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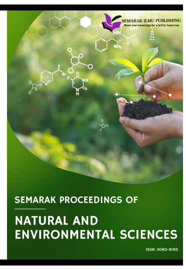

Temporal Changes in Seaweed Diversity and Abundance at Pulau Merambong, Johor: Progress and Impacts of Land Reclamation From 2014 to 2025

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ABSTRACT

Merambong Island is rich in seaweed biodiversity, despite ongoing long-term environmental disturbances such as land reclamation and shipping activities. This study assessed the temporal changes in seaweed diversity and abundance in Merambong Island from 2014 to 2025, focusing on progress and ecological impacts from the land reclamation for Forest City development. Physical specimens that were growing as epipsammic, epiphytic, epilithic, epizooic, and epipelic as well as on artificial substrate were collected using a destructive line transect-quadrat method. A total of 86 seaweed species have been recorded from 2014 to 2025, across five survey years representing pre-reclamation (2014), during reclamation (2016), and three post-reclamation periods (2019, early 2024 and late 2024). One-way ANOVA showed significant differences, where $p = 0.01$ ($p < 0.05$) that indicated substantial temporal variation. *Cladophora stimpsonii* was identified as the dominant species in Merambong Island for the recent observation in late 2024. The successfully acclimatized species throughout 2014 to 2025 observation were *Avrainvillea erecta, Caulerpa sertularioides, Gracilaria salicornia, Hypnea spinella* and *Padina minor*. Thirteen genera (Acanthophora, Avrainvillea, Bryopsis, Caulerpa, Cladophora, Dictyota, Halimeda, Jania, Laurencia, Padina, Sargassum, Tolypiocladia, and Ulva) were only observed pre-, during and post-reclamation but were absent from the most recent observation in late 2024, suggesting that they are sensitive to environmental disturbances. Comparative analysis pre-reclamation (2014) and post-reclamation (early 2024) indicated a decline in seaweed diversity. However, by late 2024 there was evidence of ongoing recovery of opportunistic species such as *Caulerpa lentillifera*. Long term monitoring revealed significant changes in species composition, spatial coverage and community structure throughout the environmental disturbance.

Keywords: Anthropogenic; impact; marine; seaweed

1. Introduction

Johor is known for its diverse biodiversity in seaweed and seagrass communities that provide valuable ecosystem services such as habitat provision, nursery grounds and food sources. Merambong Island located in Johor Strait is rich in seaweed biodiversity, and has continuously been exposed to long-term shipping activities due to Port of Tanjung Pelepas [1]. Since 2016, the area has been subjected to substantial land reclamation anthropogenic activities due to the Forest City

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project, raising ecological concerns regarding disruption, changes in physical habitat, increase in sedimentation and potentially threatening seaweed diversity and composition [2].

Seaweed is a primary producer in the coral ecosystem and forms a part of a trophic chain that can be categorized into three groups which are Chlorophyta (green), Phaeophyta (brown) and Rhodophyta (red) based on their photosynthetic pigments, cell wall structure and flagella. Seaweed depends on physicochemical parameters such as pH, salinity, dissolved oxygen, temperature, and nutrient availability. According to Chen [3], seaweed is sensitive to environmental changes, caused by both natural and human-induced disturbances.

Thus, this research aimed to compare the changes of seaweed diversity from 2014 to 2025, by combining pre-reclamation [4], during reclamation and post-reclamation studies [1,5]. This extended timeframe would allow a more detailed understanding of seasonal and anthropogenic influences on the seaweed communities in Merambong Island, particularly in the context of ongoing coastal development.

2. Methodology

2.1 Study Area

Merambong Island (1° 18’ 58” N 108° 36’ 36” E) is located approximately 1.8 km from the Port of Tanjung Pelepas (PTP), Johor, Malaysia, situated facing the mouth of Sungai Pulai estuaries. Recent specimen collection encompassed four distinct habitat types namely sandy (Station 1), mangrove/rocky (Station 2), rocky (Station 3), and muddy/mangrove substrates (Station 4) (Figure 1). Geographic coordinates for each sampling station were recorded using a Garmin eTrex GPS (Garmin, USA).

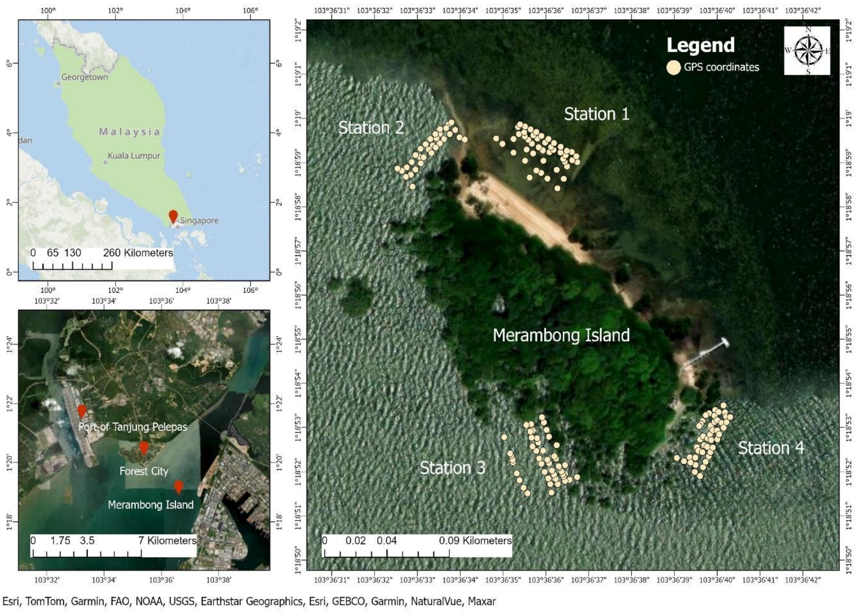

Fig. 1. The study area in Merambong Island, Johor

2.2 Compilation of published data

Published seaweed diversity data were gathered from pre-reclamation (2012-2014), during reclamation (2015-2017) and post-reclamation period (2018-now). The data originated from standardized transect-quadrat surveys and species inventories were conducted following standardized sampling protocols.

2.3 Specimen Collection

Seaweed specimen was collected from Merambong Island between November 2024 and August 2025 using destructive line transect-quadrat method along the shoreline during daylight and low tide conditions. The sampling was conducted using quadrat (50 x 50 cm) subdivided into smaller (10 x10 cm) squares with 5 replications for each station, along the 50 meters transect line.

2.4 Environmental Parameter

In-situ physicochemical parameters including pH, salinity, temperature, and dissolved oxygen were measured using a Hanna multiparameter (Hanna Instruments, Romania). Water samples were collected for *ex-situ* nutrient analysis of nitrate, phosphate, and ammonia using a Hach Portable Spectrophotometer (Hach Company, United States).

2.5 Herbarium Specimen Preparation and Morphological Identification

Collected seaweed specimens were carefully cleaned on site to remove any sand, stones, and mud. Taxonomic identification of seaweed specimens was conducted by referring to book references such as Ahmad [6] and authoritative databases such as Algaebase and World Register of Marine Species (WoRMS). Samples were dried and deposited at the Herbarium of Universiti Kebangsaan Malaysia for future reference.

2.6 Data analysis

Species abundance and diversity indices were calculated and compared temporally, supported by one-way ANOVA to evaluate the significance of observed changes.

3. Results & Discussion

Long term monitoring of seaweed diversity across pre-reclamation (2014), during reclamation (2016), and three post-reclamation periods consisted of I (2019), II (early 2024), and III (late 2024), revealed significant temporal variation ($p=0.01$, $p<0.05$). Tukey's pairwise comparison indicated very significant difference ($p=0.0007$) between post-reclamation I (2019) and post-reclamation II (2024), as well as significant difference between pre-reclamation (2014) and post-reclamation II (2024), $p=0.0131$ (Table 1). Diversity indices calculated from this data are summarized in Table 2, where Simpson and Shannon diversity index was highest in post-reclamation I (Simpson 0.978, Shannon 3.807), and lowest in post-reclamation II (Simpson 0.95, Shannon 2.996). Dominance was lowest in post-reclamation I (0.222), and highest in post-reclamation II (0.050). Diversity indices peaked in post-reclamation I, followed by a decline in post-reclamation II (early 2024) and an ongoing recovery in post-reclamation III (late 2024). The decline in biodiversity in early 2024 likely reflected habitat degradation and environmental disturbances from land reclamation, consistent with documented impacts on coastal ecosystem in the region [2].

Table 1
One-way ANOVA pair-wise tests for differences in seaweed diversity between the pre-reclamation, during reclamation, post reclamation I, II, and III. (*denoted as very significant difference value)

Source of Variation	p-value
Pre-reclamation × During reclamation	0.7103
Pre-reclamation × Post-reclamation I	0.9327
Pre-reclamation × post-reclamation II	0.0131*
Pre-reclamation × post-reclamation III	0.9327
During reclamation × Post-reclamation I	0.2367
During reclamation × post-reclamation II	0.3154
During reclamation × post-reclamation III	0.9895
Post-reclamation I × post-reclamation II	0.0007*
Post-reclamation I × post-reclamation III	0.5062
Post-reclamation II × post-reclamation III	0.1209

Table 2
Diversity indices for each sampling station in Merambong Island, Johor

Parameter	Pre-reclamation (2014)	During reclamation (2016)	Post-reclamation I (2019)	Post-reclamation II (early 2024)	Post-reclamation III (late 2024)
Species Richness	40	32	45	20	35
Simpson's Dominance Index	0.025	0.031	0.022	0.050	0.029
Simpson's Diversity Index	0.975	0.969	0.978	0.950	0.971
Shannon Diversity Index	3.689	3.466	3.807	2.996	3.555

A comprehensive species list from Merambong Island (2014–2025) successfully recorded 86 seaweed species, which consisted of 3 divisions, 13 orders and 23 families. A total of 37 species belong to the division of Chlorophyta, 14 species to the division of Phaeophyta, and 35 species to the division of Rhodophyta. During recent observation conducted in late 2024, *Cladophora stimpsonii* was emerged as the dominant species in Merambong Island. Species that successfully acclimatized and persisted throughout 2014 to 2025 observation were *Avrainvillea erecta, Caulerpa sertularioides, Gracilaria salicornia, Hypnea spinella* and *Padina minor*. Thirteen genera (*Acanthophora, Avrainvillea, Bryopsis, Caulerpa, Cladophora, Dictyota, Halimeda, Jania, Laurencia, Padina, Sargassum, Tolypiocladia*, and *Ulva*) appeared pre-, during and post-reclamation but were undetected from the most recent observation in late 2024, which aligns with previous studies that indicates decline of seaweed species (40 to 19 species) following Forest City development [5].

4. Conclusions

This study at Merambong Island reveals reclamation-induced shifts in seaweed assemblages, characterized by *Cladophora stimpsonii* dominance and persistence of five acclimatized species (*Avrainvillea erecta, Caulerpa sertularioides, Gracilaria salicornia, Hypnea spinella* and *Padina minor*) following disturbances. To date, long-term assessment of anthropogenic impacts on seaweed diversity have revealed significant decline of the diversity and the communities shows early recovery stage by the re-emergence of opportunistic seaweed such as *Caulerpa lentillifera*.

Acknowledgement
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