activities in DKMF	
Harvest nipah palm	1.4 %
Workers	1.4 %
Boat tour	10.8 %
Fisheries including mud crab, clams	68.9 %
Recreational fishing	12.2 %
Tree planting programme	5.4 %



Figure 20. Boat for fishing activities and recreational fishing.

Mangrove forest resources

Delta Kelantan mangrove area is a rich source of marine life, such as fish, shrimp, crabs. The study found that there are two sources of seafood for local fishermen, namely the mangrove DKMF and the coastal area. In general, local communities use the DKMF area to meet their subsistence needs as well as generate income. A total of 32.5% of the households surveyed are fishermen with 28.5% being fishermen in the mangrove area and its surroundings. They carry out activities such as catching fish, crabs and shrimps. There are several types of fish caught around this area, among which the popular are croaker, mullet, catfish, sea bream and grouper. The average selling price for these fish species is between RM 9/kg to RM 26/kg. Crab is abundant in mangrove areas especially mud crabs. A total of 51 households are involved in crab catching activities. The average selling price for mud RM 50/kg based on their size. Among the shrimps found in mangrove areas are tiger shrimp, white shrimp and lobster. The selling price for this is between RM 15/kg and RM 65/kg. Due to its high prices, shrimp catching is more popular than fishing.



Figure 21. Source of DKMF.

3.3 Perception towards the conservation of mangrove in DKMF

It is important to understand the perceptions of local community towards the DKMF planting area to support current and future conservation efforts of the area. Local communities were asked about their perception on the mangrove conservation including planting activities. Most of the respondents agreed with the role of mangrove as fish breeding area and habitat (mean value: 4.7), income generation especially in marine products (mean value: 4.7) and its function to protect against waves and strong wind (mean value: 4.7). They also agreed on the importance of DKMF as flora and fauna conservation area (mean value: 4.6), tourism and recreational activities (mean value: 4.2) and as source for firewood and construction materials (mean value: 4.0). However, respondents or local communities partially agreed on the importance of DKMF area as a source of daily food (mean value: 3.2) and slightly not agreed on the value of DKMF as traditional medicine. This might be due to non existence of traditional practitioners and there were no suitable mangrove forest species to make traditional medicines. Table 10 shows the results of local community's perception towards DKMF.

Table 10. Local community's perception on the value of DKMF mangroves.

The important of DKMF mangrove	Mean scale
Fish breeding area and habitat	4.7
Income generation from river and sea products	4.7
Protection from waves and strong winds	4.7
Conservation of flora and fauna	4.6
Daily food resources	3.2
Traditional medicine resources	2.8
Tourism and recreational activities	4.2
Sources of firewood and construction materials	4.0



Figure 22. Scenic beauty of Delta Kelantan Mangrove Forest.

In terms of positive and negative impacts on conservation efforts in DKMF to local communities, respondents mostly agreed that the DKMF benefited them in through increased income (86.4%), and creation of more job opportunities (70.5%). However, most of the respondents agreed on the impacts of local development (45.5%) and tourism (45.5%). However, they mostly did not agree on the impacts through increased communication skills (21.2%), business skill (16.0%) among local communities, women empowerment through small industries (10.0%) and support culture exposition (10.2 %). **Table 11** lists the impacts of DKMF. Most of the respondents were not happy on the negative impacts from the development of DKMF, such as interference by outsiders (85.4%), lack of income sources (90.6%) and lack of agricultural lands (96.6%). These indicated that the DKMF have had no significant negative impacts to local communities.

Table 11. The impacts of DKMF.

Perception of the impacts conservation of mangrove planting in DKMF to local communities					
		No	%	Yes	%
Positive	Increased income	68	13.6	433	86.4
	Job opportunities	148	29.5	353	70.5
	Local development	273	54.5	228	45.5
	Tourism	273	54.5	228	45.5
	Communication skills	395	78.8	106	21.2
	Business skills	421	84.0	80	16.0
	Women empowerment - small industries	451	90.0	50	10.0
	Culture	450	89.8	51	10.2
Negative	Interference by outsiders	428	85.4	73	14.6
	Lack of income sources	454	90.6	47	9.4
	Lack of agricultural lands	484	96.6	17	3.4

3.4 Contribution of mangrove to livelihood

Employment and Household Income

The study showed that in terms of employment, out of a total of 904 households, fishermen accounted for 22.5%, followed by businessmen at 22.3%, while 13.1% were employed in the private sector and 5.6% in the government sector.

Cash income is income earned through salary, wages, rental business, bonus and remittances by family members. Non-cash income is generated from fish catch, crops and catch from the DKMF area. In 2020, it was found that the household

income of the community in the DKMF area was lower than the average value of the national income (RM 7,089 monthly) while it was RM 4,411 for Kelantan. livestock for daily needs. The results of the analysis showed that the average household income for 2020 is RM 2,174. This average monthly income is RM 1,827 (84%) while RM 347 (16%) is from non-cash sources. As for non-cash income, most of it is generated by the catch from the DKMF area. In 2020, it was found that the household income of the community in the DKMF area was lower than the average value of the national income (RM 7,089 monthly) while it was RM 4,411 for Kelantan.



Figure 23. Local fisherman jetty.

Income Sources from DKMF

The total number of households involved in generating income from mangrove products is 143, accounting for 28.5% of households in the DKMF area. The average cash income from mangrove products per household is RM 256 while non-cash income is RM 118 (34%). The total average income from the mangrove environment is RM 374 which is equivalent to 17.2% of the total average income per household.

Poverty Rate

A household is considered poor if its monthly income is less than the Poverty Line Income. The study takes into account the per capita poverty income line (2016) for the rural poor in the state of Kelantan, which is RM 188. The poverty rate in DKMF is 19.9%. If there is no income from mangrove resources, the poverty rate can increase to 33%. Therefore, DKMF contributes economically to the local community.



Figure 24. Socio economic activities in DKMF.

4. Conclusion and Recommendation

In summary, mangrove forest ecosystems contribute significant value ecologically, economically, and socially. Therefore, it is important to conserve and maintain the mangrove forests to sustain the well-being and prosperity of local communities. The results of this study point to the important role of mangrove forests to generate income and hence, contribute to the livelihood of local communities.

Several recommendations and strategies are suggested below to enhance community income, namely diversifying economic activities, promoting local products, and fostering entrepreneurship initiatives:

- Exploring the potential for new income sources for selected communities through social forestry practices, such as community-based ecotourism, agroforestry, restoration, and rehabilitation programmes;
- Exploring the potential for joint-forest management or collaborative forest management by involving and empowering local communities in conservation efforts and the preservation of mangrove forests;

- Providing skills training and capacity building to selected communities based on potential resources for developing food products, and cottage industries, such as crafts, or skills such as nature guide; and
- Conducting CEPA programs and community engagement activities to raise awareness among local communities about the importance of mangrove forests and the environment.

By implementing these recommendations, the community can work towards increasing its income and fostering sustainable economic growth.



Figure 25. Ecotourism activity by community at Tanjung Surat, Johor.



Figure 26. Community based conservation programme at Kuala Gula, Perak.



Figure 27. Training on development of mangrove products at Sungai Acheh Penang.

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Chapter 7



Mangrove Rehabilitation Efforts in Sabah

Mangrove Rehabilitation Efforts in Sabah

Joseph Tangah

Forest Research Centre, Sabah Forestry Department, 90715 Sepilok, Sandakan, Sabah

Email: Joseph.Tangah@sabah.gov.my

1. Introduction

The mangrove and coastal ecosystems in Sabah are an invaluable asset to the country not only for their significant contribution to the nation's socio-economic development but also for their essential role in the maintenance of the quality of the coastal environment. They offer protection against strong winds and waves, preserve the coastline, assimilate waste, provide food (mangroves are the source of food and function as food chain for all life in the mangrove ecosystems, serve as important nursery and breeding ground for variety of marine life (mangroves are essential to maintain fishing industries in Sabah and Malaysia as a whole), conservation and preservation of biodiversity, sustainable ecotourism, and carbon sink as well as climate change mitigation.

Despite the decline in mangrove forests they in Sabah and nationwide, they remain one of the largest areas (approx. 390,000 ha or 60%) in the country. Following the deadly Indian Ocean tsunami in 2004, the federal government issued a directive followed by injection of millions of ringgit to protect as much as possible mangrove forests and rehabilitate highly degraded coastal areas that are prone to strong winds and giant waves.

Rehabilitation of mangroves in Sabah began in 2006, when the first restoration initiative supported by the federal government fund took off as a pilot project for restoration sites located in Sibyte Forest Reserve in Sandakan, where harvesting of mangrove wood (mainly species of *Rhizophora apiculata* and *R. mucronata*) for charcoal production is still active at that time. However, harvesting of mangrove wood in Sibyte FR ceased in 2012 due to low demand for charcoal.

Rehabilitation of mangroves requires the regeneration of mangrove vegetation either naturally or artificially by replanting in designated areas where mangrove ecosystems had existed. In Sabah, rehabilitation efforts were concentrated in highly degraded areas amounting to approximately 3,000 hectares.

Successful mangrove rehabilitation or restoration must pay attention to local hydrology and the biology of mangrove tree species and their associated ecosystems. Restored and rehabilitated mangrove ecosystems have an important ecological function and socio-economic values especially for coastal communities.

2. Mangrove forests of Sabah

Located in the northern part of island of Borneo, Sabah landmass is estimated at 7.61 million ha. It experiences an equatorial climate with the annual temperature ranging from 26°C to 33°C, relative humidity ranging from 85% to 95% and total rainfall ranging from 1,500 mm to 4,500 mm. Several forest formations occur in Sabah and extend from mangroves at sea level up to sub-alpine vegetation on Mt. Kinabalu at 4,095 m above sea level. The existence of high heterogeneity of forest formations in Sabah is due to the occurrence of various soil types and altitudinal zones.

Based on the 2020 forest cover map of Sabah, there are approximately 390,526 hectares of mangroves in the State of which 322,990 hectares within Forest Reserves under Class I – VII, and another 67,536 hectares located within state land or alienated land. These coastal plant communities in Sabah cover a larger area than any other state in Malaysia. Currently, the state has 58 Forest Reserves (FR) with mangrove vegetation of different classes (**Tables 1 and 2**), with the largest being the Class V Forest Reserve (FR) is Kuala Bonggaya and Kuala Labuk FR (41,116 ha) located within Beluran and Sandakan districts. Nonetheless, less than 8% of mangrove areas are still found on other state land and alienated land (**Table 3**). In addition, there are also privately owned mangrove forests, e.g. the Labuk Bay Proboscis Monkey Sanctuary (277 ha).



Table 1. Forest Reserves and mangroves cover in Sabah (SFD, 2020).

No	Name of Forest Reserve (FR)	FR (Class)	FR (Gazette) in Hectares	Mangroves in Hectares
1	Balembangan FR	I	371.00	147
	Balembangan FR (Extension)	I	61.90	23
2	Bukau Api-Api FR	I	856.00	168
3	Kuala Bonggaya & Kuala Labuk FR	I	13,179.00	13,075
4	Kuala Segama & Kuala Maruap FR	I	23,988.00	22,471
	Kuala Segama & Kuala Maruap FR (Extension)	I	173.25	125
5	Menumbok FR	I	3867.00	3,867
	Menumbok FR (Extension)	I	2,000.00	1,998
	Menumbok FR (Extension II)	I	6,429.00	5,910
	Menumbok FR (Extension III)	I	500.00	500
	Menumbok FR (Extension IV)	I	1,949.00	1,461
6	Pababag FR	I	436.00	212
7	Pulau Banggi & Pulau Balambangan FR	I	11,498.00	7,416
8	Segarong FR	I	2,029.00	364
9	Silabukan FR	I	10,601.00	13
10	Sitompok FR	I	586.00	380
11	Sugut Wildlife Corridor FR	I	300.00	39
12	Sungai Lasun & Pulau Evans FR	I	3,357.26	3,357
13	Sungai Maruap FR	I	6,789.00	6,352
14	Sungai Serudong FR	I	7,930.00	65
15	Tawau FR	I	13,138.00	13,138
16	Tg. Tumunong Hallo FR	I	460.00	14
17	Timbun Mata FR	I	11,497.00	177
18	Trusan Kinabatangan FR	I	9,064.00	9,064
	Trusan Kinabatangan FR (Extension)	I	3,288.00	1,567
	Trusan Kinabatangan FR (Extension II)	I	546.30	496
19	Trusan Sugut FR	I	8,680.00	1,291
20	Weston FR	I	293.00	293
	Weston FR (Extension)	I	366.00	358
21	Marudu Bay FR	I	6,877.00	6,647
Total hectares of Class I			151,109.71	100,990

No	Name of Forest Reserve (FR)	FR (Class)	FR (Gazette) in Hectares	Mangroves in Hectares
22	Bonggaya FR	II	60,340.00	274
23	Tambalugu FR	II	197.00	11
	Total hectares of Class II		60,537.00	285
24	Jembongan FR	III	1,582.00	53
25	Lemaas FR	III	1,482.00	10
26	Tagaroh FR	III	1,570.00	1
	Total hectares of Class III		4,634.00	64
27	Kg. Hindian FR	IV	496.38	326
28	Nabahan FR	IV	356.00	113
29	Padas Damit FR	IV	7,587.00	871
30	Pulau Batik Kulambu FR	IV	750.00	35
	Total hectares of Class IV		9,189.38	1,345
31	Abai FR	V	1,370.00	1,233
32	Elopura FR	V	24,607.70	24,608
	Elopura FR (Extension)	V	78.00	61
33	Kuala Bonggaya & Kuala Labuk FR	V	43,209.00	39,460
	Kuala Bonggaya & Kuala Labuk FR (Extension)	V	36.00	34
	Kuala Bonggaya & Kuala Labuk FR (Extension II)	V	1,622.00	1,622
34	Kuala Tingkayu FR	V	3,821.70	3,604
35	Kudat FR	V	7,062.00	3,589
36	Lahad Datu FR	V	9,705.31	8,728
	Lahad Datu FR (Extension)	V	48.56	45
37	Menumbok FR	V	1,843.00	1,810
38	Pulau Malawali FR	V	791.00	791
39	Semporna FR	V	22,798.00	18,470
40	Sg. Sugut, Sg. Paitan & Pulau Jambongan FR	V	38,549.00	31,071
	Sg. Sugut, Sg. Paitan & Pulau Jambongan FR (Extension)	V	144.00	141
	Sg. Sugut, Sg. Paitan & Pulau Jambongan FR (Extension II)	V	709.00	709
41	Sg. Gum-Gum & Sg. Loboh FR	V	3,079.00	2,712

No	Name of Forest Reserve (FR)	FR (Class)	FR (Gazette) in Hectares	Mangroves in Hectares
42	Sibyte FR	V	2,340.00	2,275
43	Sulaman Lake FR	V	2,555.00	2,120
44	Tawau FR	V	25,034.00	24,222
45	Trusan Kinabatangan FR	V	31,398.00	29,216
46	Bengkoka Peninsula FR	V	13,271.00	11,491
	Bengkoka Peninsula FR (Extension)	V	609.00	588
Total hectares of Class V			234,680.27	208,601
47	Batumapun FR	VI	164.00	164
48	Dagong FR	VI	65.00	13
49	Kabili Sepilok FR (Extension)	VI	14.00	14
50	Sempilor Malawali FR	VI	2,531.40	23
51	Sepagaya FR	VI	4,063.00	6
52	Sepilok FR	VI	1,235.00	1,053
53	Sg. Kapur FR	VI	1,250.00	15
54	Sg. Gologob FR	VI	7,900.00	7,900
	Sg. Gologob FR (Extension)	VI	206.00	68
55	Umas Umas FR	VI	794.00	36
Total hectares of Class VI			18,222.40	9,290
56	Balat Damit Wildlife FR	VII	4,140.00	1,739
57	Kulamba Wildlife FR	VII	20,682.00	374
	Kulamba Wildlife FR (Extension II)	VII	60.70	34
	Kulamba Wildlife Reserve (Extension III)	VII	228.24	9
58	Tabin Wildlife Reserve	VII	111,971.00	161
	Tabin Wildlife Reserve (Extension)	VII	256.00	80
	Tabin Wildlife Reserve (Extension II)	VII	1,189.27	19
Total hectares of Class VII			138,527	2,416

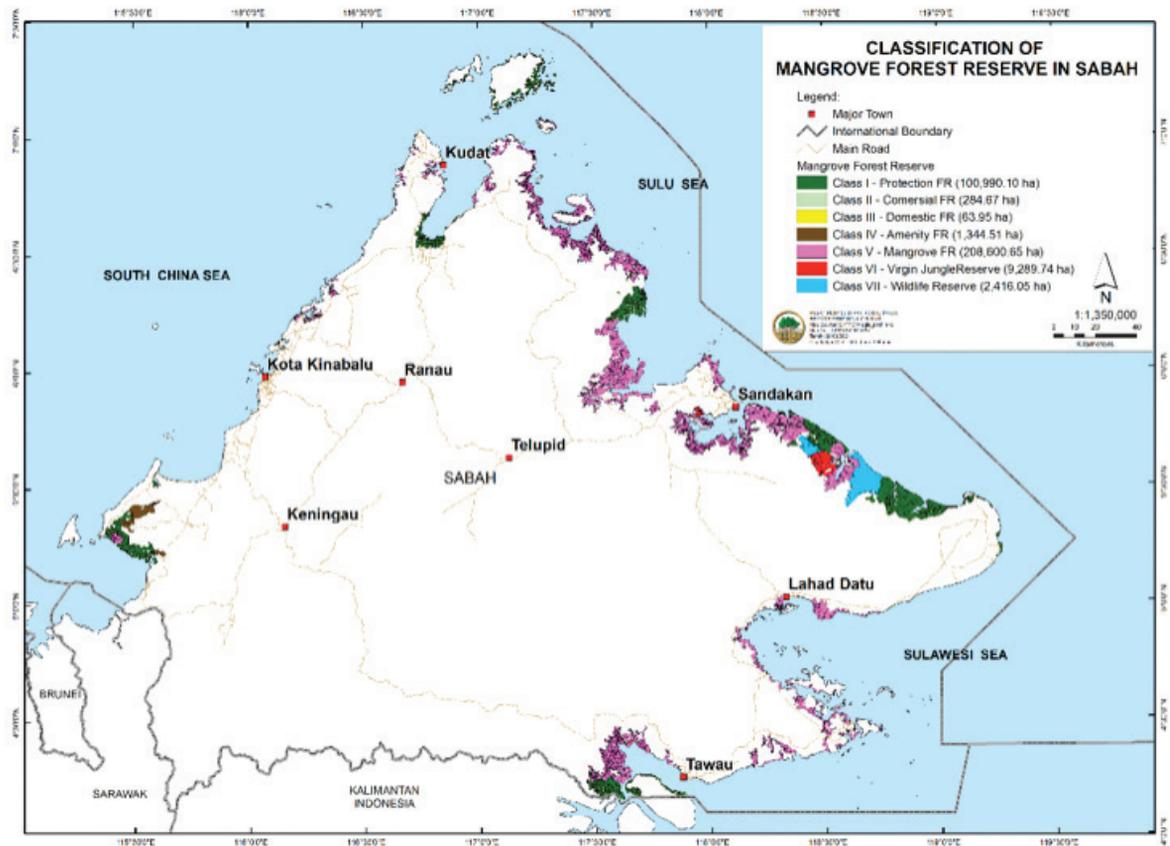


Figure. Map showing classification of mangroves Forest Reserve.

In the state of Sabah, classification of Forest Reserve with specific classes under the Forest Enactment (1968) is as follows:

- Class I – Protection Forest: for the maintenance of forest essential on climatic or physical grounds;
- Class II – Commercial Forest: for the supply of timber and other produce to meet the general demands of trade;
- Class III – Domestic Forest: for supply of timber and other produce for local consumption;
- Class IV – Amenity Forest: for local amenity and arboretum work;
- Class V – Mangrove Forest: for the supply of mangrove timber or other produce to meet the general demands of trade and for ecotourism activities;
- Class VI – Virgin Jungle Reserve: for forest research purpose; and
- Class VII – Wildlife Reserve – for the protection of wildlife.

Table 2.Total of mangrove areas within classes of Forest Reserve (FR).

FR Class	Mangroves (Ha)	Total FR (Ha)
Protection FR (Class I)	100,990.10	1,421,717
Commercial FR (Class II)	284.67	1,655,583
Domestic FR (Class III)	63.95	4,634
Amenity FR (Class IV)	1,344.51	11,403
Mangrove FR (Class V)	208,600.65	234,680
Virgin Jungle Reserve (Class VI)	9,289.74	107,048
Wildlife Reserve (Class VII)	2,416.05	139,503
Total	322,990	3,574,468

Table 3. Other mangroves areas.

Name of area	Mangroves (Ha)*	Gazette (Ha)
Sabah Parks (TPA)	20.00	245,172.00
Sabah Softwood Sdn. Bhd.	28.00	60,700.00
SAFODA	6,836.73	63,000.00
State land	59,052.00	3,389,703.00
Wildlife Conservation Area (TPA)	1,574.10	2,854.00
Wildlife Sanctuary (TPA)	25.25	26,103.00
Total	67,536	3,787,532

Currently, Sabah has two Ramsar sites, namely Lower Kinabatangan-Segama Wetlands (78,800 ha) and Kota Kinabalu Wetlands (24 ha) designated in 2008 and 2016 respectively. Mangroves in Sabah can be classified into various forest types, dominated by one or two mangrove tree species. Mangrove ecosystems with muddy substrate are found in the seaward zone (*Avicennia-Sonneratia* forests), main mangrove zone (*Rhizophora* forests), back mangrove zone (*Bruguiera* forests) and riparian fringes (*Nypa* forests).

In the seaward zone *Avicennia-Sonneratia* forests comprise mainly *Avicennia alba* and *Sonneratia alba*. With their extensive rooting systems of pencil like pneumatophores, they represent the early colonisers of the accreting seaward zone of mangrove ecosystems. The main mangrove zone formed by *Rhizophora* forests, and dominated by *Rhizophora apiculata* while *Rhizophora mucronata* occurs along river and creek banks. Typical features of these mangrove forests are their dense network of stilt roots.

The back mangrove zone normally dominated by *Bruguiera* and *Ceriops* forests and occur at the landward side of *Rhizophora* forests. They represent the back mangroves with trees of *Bruguiera cylindrica*, *Ceriops tagal*, *Xylocarpus granatum* and *Lumnitzera littorea*. In open sites, thickets of *Acrostichum* ferns are common, whereas *Calamus erinaceus* and *Oncosperma tigillarum* are common palms found in the back mangrove of Sabah. *Nypa* forests occur along the banks of rivers in the upstream where there is greater freshwater influence, such as mangrove forests in Pulau ISME-Weston. The stemless palm (*Nypa fruticans*) that grow gregariously in pure stands with dense fronds and mud-lobster mounds are a common feature.

Table 4. List of true mangrove species found in Sabah.

No	Scientific Name	Family	Local Name
1	<i>Aegiceras corniculatum</i>	Primulaceae	Kachang Kachang
2	<i>Aegiceras floridum</i>	Primulaceae	Teruntun
3	<i>Acanthus ebracteatus</i>	Acanthaceae	Jeruju Hitam
4	<i>Acanthus ilicifolius</i>	Acanthaceae	Jeruju Putih
5	<i>Acrostichum aureum</i>	Pteridaceae	Piai Raya
6	<i>Acrostichum speciosum</i>	Pteridaceae	Piai Lasa
7	<i>Avicennia alba</i>	Rhizophoraceae	Api-Api Hitam
8	<i>Avicennia marina</i>	Rhizophoraceae	Api-Api Putih
9	<i>Avicennia officinalis</i>	Rhizophoraceae	Api-Api Jangkang
10	<i>Brownlowia argentata</i>	Malvaceae	Durian Laut
11	<i>Bruguiera cylindrica</i>	Rhizophoraceae	Beus, Berus Putih
12	<i>Bruguiera hainesii</i>	Rhizophoraceae	Berus Mata Buaya
13	<i>Bruguiera gymnorhiza</i>	Rhizophoraceae	Putut
14	<i>Bruguiera parviflora</i>	Rhizophoraceae	Lenggadai
15	<i>Bruguiera sexangula</i>	Rhizophoraceae	Mata Buaya
16	<i>Ceriops tagal</i>	Rhizophoraceae	Tengar
17	<i>Ceriops zippeliana</i>	Rhizophoraceae	Tirog
18	<i>Camptostemon philippinense</i>	Malvaceae	Gapas Gapas
19	<i>Excoecaria agallocha</i>	Euphorbiaceae	Buta Buta
20	<i>Kandelia candel</i>	Rhizophoraceae	Linggayong
21	<i>Lumnitzera littorea</i>	Combretaceae	Geriting Merah
22	<i>Lumnitzera racemosa</i>	Combretaceae	Geriting Putih
23	<i>Nypa fruticans</i>	Arecaceae	Nipah
24	<i>Osbornia octodonta</i>	Myrtaceae	Myrtle Mangrove
25	<i>Rhizophora apiculata</i>	Rhizophoraceae	Bangkita, Bakau Minyak
26	<i>Rhizophora mucronata</i>	Rhizophoraceae	Bakau Kurap
27	<i>Rhizophora stylosa</i>	Rhizophoraceae	Bakau Pasir
28	<i>Sonneratia alba</i>	Lythraceae	Pedada
29	<i>Sonneratia caseolaris</i>	Lythraceae	Perepat
30	<i>Sonneratia ovata</i>	Lythraceae	Pedada Jambu
31	<i>Sonneratia x hainanensis</i>	Lythraceae	Pedada Pondan
32	<i>Scyphiphora hydrophyllacea</i>	Rubiaceae	Landing Landing
33	<i>Xylocarpus granatum</i>	Meliaceae	Nyireh Bunga
34	<i>Xylocarpus moluccensis</i>	Meliaceae	Nyireh Batu

3. The SFD-ISME collaborative project

The SFD-ISME collaborative project was initiated in 2011 and was funded by Tokio Marine & Nichido Fire Insurance Co., Lt. It aims to rehabilitate degraded mangroves in Sabah. The project is implemented by SFD with technical guidance from ISME. The main objectives of the collaborative project are to meet an annual target of planting of degraded mangroves in Sabah and to develop cost-effective methods with suitable species for mangrove rehabilitation with the available funds from ISME. The project identifies areas for replanting and adopts silvicultural techniques that will encourage sufficient vegetation cover for subsequent natural regeneration and mangrove forest recovery. Planting areas are located within the forest reserves as well as adjacent to mangrove areas such as muddy mudflats, which come under the jurisdiction of SFD. For the record, both organizations have collaborated well to ensure the successful implementation and completion of project activities during Phase One (2011-2014), Phase Two (2014-2019) and Phase Three (2019-2024).

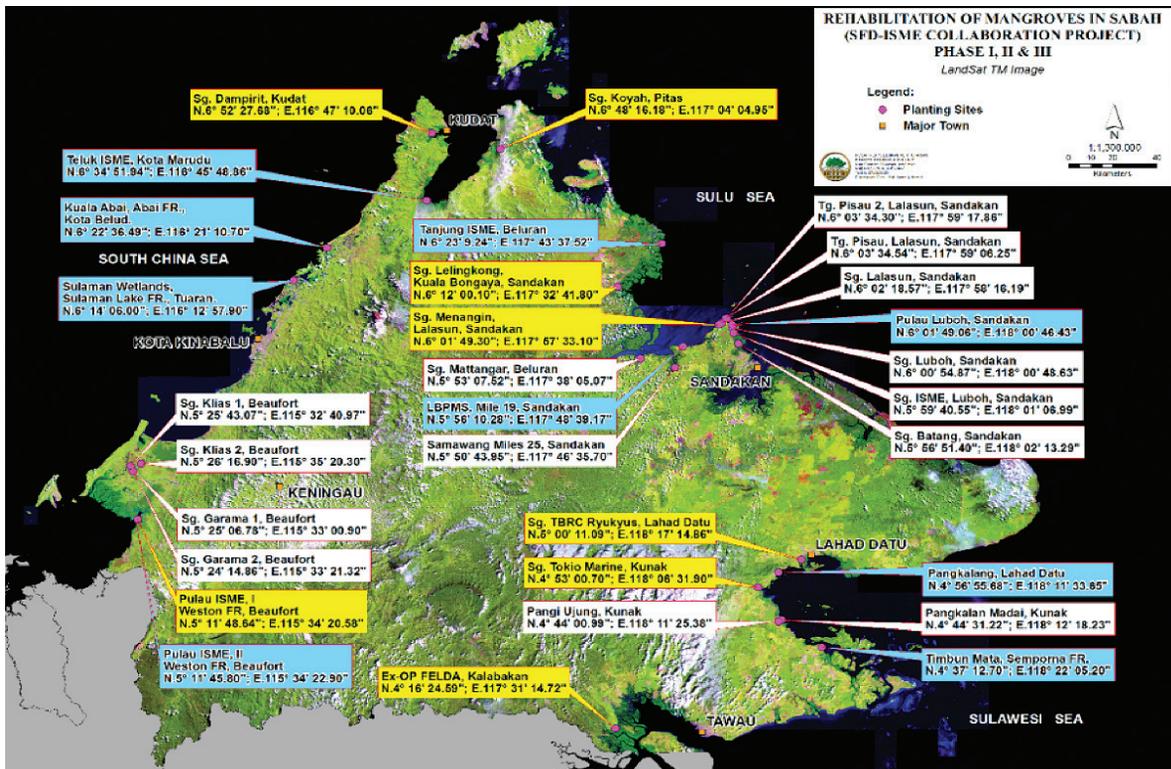


Figure 2. Map showing the locations of 31 project sites with GPS point for the SFD-ISME Collaborative project. Phase One: 2011-2014 (White box- 14 sites), Phase Two: 2014-2019 (yellow box- 8 sites) and Phase Three: 2019-2024 (Blue box- 9 sites).

The funding agency, Tokio Marine & Nichido Fire Insurance Co. Ltd. also approved funding for the extension of this mangrove collaborative project between ISME and SFD into Phase Four (2024-2029) for another five years. This collaboration presented a great opportunity for SFD to strengthen its capacity in mangrove rehabilitation. The Sabah Forestry Department is honored as Sabah is the first state in Malaysia to have such collaboration with an international agency such as ISME. The success of this project may attract other collaborative projects between institutions in Japan and Malaysia in the near future.



Picture 1. Aerial view (taken in February, 2024) of Pulau ISME-Weston, Beaufort, on muddy mangrove mudflats successfully rehabilitated with suitable true mangrove species such as *Sonneratia caseolaris* and *Kandelia candel*.



Picture 2. Signage of Phase II (2014-2019): Pulau ISME-Weston, Beaufort.



Picture 3. Signage of Phase III (2019-2024): Pulau ISME-Weston, Beaufort.



Picture 4. Aerial view (taken in July, 2023) of natural mangrove forests in Elopura FR (Class V) in Sandakan, during low tide.



Picture 5. Aerial view (taken in June, 2023) of rehabilitated abandoned shrimp ponds in Sg Tokio Marine (56 ha) within mangrove forests in Kuala Tingkayu FR (Class V), Kunak. Dense mangroves have established from the pond edges. The hillock in the centre is being developed into a durian orchard.



Picture 6. Permanent signage made of concrete at the project site, Sg. Tokio Marine, Kunak, under the SFD-ISME collaboration project in Sabah.



Picture 7. Field visit by Prof Shigeyuki Baba (Executive Director of ISME) and Dr Chan Hung Tuck (Executive Treasurer of ISME) to Sungai Mattangar, Beluran which was successfully completed under the SFD-ISME mangrove collaboration project.

4. Benefits of SFD-ISME Project in Sabah

In addition to meeting the annual target of planting of 50 ha (Phase I), 40 ha (Phase II) and 35 ha (Phase III) of designated locations of degraded mangroves in Sabah, the SFD-ISME project was accompanied by several other benefits, which included:

a.) Recognition and publicity

The project gained international and national recognition. Examples were the visits and participation in the planting activities by participants of the ISME General Assembly in 2011, Sabah Scouts in 2011, Kyoto High School Students in 2012 and staff of Tokio Marine in 2012, Tokyo High School in 2015-2016, Tokyo Metropolitan High School in 2017-2019 and Tokio Marine in 2019. The project was accorded positive publicity as reflected by the articles published in the local newspapers in Sabah. However, throughout the Movement Control Order (MCO) due to covid-19, no visitors outside Sabah were permitted entry since 2020. Post pandemic, several visit to project sites commenced in 2022, with the latest visit in February 2024.

b.) Better mangrove management and conservation by SFD

While seeking new and additional planting areas for the project, SFD has discovered some encroachments into the mangrove forest reserves during the ground surveys. Appropriate actions will be taken to halt further encroachments.

c.) **Direct involvement of staff of SFD and ISME**

It has to be pointed that not all planting activities are contracted out. Some activities, such as monitoring of growth and mortality, identification of pest problems, and carrying out of initial planting trials are implemented by staff members of SFD-ISME. Technical experts from ISME visited the planting sites during each PSC meeting in Sabah will be an added advantage to the project collaboration.

d.) **Incentives for local communities to collect planting materials**

The project has created incentives for local communities to collect and supply essential planting materials. With this arrangement, contractors do not need to employ full-time workers for gathering mangrove propagules and seedlings.

e.) **Initiation of another collaborative project**

The close working relationship between ISME and SFD resulting from this project has led to the initiation of the International Exchange Program on Coastal Resources and technical experts, a collaborative project between SFD and TBRC of University of the Ryukyus, in Okinawa.

f.) Another interesting finding on Sungai ISME in 2017 during a visit by ISME officials and scientists was two individual's hybrids of *Sonneratia x hainanensis*. It is a natural hybrid of *Sonneratia alba* (as maternal parent) and *Sonneratia ovata* (as the paternal parent). It is assumed that both maternal and paternal parent grow naturally in Sungai ISME, because the existence of *Sonneratia alba* in the project site, whereas *S. ovata* were found outside of the project sites along the Sungai ISME (a small river with 1.5m long), Sandakan.

g.) The stabilisation of mangrove mudflats which was formed due to the accumulation of sediment from the surrounding upstream river systems in Weston Bay in 2016, and by 2017, the mudflats is named as Pulau ISME, honouring the continuous support by the society in mangrove rehabilitation in Sabah, is another milestone for this SFD-ISME project collaboration. During the Second Phase (2014-2019), an area of 39 ha were rehabilitated and another 31 ha will be restored during the Third Phase (2019-2024) of the project.

h.) The highly endangered *Bruguiera hainesii*, where ten (10) mature propagules were collected from a mother tree in Manukan Islands, Kota Kinabalu, in March 2019, were raised in SFD-ISME mangrove nursery in Forest Research Centre Sepilok. Only six (6) propagules survived and four (4) seedlings were planted in Sungai ISME and two seedlings in Sulaman Wetlands. As of March 2021, only three (3) survived in Sg ISME and one in Sulaman Wetlands.

5. Other ISME Projects

When the overall performance of three mangrove rehabilitation projects implemented by ISME was evaluated, the present SFD-ISME project in Sabah, Malaysia (25) scored the highest marks compared those of the projects in Tawara, Kiribati (20), and in Gujarat, India (19). Although the SFD-ISME project scored the lowest in costs and community participation, it excelled in accessibility, collaboration, objectives, publicity, capacity building, voluntary participation and sustainability. Tokio Marine & Nichido Fire Insurance Co., Ltd, has agreed to fund Phase Four (2024-2029) of the present project. This is another achievement of the project, reflecting its sustainability.

Evaluation Criteria	Tarawa, Kiribati	Gujarat, India	Sabah, Malaysia
Accessibility	+	++	+++
Collaboration	++	++	+++
Objectives	+++	+++	+++
Costs	++	+++	+
Publicity	++	+	+++
Capacity Building	++	+	+++
Voluntary Participation	++	+	+++
Community Participation	++	+++	+
Conservation Awareness	++	++	++
Sustainability	++	+	+++
Overall Performance	20	19	25

6. The RMK development projects

The mangrove rehabilitation program in Sabah first received initial funding of RM150,000.00 in 2006 through the RMK9 programme from the federal government of Malaysia. During the following year, more fund was allocated for Sabah through the 5-year Malaysia Plan (RMK) i.e., RMK9:2006-2010; RMK10:2011-2015; RMK11:2016-2020; RMK12:2021-2025, through Sabah Forestry Department for the purpose of mangrove replanting and restoration programme.

Mangrove replanting project in Sabah has to fulfill the following criteria: the planting location falls within forest reserves, near human settlements and on seafront with potential shelter belt. Another aspect is also to monitor the flowering and fruiting pattern of several suitable mangrove species and coastal species for use in the replanting programme. Development of nursery techniques for each mangrove species and coastal species was carried out. For any restoration project, planting trial will be carried out in the designated project sites for several mangrove species before the commencement of a large-scale replanting programme of suitable mangrove species.

7. Issue and Challenges

The loss of mangroves forest in Sabah is mainly due to reclamation, illegal encroachment and land development for the cultivation for oil palms (agriculture activities), shrimp or fish farming, excessive aquaculture activities, infrastructure and urbanisation/industrial development, illegal human settlements, housing projects, and other related issues.

Encroachment is the most serious threat to the mangrove ecosystems. In the early 2008, it was estimated that approximately 10,000 hectares of mangroves have been degraded due to conversion to oil palms, illegal settlements and illegal fish/shrimp ponds. The magnitude of the mangrove degradation is varied depending on the mangrove location. The initial mangrove restoration in Sabah is located in the east coast of Sabah i.e. Sibyte FR, Sandakan, Kuala Tingkayu FR, Kunak, Semporna FR, Semporna, Kunak and Semporna FR, Tawau.

Reclamation of mangrove areas are aimed at making way for development such as housing projects, industrial development, aquaculture, agriculture and tourism activities. The prevalent mindset is that mangroves are wasteland, and they offer the cheapest means of procuring land bank and clearance to make way for other permanent land use.

For decades mangrove forests in Sabah have been harvested on a small-scale basis for fuel wood, charcoal, timber, tengar bark, pilling poles, cutch and fish traps; for example, the leaves of nipah (*Nypa fruticans*) are used for housing thatch and cigarette paper. Nipah is also a good source for manufacturing sugar, vinegar and salt. These activities may be viewed as insignificant as the magnitude of the destruction to the mangrove ecosystems reflect. Nonetheless, it may cause problems to mangrove ecosystems if these activities remain unchecked and prolonged.

Illegal squatters appear to be the real threat to mangrove ecosystems. It is estimated that more than 400 hectares of mangrove forests have been encroached and illegally occupied in patches by illegal immigrants, especially in the east coast of Sabah of Lahad Datu, Semporna, Kunak and Tawau coastal areas. The demolition of squatter colonies in the inland areas for development has driven those affected settlers into the safer places and away from the enforcement authority. Most of them prey on the mangrove forests as a place for hideout and then start colonising the mangrove area, which eventually becomes uncontrollable (source of waste dumping such as plastic etc.) to present a menace to the surrounding ecosystems.

Conflicting jurisdiction between government agencies also become the source of threat when boundary demarcation on the ground is not properly executed. There

are instances of the award of land based on arbitrary and imaginary boundary. Once the proper boundary survey is established and marked on the ground to facilitate the commencement of clearing activities, it can inadvertently include portions of mangrove forests fused inside the surveyed area. This has caused the loss of mangrove areas for other land use due to uncoordinated and technical discrepancies.

Mangroves being used by Illegal squatters appear to be a real threat to the long-term wellbeing of mangrove ecosystems in Sabah, as they can be expected to contribute uncontrolled waste disposal into mangrove forests in the absence of proper waste management control. This problem is predominant in Lahad Datu, Semporna dan Kudat districts. Under the rehabilitation programme carried out by the Sabah Forestry Department, several suitable species of mangrove plants (19 species) and mangrove associates (10 species) have been successfully used as planting material in Sabah (Table 5).

Table 5. List of mangrove plants and associates used as planting material.

No.	True mangrove	Planting material	Associate mangrove	Planting material
1	<i>Rhizophora apiculata</i>	S & P	<i>Terminalia catappa</i>	Seedlings
2	<i>Rhizophora mucronata</i>	S & P	<i>Aglaia cucullata</i>	Seedlings
3	<i>Rhizophora stylosa</i>	S & P	<i>Cratoxylum arborescens</i>	Seedlings
4	<i>Ceriops tagal</i>	S & P	<i>Talipariti tiliaceum</i>	Cuttings
5	<i>Ceriops zippeliana</i>	S & P	<i>Casuarina equisetifolia</i>	Seedlings
6	<i>Avicennia alba</i>	Seedlings	<i>Calophyllum inophyllum</i>	Seedlings
7	<i>Avicennia marina</i>	Seedlings	<i>Ficus benjamina</i>	Seedlings
8	<i>Bruguiera cylindrical</i>	Seedlings	<i>Excoecaria indica</i>	Seedlings
9	<i>Bruguiera parviflora</i>	Seedlings	<i>Terminalia copelandii</i>	Seedlings
10	<i>Bruguiera sexangula</i>	Seedlings	<i>Pouteria obovata</i>	Seedlings
11	<i>Acanthus ebracteatus</i>	Cuttings		
12	<i>Nypa fruticans</i>	Seedlings		
13	<i>Sonneratia caseolaris</i>	Seedlings		
14	<i>Xylocarpus granatum</i>	Seedlings		
15	<i>Kandelia candel</i>	S & P		
16	<i>Excoecaria agallocha</i>	Seedlings		
17	<i>Lumnitzera racemosa</i>	Seedlings		
18	<i>Lumnitzera littorea</i>	Seedlings		
19	<i>Osbornia octodonta</i>	Seedlings		

Abbreviation: S & P = propagules and seedlings. Previous names of *Ceriops zippeliana*, *Aglaia cucullata* and *Talipariti tiliaceum* were *Ceriops decandra*, *Amoora cucullata* and *Hibiscus tiliaceus* respectively.

In the world of today, AI is the major influencer in modern forestry management. The insignificant demand for mangrove products, such as cutch (mangrove extract), mangrove bark, firewood, charcoal, piling poles, and the likes, making it a huge untapped resource for other mangrove ecosystems like the trending carbon credits. The adoption of 'green economy' that targets low carbon growth, resource efficiency and socio-economic inclusivity must be addressed cautiously to achieve sustainable development in any mangrove environment.

It is also estimated from recent inventory, that Sabah's mangroves content has the highest concentration of Carbon, estimated at the range of 160 metric ton per hectare for the above ground biomass (AGB) of mangrove trees with DBH more than > 10 cm. The Carbon captured in mangrove soil is also estimated at the range of 450 metric ton of C per hectares, and this is increasing over the year. The question is: who is going to pay voluntarily for the carbon credits derived from Sabah's mangrove?

Mangroves of Sabah are today appreciated for the protection they provide from tidal waves, strong wind and coastal erosion, as well as an important breeding ground for a variety of marine life. The prevalence of natural catastrophes such as the deadly tsunami, strong wind, storms, and giant waves even make it more crucial to restore and rehabilitate mangrove ecosystems to minimise the damages and loss of human life living along the coastal areas.

It is beyond doubt, that restoring mangrove ecosystems through continuous replanting programmes is very expensive. The costs are incurred from nurturing, protecting, monitoring and managing the planted mangrove plants against pests, diseases, barnacles, storms, rodents, monkeys, goats, and vandalisms or man-inflicted damages among others. It is obvious that when these costs are added up, the mangrove restoration project is very costly and highly demanding. Nevertheless, the benefits of restored mangroves outweigh the costs of the project.

The government of today has been left with limited option but to continue supporting the mangrove restoration and rehabilitation programme particularly in highly degraded mangrove areas and coastlines that are exposed and susceptible to natural hazards. This will enable the coastal and mangrove ecosystems to be revitalised and restored to provide natural habitat for all living organisms therein.

Acknowledgments

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Chapter 8

Impacts of Sea Level Rise on Mangrove Ecosystems: A Case Study of Tanjung Burung, Perak



Impacts of Sea Level Rise on Mangrove Ecosystems: A Case Study of Tanjung Burung, Perak

Anizawati Ahmad*, Alia Izzati Hassan, Wan Ahmad Hafiz Wan Mohamed Azhary,
Mohd Fairuz Fuazi & Saiful Bahri Hamzah
National Water Research Institute of Malaysia (NAHRIM),
43300 Seri Kembangan, Malaysia.

*Corresponding author: anizawati@nahrim.gov.my

Abstract

Mangrove ecosystems found in the inter-tidal zones of tropical and subtropical coastlines, provide critical ecological services, including shoreline stabilisation, carbon sequestration, and habitat for diverse flora and fauna. With the accelerating pace of global sea level rise attributed to climate change, understanding the intricate interactions between rising sea levels and mangrove ecosystems is paramount for effective coastal management and conservation.

Changes in water depth, salinity, and hydrodynamics induced by rising sea levels have profound effects on mangrove vegetation, thus influencing growth patterns, species distribution, and overall ecosystem structure. The intricate balance between sediment accretion and inundation plays a crucial role in determining the resilience of mangrove habitats to sea level rise.

This chapter explored alterations in current speed and wave dynamics within mangrove areas, shedding light on how these changes influence sediment transport, nutrient cycling, and the ecological niches supporting mangrove-dependent species. Researchers also documented that areas that experience above 0.3 m/s of current speed will affect the growth and survival of the mangrove trees [1, 2]. The potential for mangroves to adapt to rising sea levels through migration, vertical accretion, and genetic adaptation is discussed alongside the challenges posed by anthropogenic activities, land-use changes, and altered sediment supply.

In conclusion, recognising the vulnerability and resilience of these ecosystems is essential for developing adaptive strategies that integrate ecological, social, and economic considerations in the face of ongoing climate change.

1. Introduction

The landscape most vulnerable to climate change is the intricate inter-tidal zone where land and sea converge. Among the resilient ecosystems nestled in this transitional realm, mangrove forests emerge as critical players in a dynamic dance with the rising tides.

Mangroves grow in the tidally influenced areas and play an essential role in the ecosystem. Their unique root system serves as a natural breeding ground for many species of invertebrates and vertebrates, acts as a natural buffer against the threat of high, storm-generated waves [3], winds, surges and typhoons and tsunamis [4]. Their ability to attenuate and absorb wave energy helps to stabilise the beach against coastal erosion [5]. It also plays a unique role in ecology and biology. As sentinels of the shoreline, mangroves provide an array of ecosystem services, from shoreline stabilisation and habitat provision to carbon sequestration. However, their very existence is now imperilled by the escalating phenomenon of sea level rise.

Sea level rise (SLR), driven by global climate change, presents an imminent threat to coastal ecosystems worldwide. The melting of polar ice caps and glaciers, coupled with the thermal expansion of seawater, results in a relentless encroachment of the sea onto land. This encroachment disrupts the delicate equilibrium that mangroves have maintained for centuries, challenging their adaptive mechanisms and resilience.

The SLR will cause changes in the intensity and frequency of extreme events (from combined effects of high spring tides, heavy rainfall, storm surges, high surface waves, and river flooding) [6]. These extreme events may cause temporary or permanent inundations due to increased sea and flood levels. An increase in wave heights and current velocities will intensify coastal erosion and sedimentation rates, damage to coastal structures, and loss of property and marine habitats. Similarly, saltwater intrusions will deteriorate water quality; hinder agriculture and aquaculture activities. These impacts are potentially significant, bringing discomfort to the local communities [7].

This dynamic interplay between SLR and mangrove ecosystems shall be explored. The rising seas not only jeopardise the physical existence of mangroves but also reverberate through the intricate web of ecological relationships they sustain.

In this chapter, from the mangrove realms and rising tides, the vulnerabilities of mangrove ecosystems to sea level rise, and the adaptive strategies they deploy to navigate this change will be discussed. It becomes clear that understanding the intricate dance between mangroves and rising seas is not just an ecological imperative but a crucial step towards securing the resilience of our coastal environments in the face of an uncertain future.

1.1 Objectives of the Study

The primary objective of this study was to identify and analyse the impact of rising sea levels on the hydrodynamics of the study area. The analysis and evaluation were based on the output results from the simulation of existing and projected sea level rise conditions.

Investigating mangrove growth in the context of rising sea levels involves a multidisciplinary approach that considers ecological, hydrological, and geological factors. The methodology used in this study are as follows:

2.1 Site Selection

- a. Study sites representative of different mangrove ecosystems were identified by considering variations in species composition, tidal regimes, and geomorphology.
- b. Sites with historical data on sea level rise was chosen based on where current rates of sea level rise were well-documented.

2.2 Data Collection:

- a. Sea Level Data:
 - i. Historical sea level data was acquired from reliable sources such as tide gauge records or satellite altimetry.
- b. Mangrove Growth and Health:
 - i. Field surveys were conducted to assess mangrove species composition, tree density, and canopy cover.
 - ii. Individual tree height, diameter at breast height (DBH) were measured, and leaf samples were collected for physiological analyses.
 - iii. Remote sensing tools (satellite or drone imagery) were used to assess changes in mangrove cover over time.
- c. Sediment Accretion:
 - i. Sedimentation monitoring stations were established by using sediment traps or sediment cores to measure the rate of sediment accretion around mangrove roots.
 - ii. Sediment composition and texture was analysed to understand how sediment dynamics influence mangrove growth.

2.3 Hydrological and Ecological Parameters:

- a. Hydrological surveys were conducted to measure tidal inundation patterns, salinity levels, and water quality.
- b. Nutrient availability in the soil was evaluated through soil sampling and analysis.
- c. Factors which can influence mangrove growth such as temperature, precipitation, and freshwater inflow was monitor.

2.4 Growth Modelling:

- a. Models to simulate mangrove growth was developed under different sea level rise scenarios.
- b. Various data on sea level, sedimentation, and ecological parameters were integrated into growth models to predict the potential impacts of sea level rise on mangrove ecosystems.

2.5 Historical Analysis:

- a. Historical aerial photographs, satellite imagery, and ecological surveys were analysed to assess changes in mangrove extent over time.
- b. Correlation between historical sea level rise rates with observed changes in mangrove growth and distribution was established.

2.6 Community Engagement:

- a. Engagement with local communities and stakeholders were organised to gather traditional ecological knowledge about mangrove growth and changes in sea level.
- b. Community perceptions and experiences were incorporated into the research to enhance the study's contextual understanding.

2.7 Statistical Analysis:

- a. Statistical methods were applied to identify correlations between sea level rise and mangrove growth parameters.
- b. The variability in mangrove growth patterns concerning different environmental factors were analysed.

2.8 Synthesis and Reporting:

- a. The collected data, model outputs, and community feedback were synthesised to conclude the influence of rising sea levels on mangrove growth.
- b. Comprehensive reports and visualisations were prepared to communicate findings to the scientific community, policymakers, and local stakeholders.

A comprehensive understanding of how mangrove ecosystems respond to rising sea levels can be gained by employing this multidisciplinary methodology, thus providing valuable insights for conservation and management strategies in the face of climate change.

3. Study Area

Global variations in coastal geomorphology, tidal regimes, and climate conditions result in diverse impacts of SLR on mangroves. The total mangrove forest in Malaysia is 629,038 hectares whereby 18% are located in Peninsular Malaysia, 22% at Sarawak and 60% in Sabah [8]. Case studies from Tanjung Burung, Perak provide valuable insights into the nuanced responses of mangrove ecosystems to rising seas. Compartment 113 Tanjung Burung Forest Reserve is located in the Kinta/Manjung area. Tanjung Burung (long:100.619171°, lat: 4.479632°) is under the Perak Forestry Department's jurisdiction. National Water Research Institute of Malaysia (NAHRIM), through Jawatankuasa Teknikal Mengenai Penyelidikan dan Pembangunan (JTRD), has been appointed to conduct an extensive study in this area due to the severe loss of mangrove forests. Therefore, a site visit was conducted on 19th November 2020 followed by data collection in January 2022 along the stretch of Tanjung Panchor to Tanjung Remis. Figure 1 is a picture of the study area. Field observations showed that the frontier of the mangrove line in this area is under severe threat.



Figure 1. The study area conditions.

4. Data Collection

One of the most crucial inputs in the hydrodynamic model is the bathymetry of the coastal area of interest. The tidal observations near the study area are also essential as these dictate tides' action and potential contribution to the current systems within the study area. NAHRIM had conducted field data collection from 11 February 2022 until 5 March 2022 (a total of three weeks) covering both the tidal cycle; Spring and Neap Tide events and all the methods were in line with the DID's guidelines [9]. All the locations, planning and methods for the deployment of equipment and relevant surveys at the site were proposed by NAHRIM.

The following data were acquired for the hydrodynamic model:

- a. Current speed and directions, wave height and wave directions were measured using an Acoustic Wave and Current Profiler (AWAC) in two locations..
- b. Tidal elevation were measured using tide gauges and AWACs in two locations for each equipment.

- c. Hydrographic/ bathymetric survey for bathymetry and coastlines topography survey.
- d. River discharge measurement at Sg. Panchor and Sg. Beruas.
- e. Grab sampling analysis within the project area for the sedimentation model.
- f. Total Suspended Sediment (TSS) concentrations within surrounding coastlines.
- g. Beach profiling including core sample analysis along the shorelines.
- h. Purchased wind and wave data by UKMO.
- i. Generated tidal constituents from Royal Malaysian Navy (RMN) and Department of Survey and Mapping Malaysia (JUPEM).

All the data acquired in the previous paragraph were incorporated either as input for numerical model or as calibration purposes. Observed currents and tides were needed in the simulation of coastal hydrodynamic modelling for model calibration.

It is vital to establish the baseline conditions so that once the impacts are quantified, it is possible to evaluate the relative hydrodynamic changes to the surrounding shoreline. The location of the data collection coverage area is depicted in **Figure 2**.

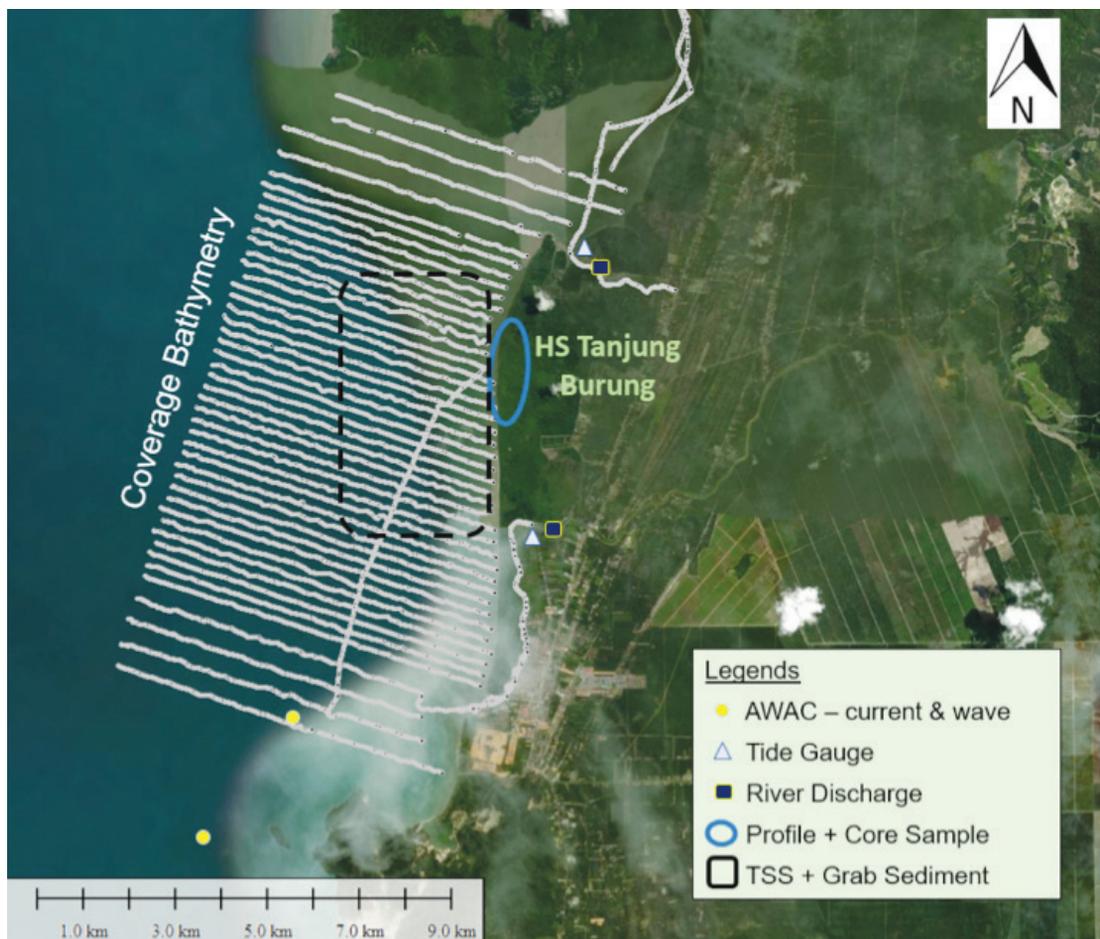


Figure 2. Summary of Data Collection Coverage Area at HS Tanjung Burung.

5. Hydrodynamic Model

MIKE 21 Flow Model FM is a versatile mesh-based modelling solution. The model was developed by Danish Hydraulic Institute (DHI) to solve complex interaction of oceanographic, coastal, and estuary environments through numerical modelling. The Hydrodynamic (HD) Model was used in this study. The hydrodynamic module simulates the water level variations and flows in response to various forcing functions in coastal areas. The development of numerical modelling in this study are as follows:

- a. Hydrodynamic Model (MIKE 21 HD) – Base Model
- b. Spectral Wave Model (MIKE 21 SW)
- c. Hydrodynamic Model (MIKE 21 HD) – SLR Model (2040, 2060, 2080 & 2100)

The MIKE 21 HD was used to study the changes in currents and water levels due to projected sea level rise. It is the basic module of the entire MIKE 21 systems that provide water levels and flow patterns within the study area. Bathymetry information including bed resistance coefficients, wind and wave field data are essential input for the HD model.

The following methodology was adopted to evaluate the potential impact:

- a. A regional model was established that describes regional coastal currents and water levels for the Strait of Malacca and Andaman Sea to provide boundary conditions to a refined local model.
- b. Detailed local model in the study was established.
- c. Hydraulic model was calibrated and verified.
- d. Design scenarios for currents and flows were determined and simulated.
- e. Baseline model and projection model was simulated to evaluate the potential impact on currents and water levels.
- f. The simulation of model were analysed and presented.

Impact assessment on the baseline and with the projected SLR scenario were determined based on three scenarios for 2040, 2060, 2080 and 2100.

5.1 Detailed Hydrodynamic Model Development

The model setup requires transforming actual world events and data into a format that could be understood. All data collected were resolved on the spatial grid selected, including the time step required. Simulations for the hydrodynamic model were carried out to simulate SLR conditions according to Sea Level Rise Projections for Malaysia [10] in the year 2040, 2060, 2080 and 2100 with 0.16, 0.29, 0.46 and 0.67 m increment respectively. The hydrodynamic models were simulated for the various years of interest by increasing the tidal boundary conditions corresponding to the projection of sea level rise.

The bathymetry data for the model set-up was incorporated based on a C-MAP digital chart and surveyed data. The bathymetry data were transformed into a MIKE 21 readable format. The grid resolution of the model varied as the flexible mesh was used to compute, which ranged from 1km² to 20m²; with finer resolution of about 20m² at the chosen Tanjung Burung coastline, as depicted in **Figure 3**.

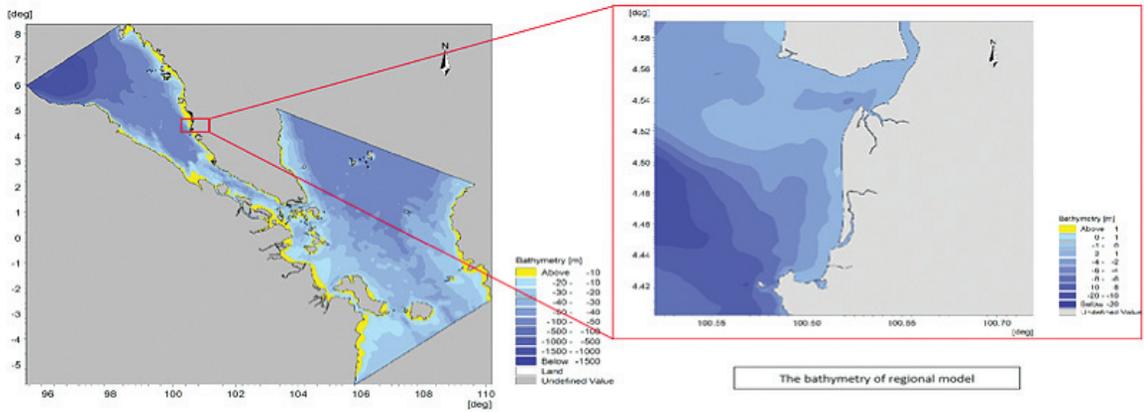


Figure 3. The Regional Grid Model Bathymetry.

The simulation of the model was conducted from 10 February 2022 and 2 March 2022. The simulation period of the HD model has included neap and spring tidal conditions and 1 to 3 days of the warm-up period to avoid any inaccuracies that could occur during the initial state of the simulations.

The model was calibrated according to DID Guideline, the ‘Guidelines for Preparation of Coastal Engineering Hydraulic Study and Impact Evaluations, 5th Edition,’ published in December 2001 and additional information published in 2013 [9, 11]. The calibration of the model for water levels to within root mean square error (RMSE) of less than 10%, current speeds to within RMSE of less than 20% and current directions to within RMSE of less than 20°. The calibration of the model for this study are presented in **Figures 4** to 6 below.

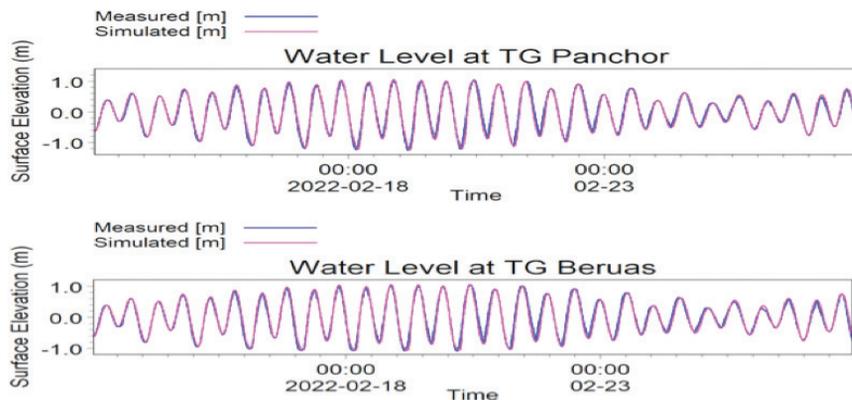


Figure 4. Calibration of Water Level for Local Grid Model TG1 and TG2.

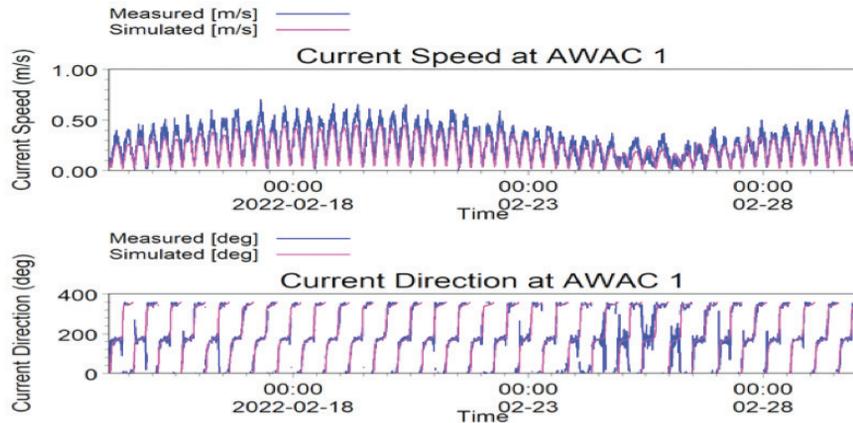


Figure 5. Calibration of Current Speed and Direction at AWAC 1.

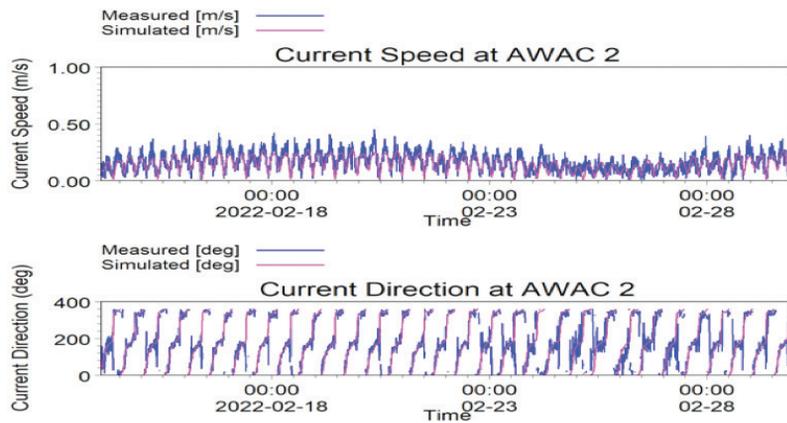


Figure 6. Calibration of Current Speed and Direction at AWAC 2.

In order to assess the deviation between predicted/measured and simulated data, RMSE WAS used to measure the fitness between values predicted by a model and measured values. The extracted water levels from the model simulation compared well with the measured tides with RMSE values within an acceptable deviation of 10% specified in the DID guidelines [9, 11]. The percentage of RMSE results for water level stations TG1 and TG2 and the current speed and direction of AWAC 1 and 2 are listed in **Table 1**.

Table 1. RMSE of Water Level, Current Speed and Direction for Local Grid Model.

Point	RMSE (%)		RMSE Current Direction (Degree)
	Water Level &	Current Speed (%)	
TG Bagan Panchor	10.3		-
Tide Gauge Beruas	10.6		-
AWAC 1	8.6		8.8
AWAC 2	5.9		11.4

6. Results and Discussion

The mean and maximum statistical analysis results of water levels are presented in **Figures 7 to 11**. The surface elevation at the model baseline condition showed that the mean water level for the baseline condition is between 0.2 and 0.4 m. Meanwhile, the maximum water level is between 1.0 and 1.2 m.

The surface elevation for sea level in 2040 is projected to rise to a value of 0.2 m compared with the baseline model in which the maximum water level falls between 1.2 and 1.4 m, while the mean water level is projected to be similar to the baseline, which is between 0.2 - 0.4 m.

The surface elevation for rising sea levels in 2060 is expected to show a maximum water level similar to 2040 model. Despite showing an equivalent maximum water level, the model shows an increasing flooding area in 2060 mainly in the northern part of Sg Panchor. The mean surface elevation shows an increment where the water level is between 0.2 – 0.6 m.

The maximum surface elevation for rising sea level in 2080 is projected to increase to between 1.4 – 1.6 m while mean surface elevation is projected to be between 0.4 to 0.6 m. In 2100, it is projected maximum surface elevation to be between 1.6 and 1.8 m while it is between 0.6 and 0.8 m for mean surface elevation.

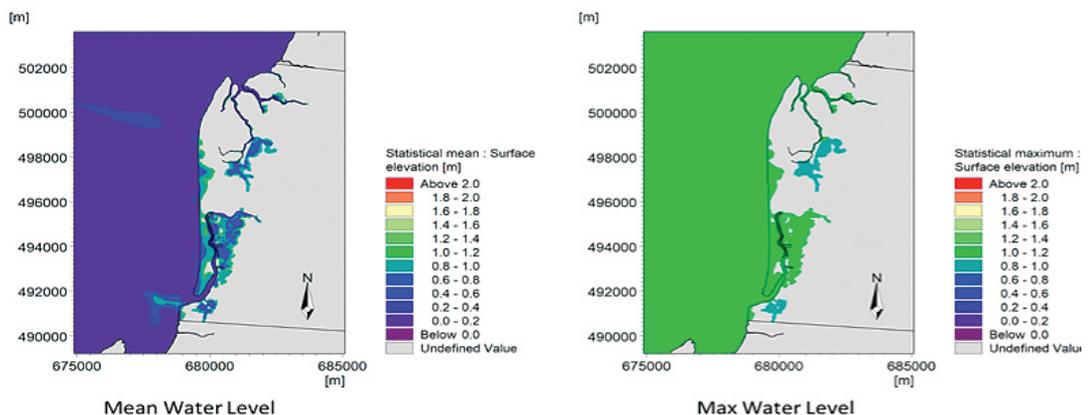


Figure 7. Statistical Mean and Maximum Water Level during Existing Condition.

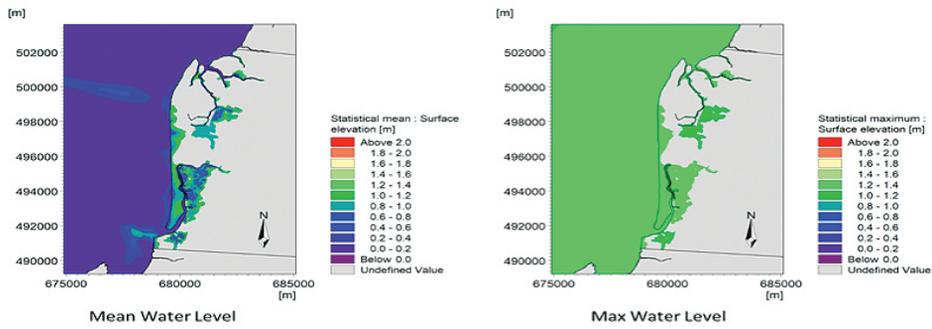


Figure 8. Statistical Mean and Maximum Water Level during SLR 2040.

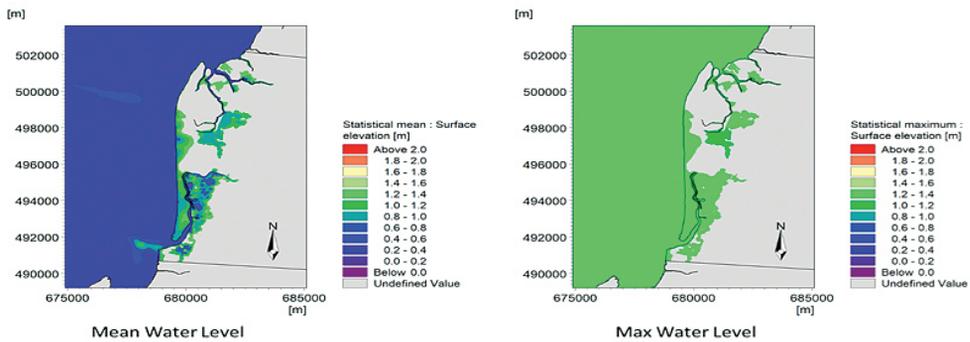


Figure 9. Statistical Mean and Maximum Water Level during SLR 2060.

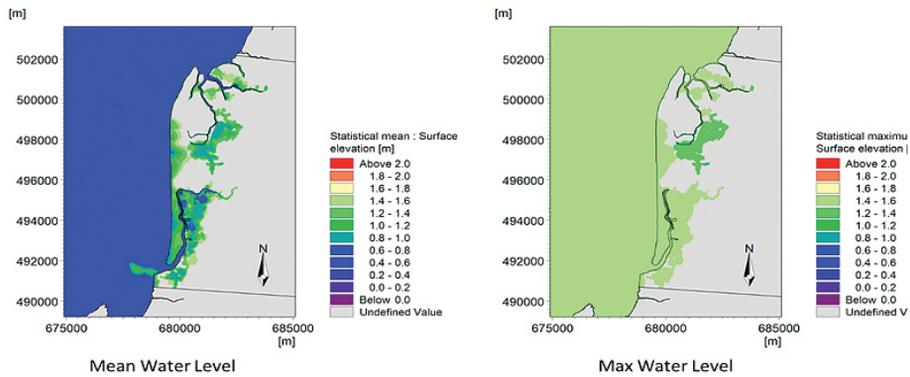


Figure 10. Statistical Mean and Maximum Water Level during SLR 2080.

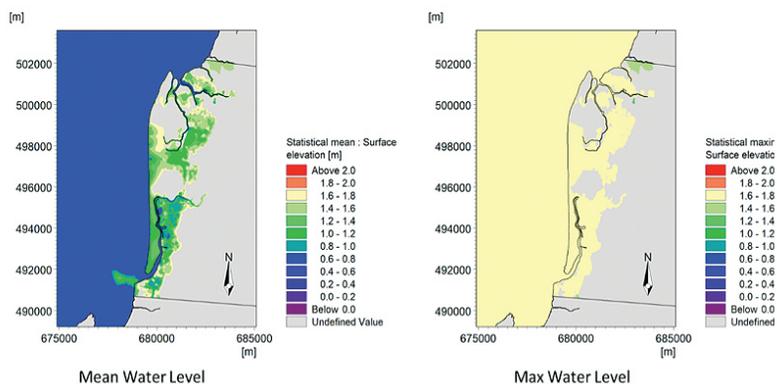


Figure 11. Statistical Mean and Maximum Water Level during SLR 2100.

The difference in mean surface elevation from baseline to the projected year 2100 ranges from 0.2 m to 0.4 m. At the same time, the maximum surface elevation difference is 0.2 m to 0.6 m. The results are presented in **Figure 12**.

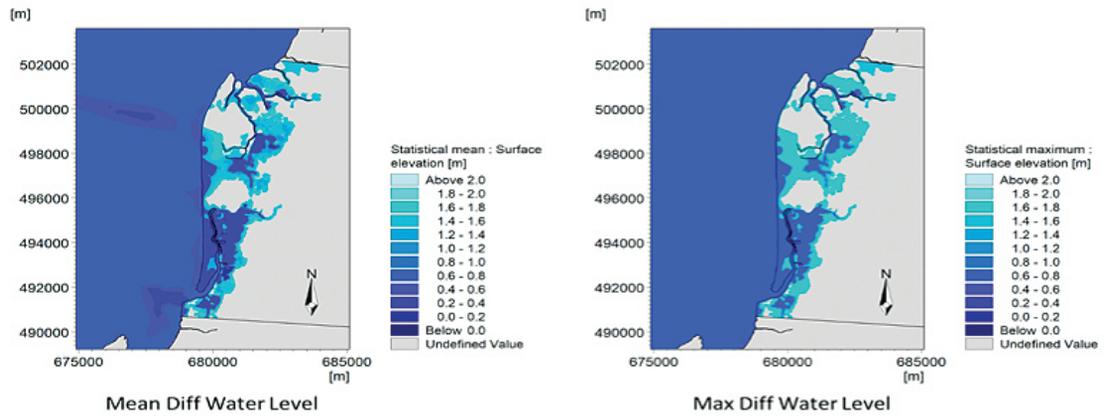


Figure 12. Difference of Mean and Maximum Water Level – Existing vs. SLR 2100.

The model output for the risk of inundation area for projected years is shown in **Figure 13**. With the increasing level of surface water level intrusion, the area of inundation is projected to increase. The result is shown in **Table 2**.

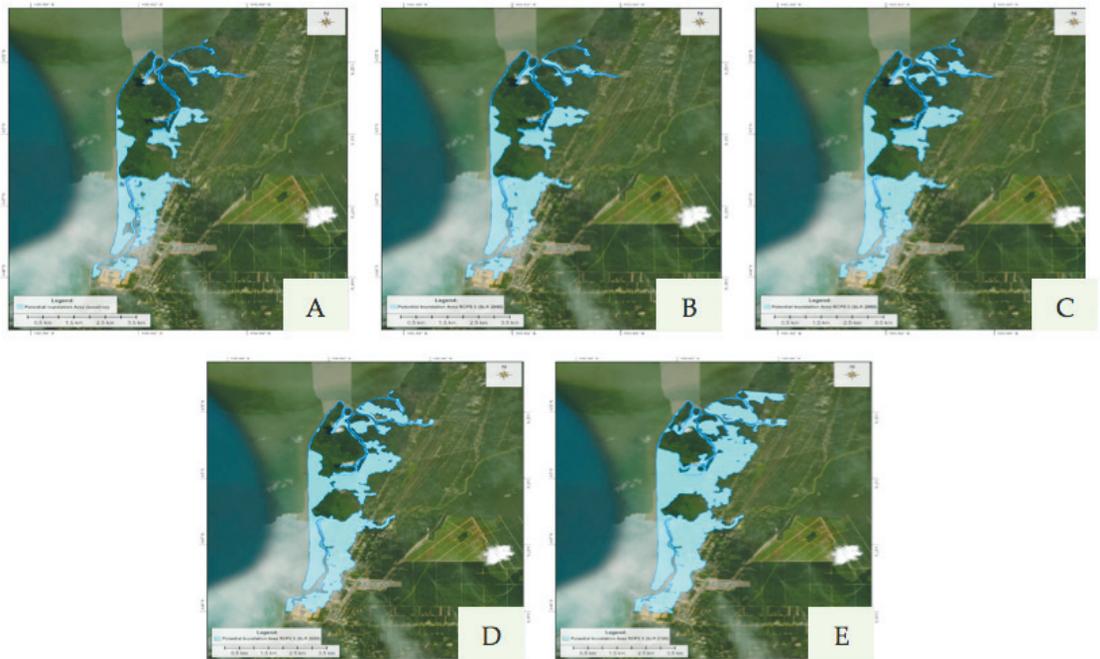


Figure 13. The Image Shows the Results of the Simulation of Sea Level Rise According to Respective Conditions; (A) Baseline, (B) SLR 2040, (C) SLR 2060, (D) SLR 2080 and (E) SLR 2100. The Blue Polygon Represents the Risk of Inundation Area According to RCP8.5.

It was projected that in 2100, an additional 982.16 ha would be affected by sea level rise. Therefore, mangrove forests within the area should be monitored and secured. The total area affected due to inundation of SLR is described in **Table 2** as follows:

Table 2. Summary of Projected Inundated Area due to SLR In Accordance to SLR Scenario.

Scenario (Year)	Total Area Inundated (km ²)	Total Area Inundated (ha)	Projected Additional Area Inundated (ha) (SLR year – Baseline)
Baseline	7.636	763.64	-
SLR 2040	9.178	917.76	154.12
SLR 2060	10.649	1,064.9	301.26
SLR 2080	13.036	1,303.6	539.96
SLR 2100	17.458	1,745.8	982.16

7. Mitigation Measures

Several mitigation measures can be implemented to reduce the impact of sea level rise. Mangrove replanting can be done with suitable species that can adapt to the changing environment. Hardy mangrove species can withstand the high tides and waves at the front and mangrove that can be reproduced quickly will be planted behind to shore up the coastline. Saplings encourage more natural growth of mangroves and replace those already lost. Mangrove or bamboo wood poles can be erected as front barriers to dissipate the wave energy. This method also might promote sedimentation in the area. However, potential wildlife threats such as monkeys should be monitored.

Coastal erosion arising from the sea level rise impact can be mitigated by constructing proper coastal protection structures. These structures need to be adequately designed to account for potential erosion; for example, biodegradable sacks are filled with suitable mud and put in the undercut beneath the berm. Various sizes of rocks can be installed in front to add support to the shoreline. Monitoring is recommended to ensure mitigation works are conducted promptly.

Sedimentation is anticipated to occur in the vicinity of the study area. Monitoring is recommended to ensure mitigation works are conducted promptly if the rise of water level is found to be the primary cause of sedimentation within the area.

Monitoring beach profile change is a common and effective way of measuring erosion and accretion in the area. Based on the model results, some areas along the shoreline might encounter sedimentation in the future. It is an indication of sand overtopping. A beach profile monitoring is proposed using survey transects running toward the shore from the dune to the Mean Lower Low Water (MLLW) mark. Twenty (20) survey transect lines with alongshore line intervals of 10 m extending along the beach can be done to evaluate the possible change in the beach elevation.

This may be accomplished through communication, education, and public awareness. Providing capacity development and awareness-raising activities to local communities and involving communities and stakeholders in science-based techniques to repair degraded forest locations. Communities must be involved to develop a sense of belonging and to ensure long-term conservation initiatives. Collaboration with NGOs or stakeholders in the implementation of environmental policies. Long-term commitment and synergistic collaboration should be formed.

8. Technology Development

Technological advancements have significantly enhanced the capabilities and precision of studies investigating mangrove growth in the context of rising sea levels. The technologies applications in this study are:

8.1 Remote Sensing:

Satellite Imagery and Aerial Photography: High-resolution satellite imagery and aerial photography provide valuable tools for monitoring changes in mangrove extent, canopy cover, and land-water dynamics over large spatial scales.

Unmanned Aerial Vehicles (UAVs or Drones): Drones can capture detailed, high-resolution images of mangrove ecosystems, offering a cost-effective and flexible means for monitoring changes in topography, vegetation structure, and health.

8.2 Geographic Information Systems (GIS):

Spatial Analysis: GIS allows researchers to integrate and analyse various spatial datasets, such as sea level rise projections, mangrove distribution, and hydrological parameters, facilitating a comprehensive understanding of the spatial relationships within the ecosystem.

8.3 Global Navigation Satellite Systems (GNSS):

Ground Truthing: GNSS technology enables precise georeferencing of field data and assists in ground-truthing satellite imagery, ensuring accuracy in mapping and monitoring mangrove growth and distribution.

8.4 Sea Level Monitoring Instruments:

Tide Gauges: Traditional tide gauges and more modern acoustic or radar tide gauges provide continuous records of sea level variations, aiding in understanding tidal dynamics and long-term trends.

Satellite Altimetry: Satellite altimeters measure sea surface height globally, providing high-precision data on sea level variations and trends.

8.5 Sedimentation Monitoring Tools:

Sediment Traps and Cores: Sediment traps and cores equipped with sensors help quantify sediment accretion rates around mangrove roots, contributing to the understanding of how sediment dynamics affect mangrove growth.

8.6 Aquatic Sensors:

Water Quality Sensors: Deploying sensors for parameters, such as salinity, temperature, and nutrient levels helps researchers understand the hydrological conditions influencing mangrove ecosystems and their growth.

8.7 Modelling and Simulation Tools:

Hydrodynamic Models: Numerical models simulate water flow, tidal patterns, and sediment transport, aiding in predicting how rising sea levels might affect mangrove habitats.

Mangrove Growth Models: Advanced modelling tools incorporate factors, such as sea level rise, sedimentation rates, and hydrological conditions to simulate mangrove growth under different scenarios.

8.8 Community Engagement Platforms:

Mobile Apps and Social Media: Utilising mobile applications and social media platforms for community engagement allows researchers to collect real-time data, observations, and traditional ecological knowledge from local communities.

8.9 Climate Data Platforms:

Access to Climate Data: Online platforms that provide access to historical and future climate data facilitate the integration of climate variables into studies on mangrove growth and response to sea level rise.

8.10 Collaborative Platforms:

Online Collaboration Tools: Platforms that enable collaborative work and data sharing among researchers globally, fostering interdisciplinary approaches and accelerating the pace of scientific discovery.

These technologies collectively contribute to a more comprehensive and precise understanding of the complex interactions between rising sea levels and mangrove ecosystems, ultimately aiding in the development of effective conservation and management strategies

Conclusion

Mangrove ecosystems are threatened by anthropogenic activities, including deforestation, aquaculture, and urbanisation. The destruction of mangrove habitats undermines their capacity to attenuate waves and provide other ecosystem services. Conservation efforts are crucial to safeguard these ecosystems and enhance their resilience in the face of rising sea levels.

Integrated coastal management approaches that consider both natural and human dimensions are essential. Balancing the need for development with the preservation of mangrove ecosystems requires a comprehensive understanding of the ecological services they provide, including wave attenuation.

By using MIKE 21 HD, the hydrodynamic conditions of the study area were developed to study the impact of sea level rise. The results suggested that the area of inundation is projected to increase from 763.64 ha to 1,745.8 ha in 2100. The water level can reach up to 1.6 to 1.8 m along the south coast of the study area.

In conclusion, the intricate relationship between sea level rise, mangrove forests, and the attenuation of waves underscores the importance of these ecosystems in coastal resilience. Recognising and preserving the ecological functions of mangroves contribute not only to the protection of coastlines but also to the overall health and sustainability of coastal ecosystems. As sea levels continue to rise, mangroves stand as natural guardians, offering an important solution for mitigating the impact of climate change on coastal areas.

Acknowledgments

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A photograph of a person in a dark shirt measuring the diameter of a tree trunk with a yellow measuring tape. The person is standing in a dense forest with many tall, thin trees and a thick canopy of green leaves. The lighting is bright, suggesting a sunny day.

Chapter 9

Assessing the Impact of Stilt Root Systems on Coastal Protection: A Hydrodynamic Simulation Study

A close-up photograph of mangrove stilt roots. The roots are thick, woody, and gnarled, extending from the ground up to support the trees. They are covered in a layer of green moss or algae. The background is dark and out of focus, showing more of the mangrove forest.

Assessing the Impact of Stilt Root Systems on Coastal Protection: A Hydrodynamic Simulation Study

Mohd Rizuwan Mamat^{1*}, Tariq Mubarak Husin¹ & Anizawati Ahmad²

¹Forest Research Institute Malaysia, 52109 FRIM, Kepong, Selangor

²National Hydraulic Research Institute of Malaysia (NAHRIM),
43300 Seri Kembangan, Malaysia

*Corresponding author: rizuwan@frim.gov.my

1. Introduction

Mangrove forests thrive in the upper intertidal zones of soft-sediment shores in tropical and subtropical regions [1]. This ecosystem is widely regarded as one of the most productive natural ecosystems globally and has well-established ecological, economic, and cultural characteristics [2]. It supports fisheries and biodiversity while also protecting coastlines from erosion and extreme weather events. These natural defences are highly desirable because they offer cost-effective solutions that deliver multiple benefits and contribute to both community and ecological resilience [3]. The unique design of this ecological system enables it to absorb hydrodynamic turbulence and maintain the function and structure of the ecosystem [4], attenuating the energy of tsunamis, cyclones, and storm surges while reducing the velocity of the channel floodplain [5].

Mangrove roots generate currents through jets, eddies, and turbulence, which dissipate the flow and energise the boundary layer separation, shear layer eddy mixing, and flow reattachment [6]. The decline in the drag coefficient for mangroves, which are considered to be the most rigid vegetation, was the most rapid as the Reynolds number increased. Wave dissipation in mangrove forests is caused by the frictional drag of dense trunks and induced roots [7] and is strongly influenced by the ratio of stem length to water depth, stem density, and forest density [8]. Additionally, forest characteristics such as stem and root diameter, forest floor slope, bathymetry, and wave characteristics [9] also play a significant role. The current velocity can fluctuate depending on the porosity, with less fluctuation behind a highly porous area [10]. These ecosystems can also create bed resistance by obstructing the flow of water through the forest [11] and may be more effective at protecting coastlines threatened by climate change than man-made structures [12].

The effectiveness of mangrove ecosystems in preventing soil loss and shoreline erosion has been well-documented [7]. By enhancing sediment deposition and promoting tree growth, these ecosystems can strengthen the anchorage of seedlings and stabilise the shoreline. For example, *Rhizophora mucronata* is commonly found in low-to mid-intertidal areas and invests more in root growth further down the intertidal gradient. Although many studies have focused on the attenuation of regular waves and the effect of wave characteristics on emerging and rigid vegetation [8], there is still a lack of datasets for model validation. Furthermore, most studies have not quantified the level of coastal defence in terms of service and information to coastal communities or the substrate and hydrological requirements for mangrove establishment [13, 14]. However, mangroves can play an important role in reducing the risk of coastal hazards, and the success of using mangroves for coastal defence is often hampered by a lack of reference to these requirements.

The scientific community has confirmed the role of mangroves in reducing sea-wave velocity. For instance, studies have shown that six-year-old mangrove forests that are 1.5 km wide can attenuate open sea wave heights from 1 meter to 0.05 meter [15]. Moreover, approximately 70% of the near-shore wave height can be reduced by mangroves [7]. Research indicates that mangroves are capable of absorbing 30-40% of the total force of a tsunami [16] and up to 90% with a stand density of 3000 trees per hectare [9]. The model estimates a 50% decline in wave energy by going 150 m into a *Rhizophora*-dominated forest at high tide and a 50% energy reduction within a 100-meter belt width of *Sonneratia* forests [1], which ranges the total dissipation from 200 m to 300 m. This finding is supported by [13], who observed a total reduction of 35% over the first 80 m of the forest, which estimates 228.5 meters for 100 m of energy dissipation. Fully grown mangrove forests can significantly attenuate the wave energy of a wind-generated surface by 20% per 100 m [12]. Another study found that mangrove forests can reduce wave height by approximately 20% over 100 m, and can reach up to 60% over a vegetation width of 300 m [17]. Both [12, 17] estimated a vegetation width of 500 m to allow total dissipation of wave energy. The above studies pointed to the vegetation width range for total dissipation of wave is 200 meters to 500 meters. These previous studies demonstrated that the minimum shoreline belt width required to enable coastal forests to function as natural shoreline protectors was 200 m.

This study also examined the potential protective role of mangroves in relation to wave dissipation [6] through an analysis of the root architecture of individual species and trees using Computational Fluid Dynamics (CFD) with Fluent analysis. The 2D and 3D numerical models were capable of simulating the fluid flow in an open channel. The assessment of mangrove protection and design is referred to as distributed drag, which is characterised by tree drag or bed friction coefficients. However, there is a lack of understanding on how tree drag coefficients vary with tree morphology, density, and arrangement, which is a significant source of uncertainty [1]. Numerical models of tree drag allow mangrove forest managers to effectively design mangrove restorations to maintain the natural protection function of coastal communities and assets [18].

Enhancing the management of mangrove areas may increase wave attenuation by determining the required forest bandwidth that considers wind and swell waves as well as a dense mangrove forest, including species with aerial roots [14]. Prior to this, a deeper analysis of the drag characteristics of the stilt-root model must be conducted to observe the disturbance created by the stilt-root model. A 3D stilt root model was developed to mimic shoreline species, and the reduction in drag value could be explained both vertically and horizontally by the velocity behaviour in response to mangrove trees [19]. Fluent analysis was conducted under specific flow conditions to investigate seawater flow through the stilt root model, which slows down the initial velocity. Velocity dissipation was measured from the velocity value extracted from the analysis path of the specimen.

In Malaysia, mangroves serve three primary purposes: pole and charcoal production, shoreline protection, and wave barriers to protect against severe storm events. However, their decline accelerates owing to both natural and human-induced pressures, which may decrease the effectiveness of the barrier function [20]. Therefore, forest managers must preserve and select appropriate species to create better wave barriers and contribute to coastal risk-reduction strategies [9, 13]. Knowledge of wave dissipation through coastal forests would enable forest managers to restore or plant mangroves in degraded and deforested settings to support the establishment of mangrove seedlings [14]. Additionally, artificial protection may be necessary to protect mangrove seedlings, especially at the edge of mangrove forests in areas with deeper channels and strong currents [21]. By lowering current velocities in the forest and decreasing erosion, these measures can help ensure the successful use of mangroves in coastal defence strategies. Involving coastal communities, planners, managers, and engineers in such initiatives is crucial [12]. Community-based approaches and mechanisms are essential to ensure the sustainable use of mangroves for shoreline protection and wave barrier functions [13].

2. Materials and Methods

2.1 Study site

The study site adopts the location of sensors installed by NAHRIM for wave attenuation analysis, at Lekir, Perak, Pulau Klang, and Selangor. However, due to limitation of field data, this study used data from the study plot at Lekir, Perak, to model the stilt root model, whereas velocity dissipation analysis based on density used data from the study plot at Pulau Klang, Selangor (**Figure 1**). A temporary plot measuring 10m × 10 m was established at Lekir, and data on tree species, DBH, location, and height were recorded. The aboveground architecture of stilt roots, including the diameter of tree trunks and roots, azimuth of roots, height of roots from the ground level, distance between trees, and spacing of plantings, was recorded for the analysis of drag coefficients. At Pulau Klang, three temporary plot sizes were established to measure the density of mangrove stands per hectare,

representing low (2125), average (3850), and high (5250) densities, located at GPS coordinates (3.06076, 101.30462), (3.05886, 101.30310), and (3.04792, 101.29761) respectively. The data collected from these plots will be used to further our understanding of the factors that influence the growth and survival of mangrove forests in these locations.

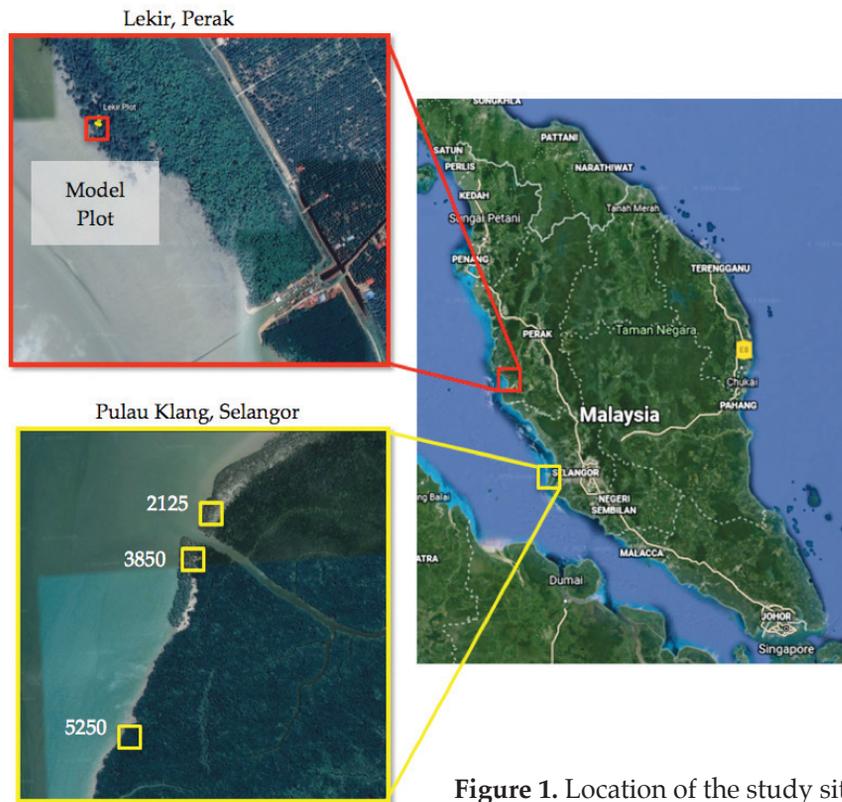


Figure 1. Location of the study sites.

2.2 Stilt Root Model

The model, located in Lekir, Perak, comprised 11 trees from two species, *Rhizophora apiculata* and *Sonneratia alba*, with ratios of 55% and 45% respectively. However, this study selected only four of these trees, which were successfully simulated to determine the drag value of the stilt root model and were capable of defining the velocity-dissipation trend. The selected stilt root models are listed in **Table 1** and consisted of two models for each species.

Table 1. Trees for stilt root model.

Model	Species	Local name	ID	DBH (cm)	Height (m)
1	<i>Sonneratia alba</i>	Perepat	3	47.3	22
2	<i>Rhizophora apiculata</i>	Bakau Minyak	4	23.7	18.5
3	<i>Sonneratia alba</i>	Perepat	6	33	18
4	<i>Rhizophora apiculata</i>	Bakau Minyak	8	18.5	15

The above-ground architecture of the stilt root model was modelled in 3D (**Figure 2**) using the SketchUp program, considering the diameter and orientation of each root. The analysis of the drag coefficient of these stilt root models focused on a plane surface parallel to seawater velocity. These plane surfaces were sliced vertically from the stilt root models at constant spacing, and these slices contained the root cross section as the main geometry input for the simulation.

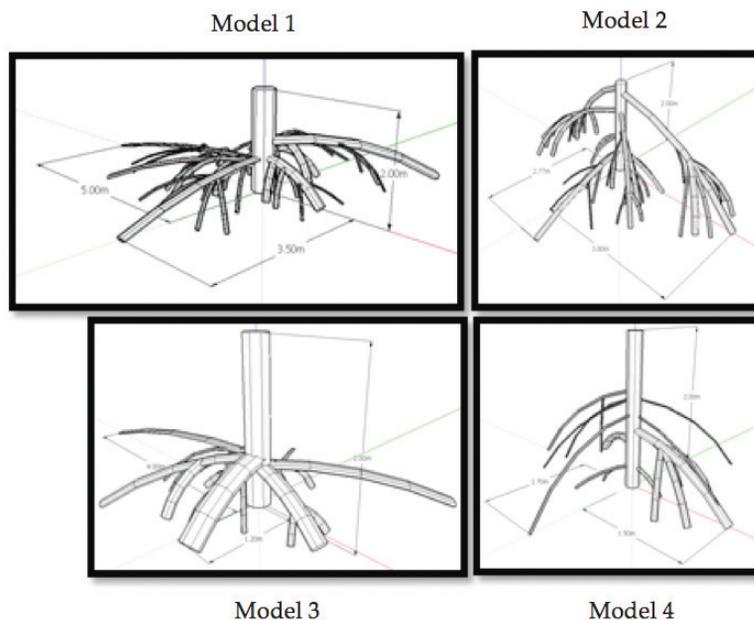


Figure 2. Stilt root models.

2.3 Computational Fluid Dynamics

The Computational Fluid Dynamics (CFD) software ANSYS Fluent was employed to conduct a thorough analysis and determine the drag coefficient of the above-ground stilt root system. The same approach was used to evaluate the dissipation behaviour of the seawater velocity along an in-line specimen. To ensure accuracy, simulations were conducted in two dimensions (2D) and vertical variation was considered to minimise hydrodynamic errors [22]. The first analysis calculated the drag value on the surface plane of the sliced cross sections, while the latter assessed the velocity dissipation for the shoreline belt width.

Two-dimensional specimens were meshed using a triangular method with an element size of 0.025 m. The density of seawater was 1023.387 kilograms per cubic meter, and the viscosity was 0.000959 kilograms per meter per second for both analyses. The Reynolds numbers for the mangrove root drag analysis and velocity reduction were 356,852 and 320,142, respectively, which classified both analyses as turbulent flow. Therefore, this study utilised a standard k-epsilon turbulent viscous model of the SIMPLEC solution type. The analysis was performed using a pressure-based approach, absolute velocity formulation, and steady time series.

Both analyses utilised the average water velocity at the inlet, which represents the average water velocity in the mangrove stands. The average magnitude of water velocity is approximately 0.1 m.s^{-1} [1]. This inlet velocity value was also employed by [5], who satisfied the Froude number similarity with the real field scale of tidal flow and storm surge, 0.2 m.s^{-1} and 0.5 m.s^{-1} . Hence, in this study, the researchers utilised 0.1 m.s^{-1} for the inlet velocity value in the drag analysis of the stilt root model and the velocity dissipation of the tree stand. The results generated from these simulations, in which the average velocity magnitude was applied to the inlet, were multiplied by the velocity ratio of the extreme velocity conditions, which was 0.5. The simulation was assumed to produce a significant reduction in the drag value of the flow redistribution in the horizontal plane with channel-average velocity [19].

2.4 Stilt Root Drag Value

The first step in the analysis was to determine the drag value of the stilt root model. A series of simulations were conducted in 3D but unfortunately resulted in errors. As a result, the analysis was simplified to a 2D model. The drag value is proportional to both the frontal area and the squared velocity. It is important to note that an increase in velocity in the lower frontal area results in overall drag reduction [19]. In this study, the drag coefficient of the stilt root model was analysed by creating horizontal slices of the model at intervals of 0.25 meters (as shown in **Figure 3**).

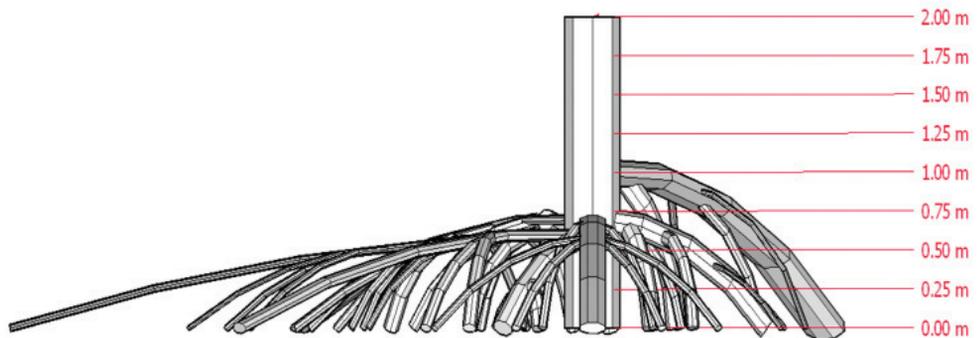


Figure 3. Vertical interval of specimen slices.

Based on **Figure 3**, six specimens were selected for the drag value analysis, which consisted of cross sections of mangrove stilt roots. Simulations for slices above 1.25 m and below 2.00 m were excluded owing to similar cross sections as slice 1.25 m. Therefore, this study focused on simulations with stilt root heights from 0 m to 1.25 m of stilt root height, as shown in **Figure 4**.

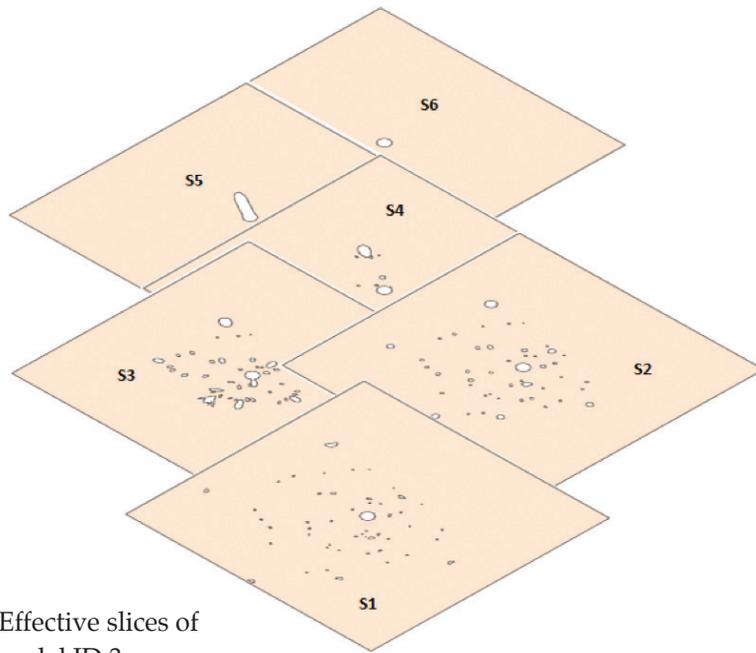


Figure 4. Effective slices of stilt root model ID 3.

The four stilt root models were successfully analysed for their drag values and velocity dissipation. A summary of the drag value results for the four models comprising 26 slices of the specimens is presented in **Table 2**. Additionally, images of the velocity contour, drag force, and drag value along the velocity flow in each slice were captured for further examination.

Table 2. Effective slices of stilt root model and range.

Stilt Root	No of Slices	Slice Range (m)	Root Height (m)
Model 1	6	0 - 1.25	1.07
Model 2	9	0 - 2.00	1.91
Model 3	4	0 - 0.75	0.66
Model 4	7	0 - 1.50	1.29

2.5 Velocity Dissipation

The aforementioned velocity dissipation analysis involved the utilisation of a specimen preparation technique that incorporated the slice that exhibited the highest drag value. This approach employs the height of the stilt root model at the aforementioned maximum drag value to prepare the specimen for analysis. The aforementioned analysis encompassed the preparation of specimens based on the three distinct tree stand densities. Specifically, these densities comprised 2125, 3850, and 5250 trees per hectare, which corresponded with low, average, and high stand densities respectively.

The velocity of the line distribution in the model was noticeably reduced compared with the average channel velocity. A slower velocity along the line near the trees would also decrease the force on the tree and alter the drag force over distance [19]. Consequently, in this study, the specimens were arranged with in-line distribution according to the specified density, with calculated tree gap spacing of 2.17 m, 1.61 m, and 1.37 m for specimens 2125, 3850, and 5250 respectively (Figure 5).

Figure 6 shows the boundary conditions assigned to the specimen prior to calculation. The analysis path was designated as the centre of the tree stem diameter following the inline distribution. The velocity magnitudes observed along the analysis path were recorded to analyse the velocity dissipation behavior of each stilt root model. The focus of the velocity dissipation analysis was on the path at the centre of the specimen, extending from the inlet to the outlet, within the fluid domain.

In this study, four specimens were analysed to examine the dissipation behaviour of an in-line tree stand with three densities. The cross-section of the sliced stilt root model on the specimen influenced the velocity that intersected the analysis path. Therefore, this study concluded that it is applicable only to a single path for analysis within the fluid domain. These specimens were prepared by crossing the stilt root model at the maximum drag value, which is the minimum shoreline belt width for a coastal forest stand. This width can be calculated using the equation generated from the trend line when the velocity is completely dissipated ($Y = 0$). The outer dimensions of the specimens varied owing to the different tree gap spacings.

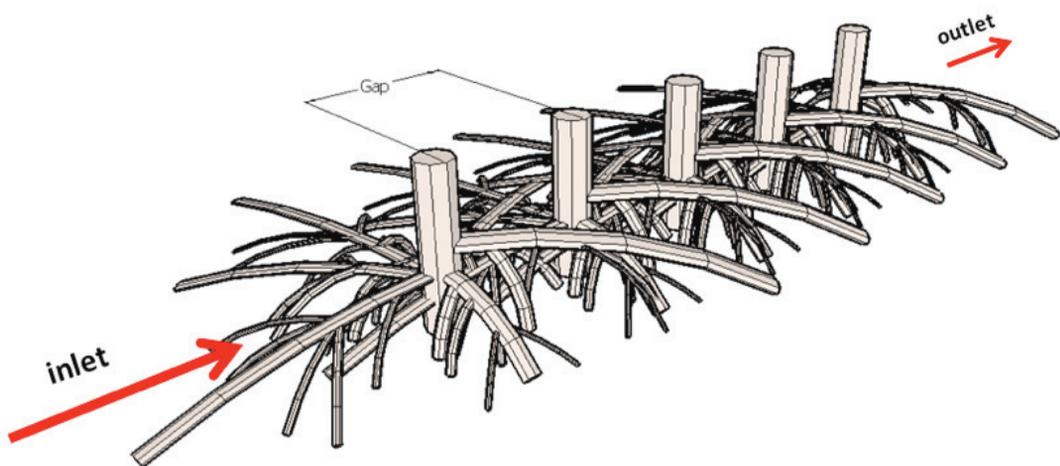


Figure 5. Stilt root models for velocity reduction in-line distribution.

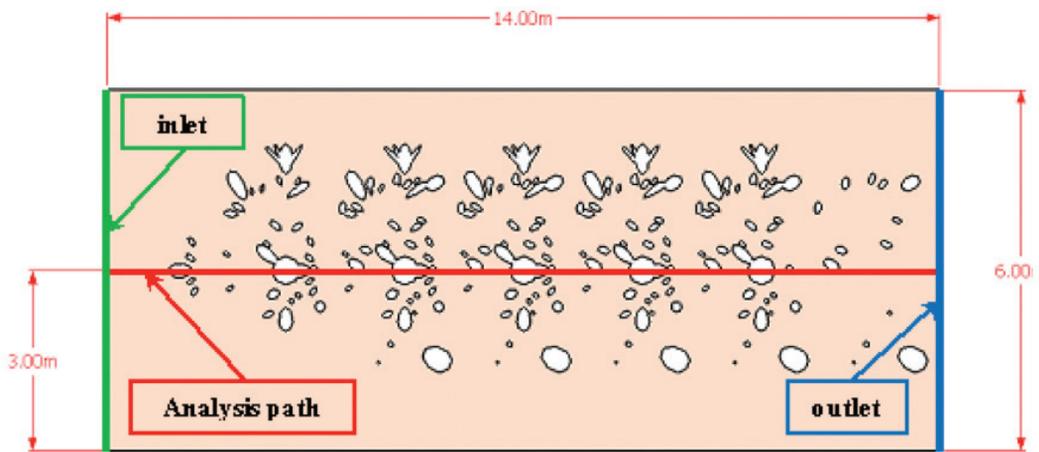


Figure 6. Specimen for velocity reduction in-line distribution.

3. Results

3.1 Stilt Root Drag Value

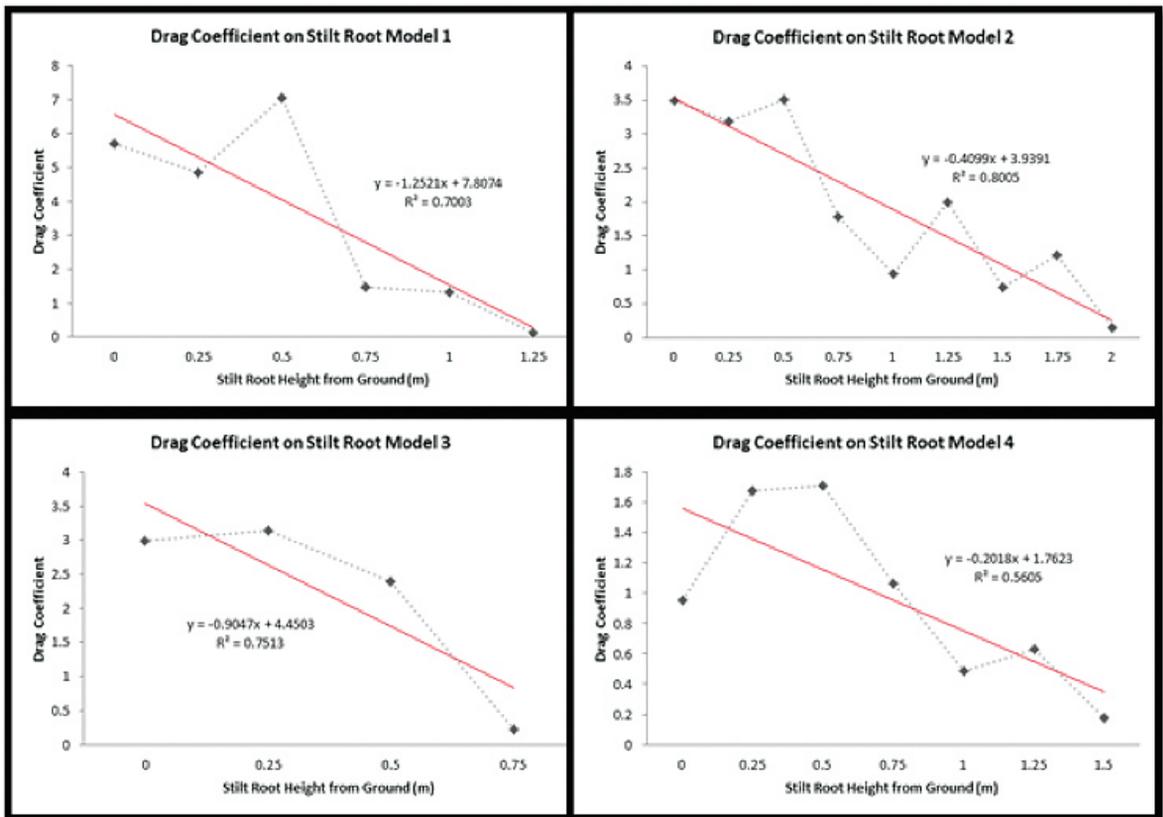


Figure 7. Drag coefficients for all stilt root models.

The results of the drag coefficient analysis of the specimens revealed that the maximum drag values were 7.0493, 3.5041, 3.1364, and 1.7067 for Models 1, 2, 3, and 4, respectively (**Figure 7**). Specifically, the height of slice for these values was 0.5 meters for Models 1, 2, and 4, while it was 0.25 meters for Model 3. The percentage ratio of the height of the maximum drag coefficient to the mangrove stilt root height from the ground level was 40% for Model 1, 25% for Model 2, and 33% for Models 3 and 4. The average total height of the four root models was 1.233 m. The results indicate that the average percentage ratio of the slice height at the maximum drag value was 32.75%, which was approximately 0.404 m from the ground level. The drag coefficient values decreased from the bottom to the top of the stilt root model.

When seawater flows through a forest, the velocity at which it passes through each mangrove tree is influenced by the drag. A higher drag value reduces the seawater velocity. The highest velocity was expected to occur in the uppermost vertical slices, which comprised only the cross section of the DBH for that particular tree. This finding aligns with those of [19], who observed that the velocity profile was almost uniform, except in the vicinity of the bed, where the velocity decreased in the root zone and was higher above the root zone.

Velocity Dissipation

The flow velocity in the in-line model was observed at three stand densities: 2125, 3850, and 5250. The trend line is extracted from the velocity values through the analysis path. From the simulation results of the velocity behaviour, it was observed that the trend line showed a decrease in velocity from the inlet at the first stilt root to the outlet at the last stilt root model in-line distribution, except for Model 3 at a density of 5250. This finding is similar to that of [6] who estimated a 40% decrease in the velocity magnitude of the initial flow. The results of the velocity behaviour for density 2125 for the four-stilt root model are shown in **Figure 8**, and the length of the tree distribution with a 2.17 m tree spacing gap that could totally dissipate the inlet velocity are summarised in **Table 3**.

Table 3. Total dissipation lengths for stilt root models 2125 density.

Root	Model 1	Model 2	Model 3	Model 4
Length	27.00	40.60	26.10	70.60

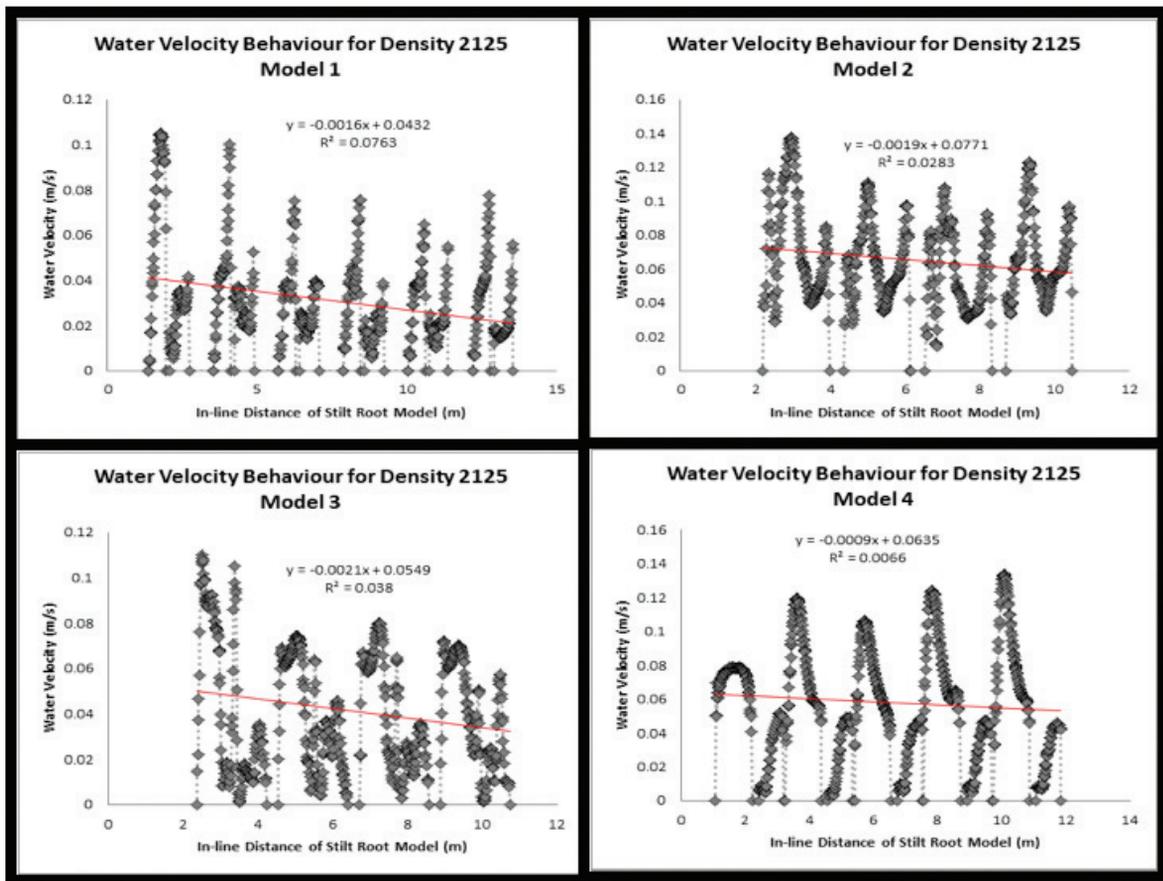


Figure 8. Velocity behaviour of stilt root models for density 2125.

The results of the velocity behaviour for a density of 3850 kg/m³ in the four-stilt root model are shown in Figure 9. Additionally, the findings on the length of the tree distribution capable of entirely dissipating the inlet velocity, with a 1.61 m tree spacing gap, are detailed in Table 4.

Table 4. Total dissipation lengths for stilt root models 3850 density.

Root	Model 1	Model 2	Model 3	Model 4
Length	26.30	31.40	17.30	315.00

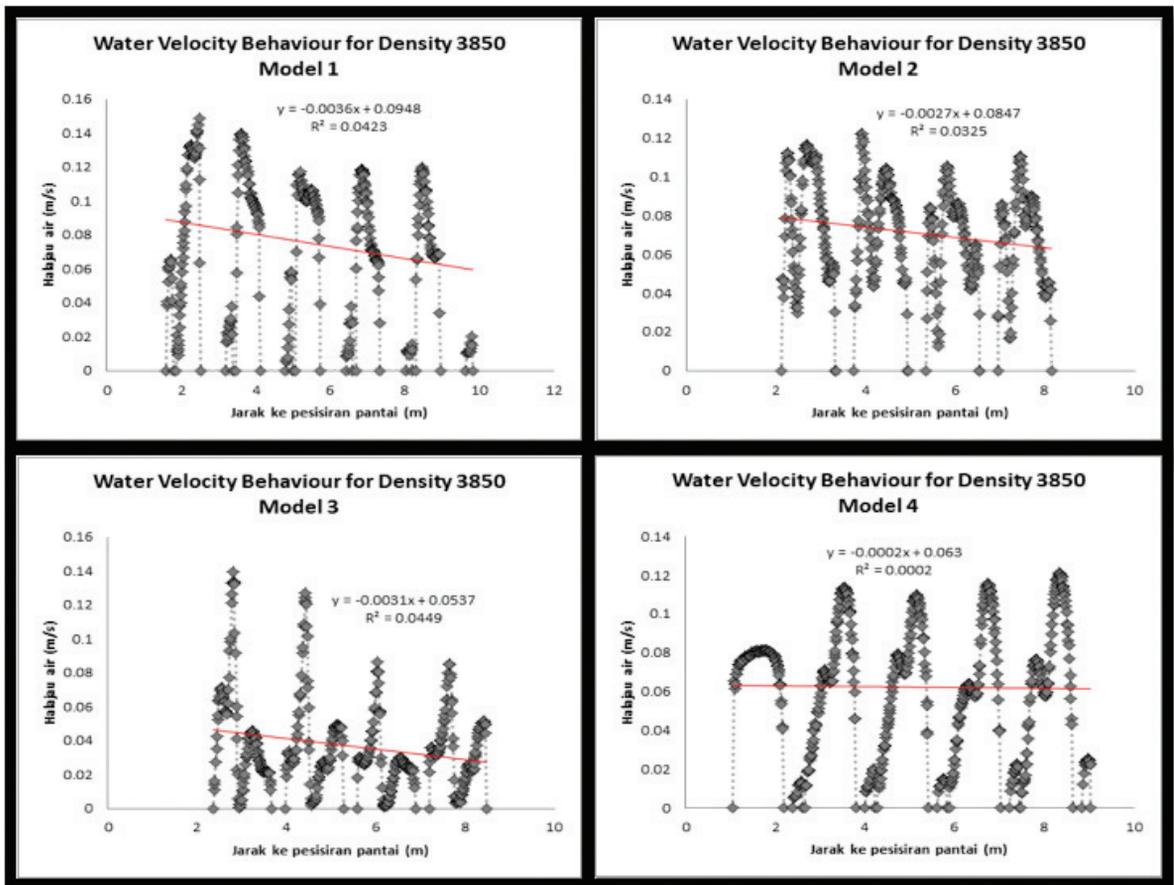


Figure 9. Velocity behaviour of stilt root models for density 3850.

The findings related to the velocity behaviour for a density of 5250 for the four stilt root models are presented in **Figure 10**, and the extent of the tree distribution with a 1.37 m tree spacing gap that can completely dissipate the inlet velocity is detailed in **Table 5**.

Table 5. Total dissipation lengths for stilt root models 5250 density.

Root	Model 1	Model 2	Model 3	Model 4
Length	23.70	18.20	-14.40	16.60

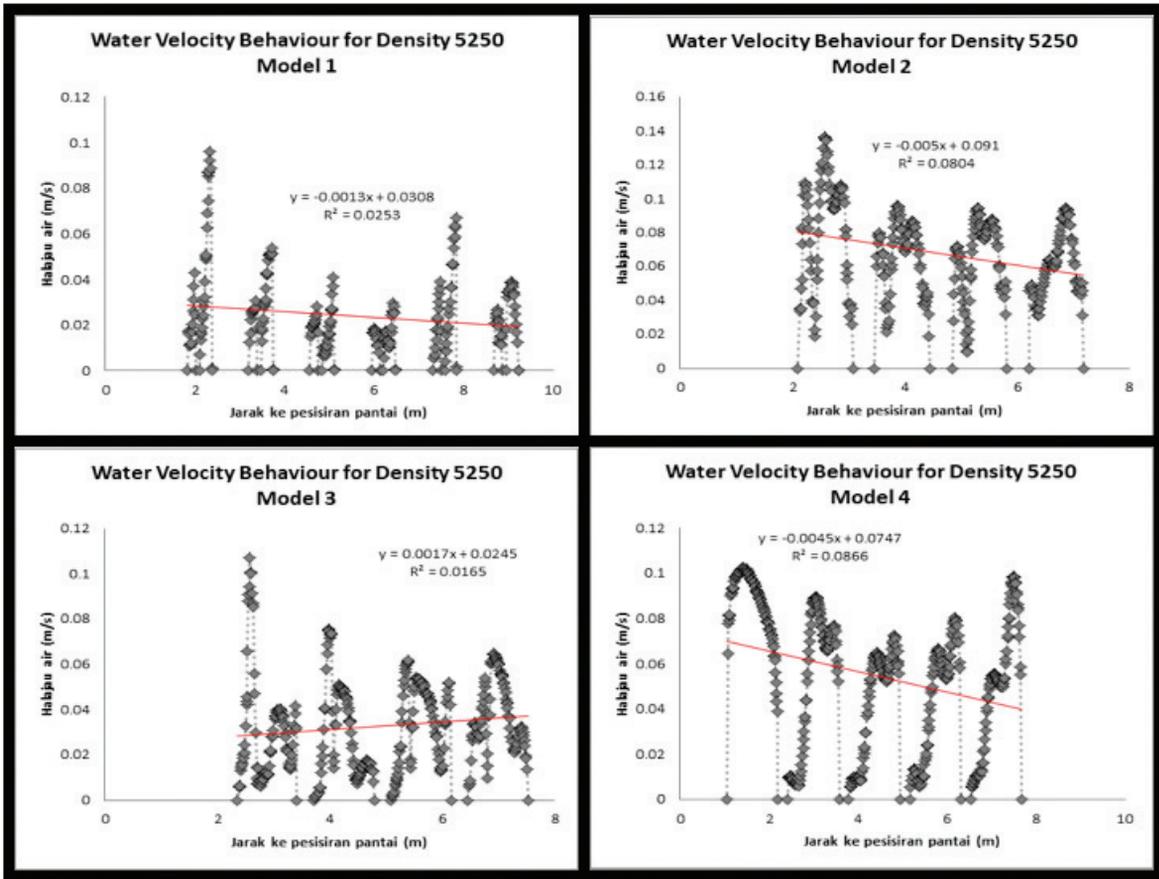


Figure 10. Velocity behaviour of stilt root models for density 5250.

The architecture of the stilt root model has a substantial impact on the velocity dissipation behaviour, which aligns with the findings of [6], who stated that root properties and coordination play a crucial role in reducing flow velocity owing to root densities and cross-sections. The research conducted by [6] supports the idea that the properties and coordination of roots significantly influence velocity dissipation behaviour.

4. Discussion

The analysis of drag distribution within the stilt root model revealed a progressive increment towards the ground level, indicating a notable deceleration of water flow velocity around the coastal stand within the stilt root system as opposed to the stem. This observation underpins the inference that drag values correlate positively and linearly with the cross-sectional area of the stilt root model and can be effectively approximated by employing the stem diameter at breast height (DBH). It was deduced that, for a stilt-rooted coastal tree, an increase in DBH is associated with a consequent elevation in drag values for a given tree stand.

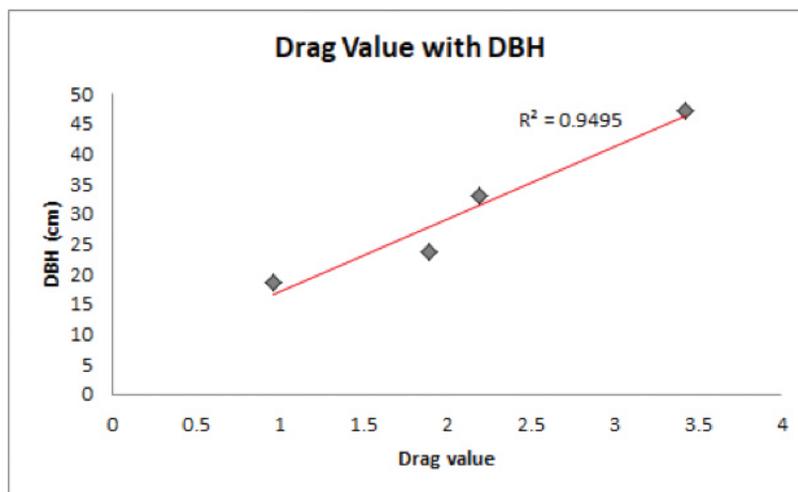


Figure 11. Relationship drag value and DBH.

The findings from the simulations executed with four distinct models, each with different densities, are shown in **Table 6**. Nonetheless, given the significant differences observed in the outcomes of Models 3 and 4, which exceeded the permissible limits, it was deemed necessary to eliminate them from subsequent evaluations.

Table 6. Summary of dissipation length.

Density	Simulation Result Length			Modified Data Length		
	2125	3850	5250	2125	3850	5250
Model 1	27.00	26.30	23.70	27.00	26.30	23.70
Model 2	40.60	31.40	18.20	40.60	31.40	18.20
Model 3	26.10	17.30	-14.40	26.10	17.30	-
Model 4	70.60	315.00	16.60	70.60	-	16.60
Average				41.08	25.00	19.50

The refined results, deemed satisfactory, are compiled in **Table 7**, showing the average dissipation lengths across the four stilt root models for a density of 2125 and across three models for densities of 3850 and 5250, inclusive of planting spacing gaps. It is paramount to acknowledge that the velocity dissipation length serves as an indicator of the minimal shoreline width required for the attenuation of the seawater velocity.

Table 7. Average of shoreline width for all densities.

Stand Density	2125	3850	5250
Planting Spacing Gap	2.17	1.61	1.37
Shoreline Width	41.08	25.00	19.50

When plotting the averages of the shoreline belt widths against stand density, a linear correlation was established, as depicted in **Figure 12**. The derived equation $y = -0.007x + 54.702$ elucidates the relationship between the minimum shoreline belt width (Y-axis) necessary for the comprehensive dissipation of seawater velocity through mangrove trees and stand density (X-axis).

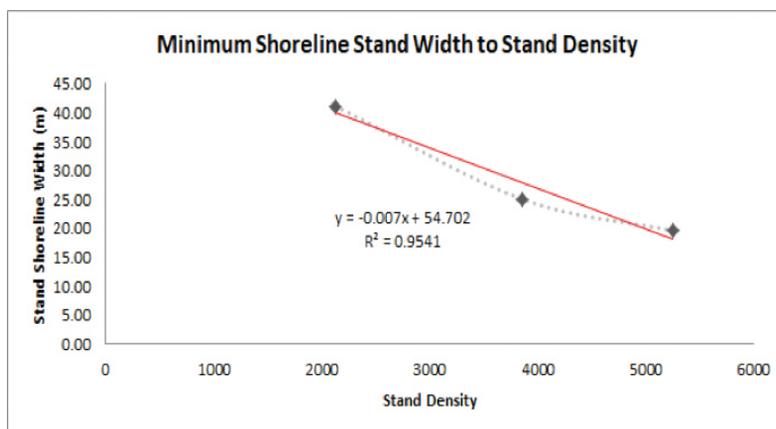


Figure 12. Average shoreline belt width with density.

Figure 13 shows the determination of spacing gaps for new plantations using a derived trend line and equation, $y = 27.277x - 18.3$, correlating with the minimum shoreline belt width (Y-axis) with the planting spacing gap (X-axis). The formulation for ascertaining the dissipation length, predicated on the velocity magnitude averages of 0.1 m.s^{-1} from four stilt root models, provides a foundational metric. In scenarios of heightened seawater velocity, 0.5 m.s^{-1} , the stipulated minimum shoreline belt width is deduced by amplifying the baseline width by the velocity ratio. Employing the lowest observed density of 2125, the calculated minimum shoreline belt width stood at 41.08 m, which, under extreme velocity conditions (velocity ratio of 5), escalates to 205.4 m. This delineation positions the coastal forest as a pivotal natural barrier against shoreline erosion, aligning with findings by [9, 14], who posited minimum shoreline belt widths of 200 m and 228.5 m respectively, to fully mitigate wave energy.

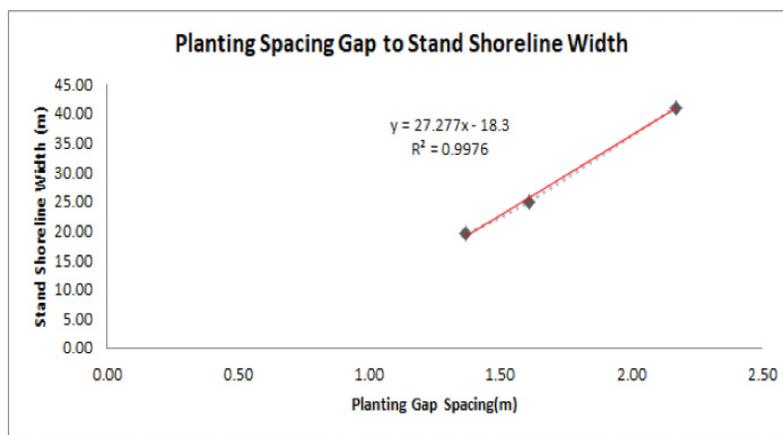


Figure 13. Average shoreline belt width with spacing gap.

5. Conclusion

Mangrove forests are highly productive ecosystems that provide multiple benefits such as fisheries, biodiversity, and coastline protection. These are cost-effective solutions that deliver multiple benefits and contribute to both community and ecological resilience. Wave dissipation in mangrove forests is due to the frictional drag of dense trunks and induced roots, and is strongly influenced by the ratio of stem length to water depth, stem density, and forest density. These ecosystems can also create bed resistance by obstructing the flow of water through the forest, and may be more effective at protecting coastlines threatened by climate change than man-made structures. However, studies on storm surge wave attenuation and the ability of natural habitats to protect against damage are lacking. Approximately 35% of the world's mangrove forests have disappeared over the last two decades, and many of these ecosystems are at risk of being submerged due to sea level rise. Therefore, it is important to have data on the density and width of trees planted, diameter of trunks and roots, floor shape, bathymetry, and spectral features of waves to maintain the protective function of mangroves.

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Chapter 10

**Soil Dynamics in Sustaining Mangrove
Ecosystems of Peninsular Malaysia**

Soil Dynamics in Sustaining Mangrove Ecosystems of Peninsular Malaysia

Mohamad Fakhri Ishak*, Jeyanny Vijayanathan, Rosdi Koter & Tariq Mubarak Hussin

*Corresponding author: mohamadfakhri@frim.gov.my

1. Introduction

Soil is one of the important elements in supporting the presence of diverse tree species. The properties of soil vary from the hilly regions to the coasts, these variations will subsequently influence the presence of various tree species. Peninsular Malaysia has a coastline of about 1,972 km that borders South China Sea, Straits of Johor in the south, and Straits of Melaka in the west. The eastern coastline of Peninsular Malaysia is nearly covered 91% by sandy soils while about 72% of the coastline in the western side is made up of muddy sediments [1].

Sandy areas are more suitable for species such as *Casuarina* sp. while muddy areas are dominated by mangroves sp. The diversity of mangroves can be seen at the muddy shorelines in our country with major species comprising *Avicennia* sp., *Rhizophora* sp., *Bruguiera* sp., and *Sonneratia* sp. growing alongside with many other lesser known species. In its natural condition, the soil is saline, has a high water table, and is perpetually anaerobic, with limitation of oxygen content. The adaptation of mangrove species is highly dependent on the types of substrates they grow on, such as clay or sandy mud, as well as whether they are soft or firm. The artistic root systems such as pneumatophores, stilts as well as buttresses thrive well on different soil properties.

The soil where mangroves are found are also sensitive to changes in the environment either due to natural occurrences or due to anthropogenic naturally or due to human activities. Activities that involve draining water out for the purpose of agricultural or development activities will cause changes to the soil either in physical or chemical properties. The anaerobic site will become aerobic, which subsequently influences the bio-geochemical transformation processes and transform the soil into acidic soils. Once drained, soils which are poor in iron will form non-acid sulphate soils whereas iron rich soil will form either potential acid sulphate soils or true acid sulphate soils [2].

Observations and studies on mangrove ecosystems have been carried out involving natural and planted mangrove stands. As a result of this observation, it has been identified that mangrove tree species grow according to soil suitability.



Mature *Rhizophora* stands thrive on muddy substrates enriched with organic matter.



Avicennia stands prefer muddy soils overlooking the sea and requires lesser organic matter composition.

2. Kuala Sepetang, Perak

Kuala Sepetang, Perak has been recognised as one of Peninsular Malaysia's well-managed mangrove species stands. The area's well-developed mangrove species stand may be related to suitability of the soil. The soil in this area is constantly anaerobic, with deep profile and soft structure (massive), exhibiting high organic materials in the form of hemic and sapric. The soil status in terms of its physical and chemical properties for this area are shown in **Table 1**. The soil texture was silty clay where the percentage of clay particle was 44-52%. Most mangrove species are able to withstand electrical conductivity (EC) level up to 35 mS/cm [3] and the level reported for this area was far below the critical range and constantly influenced by tidal inundation.

Table 1. Soil physico-chemical properties of Kuala Sepetang, Matang, Perak.

Profile Depth (cm)	Cond. mS/cm	Wet pH	N %	Org C (%)	Avail. P (ppm)	Exchangeable Cations (cmol/kg)			CEC cmol/kg
						Ca ⁺⁺	Mg ⁺⁺	K ⁺	
0-25	8.23	6.88	0.42	8.45	50.60	9.64	33.77	11.59	50.80
25-50	8.97	7.19	0.39	8.67	42.02	3.96	30.30	10.49	30.40
50-75	7.55	7.24	0.35	8.53	54.67	3.13	23.99	7.88	47.10
75-100	9.16	7.38	0.30	7.65	60.17	2.40	24.00	7.48	37.05

Profile Depth (cm)	Coarse sand %	Fine sand %	Silt %	Clay %
0-25	14	13	28	48
25-50	9	10	30	52
50-75	11	11	32	48
75-100	11	14	34	44



Soil environment and the soil profile under *Rhizophora* stands in Kuala Sepetang, Perak.

3. Sungai Haji Dorani, Selangor

Sungai Haji Dorani is located adjacent to D'Muara Resort and 5 km from the Sungai Besar town in Selangor. This muddy plain faces high levels of wave pressure potentially leading to erosion. A pioneer study showed that mangrove tree species were successfully planted. Installation of breakwater system or known as geotube in this area was put to use in 2007, as a frontline barrier to minimise wave energy hitting the coastal soil.

At the initial stage of geotube installation, sediment deposition and erosion on the ground surface in the area occurred intermittently. It was estimated that the erosion rate for areas with and without geotube was between 1.1 - 1.3 m/yr and 3.5- 4.9 m/yr respectively [5]. This situation was a grave challenge for the cultivation of mangrove trees. High soil surface erosion provided loose anchorage for planted trees and the constant mud deposition caused the planted trees to be uprooted. Strong wave currents brought along massive amounts of mud in August 2009 leaving most of the area covered with it for almost \pm 33 cm depth which led to sudden mortality of healthy *Avicennia* trees planted almost two years earlier [4]. After seven years, it was observed that the soil became more stable, with maximum erosion and accretion recorded at 11 cm and 6 cm respectively, compared with in 2010 in which erosion was measured at 28 cm [6].

The property and nutrient levels of soil in Sungai Haji Dorani within 0 - 35 cm were almost at par with soil properties at Matang mangrove whereas the soil pH and EC values concur with another study in the same area [7]. However, the soil N levels in Sungai Haji Dorani was much lower than Matang mangrove, probably due to less dense vegetation at the site. Other factors, such as soil movement in which the coastal soil were prone to, due to drastic sea wave disturbance, should be taken into consideration which reciprocally affect the soil structure, limiting good tree establishment.

Installation of geotube stabilised soil movement and supported the innovative planting technique which showed successful establishment of mangroves stands in Sungai Haji Dorani.



Massive soil properties in the area between the geotube and the shoreline in Sungai Haji Dorani.



Stable soil formed due to the installation of geotube and innovative planting techniques resulted healthy *Rhizophora* stand establishment.

Table 2. Soil properties of muddy plains at Sungai Haji Dorani, Selangor.

Parameters	Sungai Haji Dorani	
	0-15 cm	15-30 cm
pH	7.67±0.04	7.64±0.03
Electric conductivity (mS/cm)	11.02±0.84	12.05±0.57
Nitrogen (%)	0.14±0.01	0.12±0.01
Available P (ppm)	51.97±4.75	61.98±4.62
Exch. K (cmol/kg)	8.76±1.18	11.83±1.32
CEC (cmol/kg)	16.48±1.67	19.70±1.42

± represent standard error values

Mangroves are sensitive to environmental changes and simultaneously these changes can affect the soil physical and chemical properties. Submerged and soft mangrove soil will dry out and display compaction when drainage occurs. At the same time, this soil also has the potential to undergo soil acidification which is a major threat for tree growth. Apart from that, seasonal wave effects and tidal changes can transport sand in huge quantities to the shore, forming a thick layer of sand at the base of the mangroves, suffocating the trees and disrupting their survival.



The massive sand embankment washing over the shore causing severe damage and mortality to the mangrove stand in Banting Selangor (left) and Kuala Muda, Penang (Right).



Drained mangroves soil display dry and compacted soils that allow invasive species, such as grasses and shrubs, that compete with the planted mangrove trees.

4. Conclusion

In sum, mangrove ecosystems depend on the species of the mangrove and environmental changes. Understanding the original nature of mangrove soils, environmental factors, location, wave pressure, species selection and planting techniques are pertinent for the establishment of healthy mangroves that can sustain the soil environment.

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Status of Mangroves in Malaysia is a successor to the book with a similar title that was published in 2020. The current publication is an update on the status, extent and distribution of mangroves in Malaysia. The concept of this book is similar to the previous one, where the latest information on mangroves are included to expose the reader to the richness of our priceless, pristine mangrove ecosystem in Malaysia.

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