



# THREATENED MANGROVE ECOSYSTEMS

Rupat Island, Riau

## Abstract

Known for its mangroves and white beaches, RUPAT island is a popular tourist destination and hub for coastal activity (Aziz, 2023). Between the years 1980 and 2001, mangrove areas across the globe declined between 30-50%, with 16% of mangrove species now facing extinction (Cárdenas, 2017; Hastuti et al, 2023). Sites such as RUPAT require ever increasing protection to mitigate and prevent further damage.

Various ecosystem services are provided by RUPAT's mangrove ecosystems including blue carbon sequestration, a key element of global CO<sub>2</sub> storage (Alongi, 2012; Charoenlerkthawin et al, 2024). Also identified were numerous financial benefits to the local community, which can be summarised as support of coastal productivity (Charoenlerkthawin et al, 2024; Ilahi et al, 2024). Provision of habitats, particularly for benthic fauna is another key benefit of these ecosystems (Nasution et al, 2021).

Reviewing the literature, most sources suggest there are four major threats to RUPAT's coastal ecosystems. These include deforestation (typically for aquaculture and logging), pollution, sea level rise and tourism (the two latter threats being anticipated to greatly increase) (Hadi and Jamilah, 2025).

In regard to mangrove remediation, most successful schemes have resulted from small-scale community driven projects; cost and lack of effective governance were identified as the two key barriers to progress in this matter (Berutu et al, 2023; Hadi and Jamilah, 2025). Despite these limitations, ease with which large quantities of inexpensive data can be procured, has increased the efficiency with which future conservation schemes can be carried out (Agustiyara et al, 2023).

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# 1 Introduction

## 1.1 Setting –

Rupat island is a small, low-lying tropical island (roughly 1500km<sup>2</sup>) located in the province of Riau (figure 1) (Bing Maps, 2023). Located in the Malacca Strait, it faces Malaysia to the north-east, and Dumai City to the south-west; a key feature of Rupat island is its connectivity to Malaysia (Bing Maps, 2023; Prayuda et al, 2025).

It is separated from the mainland by the Rupat Strait and made up of two distinct localities shown in figure 2: North Rupat (Rupat Utara) and Rupat District (Bing Maps, 2023). North Rupat's mangroves far outweigh any other district in the Bengkalis Regency, accounting for over 10,000 hectares (Rustam et al, 2022).

The vast majority of human populations exist around the coastline, with the local economy relying heavily on the fishing and tourism industry (Husaini et al, 2021). Rupat's beaches are renowned for their beauty (partly due to their high silica content taken from the Malacca Strait) (Aziz et al, 2023). This makes them

a popular destination for both domestic and international tourists (Aziz et al, 2023).

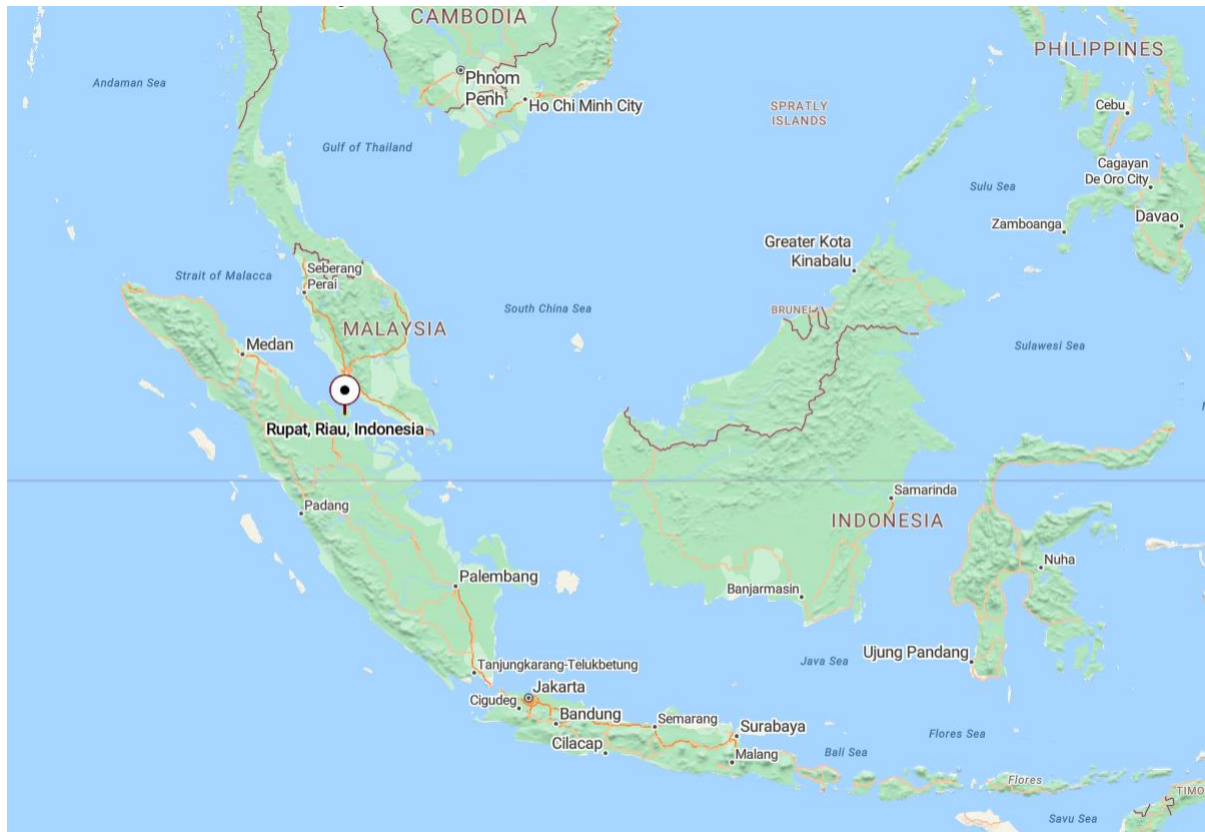


Figure 1 Rupert Island location within Indonesia (Bing Maps, 2023)

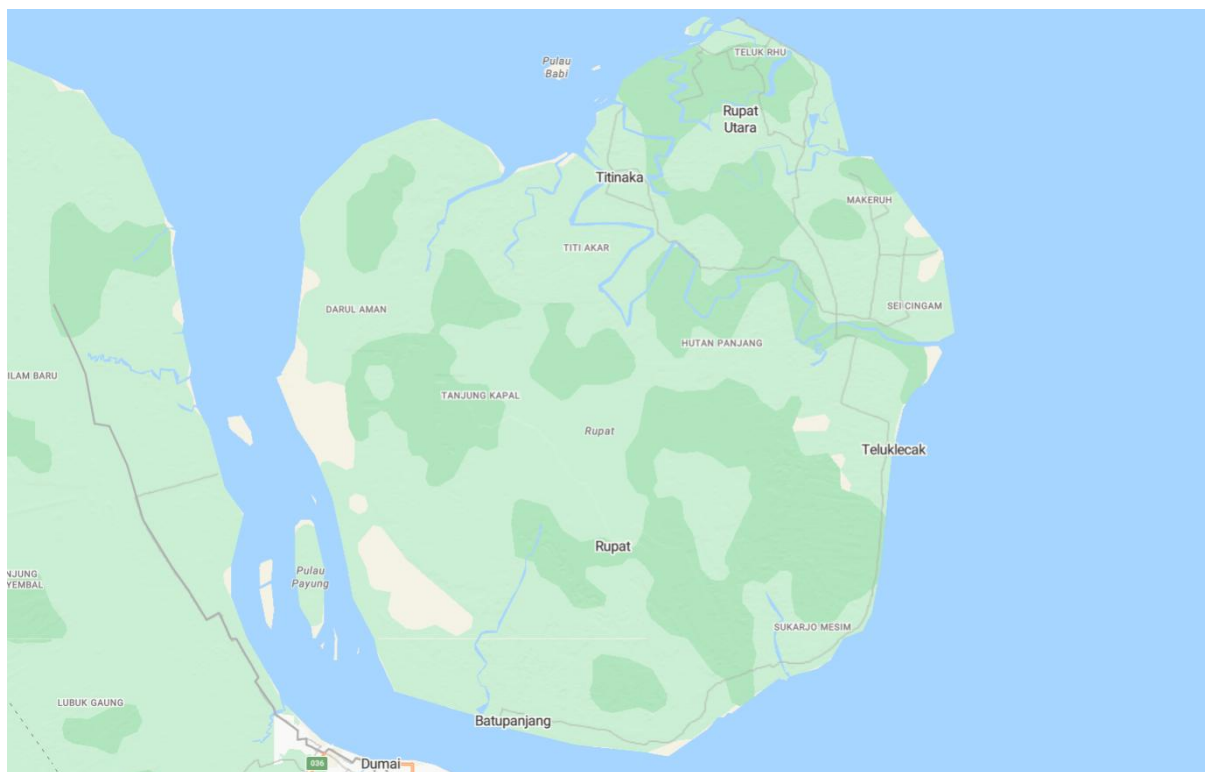


Figure 2: Map of Rupert Island (Bing Maps, 2023)

## 1.2 Ecosystem Significance –

One of the key ecosystem services provided by sites like Rupat include blue carbon sequestration which, despite its land coverage, accounts for a significant percentage of global carbon storage and is particularly relevant in light of rising atmospheric CO<sub>2</sub> levels (Alongi, 2012; Yllano, 2023). This can be seen in figure 3, where mangrove belowground biomass is shown to outweigh any other forest type (over four times the capacity of boreal forest, the next largest store) (Alongi, 2012).

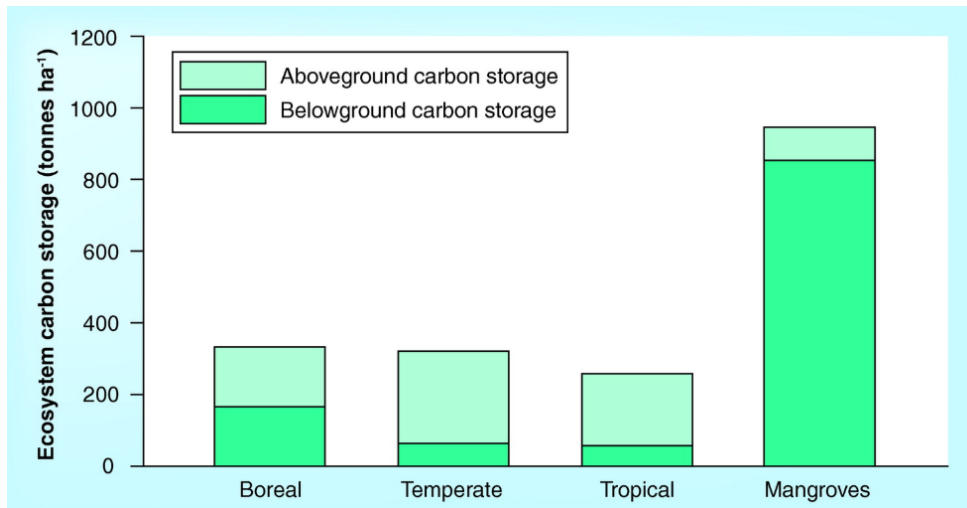


Figure 3: Ecosystem carbon storage (Alongi, 2012)

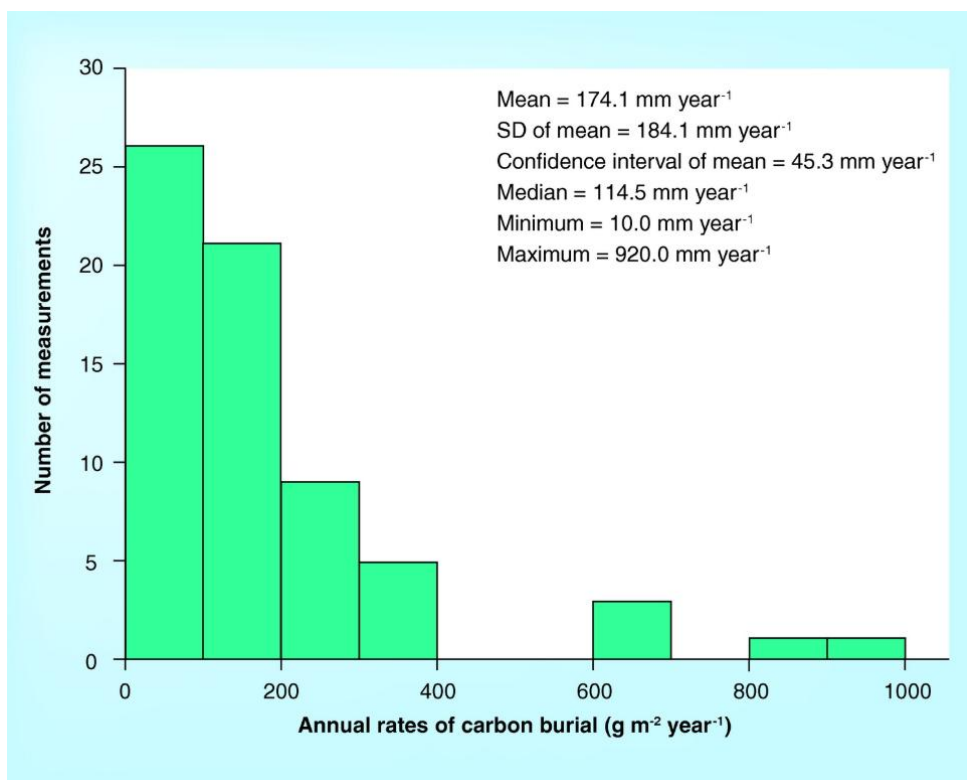


Figure 4: Annual carbon burial rates (Alongi, 2012)

Benthic fauna in Rupert's coastal environments consists of many keystone species, which underpin overall ecosystem health, acting as a food source and contributing to water filtration (Nasution et al, 2021). They are relied upon for the many ecosystem services provided by these areas, particularly the fishing industry, which is accountable for much of the local economy (Ilahi et al, 2024). As many of these species are immobile, they are also one of the most threatened groups with relation to sea level rise, habitat destruction and pollution (being unable to evade changing conditions) (Fathurrahman et al, 2025; Nasution et al, 2021).

Nurhati and Murdiyarso (2023) in the National Strategy for Mangrove Ecosystem Management, state that:

"Based on the National Mangrove Map issued by the Ministry of Environment and Forestry (KLHK) in 2021, Indonesia's mangroves cover an area of 3,364,080 ha, or nearly a quarter of the world's mangroves"

Indonesia relies on coastal areas for roughly 28% of its national income (Hadi and Jamilah, 2025). This makes sites such as Rupert integral to the national economy, on top of the cultural and social benefits they provide (Hadi and Jamilah, 2025; Hastuti et al, 2023). Again in relation to the local economy, mangroves provide a wide range of material and economic resources including food, building materials and ecotourism potential (Berutu, 2023). In the study carried out by Berutu (2023), mangrove restoration projects can be shown to have the potential for significant economic as well as social benefit, particularly for the long term.

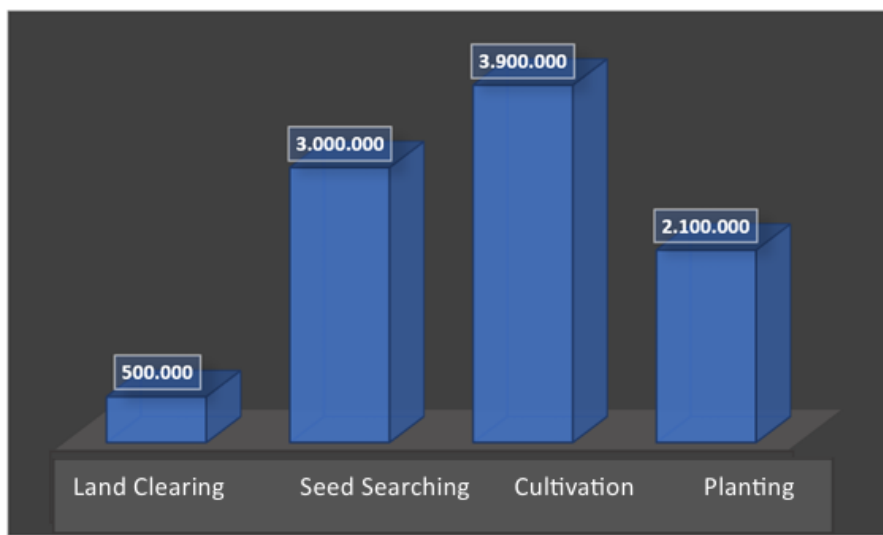


Figure 5: Graph of community income from mangrove restoration (1,000,000rp equivalent to roughly \$60) (Berutu, 2023)

## 2 Discussion

### 2.1 Deforestation –

A major threat faced by Rupert island is deforestation. In recent years remote sensing using LIDAR and satellite technology has played a key role in the monitoring of land use change across Rupert (Agusti et al, 2025). Data from these technologies typically manifest in spectral images (figure 6), which particularly useful in providing an insight into land use change over time (table 1); the mangrove vegetation index (MVI) being most relevant to this study (Agusti et al, 2025). Given the scope of data provided, these developments provide potential widespread benefits to forest governance (Agustiyara et al, 2023).

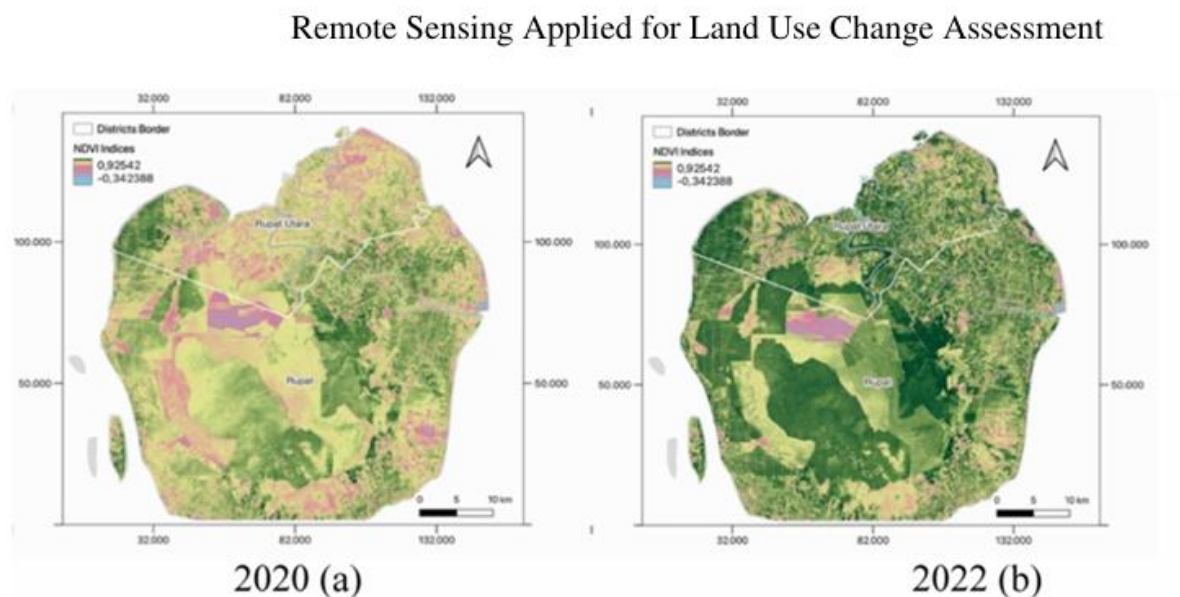


Figure 6: Rupert land use change between 2020-2022 (Agustiyara et al, 2023)

| No | Detailed changes                                                | Hectares  |
|----|-----------------------------------------------------------------|-----------|
| 1  | A new mangrove emerged in 2023                                  | 127,02    |
| 2  | Mangrove decreased in 2023 after being present in 1989 and 2006 | 240,38    |
| 3  | Mangrove only existed in 1989, but not in 2006 and 2023         | 151,77    |
| 4  | Mangrove only existed in 2006, but not in 2023                  | 37,30     |
| 5  | Mangrove reappeared or increased in 2023 after existing in 1989 | 44,94     |
| 6  | Mangrove reappeared or increased in 2023 after existing in 2006 | 55,66     |
| 7  | Mangrove consistently present from 1989, 2006, to 2023          | 10.385,75 |

Table 1: Mangrove area changes since 1989 (Darlis et al, 2024)

Although technologies such as LIDAR have provided a vast body of data, the insight they provide is purely visual (Agusti et al, 2025; Agustiyara et al, 2023). Key indicators of ecosystem health may be overlooked if these technologies are used in isolation, without the benefit of data collection on the ground (e.g. surveys and land use assessments) (Agustiyara et al, 2023). In addition to this, enhanced monitoring, whilst useful in illuminating the issues, is still ultimately dependent on the action taken. In Rupert's case, restoration efforts are limited, particularly at the national scale (Agustiyara et al, 2023; Berutu et al, 2023; Hadi and Jamilah, 2025).

The primary driving forces behind mangrove deforestation include logging (particularly when illegal) and shrimp farming (table 3 + 4), a practise which involves clearing land for net traps (Ilahi et al, 2025). Rupert's economy relies heavily on fisheries, however, alternative techniques can provide support to both mangroves and fisheries (Rustam et al, 2022). One such strategy is silvofishery, which involves channelling water through pond trenches, bordered by mangroves (Fairatmos, 2025; Rustam et al, 2022). These methods provide nutrient cycling and support biodiversity whilst maintaining yield (Fairatmos, 2025). Other benefits include enhanced water quality (including disease resistance), and improved quality of catch (Fairatmos, 2025).

| No. | Name of company/Business owner            | Pond area (ha) | Land area (ha) |
|-----|-------------------------------------------|----------------|----------------|
| 1.  | Kelompok Pembudidaya Ikan Lapin Bersama   | 8              | 8              |
| 2.  | Pembudidaya AHOI                          | 2              | 2              |
| 3.  | Kelompok Pembudidaya Dokoh Jaya           | 4              | 4              |
| 4.  | Kelompok Usaha Bersama Bintang Tri        | 2              | 2              |
| 5.  | PT. Fisheri Berkah Utama                  | 3              | 8              |
| 6.  | CV. Sumber Rezeki                         | 8              | 8              |
| 7.  | Kelompok Pembudidaya Ikan Bangkit Bersama | 2              | 2              |
| 8.  | Kelompok Pembudidaya Ikan Lele Pesisir    | 0.4            | 1              |
| 9.  | Kelompok Pembudidaya Ikan Ulu Medang      | 0              | 2              |
| 10. | Pembudidaya Muhammad Agustar              | 1              | 2              |
| 11. | Pembudidaya Abdul kadir                   | 0.15           | 7              |
| 12. | Kelompok Pembudidaya Songeng Maju Bersama | 0              | 4              |
| 13. | Yayasan Rupert Utara Madani               | 1              | 1              |
| 14. | Pembudidaya Evi                           | 4              | 4              |
|     | Total (ha)                                | 35.55          | 55             |

Table 2: Shrimp cultivation area across North Rupert (Ilahi et al, 2024)

| No. | Name of company/Business owner                | Pond area (ha) | Land area (ha) |
|-----|-----------------------------------------------|----------------|----------------|
| 1.  | Kelompok Pembudidaya Ikan Samudra Tanjung     | 2              | 2              |
| 2.  | Kelompok Pembudidaya Harapan Selat Morong     | 4              | 4              |
| 3.  | Kelompok Pembudidaya Ikan Laut Ketapang       | 2              | 6              |
| 4.  | Kelompok Pembudidaya Ikan Teluk Pelam Lestari | 2              | 8              |
| 5.  | PT. Mitra Hayati Sejahtera                    | 6              | 6              |
| 6.  | PT. Marindo Utama Lestari                     | 50             | 50             |
| 7.  | PT. Tambak Libu Sagara                        | 30             | 30             |
| 8.  | Kelompok Pembudidaya Ikan Bina Sejahtera      | 4              | 4              |
|     | Total (ha)                                    | 100            | 110            |

Table 3: Shrimp cultivation area across Rupert District (Ilahi et al, 2024)

Mangrove restoration has received limited attention across Rupert, although a notable project was carried out in the village of Batu Panjang (figure 7 + 8), largely spearheaded by the local community (Berutu et al, 2024). This involves cultivating and planned planting of mangrove seeds (Berutu et al, 2024; Charoenlerkthawin et al, 2024).

Difficulties arise when ensuring plants establish in the early growth faze; this may require aids such as bamboo fencing to trap sediment and increase rooting success (coastal abrasion from accelerated wave / tide action can greatly inhibit this) (Charoenlerkthawin et al, 2024). Once initiated, natural succession should take hold, beginning with the pioneer species (Charoenlerkthawin et al, 2024). Due to the dynamic nature of

tidal and wave processes, monitoring is key throughout the entire process (Charoenlerkthawin et al, 2024).



Figure 7: Mangrove seedling nursery Batu Panjang (Berutu et al, 2023)



Figure 8: Mangrove planting Batu Panjang (Berutu et al, 2023)

Further inland, acacia and palm plantations have resulted in peat degradation and peat fires (Tonoto (2015). Tonoto (2015) suggests that the major issues which contribute to peatland fires includes poor land management strategies as well as insufficient law enforcement. They also stress the importance of protecting the central peat dome (an area of >4m depth, figure 9), in order to conserve natural function of the drainage basin, as well as a valuable carbon store (Tonoto, 2015). Whilst these areas are not coastal, changes in their function are deeply interrelated with coastal systems by proxy.

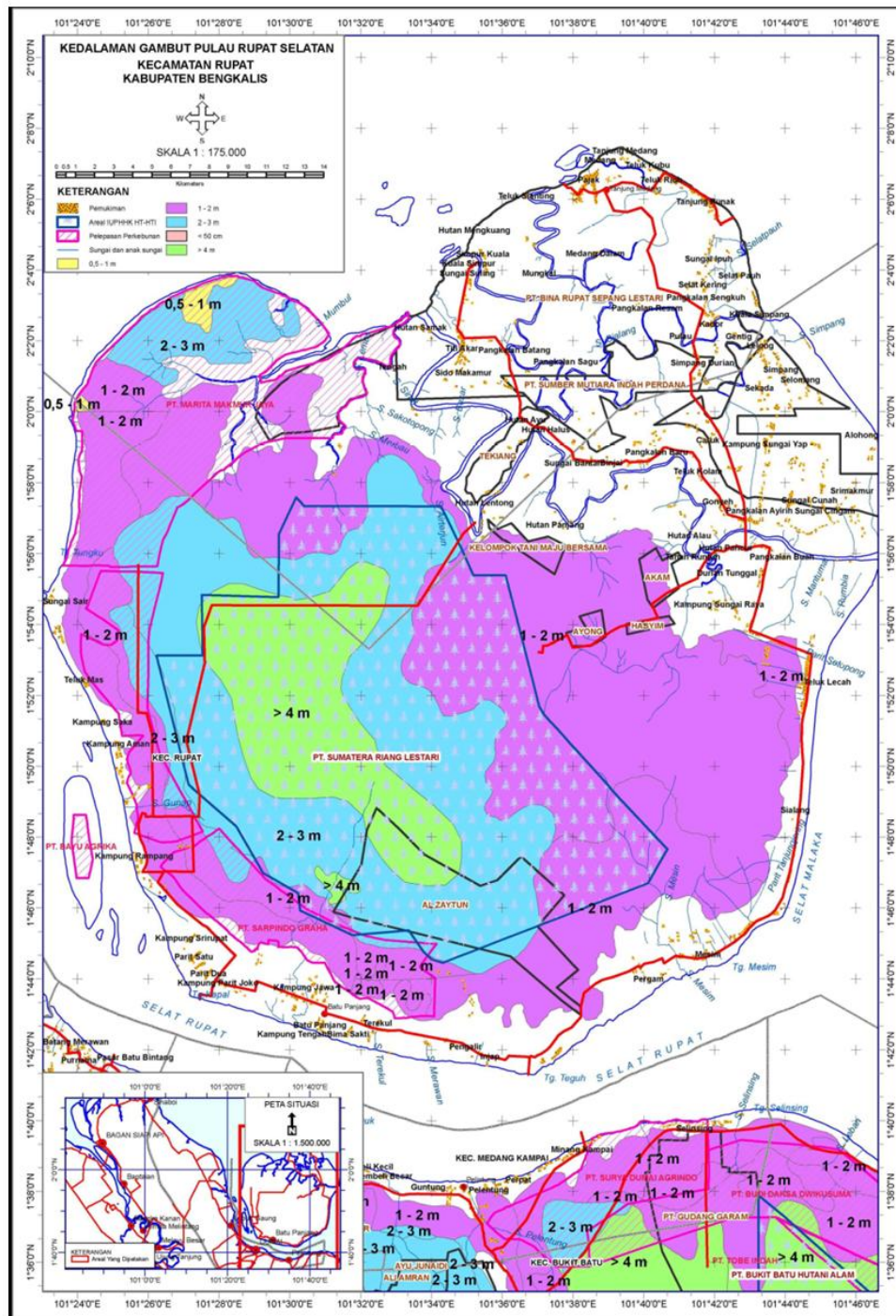


Figure 9: Peat depth across Rupat District (Tonoto, 2015)

## 2.2 Sea Level Rise and Pollution –

Sea level rise is arguably the biggest threat to Rupat island due to its low-lying nature (Husaini et al, 2022). Early symptoms of damage include changes to bathymetry, unbalanced coastal accretion / abrasion and changes in marine sediments (Rifardi, 2021). These changes heavily influence marine biology in the area (Rifardi, 2021).

Tidal variation on Rupert consists of currents moving from the south-east to the north-west at low tide, and south-east to north-west at high tide (in accordance with the currents in the Malacca Strait) (Fathurrahman, 2025). Changes in the coastline happen in accordance with these currents (albeit with increased intensity due to sea level rise) (Fathurrahman, 2025).

Echo sounding, carried out across sixty stations, has provided data on changes to the bathymetry of the Rupert Strait over the last 28 years (Rifardi, 2021). This has shown a general trend of deepening, despite ample sediment supply from the Malacca Strait and river discharge (Rifardi, 2021). Rifardi (2021) suggests that this is the result of the rapid development of Dumai City, leading to erosion of surface soils. Rifardi, Nedi and Aminah (2023) build upon the role of human activities as major influences on coastline change. This includes urbanisation, shown in the Tanjung Kapal port and various other land management practises such as land clearing (Rifardi, Nedi and Aminah, 2023).

From a sustainability perspective, coastal abrasion and changing oceanic currents are already leading to deficiencies in local business infrastructure (Ilahi et al, 2025). Husaini et al (2022) identified the rate of coastline abrasion to be upwards of 3.5 meters per year. Table 4 describes coastal vulnerability using a numeric index, revealing a correlation between vulnerability and location, with sites in the south / south-west being most at risk (Husaini et al, 2021).

| No | Area                  | Total  | Vulnerability |
|----|-----------------------|--------|---------------|
| 1  | Pergam, Rupert        | 109.54 | Very High     |
| 2  | Tanjung Jaya, Rupert  | 80     | Very High     |
| 3  | Kedur, Rupert         | 50.6   | High          |
| 4  | Teluk Rhu, Rupert     | 48.99  | Medium        |
| 5  | Batu Panjang, Rupert  | 42.43  | Medium        |
| 6  | Tanjung Lapin, Rupert | 34.64  | Medium        |
| 7  | Tanjung Punak, Rupert | 28.28  | Medium        |
| 8  | Tanjung Kapal, Rupert | 28.28  | Medium        |
| 9  | Makeruh, Rupert       | 12.65  | Low           |

Table 4: Coastal vulnerability index (CVI) (Husaini et al, 2021)

Changing oceanic conditions have given rise to increasingly frequent flooding and storm surge events, as well as unpredictable weather patterns, which have impacted coastal communities in Rupert (Fathurrahman et al, 2025). Traditionally, hard engineering strategies have been favoured across many sites (example shown in figure 10), despite limitations regarding upfront costs, maintenance, and harmful impacts on local ecology (Magdalena et al, 2022; McIvor et al, 2013). More recently, studies have looked towards soft engineering strategies, including mangrove restoration, as a cost-effective and sustainable alternative, which works on a basis of environmental synergy (Charoenlerkthawin et al, 2024; Magdalena et al, 2022).

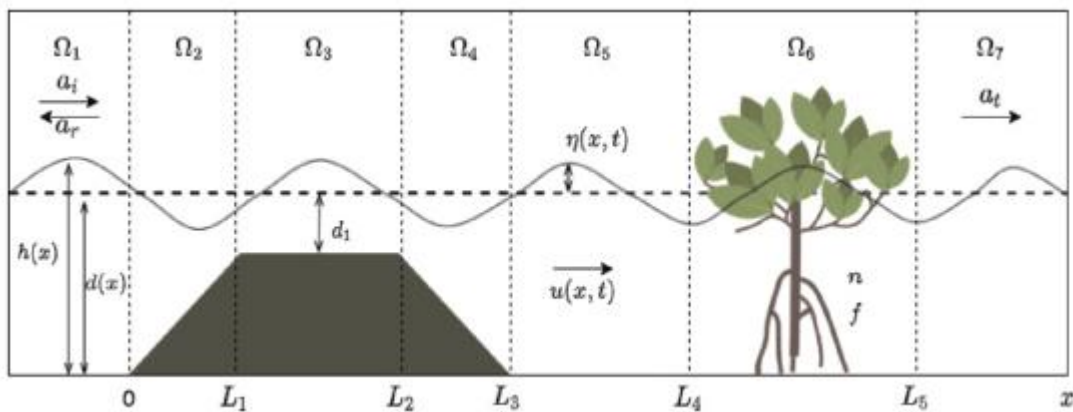


Figure 10: Submerged breakwater coastal defences (Magdalena et al, 2022)

As a prospective mariculture centre, Rupert relies on stable oceanic conditions for seaweed, vanamei shrimp and white snapper cultivation (Ilahi et al, 2025). Aside from rising sea levels, pollution, largely from growing development in Dumai City, poses an ever-growing threat in the form of ocean acidification (Aulia et al, 2024; Oktaviani et al, 2023). Much of the benthic fauna around Rupert is heavily sensitive to these changes, particularly bivalves including the endemic sharp razor clam species (figure 11) (Nasution et al, 2022; Nasution et al, 2021).



Figure 11: Bivalve species diversity (including the endemic sharp razor clam *Pharella acutidens*) (Nasution et al, 2021)

Sources often use contrasting standards when referring to the extent of pollution in the coastal waters around Rupert. Aulia et al (2024), describes all sites they measured in the Rupert Strait as “lightly polluted” referring to the pollution index, whilst Ondara et al (2022), states that heavy metals (specifically copper, cadmium and zinc) have (across around 30% of sites) “exceeded specified quality standards set by the Ministry of Environment”. Retnawaty et al (2023) identifies seasonal variance in water contamination, with higher pollution being observed in the dry season compared with the wet season. Despite minor distinctions there is general consensus around an increasing future risk of pollution, particularly to the Rupert Strait (Aulia et al, 2022; Ondara et al, 2022).

Aulia et al (2022) comments on the dissolved oxygen (DO) and biological oxygen demand (BOD), which shows wide variation between high and low tide. This reflects current patterns in the Rupert Strait which routinely circulate nutrients (Aulia et al, 2022).

## 2.3 Tourism –

In order to gauge the current size of the ecotourism industry on Rupert, one study surveyed visitors 'Willingness to Pay' (WTP), using questionnaires (randomly sampled qualitative data) (Warningsih et al, 2021). Results showed that, on average, visitors were willing to pay 15,000Rp (equivalent to £0.68) as an entrance fee. Extrapolated to a monthly rate, this figure could provide around 230,000,00Rp (£10,425) for maintenance of tourist spots and general conservation efforts (Warningsih et al, 2021).

Rupat's tourism potential is nationally recognised, meaning it has fallen under the designation of the National Tourism Strategic Area (KSPN) (Husaini et al, 2022). This will heavily influence infrastructure development going forward, and has largely unknown implications for the environment (Husaini et al, 2022). Whilst financially beneficial, if practised unsustainably, it could heavily damage natural ecosystems. This is alarming as Prayuda et al (2021), suggests that the infrastructure for ecotourism is not yet present. Warningsih et al (2021) agrees, stating that environmental disadvantages of tourism are significant, and have to be considered.

Hadi and Jamilah (2025) emphasise the importance of governance, specifically the role of long-term management, to sustain progress without stagnation:

"policy entrepreneurship, while capable of catalyzing dramatic developmental transformation, remains fundamentally vulnerable to political transitions in the absence of robust institutional embedding mechanisms." (Hadi and Jamilah, 2025).

## 3 Conclusion

### 3.1 Overall Findings –

In Indonesia around 26% of overall GDP is sourced from marine and coastal resources / activities (Berutu et al, 2024). Rupert's coastal environments represent a small component of the wider national picture, whilst having major local significance in their support of livelihoods and culture. In the uncertain landscape of climate change, the role of these environments is invaluable to maintaining a sustainable future.

Plans to expand tourism and fishery infrastructure pose threats to the ecology on Rupert island, particularly as the infrastructure for ecotourism is not supported (Ilahi et al, 2025; Prayuda et al, 2025). Despite the short-term economic benefits practises such as logging may have, they have been shown to decrease long term productivity, and damage the island through coastal erosion and habitat destruction (Husaini et al, 2021).

### 3.2 Future Action –

The development of technology, particularly satellite mapping, has huge potential in combating deforestation due to its broad scope and cost-effectiveness (Agusti et al, 2025; Agustiyara et al, 2023). Given the success of grassroots schemes demonstrated in Batu Panjang, future management should look to increase the scope of such projects by connecting with stakeholders and taking advantage of technology / citizen science where possible (Berutu et al, 2023; Darlis et al, 2024).

Because the local economy is a key factor in remediation efforts, alternatives have to show robust economic results, such as those demonstrated in silvofishery (Berutu et al, 2023; Fairatmos, 2025). Equally, it is important to recognise the importance of environmental resilience, and that unsustainable practises can negatively impact livelihoods long-term.

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