CHOE JIA YI

MASTER OF SCIENCE

2025

THE EFFECTS OF TWO EMERGENT MACROPHYTES (*Hanguana malayana* AND *Pandanus helicopus*) ON THE WATER PARAMETERS AND SEDIMENTATION RATES IN TASIK BEROMBAK, SETIU, TERENGGANU

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CHOE JIA YI

Thesis Submitted in Fulfilment of the Requirement for the Master of Science in the Faculty of Science and Marine Environment Universiti Malaysia Terengganu

MAY 2024

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Dedicated this thesis to:

My parents, supervisors, friends

Who are my anchor throughout the storm & turbulence

I owe you guys, big time

Thanks a lot

Abstract of thesis presented to the Senate of Universiti Malaysia Terengganu in fulfilment of the requirements for the degree of Master of Science

THE EFFECTS OF TWO EMERGENT MACROPHYTES (*Hanguanamalayana* AND *Pandanus helicopus*) ON THE WATER PARAMETERS AND SEDIMENTATION RATES IN TASIK BEROMBAK, SETIU, TERENGGANU

CHOE JIA YI

MAY 2024

Main Supervisor : Associate Professor Rohani Shahrudin, Ph.D

Co-Supervisor : Associate Professor Poh Seng Chee, Ph.D

Faculty : Faculty of Science and Marine Environment

Emergent macrophytes plays crucial role in maintaining health and functionality of lake ecosystems, but their rapid growth can have adverse effects. In Tasik Berombak, Setiu, anthropogenic activities have altered macrophyte abundance and lake structure, with *Hanguana malayana* emerging as a dominant species, reducing lake's surface area. However, the specific impacts of *H. malayana* on Tasik Berombak remain poorly understood. This study aimed to investigate the effects of emergent macrophytes on water parameters and sedimentation rates in the lake. Three sampling sites were selected: areas dominated by *H. malayana*, areas dominated by *Pandanus helicopus*, and a non-vegetated control site. Kruskal-Wallis test indicated that concentrations of chlorophyll-a and total dissolved nitrogen (TDN) at *H. malayana*-dominated site were significantly different from those at *P. helicopus*-dominated and non-vegetated sites, H (2) = 8.3, p = 0.015 (chlorophyll-a); H (2) = 15.7, p <0.001 (TDN). *Hanguana malayana*-dominated site had the highest chlorophyll-a (0.02 ± 0.01 mg/L) as compared to *P. helicopus*-dominated (0.02 ± 0.01 mg/L) and non-vegetated sites (0.01 ± 0.01 mg/L). By contrast, the concentration of TDN was the lowest in *H. malayana*- dominated site (0.22 ± 0.02 ppm), as compared to *P. helicopus*-dominated (0.31 ± 0.07 ppm) and non-vegetated sites (0.38 ± 0.13 ppm). Total suspended solid (TSS) values varied significantly across all three sites, *H*

(2) = 23.0, p <0.001, with the highest mean TSS value observed in *P. helicopus*-dominated area (8.60 ± 4.38 mg/L), followed by *H. malayana*-dominated area (6.09 ± 3.37 mg/L) and non-vegetated area (3.67 ± 0.76 mg/L). Sediment deposition rate was significantly higher in the unvegetated area compared to the vegetated area, H (2) = 15.0, p <0.001. The sedimentation rate in non- vegetated area was 0.132 ± 0.092 g/m^2/day, while in *H. malayana*-dominated and *P. helicopus*-dominated areas was 0.067 ± 0.01 g/m^2/day and 0.03 ± 0.015 g/m^2/day, respectively. Each sampling site also displayed different controlling factors which influenced sedimentation rates. Total dissolved phosphorus (TDP) was the primary factor in vegetated areas, while pH was most influential in non-vegetated area. In conclusion, emergent macrophytes significantly influence water quality parameters and reduce sedimentation rates in Tasik Berombak.

Abstrak tesis yang dikemukakan kepada Senat Universiti Malaysia Terengganu
sebagai memenuhi keperluan untuk Ijazah Sarjana Sains

KESAN DUA MAKROFIT MUNCUL (*Hanguana malayana* DAN *Pandanus helicopus*) TERHADAP PARAMETER AIR DAN KADAR PEMENDAPAN DI TASIK BEROMBAK, SETIU, TERENGGANU

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Penyelia Utama : Profesor Madya Rohani Shahrudin, Ph.D

Penyelia Bersama : Profesor Madya Poh Seng Chee, Ph.D

Fakulti : Fakulti Sains dan Sekitaran Marin

Makrofit muncul memainkan peranan penting dalam mengekalkan kesihatan dan kefungsian ekosistem tasik, tetapi pertumbuhannya yang cepat membawa kesan buruk. Di Tasik Berombak, Setiu, aktiviti-aktiviti antropogenik telah mengubah kelimpahan makrofit dan struktur tasik, dengan *Hanguana malayana* sebagai spesies dominan yang mengurangkan keluasan permukaan tasik. Walau bagaimanapun, kesan *H. malayana* terhadap Tasik Berombak masih kurang difahami. Kajian ini bertujuan untuk menyiasat kesan makrofit muncul terhadap parameter air dan kadar pemendapan di Tasik Berombak. Tiga kawasan pensampelan dipilih, iaitu kawasan didominasi *H. malayana*, kawasan didominasi *Pandanus helicopus*, dan kawasan tanpa tumbuhan sebagai kawalan. Ujian Kruskal-Wallis menunjukkan kepekatan klorofil-a dan jumlah nitrogen terlarut (TDN) di kawasan didominasi *H. malayana* berbeza secara signifikan daripada kawasan didominasi *P. helicopus* dan kawasan tanpa tumbuhan, H (2) = 8.3, p = 0.015 (klorofil-a); H (2) = 15.7, p <0.001 (TDN). Kawasan didominasi *H. malayana* mempunyai klorofil-a tertinggi (0.02 ± 0.01 mg/L) berbanding kawasan didominasi *P. helicopus* (0.02 ± 0.01 mg/L) dan kawasan tanpa tumbuhan (0.01 ± 0.01 mg/L). Sebaliknya, kepekatan TDN adalah terendah di kawasan didominasi *H. malayana* (0.22 ± 0.02 ppm), berbanding kawasan didominasi *P. helicopus* (0.31 ±

0.07 ppm) dan kawasan tanpa tumbuhan (0.38 ± 0.13 ppm). Sementara itu, nilai jumlah pepejal terampai (TSS) berbeza secara signifikan di ketiga-tiga kawasan, *H* (2) = 23.0, p <0.001, dengan nilai TSS purata tertinggi di kawasan didominasi *P. helicopus* (8.60 ± 4.38 mg/L), diikuti oleh kawasan didominasi *H. malayana* (6.09 ± 3.37 mg/L) dan kawasan tanpa tumbuhan (3.67 ± 0.76 mg/L). Kadar pemendapan sedimen di kawasan tanpa tumbuhan adalah jauh lebih tinggi berbanding kawasan bertumbuhan, *H* (2) = 15.0, p <0.001. Kadar pemendapan di kawasan tanpa tumbuhan adalah 0.132 ± 0.092 g/m^2/hari, manakala kawasan didominasi *H. malayana* dan *P. helicopus*, adalah 0.067 ± 0.01 g/m^2/hari dan 0.03 ± 0.015 g/m^2/hari, masing-masing. Setiap kawasan persampelan menunjukkan faktor kawalan berbeza yang mempengaruhi kadar pemendapan. Jumlah fosforus terlarut (TDP) adalah faktor utama di kawasan mempunyai tumbuhan, manakala pH adalah faktor paling berpengaruh di kawasan tanpa tumbuhan. Kesimpulannya, kehadiran makrofit muncul mempengaruhi parameter kualiti air secara signifikan dan mengurangkan kadar pemendapan di Tasik Berombak.

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I would like to thank my friends who have helped me a lot to complete my field sampling and laboratory analysis. During sampling, we faced a lot of obstacles involving much strenuous activities to enter the lake due to weather and logistic conditions. It was impossible for me to complete the sampling by myself. Besides, I am grateful for all the guidance given by them during laboratory analysis, that enables me to get hold onto all the procedures to complete sample analysis.

It was especially hard when I fall sick during sampling period and MCO, that my friends have assisted me a lot to get the sampling and analysis done in the given time periods. Also, emotional and mental supports I received from my supervisors, friends and family helped me to get through all these hardships. Without them, it would be much difficult for me in pursuit of this study.

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APPROVALS

I certify that an Examination Committee has met on **23 May 2024** to conduct the final examination of Choe Jia Yi, on her Master of Science thesis entitled "The effects of two emergent macrophytes (*Hanguana malayana* and *Pandanus helicopus*) on the water parameters and sedimentation rates in Tasik Berombak, Setiu, Terengganu" in accordance with the regulations approved by the Senate of Universiti Malaysia Terengganu. The Committee recommends that the candidate be awarded the relevant degree. The members of the Examination Committee are as follows:

Muhammad Hafiz Bin Borkhanuddin, Ph.D
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Faculty of Science and Marine Environment,
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____

WAN MOHD KHAIRUL BIN WAN MOHAMED ZIN, Ph.D.
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Date

This thesis has been accepted by the Senate of Universiti Malaysia Terengganu in fulfilment of the requirement for the degree of Master of Science.

WAN MOHD KHAIRUL BIN WAN MOHAMED ZIN, Ph.D.
Professor/Dean,
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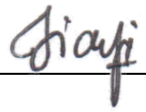
Universiti Malaysia Terengganu

Date:

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UMT or other institutions.



CHOE JIA YI

Date: 20 / 4 / 2026

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LIST OF ABBREVIATIONS

Fe	Iron
Mn	Manganese
Cu	Copper
Pb	Lead
pH	Potential of hydrogen
spp.	species
SPSS	Statistical Package for the Social Sciences
N	Nitrogen
P	Phosphorus
DOC	Dissolved organic carbon
TSS	Total suspended solids
n.d.	No date
et al.	And others
sp.	Species
TC	Total carbon
TOC	Total organic carbon
DIC	Dissolved inorganic carbon
IC	Inorganic carbon
TDN	Total dissolved nitrogen
TDP	Total dissolved phosphorus
TSS	Total suspended solids
IUCN	The International Union for Conservation of Nature
GPS	Global Positioning System
N	North
E	East

GF/F	Glass Microfibre Filter
HDPE	High Density Poly Ethylene
UV-Vis	Ultraviolet–visible spectroscopy

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Freshwater lakes hold significant roles in supporting life on earth. Lakes serves different provisioning services such as food sources, fisheries, water supply, power generation, transportation, recreation and tourism (Sterner *et al*., 2020), biodiversity and habitat (Sharip & Zulkifli, 2007; Reid *et al*., 2018). The earliest limnological studies done on the lake in Malaysia was Tasik Bera, which is the first Ramsar site recognized in Malaysia in 1995 and has been intensively studied up until now (Gharibreza & Ashraf, 2016; Ismail, 2021; Ismail *et al*., 2023; Pereira *et al*., 2024). There are different types of flora stands that inhabit in lake which act as an indicator of the lake water condition.

Aquatic macrophytes or known as hydrophytes are macroscopic plants that grow near or in the water. Aquatic macrophytes can be divided into emergent, free-floating, floating-leaved and submerged macrophytes; either rooted to land or root submersed in water (Lesiv *et al.*, 2020). Majority of macrophytes are considered as angiosperms and they are the major components habitually seen around stream and lake ecosystems. Among all types of macrophytes, the structure of emergent macrophytes where the roots anchored in the soil, other vegetative parts extending through water column makes them have larger role in regulating ecosystem dynamics, whether it be abiotic and biotic, especially in regions that are shallower.

Contribution of macrophytes towards the lake's water quality is evident by studies done such as regulating dissolved oxygen levels (Stansbury & Admiraal, 2004; Bunch *et al*., 2010; Bunch *et al*., 2015), regulating nutrients concentration (Wang *et al*., 2009; Gao *et al.*, 2020; Preiner *et al.*, 2020), serving as a food source and habitat (Nurminen & Horppila, 2002; Cazzanelli *et al*., 2008), aiding in water purification and phytoremediation (Haziq *et* al., 2020; Ismail *et al*., 2021). However, it is important to acknowledge that while the presence of macrophytes can bring numerous benefits to lake ecosystem, the influence of macrophytes may differ depending on several factors including the macrophytes types, species, density, the structure and ecological characteristics of the lake (Gao *et al.*, 2020; Manolaki *et al.*, 2020). That could possibly bring about adverse effects to the quality of water.

In addition to their effects on water quality, the presence of macrophytes can exert substantial beneficial effects on sedimentation processes. These effects encompass sediment filtration and stability (Madsen *et al*., 2001; Horppila & Nurminen, 2003), alteration of sediment composition, nutrient retention (Horppila & Nurminen, 2003), and the provision of habitat (Madsen *et al*., 2001). However, it is worth noting that the specific impact on sedimentation dynamics may vary depending on the macrophyte species involved, where certain species could potentially introduce unfavourable changes to sedimentation patterns.

Tasik Berombak is a freshwater lake wetland in Setiu, Terengganu that have biological and social significance to the local people. Tasik Berombak is a lake where its water sources mainly fed by precipitation and small river tributaries (Sathiamurthy, 2005). Tasik Berombak was once a pristine lake that are open to the local people and being utilized by them for several water-related activities, such as fishing, waterway to cross from the village (Kampung Bintang) to near shore, leisure purposes. There was a cashew plantation founded four decades ago and then replaced by the current oil palm plantation that's when the few main entrance of the lake then become close to the public. Since then, the usage of the lake by locals shrinks and left those who fish in the lake.

1.2 Problem Statement and Justification of Study

The problem began when Tasik Berombak's hydrological system was significantly altered as a result of channelization to drain the land for oil palm plantations. These efforts have resulted in significant changes in the water flow (Sathiamurthy, 2005), followed by changes in its ecosystem, including the organisms residing in the lake. The dominant macrophyte species, *H. malayana*, is experiencing rapid expansion, resulting in a reduction in the size of the water body (Figure 1.1). The Majlis Pengurusan Taman Negeri Terengganu (MPTN) has put forward a proposal to remove the plant from the lake. However, the comprehensive extent of the effects caused by the excessive presence of *H. malayana* on Tasik Berombak and its surrounding ecosystem is still poorly understood.

Figure 1.1 *Hanguana malayana* (within yellow line) inhabiting the margin of Tasik Berombak and extending towards the centre of the lake.

Given the critical role of Tasik Berombak in the local ecosystem and its susceptibility to human-induced alterations, further study is needed to understand the effects of the overabundance of *H. malayana* on the lake ecosystem. Existing research on macrophytes and water quality primarily focuses on temperate regions, with limited attention given to tropical areas like Malaysia. Therefore, this study was done to understand the impacts of emergent macrophytes on water parameters and sedimentation of Tasik Berombak and similar tropical lake systems.

1.3 Study Objectives

There are two objectives of this study:

1. To quantify the effects of two different macrophytes on the water parameters in Tasik Berombak.
2. To determine the effects of the different macrophytes on the sedimentation accumulation rate in Tasik Berombak.

1.4 Thesis Outline

This thesis is structured to answer these objectives where the structure is as follows:

Chapter 1 provides the background of the research, the problem statement and justification to carry out this study. The objectives of the study also were presented here in this chapter.

Chapter 2, the Literature Review, looks on previous works on the ecological studies of lake ecosystem, the types of macrophytes and its roles on lake ecosystem such as its influence on physico-chemical parameters (nutrient and carbon cycling, chlorophyll a, total suspended solids, temperature, dissolved oxygen, pH and sedimentation). Details on the macrophytes chosen for this study were provided.

Chapter 3, the Methodology section describes the framework of this study in general, including maps of sampling site, exact location of sampling area, and sampling design. Details on the methodology for each objective were described in the respective chapters.

Chapter 4 answers Objective 1, which is to investigate the impacts of emergent macrophytes on water parameter. This section includes brief introduction and detailed methodology related to the objective, reporting and discussion on the findings regarding the effects of two different macrophytes and non-vegetated area on the water parameters in Tasik Berombak.

Chapter 5 answers Objective 2, which is to investigate the impacts of emergent macrophytes on sedimentation rate. This section includes brief introduction and detailed methodology related to the objective, reporting and discussion on the findings regarding the effects of two different macrophytes and non-vegetated area on the sedimentation accumulation rate in Tasik Berombak.

Chapter 6, the Conclusion and Recommendations section summarises the findings of this study, stating limitations and proposed recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Lake Ecosystem in Malaysia

In Malaysia, there are approximately 90 lakes, including natural and man-made lakes (Sharip & Zulkifli, 2007). As lakes serves numerous purposes, thorough studies regarding the ecosystem's function are vital for management and restoration. Studies of lake ecosystem related to macrophytes encompasses aspects, namely flora and fauna biodiversity (Ismail *et al*., 2018), water quality and pollution (Yule, 2004; Shuhaimi-Othman *et al*., 2007), sediment dynamics (Gharibreza *et al*., 2013), land-use change and development (Sayok *et al*., 2009).

Due to rapid urbanization, particularly haphazard development, is a predicament for Malaysia lakes. This has led to the introduction of external input, such as nutrients (Total Nitrogen and Total Phosphorus) and nutrient-rich sediment into the lake, resulting in alterations to water quality, pollution, and eutrophication (Sharip & Zulkifli, 2007; Salameh & Harahsheh, 2010; Othman *et al*., 2014). Reports stating that over half of Malaysia's lakes are eutrophic, classified between Class II – III according to the National Water Quality Index standard (Sharip *et al*., 2014).

Eutrophication prompted imbalance of these complex lake ecosystems and has had a significant impact on the living organisms inhabiting within the lake and human health (Salameh & Harahsheh, 2010). It has elevated biological productivity such as phytoplankton biomass, and population of aquatic plants, aquatic plant shift and weed infestation, clogging waterways (Sharip *et al*., 2012; Othman *et al*., 2014). Despite that, species-specific responses exhibit with each different macrophytes species. Tolerable species thrives in such conditions while less adaptable species struggle to survive under such circumstances.

2.2 Macrophyte Ecology in Lake Ecosystem

2.2.1 Type of Macrophytes

Macrophytes are aquatic plants that can be seen through naked eye. Macrophytes can be classified into four groups based on their growth form, which are emergent macrophytes, free-floating macrophytes, floating-leaved macrophytes and submerged macrophytes. Emergent macrophytes are plants with roots anchoring the soil near water and the other vegetative parts appear above water surface. Free-floating macrophytes are plants with submersed roots and other vegetative parts floating on water surface, whereas floating-leaved macrophytes are plants with leaves floating on water surface and other vegetative parts constantly inundated. Submerged macrophytes are plants with all vegetative parts primarily inundated in water, in which their roots clinging to the substrate below the water column (Ismail *et al*., 2021).

Among the four macrophytes types mentioned, emergent macrophytes are believed to be the most high-yielding plants as all its vegetative parts emerge at all three states (Hasan & Chakrabarti, 2009); having the roots in the soil and other vegetative parts emerge in and above water, thus enable the macrophytes to maximize the utilization of available elements for growth. Lake conditions that are shallow and have periodic inundation favours the expansion of emergent macrophytes (Pereira *et al.*, 2012; Albertoni *et al*., 2014).

2.2.2 Roles of Macrophytes in Lake Ecosystems

Macrophytes form significant part of lake's biome and are the highest yielding vegetation on earth (Ondiviela *et al*., 2014; Gautam *et al.*, 2021). Presence of emergent macrophytes serves a few functions in the limnological system. The roles of emergent macrophytes discussed in the following subsections will revolve on their impacts on water parameters, primary production and ecological role and carbon content.

Macrophytes play important ecological roles as bioindicator in aquatic ecosystems to infer water pollution. Given the sensitivity of macrophytes towards changes in water quality (Kolada, 2010; Polechońska & Klink, 2022) and integrated responses to various water parameters such as heavy metals, nutrients, organic matter, pH (Vymazal, 2007; Marengoni & Chambo, 2021; Gautam *et al.*, 2021), makes them an informative bioindicators in both temperate and tropical lake ecosystems. Often, emergent macrophytes are being associated with high nutrient concentrations and poor light penetration. Due to their less mobile status, they cannot avoid the pressure of any changes in water. Thus, these macrophytes are an efficient display of the environmental status with the condition of high nutrients content, chlorophyll-a concentration and suspended matter, as they thrived the best in such state among the other types of macrophytes (Pereira *et al.*, 2012).

Water contamination has been a critical issue for decades. Introduction of macrophytes for the purpose of phytoremediation have shown promising outcomes. The ideal properties of phytoremediator were rapid growth rate and biomass production, relatively extensive root system, ease in monitoring and wide range of heavy metals tolerance (Sood *et al*., 2012; Coimbra & Borges, 2023; Munyai & Dalu, 2023). Sood *et al*., 2012 concluded macrophytes species *Azolla* exhibit all these properties with high efficacy in remediation. Another study in Canada found that *Glyceria grandis* exhibit similar traits and possess utmost capacity in remediation. It was also found that the element concentrations were higher in roots than of shoots (Wilkinson *et al*., 2023). To testify the relationship between metal concentration in sediment and water column, four main metals (Fe, Mn, Cu, Pb) were tested to identify the efficacy of remediation by 8 types of macrophytes. It was found that the concentrations of these metals were significantly higher in sediment than in water column. The metal concentrations found in macrophytes were Fe > Mn > Cu > Pb and the highest concentration recorded were in *Mentha aquatica* and *Myriophyllum spicatum*, suggesting that each macrophyte species has their own capabilities in remediating elements (Brankovic *et al*., 2012). Similar results were reported regarding the efficacy of macrophytes in remediating heavy metals (Munyai & Dalu, 2023). Besides, emergent macrophytes were found to display better performance in removing heavy metals (Fe, Mn and Cu) and its efficacy was environmentally-dependent (Coimbra & Borges, 2023However, limitation arise although studies show good remediation results. Remediation efficacy was limited to the depth where the plant roots reach, the ratio of lake surface and macrophytes stand, and macrophytes tolerance to pollutants (Sood *et al*., 2012). Thus, as suggested by Brankovic *et al*. (2012), presence of different macrophyte species in lake ecosystem could enhance the remediation effort, as the tolerance mechanisms is species specific and environmental state dependent (Dhir *et al*., 2009; Wilkinson *et al*., 2023).

Emergent macrophytes can take up heavy metals more effectively because of rapid growth rate and plant biomass and remediate the elements from both water column and sediment. Hence, utilization of macrophytes not only mitigate sewage discharge and the damage caused towards the aquatic ecosystems, but it can also minimize the cost in constructing wastewater treatment sites to remove contaminants from raw sewage (Thomaz *et al*., 2008; Thakur *et al.*, 2023; Wilkinson *et al*., 2023). Despite their functional roles as remediator and indicator, water quality changes such as organic and inorganic build up could adversely impact the composition of emergent macrophytes (Partanen *et al*., 2009).

Diverse range and distribution of macrophytes extends beyond aquatic environments, where its diversity contributes to environmental structuring across various habitats, offering to not only living aquatic organisms (Rejmankova, 2011; Lesiv *et al.*, 2020; Alahuhta *et al*., 2021), also provides habitat for bird species (Kumar *et al*., 2023). It has been widely recognized that macrophytes increase habitat heterogeneity that affects organisms' abundance and biodiversity (Thomaz & Cunha, 2010; Alahuhta *et al*., 2021). Different plant parts provide different substrate for various organisms' attachment, for example algae and other microorganisms attached themselves to submersed leave, stems and roots; emergent leaves and stems associated with spiders' abundance and richness (Cunha *et al*., 2012); provide refuges for small fish and other invertebrates (Okun & Mehner, 2005; Ziegler *et al*., 2015; Ismail *et al*, 2021).

Macrophytes are an integral element of aquatic ecosystems at the first trophic level in food web by providing net primary productivity of freshwater ecosystem to support consumers such as herbivores and detritivores (Rejmankova, 2011; Kelly & Schallenberg, 2019; He *et al*., 2021; Chaurasia, 2022) in higher trophic level. Food web dynamics and its length often being affected by few factors such as chlorophyll a, density and richness of benthic invertebrates, exotic fish (Kelly & Schallenberg, 2019), lake size (Post *et al*., 2000; Post, 2002), macrophytes community structure which exert significant impact in altering the food web structure by providing refuge to organisms (Ziegler *et al*., 2015; He *et al*., 2021). Apart from that, the macrophyte stands also contribute to the ecosystem biodiversity (Zeng *et al*., 2012; Lesiv *et al.*, 2020).

Although high macrophyte biomass could provide more food sources to organisms in secondary trophic level, yet large coverage of macrophytes could adversely affect the food chain by factors such as decreased prey-predator interaction leading to imbalance abundance between trophic levels (Bartholomew *et al*., 2000). Study done by He *et al*. (2021) suggests that moderate macrophytes volume, diversity along with enhanced evenness facilitate formation of longest food chain length in Lake Poyang.

2.2.2.1 Nutrient cycling

Aquatic macrophytes play a vital role in regulating nutrient cycling, particularly for nitrogen and phosphorus (Blindow *et al*., 2014; Lesiv *et al.*, 2020). Their extensive root systems facilitate nutrient absorption from the water column, improving water quality and preventing eutrophication. Study by Dhote (2007) demonstrated the effectiveness of *Eichhornia crassipes* and *Hydrilla verticillata* in removing both nitrogen and phosphorus, maintaining water clarity. Similarly, Wilkinson *et al*. (2023) found that *Scirpus microcarpus* actively absorbs these nutrients, with the highest uptake occurring in roots and shoots. Moreover, Zeng *et al*. (2017) observed a significant decrease in phytoplankton density and risk of algal blooms with increasing macrophyte biomass, highlighting their efficacy in nitrogen removal. Translocation of nutrients from roots to shoots facilitates nutrient removal through targeted harvesting at their shoots (Wilkinson *et al*., 2023). However, senescence and decomposition of plant matter within the ecosystem releases these stored nutrients back into the water column, providing sustenance for microbial communities and contributing to the overall nutrient pool of the ecosystem (Wetzel, 2001; Du *et al.*, 2020; Mutshekwa, 2020).

Emergent macrophytes rely on sediment as primary nutrient source for growth, efficiently uptaking nutrients stored in sediment, preventing its discharge into water column (Bai *et al*., 2012; Lesiv *et al.*, 2020; Riis *et al*., 2020). However, excessive nutrient release from sediment resuspension can results in water quality deterioration (Coffey *et al*., 2019; Chen *et al*., 2021). Furthermore, emergent macrophytes alters sediment characteristics and modify redox potential by their roots, impacting nutrient availability at sediment-water interface (Ali *et al*., 2019). While nutrient enrichment encourages macrophyte growth, prolonged exposure to such conditions may not benefit these plants. Heegaard *et al*. (2001) found that nutrient-enriched environments trigger biodiversity loss, resulting in decline of certain macrophyte species. Simultaneously, higher tolerance species emerge and eventually dominate the lake ecosystem. Specific release of nutrients concentration depends on the types of macrophytes and their associated microflora. Among the four emergent macrophytes studied, *Typha latifolia* effectively restricts nutrient release from sediment. This trend aligns with findings from Dhote and Dixit, (2009) and Song *et al*. (2019), demonstrating their effectiveness in nutrient assimilation. While the ability of macrophytes species in absorbing nutrients differs among species, but it shows linkage in the functions of macrophytes in nutrient cycling of sediment and water column.

2.2.2.2 Oxygen production

Presence of macrophyte species, density and canopy shading are strongly associated with the oxygen dynamics of ecosystems, restricting light penetration for leaves photosynthesis, lowering oxygen available for fish and invertebrates' utilization (Caraco & Cole, 2002; Ishikawa *et al*., 2019). Thus, volume of macrophyte biomass of 30 – 60% is appropriate to maintain good water state in ecosystem (Ishikawa *et al*., 2019). As mentioned, the complex dense root system of macrophytes houses various organisms, including microscopic organisms that produce oxygen such as algae. These algae also produce oxygen as a by-product of photosynthesis (Chapman, 2013; de Godos *et al*, 2016; Chaurasia, 2022) and diffuse to adjacent strata (Lesiv *et al.*, 2020) further increases the dissolved oxygen concentration of water column. Increased oxygen concentration in sediments improve microbe's ability to promote nutrient cycling in sediments, then release into water column for the utilization of aquatic organisms. The amount and rate of oxygen diffusion were species dependent and affected by light exposure (Lesiv *et al.*, 2020; Nikolakopoulou *et al.*, 2020). However, the level of oxygen is not constant at all time. As the peak of photosynthesis ceases slowly from mid-day to night following the rate of photosynthesis decrease as light availability decreases, creating diurnal variations in oxygen concentration (Evans *et al*., 2003, Arbib *et al*., 2017). It was found that the amount of oxygen produced are higher during summer when algae have higher productivity associate with increased solar radiation, simultaneously enhance nitrogen uptake in water column (Godos *et al*., 2016).

Changes in oxygen level alters nutrient cycling associated with macrophyte beds. Constant low level of oxygen events diminishes nitrification and denitrification processes (Volpert, 2020, Dan *et al*., 2021), but increases phosphorus release from sediment (Volpert, 2020). As plants transport oxygen from leaves to roots, it stimulates organic matter decomposition and nitrifying bacteria growth at macrophyte beds, providing increase nutrient availability in water column (Zhang *et al*., 2022). Macrophytes also utilizes more of the oxygen available in the ecosystem during their respiration at night when there is no photosynthesis. Oxygen dynamic can be influenced by decomposition and organic matter. Oxygen is being consumed during break down of the organic matter by decomposers as they respire throughout the process. The consumption of oxygen during decomposition on top of the limited oxygen availability results in anoxic zones at the lakebed (Wetzel, 2001). Warmer temperature also tends to increase the microbial activity during decomposition, accelerate oxygen consumption. Nutrients released as decomposition continues increases its bioavailability in water, then stimulate algal growth. High abundance of algae enhances oxygen utilization during their respiration and decomposition. The cycle of oxygenation is counterbalanced by various processes taken place within the ecosystem under natural circumstances. However, it can be disrupted by external factors that disturb the dynamic such as introduced nutrients, pollutants, invasive species or land use change.

2.2.2.3 Water parameters

Presence of macrophytes is correlated to water environmental variables (Takamura *et al*., 2003). pH is one of the environmental limiting factors of aquatic species distribution. While different species exhibit different tolerance to pH, the optimal pH for species to live and thrive are between pH value of 6 to 9 for freshwater habitat. Usually, polluted water bodies have low pH value (< 6) than high pH value (> 9) because pollution caused by anthropogenic activities are often acidic than basic. The presence of certain aquatic plants such as water lilies, Venus flytraps, pitcher plants are the indicators of low pH conditions (USEPA, 2024).

Fluctuation of pH pressurize most of the species and have detrimental effects on their growth and survival. Such fluctuations give rise to lowered reproduction, growth, disease and death, which results in reduced biodiversity of the ecosystem and the shift in the aquatic macrophyte composition (Fondriest, 2013; USEPA, 2024). Variation of emergent macrophytes composition is strongly correlated with the lake pH and chemical components. As the pH changes, it also alters the chemical substance state, for example the solubility, transport and availability of these chemical to the living organisms (Rameshkumar *et al*., 2019). Then, these chemical constituents will become toxic to the aquatic organisms and those who utilize the sources of the particular ecosystem (Fondriest, 2013; USEPA, 2024).

Besides, pH also has the tendency to alter sediment settling. Lower pH value especially between 4.7 – 5.8 lowers the sedimentation rate. This is due to the acidity of water decreased the cation solubility that encourage formation of particles. Moreover, acidic water restrains microbial activities that play a part in sediment settling and decomposition of organic matter (Stomp *et al*., 2007), and vice versa for alkaline water condition (Chen *et al*., 2019).

Presence of macrophytes can influences the temperature in both water and sediment due to shading (Elliot, 2022). High macrophytes biomass increase shading effect and decreasing solar radiation reaching bottom of water, creating lower temperatures in lower strata than surface water (Albright *et al*., 2022). In sediment wise, shading shows more impact on vegetated area than non-vegetated area during cold weather. Study done by Gilson & Davies (2020) shows that during colder months, the temperature of sediment below vegetative canopy was higher by 2°C but 2 – 4°C lower during warmer months, suggesting that canopy act as the buffer of temperature fluctuations. While it was suggested that canopy induce thermal stratification, yet study has shown that in order for it to take effect, the presence of macrophyte must have at least occupy 50% of water column height (Vilas *et al*., 2017).

Water temperature has been seen as one of the prime factors that impact vegetation growth. Although the macrophytes response may be subject to individual plant species, in general, alteration in temperature will affect plant's phenology, nutrient uptake, competition, metabolic and enzymatic processes (Hossain *et al*., 2017). Then, changing their growth rates, forms and their assemblages. Increase abundance of emergent macrophytes as temperature increases up to optimum value, metabolic processes of plant increases, the N and P contents in water rises and subsequently enhances their reproductive capacity and support growth (Buschmann *et al*., 2004; Dhir, 2015). However, increased temperatures favour the growth of few species that could tolerate higher temperature will in turn reduces the species diversity and richness of macrophytes in the ecosystem (Feuchtmayr *et al*., 2010).

Even though increase in temperature increases photosynthesis rate to its peak, temperatures beyond the optimal degree will then result in a plunge in the rates and have adverse outcome on the primary production instead (Tait & Schiel, 2013), causing significant changes in the dispersal, structure and community of present macrophytes. As temperature rises, dissolved organic carbon (DOC) contents increases, causing brownification of water which possess ecological as well as societal trade-offs.

Ability of macrophytes in regulating chlorophyll a concentration was shown by various studies (Albertoni *et al*., 2014; Søndergaard *et al*., 2017; Lawniczak-Malinska & Achtenberg, 2018; Song *et al*., 2019; Mowe *et al*., 2019). High phytoplankton population was usually associated with high concentration of chlorophyll a. As macrophytes and phytoplankton are primary producers, they compete for essential elements such as nutrient (phosphorus) for growth (Søndergaard *et al*., 2017). The underlying mechanism of reduced chlorophyll a concentration by macrophytes was the outcome of competition between macrophytes and phytoplankton. While macrophytes outcompete phytoplankton, nutrients were mostly absorbed by macrophytes to grow and expand, thereby reducing the chlorophyll a concentration with high density of macrophytes. Apart from that, allelopathy interactions between macrophytes and phytoplankton was recorded (Song *et al*., 2019; Mowe *et al*., 2019). Aquatic macrophytes especially submerged species exhibit greatest allelopathic effects on phytoplankton, inhibiting phytoplankton growth. The effects of such interactions were suggested as species dependent (Mulderij *et al*, 2007).

Presence of macrophytes have shown to reduce TSS content (Karathanasis *et al*., 2003; Dhote, 2007; Al-Kenzawi & Al-Rawi, 2009; Ng & Chan, 2021). The efficiency of macrophytes TSS reduction was based on the root and leave structures, and microbes binding on macrophytes (Ng & Chan, 2021). The root system of macrophytes act as filters, capturing and retaining suspended particles. Furthermore, their root system also stabilize sediment by reducing water velocity, diminishing impacts of resuspension induced by wind and waves (Madsen *et al*., 2001; Al-Kenzawi & Al-Rawi, 2009). Particles such as sand, silt, clay, gravel and decomposed bacteria and algae, chemical pollution can contribute to total suspended solids (Wetzel, 2001). High concentration of suspended solids decreases water clarity, which then turns clear water into murky state, more light scattered thanks to the humic substances in the water (Gray *et al*., 2000; Wetzel, 2001).

With regards to water quality, high amount of TSS lead to temperature increase and dissolved oxygen decrease. This is due to the ability of suspended solids in absorbing more heat from the sun rather than water molecules. Then, only from suspended solids, the heat is transferred to the water via conduction. As colder water is capable in holding more dissolved oxygen, so the oxygen level drop when water temperature becomes warmer (Wetzel, 2001). Blocked sunlight from reaching into the water bodies also halting the photosynthesis activities and result in reduced productivity and decreased oxygen available for the survival of plants and animals.

2.2.2.4 Carbon content

Macrophytes have shown great carbon sequestration potential in lake ecosystem (Maqbool & Khan, 2013). Yet, the potential of macrophytes in sequestering carbon are species dependent, and can occur in two-way interaction (Reitsema *et al*., 2018). Macrophytes regulating carbon cycle through uptake of carbon from water column during photosynthesis and contribute back to sediment during decomposition of dead parts. Variations of carbon content were observed in different emergent macrophytes species and their biomass. Two similar studies done (Wang *et al*., 2011; Maqbool & Khan, 2013) on the efficiency of emergent macrophytes in carbon uptake shows that *Typha* sp. exhibit highest carbon content. Studies have shown that lakes can act as a regulator for the global carbon cycle because of its considerable contribution in regulating the climate (Sobek *et al*., 2006; Tranvik *et al*., 2018). Lakes can absorb heat and the amount being absorb are based on the deepness of the lake and the heat effect on shallower lakes are stronger (Lacoul & Freedman, 2006). Lakes with a shallower depth (< 10 m) generally have a mean DOC concentration higher than deeper lakes (Toming *et al*., 2020). A huge fraction of carbon dioxide in the atmosphere will be absorbed by all types of water bodies (Mendonca *et al*., 2017).

The reaction of carbon dioxide with water molecules then dissolves into proton and bicarbonate. This dissolved inorganic carbon (DIC) equilibrium stability depends on the pH, temperature, ionic strength and buffering (Pedersen *et al*., 2013). Thus, increased atmospheric carbon dioxide might increase the DIC, photosynthesis and productivity of macrophytes. High DIC concentration ready for the algae uptake and increase their productivity will then result in carbon dioxide release, together with high pH enhances the amount of atmospheric carbon dioxide (Kragh & Sand-Jensen, 2018). Similar trend was observed and reported in studies conducted by Cole *et al*. (2007) and Raymond *et al*. (2013) that gases such as carbon dioxide, methane and nitrous oxide are released to the air, whereby those amount of gases being release increases as productivity enhanced.

For dissolved organic carbon (DOC), it regulates the carbon and energy cycle of water greatly. DOC concentration in lake can be explained mostly by the lake's physical, weather and hydrological properties, less on the morphology of the lake (Toming *et al*., 2020). In the study, it shows that rainfall, altitude, discharge, lake volume and area had inverse effects towards DOC concentration. As temperature become warmer, colder lakes releases more carbon dioxide to the atmosphere, turning the lake into a carbon source rather than a carbon sink which stores carbon in sediments (Weyhenmeyer *et al*., 2015).

2.2.2.5 Organic matter and Sedimentation

Study done by Lawniczak-Malinska *et al*. (2018) stated that emergent macrophytes and its growth forms have positive effects on contribution to lake shallowing, promoting sedimentation in comparison with non-vegetated areas. Similar outcome was observed in a study conducted by Li *et al.* (2016). The smaller the lakes, the faster the shallowing takes place and higher emergent macrophytes overgrowth and succession.

Throughout the study, it was found that the mean sedimentation rate was 0.4 cm / year. Shallowing of lakes are put at risk of its susceptibility to vanish due to their low resiliency. Eutrophication brings about excessive autochthonous matters transportation into the water bodies that accelerate the lake disappearing. This is a result of the profound growth of various phytoplanktons and submerged macrophytes that are unable to survive through the condition and decay, hasten the deposition of organic matter to the sediment. Besides, plant characteristics and flooding period also determined the amount of sedimentation (Li *et al*., 2016). Lakes that experience overgrowth of macrophytes are found to have higher nitrogen and phosphorus concentration (Lawniczak-Malinska & Achtenberg, 2018). High level of phosphorus was shown to be influenced proportionately by pH and IC concentration (Wetzel, 2001; Pagano & Titus, 2007; Cerozi & Fitzsimmons, 2016), which indicated that these three factors are indirectly associated with sedimentation rate.

2.3 Macrophytes Under Investigation

In this study, *Hanguana malayana* and *Pandanus helicopus* were chosen to investigate the effects of emergent macrophytes towards the water parameters and sedimentation rate of Tasik Berombak.

2.3.1 Description of ***Hanguana malayana***

Hanguana malayana, usually known as Bakong by its vernacular name is a giant perennial helophyte that can grow up to 4 metres tall. Its rhizomatous stem and its end segment can extend to approximately 15 centimetres in diameter. The erect lanceolate leaves mostly have height between 1.5 to 2 metres, but it can grow up to 3.5 metre long. The broad leaves are spongy-leathery with sturdy midrib, appear in V-shape and has sharp margin. The plant is medium to dark green in colour, producing green or yellow flowers and the ripe fruit appears shiny, dark purple reddish in colour (Rahman *et al*., 2010) (Figure 2.1).

Hanguana malayana grows in open lowland area, along the banks of freshwater bodies, such as rivers, lakes, or swamp forest. This plant is classified as Least Concern in the IUCN Red List of Threatened Species. The distribution of this plant is along equatorial tropics countries like Malaysia, Philippines, Thailand, Vietnam and are also found in Micronesia (Palau) and Northern Australia (Rahman *et al*., 2010; MyBIS, 2023; WFO, 2023).

Figure 2.1 A group of *Hanguana malayana* with their inflorescences.

2.3.2 Description of *Pandanus helicopus*

Pandanus helicopus is a dioecious plant can grow up to 7 metres in height with submerged roots. The base of the plant is somewhat yellowish orange and standing upright. The stems are irregularly branched with diameter 2 centimetres. It has long, deflexed leaves growing up to 180 centimetres in height with spiky margins and underside of midrib. The fruit is cylindrical and golden brown in colour, around 3 millimetres in diameter and a spindly stigma (MyBIS, 2023).

Pandanus helicopus grows alongside open waters, such as rivers, lakes, pools, marshland and riparian forest (Figure 2.2). The distribution of this plant is native to Malaysia, Thailand, Borneo and Indonesia (Munawaroh & Isnaini, 2019; MyBIS, 2023). From ecological perspective, *P. helicopus* contributes to the primary production of lake ecosystem and as food source for proboscis monkey (Sharip & Jusoh, 2010; Pantau Gambut, 2017). The presence of *P. helicopus* is important as a refuge for terrapins and false gharial, a species of freshwater crocodilian native to Peninsular Malaysia, Borneo, Sumatera and Java. It also houses a variety of bird species, fishes and dragonfly (MyBIS, 2023).

Figure 2.2 *Pandanus helicopus* inhabiting the margin of Tasik Berombak.

2.4 Previous studies on the impact of the excessive growth of macrophytes

Uncontrolled growth of macrophytes can alter the aquatic ecosystems in a range of aspects, such as threatening ecosystem function, biodiversity, and human use. It is particularly critical when the overgrowth of macrophytes is because of introduced species, for the reason that the controlling factors or limitations of its original habitat may not be existing in the new territory. The unrestricted growth of introduced species will then become invasive and restructure the native species assemblages in a short period of time. This phenomenon is particularly worrying for ecosystems that have great biodiversity, which those indigenous plant species are threatened when the invasive plants started to eliminate the natives and dominate the environment.

Overgrowth of macrophytes also impacts human daily water-related activities, for example fishing, recreational and tourism, navigation and energy production (Thomaz *et al*., 2008). Anthropogenic cause or natural succession are the two factors attribute to the overgrowth of emergent macrophytes and change in species composition. Especially, anthropogenic pressures such as agriculture, drainage ditching and infrastructure, hasten macrophytes growth to huge extent due to increased loading of nutrients, suspended solids which later lead to deterioration of the ecosystem (Heegaard *et al*., 2001; Arts, 2002; Lacoul & Freedman, 2006; Partanen *et al*., 2009, Alahuhta *et al*., 2011). The nutrients and suspended solids originate from human induced activities will be delivered to the connected water bodies. Although study done regarding the leaching of nutrients and suspended solids that reaches the water bodies are just a fraction of the total amount of discharge from the development sites. Ultimately, those leaches concentration transported into the ecosystems still bounded by the water retention capacity of the higher elevated water bodies down into the lower catchments across the whole hydrology network complexity. Thus, the catchment properties itself and vicinal human interference driven by the modification of land use are to be considered as a more direct cause that influences the ecosystems especially emergent macrophytes as they populate at the littoral zone (Brett & Benjamin, 2008; Alahuhta *et al*., 2013).

Excessive nutrients loading causing eutrophication will induce loss in emergent macrophytes (Arts, 2002; Lacoul & Freedman, 2006), and that later decline the community structure of macrophytes (Heegaard *et al*., 2001; Penning *et al*., 2008). However, Alahuhta *et al*. (2011) found that drainage ditching has a positive impact in promoting macrophytes overgrowth and is highest among the three anthropogenic activities, which are agriculture, drainage ditching and infrastructure. Such outcome perhaps linked to the tolerance level of emergent macrophytes being higher than submerged macrophytes on high loading of suspended matters, nutrients content and reduced light penetration (Toivonen & Huttunen, 1995).

As mentioned, emergent macrophytes usually obtain nutrients through sediments and carbon dioxide from the atmosphere (Alahuhta *et al*., 2013). Due to the morphology of emergent macrophytes inhabiting in the intersection region of land and water, they exhibit the swiftest response to the pressures induced by anthropogenic factors towards hydrologic condition, such as water level fluctuations, depth and water bodies' structures (Partanen *et al*., 2009; Alahuhta *et al*., 2012).

In conditions such as higher trophic level lakes, nutrient availability is not a limiting factor, but in eutrophic and hypertrophic lakes, high primary production will induce lessened distribution of emergent macrophytes (Arts, 2002). Thus, Alahuhta *et al*. (2012) suggested that this might be the case where such condition have diminished the impact of agriculture towards their study outcome. Due to the increased precipitated matter, it forms larger low-water level lake region that favours the emergent macrophytes of strong colonization ability (Santamaria, 2002). Consequences of macrophytes cover expansions is the dominance of limited species varieties, creating an ecosystem with low species diversity and reduced ecological functioning of the lake (Lougheed *et al*., 2008).

CHAPTER 3

METHODOLOGY

3.1 Study Area

The study area is located at Tasik Berombak of Setiu, Terengganu (Figure 3.1). Tasik Berombak is a freshwater lake located in Setiu district of Terengganu state in Malaysia. The lake stretches a long 4 km with 200 m width. In the past, Tasik Berombak was a brackish water lagoon. Yet, Tasik Berombak has now transformed into a lake completely in the process of time, as it moves further away from the sea level.

The lake serves as hydrological control of the surrounding area. When monsoon season approach, some flood affected areas can be controlled. In addition to flood mitigation, the lake also supplies fresh water to Setiu Lagoon which is an economic resource for the local population (TRDI News, 2016). The uniqueness of the lake not limited only to its history. With its vast area, housing a rife of flora and fauna, is a focus for more research to be carried out to ensure the biodiversity, beauty and integrity of the nature to be preserved.

Two sampling sites were selected in the lake based on the presence of different emergent macrophytes, and one site without any macrophytes was chosen as a control site. The GPS coordinates for these sites were 5 °40 2 N 102 °41 20 E (*H. malayana*), 5 °40 6 N 102 °41 13 E (*P. helicopus*), and 5 °40 5 N 102 °41 20 E (non-vegetated area) (Figure 3.1).

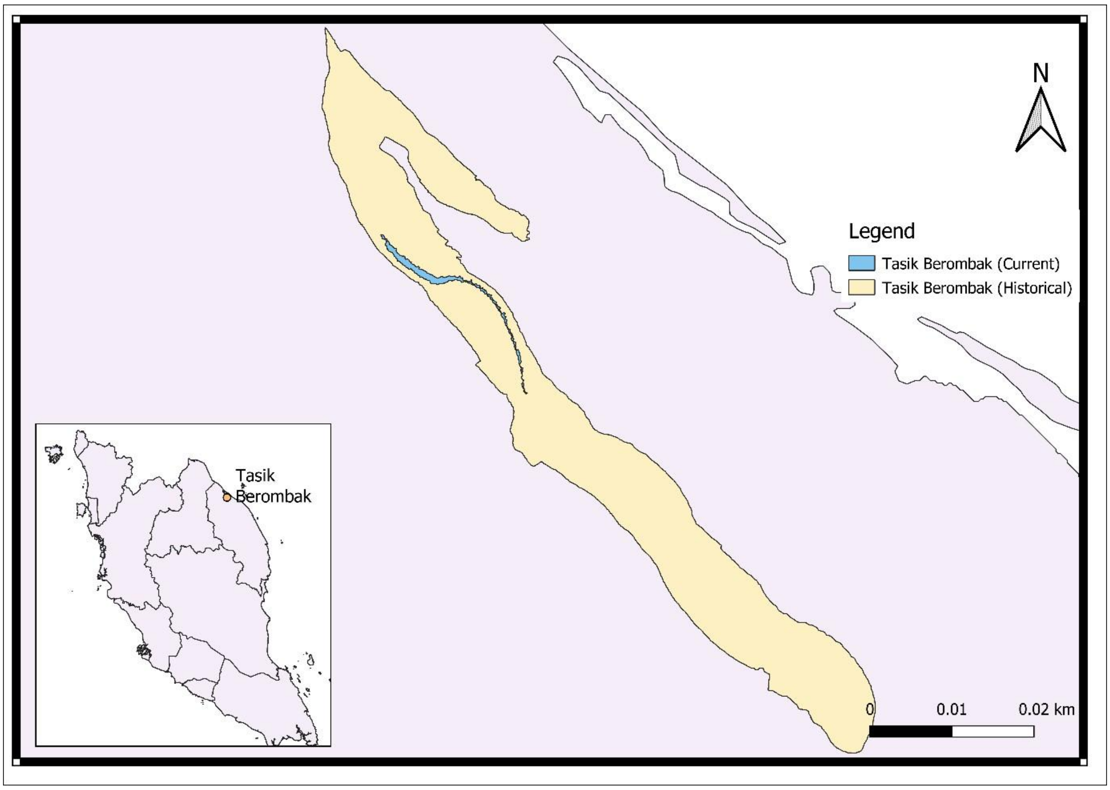

Figure 3.1 Map showing the location of Tasik Berombak in Setiu, Terengganu. The blue area indicates the current accessible part of the lake.

3.2 Sampling

Sampling was conducted between February 2019 and January 2020, with approximately 2 months interval between samplings. A total of three sampling sites were identified within the lake. Two of which were vegetated area and a non-vegetated area (Figure 3.2).

Figure 3.2 Map showing the sampling points of this study indicated with the pink dot symbol. The first and third points on the lake indicates vegetated area (*H. malayana* and *P. helicopus*), and the other points indicates non-vegetated area.

In-situ physico-chemical parameters were measured using YSI Handheld Multiparameter Instrument. Parameters recorded include water temperature (°C), conductivity (ms/cm), total dissolved solids (g/L), salinity, dissolved oxygen (%), dissolved oxygen (mg/L), pH. Water depth of the lake was taken using SM-5 Portable Water Depth Sounder Gauge.

In each sampling points, 9 L water samples collected, with 5 L stored in a 5-

litre bottle and the remaining 4 L divided into four individual 1-litre bottles. The water samples were kept at -20°C once reached to laboratory until filtration process taken place. Water samples were vacuum filtered through Whatman Glass Microfibre Filter (GF/F) 0.7 µm pore size pre-baked at 450°C for 3 h to remove any adhered carbon particles. Water samples were analysed for total suspended solids, nutrient, carbon and chlorophyll a content.

For sediment settling experiment, total of nine sediment traps were deployed, three traps at each site (Figure 3.3). The traps were retrieved and deployed during each sampling session for determination of sediment deposition amount. The summary of methodology framework was displayed in Figure 3.4.

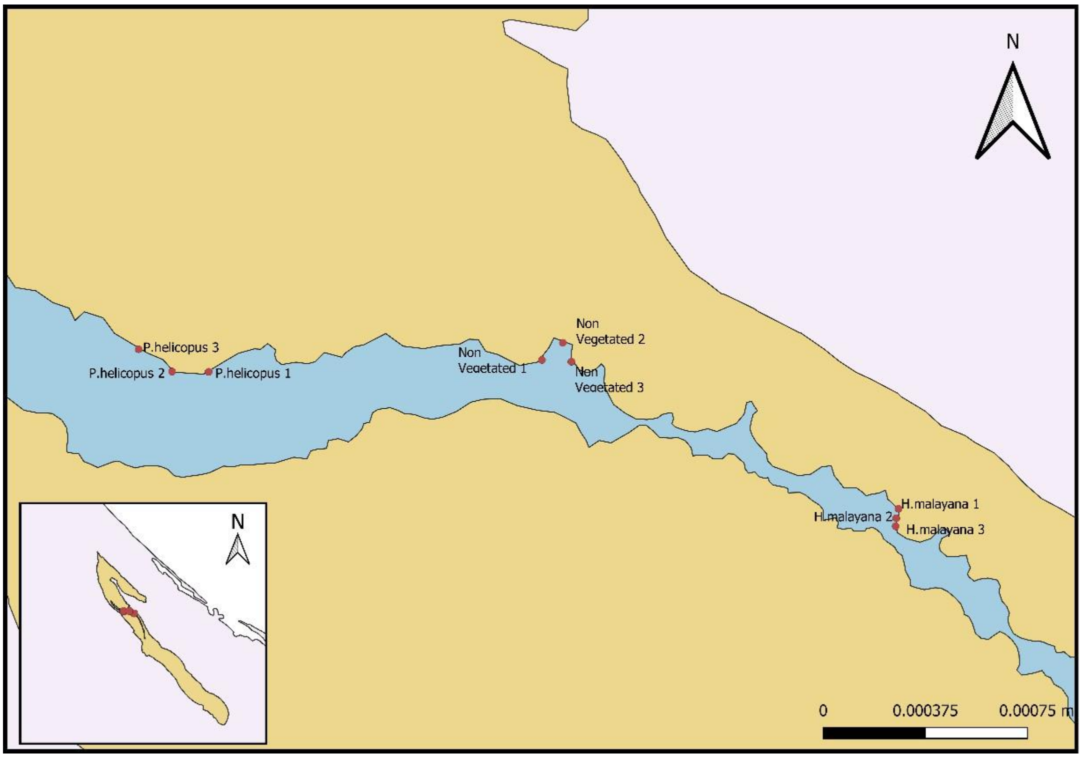

Figure 3.3 The map shows the shape of Tasik Berombak in Setiu, Terengganu. The red dots indicate the sampling locations across the two distinct vegetation types and the control site, which is non-vegetated.

3.3 Method of Analysis for Ex situ Water Parameters

The analysis of ex situ water parameters was conducted using established methods to determine various physicochemical properties. These properties listed in the accompanying table (Table 3.1), were measured following prescribed analytical techniques, with the specific protocols for each parameter described in detail in the respective chapters of this thesis. Chapter 4 outlines the comprehensive methodology employed for the water parameter analysis, including instrumentation, and calibration procedures. Chapter 5 provides the detailed methodology for the sedimentation rate experiment, including the experimental setup and data collection techniques.

Table 3.1 Lists of methods performed on water samples based on the determination of different properties.

Samples determination	Types of analysis
Chlorophyll a	Jeffrey & Humphrey Trichromatic Method (1997)
Total carbon	APHA Method 5310-B (1998)
Total organic carbon	APHA Method 5310-B (1998)
Inorganic carbon	APHA Method 5310 B (1998)
Total dissolved nitrogen	Modified APHA Method 4500-N (1998)
Total dissolved phosphorus	Modified APHA Method 4500-P (1998)
Total suspended solids	APHA Method 2540-D (1998)

3.4 Sediment Settling Experiment

Sediment traps were deployed for sediment settling experiment. In each sampling points, three sediment traps were deployed and retrieved during every sampling. Sediment accumulated in the traps were transferred into a 5-L HDPE bottle and brought back to the laboratory. The collected sediment was transferred into measuring cylinder to let sediment settle. The settled sediment was then poured into aluminium dish and dried at 60°C until constant weight obtained. The dry weight recorded was calculated as $g/m^2/day$, where m^2 is the surface area of the measuring cylinder and day indicates the number of days the sediment trap deployed per sampling session (Anisah *et al*., 2011).

3.5 Statistical Analysis

3.5.1 Water sample analysis

Kruskal-Wallis test was applied to discern any significant differences among test results obtained from in-situ and laboratory analysis. Results that showed significant differences ($p < 0.05$) were then further analysed using Dunn's post-hoc test to determine the specific factors among all the parameters that influences one another. Spearman correlation coefficient test was conducted on all sampled parameters for better understanding of their interaction and was presented in the form of heatmap in the following sub-chapter results and discussion section.

3.5.1 Sediment settling analysis

Data obtained from sediment traps were processed using non-parametric Kruskal-Wallis and Dunn's Post-hoc test. Best Fit Model was used as a predictor to indicate the relationship of all data. A prediction formula was generated for each sampling area of different vegetation with the most influential factor or factors that affected the sedimentation rate. The summary of methodology framework was presented in Figure 3.4.

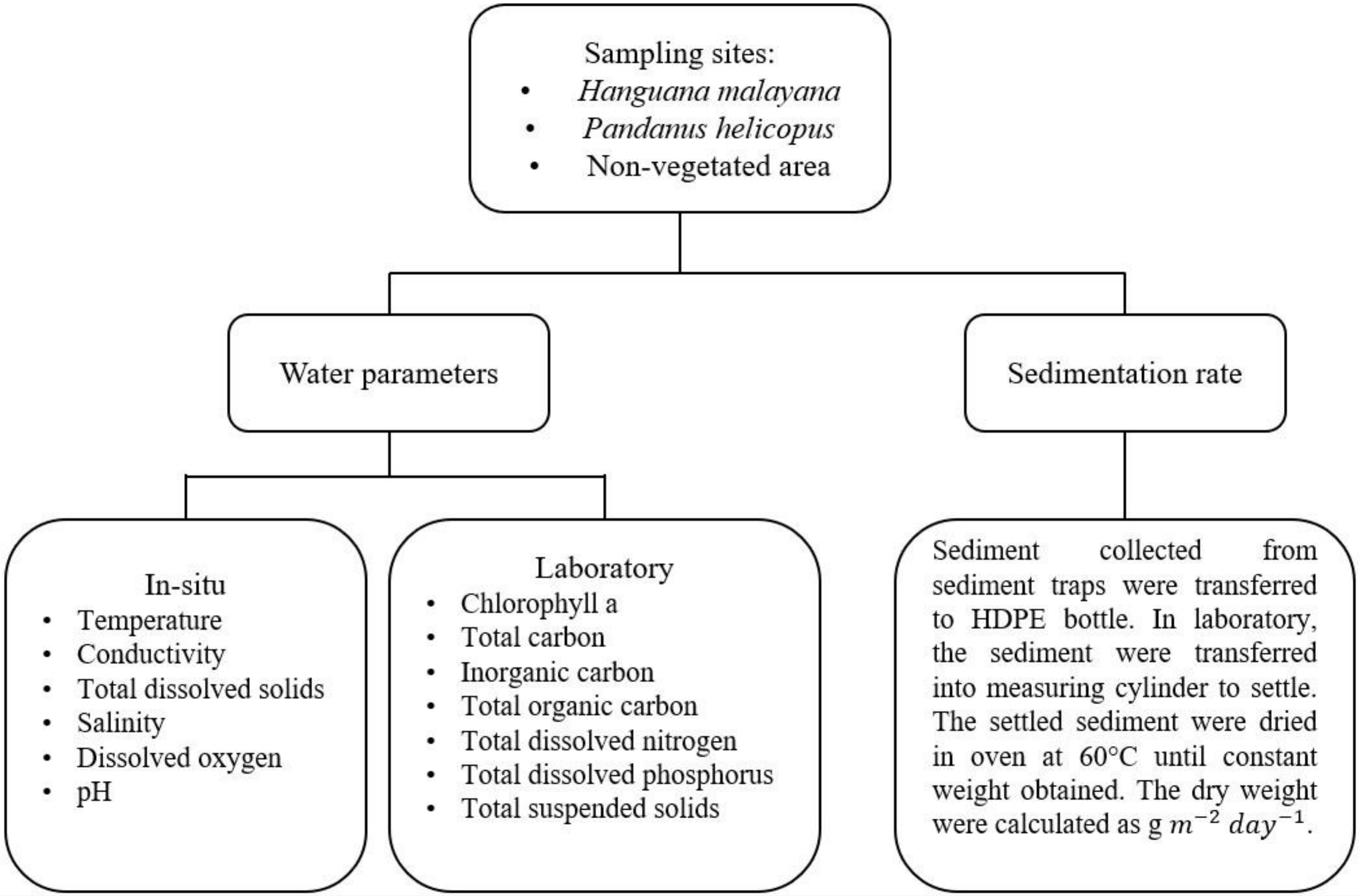

Figure 3.4 Summarised methodology of this study.

CHAPTER 4

THE EFFECTS OF EMERGENT MACROPHYTES ON WATER PARAMETERS OF TASIK BEROMBAK

4.1 Introduction

Emergent macrophytes are aquatic plants that grow along littoral zone of water bodies, approximately 1 m to 1.5 m depth (Rejmánková, 2011). The physiological characteristics that distinguish emergent macrophytes from other types are the roots above water column. This trait contributes to their status as the most productive species among macrophytes (Rejmánková, 2011). From the comprehension of previous studies, emergent macrophytes acclaimed to hold various positive effects on improving the water quality such as lowering the concentration of nutrient levels or dissolved organic matter (Dhote & Dixit, 2009; Wu *et* al., 2011; Gacia *et* al., 2019; Akwuma *et al*., 2021) and heavy metals removal (Laing *et al*., 2009; Yadav & Chandra, 2011) in the water by uptaking through roots. Good quality freshwater resources are indispensable because of the various core services bring forth to the society, such as supplying fresh drinking and bathing water, recreation purposes, fisheries and power generation, thus providing values socially, ecologically and economically (Water Quality, 2016).

Setiu Wetlands is a basin comprises of nine diverse ecosystems which are sea, beach, mudflat, lagoon, estuary, river, island, coastal area and mangrove forest. Each of these habitat features distinct and complex physical environment that sustain unique biological entities. The wetlands thus serve as a crucial source of natural resources, contributing significantly to the livelihoods of the local community (Salim *et al*., 2015). Tasik Berombak is a large freshwater lake as part of Setiu Wetlands mainly fed by precipitation and a limited number of river tributaries. The lake holds hydrological significance for the Setiu lagoon as it serves as the primary water source (Sathiamurthy, 2015). Although there have been documented studies on water parameters (Suratman *et al*., 2014; Suratman *et al*., 2016; Zaideen *et al*., 2017; Ismail *et al*., 2020) and nutrients (Suratman & Latif, 2015; Poh *et al*., 2019) in the Setiu Wetlands, none of them specifically focused on Tasik Berombak.

The current matter of interest in Tasik Berombak is the rapid growth of a type of emergent marophyte species, which is *H. malayana.* Overgrowth of plant could cause detrimental effects towards the ecological function of the ecosystem, such as nutrient, carbon cycle and reflux, oxygenation, high suspended solids content (Caraco *et al*., 2006; Kagami *et al*., 2019) which can impair the quality of water. The variables that were being measured are physico-chemical parameters such as water temperature, conductivity, total dissolved solids, salinity, dissolved oxygen, pH, chlorophyll a, carbon concentration, total dissolved nitrogen and phosphorus and total suspended solids.

4.2 Methodology

4.2.1 Sampling Design

A total of 9 litres of surface water were taken using HDPE bottles at each sampling location, with 5 L stored in a 5-litre bottle and the remaining 4 L divided into four individual 1-litre bottles. The water samples were then placed into an icebox with ice loaded immediately after being taken from the site and frozen to -20°C at the laboratory.

In-situ physical parameters were measured using the YSI Handheld Multiparameter Instrument. Parameters recorded include water temperature (°C), conductivity (ms/cm), total dissolved solids (g/L), salinity, dissolved oxygen (%), dissolved oxygen (mg/L), pH. Water depth of the lake was measured using the SM-5 Portable Water Depth Sounder Gauge.

Water samples (3 replicates) were analyzed for chlorophyll a, total carbon (TC), total organic carbon (TOC), inorganic carbon (IC), total dissolved nitrogen (TDN), total dissolved phosphorus (TDP) and total suspended solids (TSS) analysis.

4.2.2 Sample Analysis

The samples collected were filtered and frozen until further analysis could be carried out. Samples determinations were done using their respective methods, some with modifications.

4.2.2.1 Chlorophyll a

Filtered GF/F were folded with residue inward and put into 50 mL centrifuge tube wrapped with aluminium foil. The extraction was done by adding 5 mL of 90% acetone solution into the tube and ground using a glass rod. The glass rod was rinsed with an additional 90% acetone solution to make up to 10 mL, cap tightly and vortex until homogenized. All centrifuge tubes were kept in the dark at 4°C for 12 h.

Prior to determination using spectrophotometer, all tubes were centrifuged at 4°C, 4000 rpm for 20 min. Then, the solution was poured into a 1 cm cuvette and read using a Shimadzu UV-1800 UV-Vis Spectrophotometer (Shimadzu, Japan) at four wavelength absorbances, namely 750 nm, 664 nm, 647 nm and 630 nm. The obtained values were used to determine the chlorophyll a concentration in microgram per litre (µg/L) and convert to milligram per litre (mg/L) using formula (Equation 4.1 and Equation 4.2 respectively) (Jeffrey & Humphrey Trichromatic Method, 1997):

$$\text{Chlorophyll a (mg/L)} = \frac{(11.87 \times E_{664-750} - 1.54 \times E_{647-750} - 0.08 \times E_{630-750}) \times v}{V \times L}$$

(Equation 4.1)

Where $E_{664-750}$ = corrected value for absorption at 664 nm,

$E_{647-750}$ = corrected value for absorption at 647 nm,

$E_{630-750}$ = corrected value for absorption at 630 nm, V = volume of filtered water (L)
L = cuvette length (cm)
v = volume of 90% acetone used (mL)

$$\text{Chlrophyll a (mg/L)} = \frac{value\ of\ chlorophyll\ a\ obtained\ in\ \mu g/L}{1000}$$

(Equation 4.2)

4.2.2.2 Total carbon, total organic carbon and inorganic carbon

The water samples for carbon content analysis were acidified to pH 2 for preservation and kept in blue cap glass bottle in refrigerator of 4°C. The samples were then transferred into glass vials for detection by Shimadzu TOC Analyzer. The values obtained were Inorganic Carbon and Total Carbon. Total Organic Carbon was then obtained by deduction of Total Carbon and Inorganic Carbon (APHA Method 5310-B, 1998).

4.2.2.3 Total dissolved nitrate

Water samples were kept frozen in a -20°C freezer after filtration. Prior to analysis, the water samples were defrosted, and 10 mL of samples were taken and placed into acid washed 50 mL centrifuge tube and add 5 mL of persulfate oxidising agent. Both solutions were mixed well and autoclaved for 55 min at 120°C for the digestion process. Centrifuge tubes were removed from the autoclave machine and let to cool until room temperature was reached. Then, the digested water samples were filtered through Whatman 0.45 µm pore size filter paper.

For determination of nitrate, vanadium (III) chloride reduction method were adopted. Each sample replicate containing 4 mL of water sample was spiked with 1 mL of mix reagent comprising Sulfanilamide, N-(1-napthyl)-ethylenediamine dihydrochloride (NED), vanadium (III) chloride and deionized water, mixed well and placed in 60°C water bath for 25 min for reduction to take place. The tubes were removed from the water bath and let cool to room temperature. The samples were then read at 540 nm absorbance using UV-Vis Spectrophotometer with a series of nitrate standard and deionized water as blank (Modified APHA Method 4500-N, 1998).

4.2.2.4 Total dissolved phosphorus

The steps to process water samples for phosphorus determination were repeated as of the first part of nitrate determination. For determination of phosphorus, ascorbic acid method was adopted. Each sample replicate containing 20 mL of water sample were spiked with 2 mL of combined reagent of sulphuric acid, potassium antimonyl tartrate solution, ammonium molybdate solution and ascorbic acid. The reagent and water samples were mixed thoroughly and let sit for 10 min. The samples were then read at 880 nm absorbance using UV-Vis spectrophotometer with a series of phosphorus standard and deionized water as blank (Modified APHA Method 4500-P, 1998).

4.2.2.5. Total suspended solids

One litre of water samples was filtered through pre-weighed and pre-baked Whatman 0.7 µm pore size GF/F. Then, the filter paper was dried in oven at 60°C until constant weight was obtained. The final weight was recorded and substitute into the formula below (Equation 4.3) (APHA Method 2540-D, 1998):

$$\text{TSS (mg/L)} = \frac{(final\ weight\ (g) - initial\ weight\ (g)) \times 1000}{sample\ volume\ in\ litre}$$

4.2.3 Data Analysis

Kruskal-Wallis test was applied to discern any significant differences among test results obtained from in-situ and laboratory analysis. Results that showed significant differences were then further analysed using Dunn's post-hoc test to determine the specific factors among all the parameters that influences one another. Correlation coefficient test was conducted on all sampled parameters for better understanding of their interaction and was presented in the form of Heatmap in the following sub-chapter results and discussion section.

4.3 Results and Discussion

Physicochemical properties of the water samples were analysed and presented in boxplot as (Figure 4.1). The difference in means for each parameter between each sampling point was analysed using Kruskal-Wallis test for non-parametric samples and Dunn's post-hoc test was performed on parameters with statistical significance (Table 4.1).

Variation was recognised in two separate plant species, which were *H. malayana* and *P. helicopus*. Non-vegetated area act as the control to compare the differences between the two vegetated area. From the distribution of physicochemical properties in Figure 4.2, *H. malayana* dominated area shows higher concentrations of chlorophyll-a and carbon group, whereas *P. helicopus* dominated area shows higher concentrations of total dissolved phosphorus and total suspended solids. In non-vegetated area, total dissolved nitrogen shows higher concentration among all three sites.

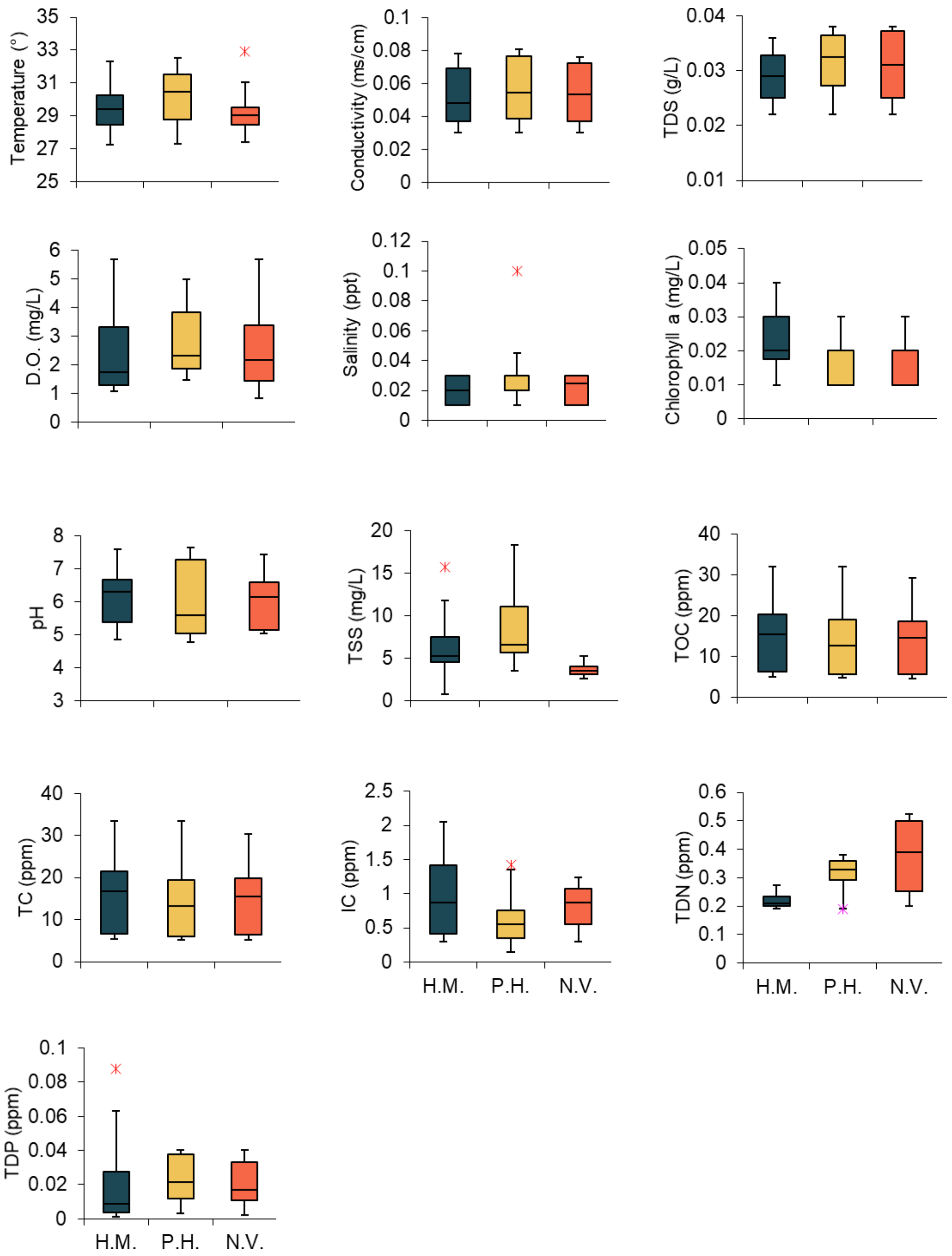

Figure 4.1 Boxplot chart for physicochemical water quality data obtained at Tasik Berombak. Where H.M. = *Hanguana malayana*; P.H. = *Pandanus helicopus*; N.V. = non-vegetated area. The red symbol (*) in boxplot temperature, salinity, TSS, IC, TDN and TDP represents outlier of respective data.

Table 4.1 Summary of water physicochemical parameters at three sampling locations in Tasik Berombak.

Parameters	Sampling locations					
	Hanguana malayana		*Pandanus helicopus*		Non-vegetated	
	Range	Mean ± S.D.	Range	Mean ± S.D.	Range	Mean ± S.D.
Temp (°C)	27.27 - 32.30	29.56 ± 1.51a	27.33 - 32.55	30.21 ± 1.64a	27.43 - 32.90	29.46 ± 1.58a
Cond (ms/cm)	0.03 - 0.08	0.05 ± 0.02a	0.03 - 0.08	0.06 ± 0.02a	0.03 - 0.08	0.05 ± 0.02a
T.D.S. (g/L)	0.02 - 0.04	0.03 ± 0.01a	0.02 - 0.04	0.03 ± 0.01a	0.02 - 0.04	0.03 ± 0.01a
Sal (ppt)	0.01 - 0.03	0.02 ± 0.01a	0.01 - 0.10	0.03 ± 0.02a	0.01 - 0.03	0.02 ± 0.01a
D.O. (mg/L)	1.09 - 5.68	2.57 ± 1.59a	1.48 - 4.99	2.79 ± 1.20a	0.85 - 5.68	2.59 ± 1.56a
pH	4.84 - 7.60	6.20 ± 0.89a	4.78 - 7.65	6.01 ± 1.13a	5.03 - 7.43	6.03 ± 0.88a
Chl a (mg/L)	**0.01 - 0.04**	**0.02 ± 0.01a**	**0.01 - 0.03**	**0.02 ± 0.01b**	**0.01 - 0.03**	**0.01 ± 0.01b**
TSS (mg/L)	**0.80 - 15.70**	**6.09 ± 3.37a**	**3.50 - 18.30**	**8.60 ± 4.38b**	**2.60 - 5.30**	**3.67 ± 0.76c**
TC (ppm)	5.48 - 33.46	16.94 ± 9.67a	5.20 - 33.46	15.07 ± 9.85a	5.6 - 30.26	15.49 ± 8.75a
TOC (ppm)	5.01 - 32.04	15.96 ± 9.39a	4.71 - 32.04	14.47 ± 9.53a	4.69 - 29.40	14.67 ± 8.56a
IC (ppm)	0.30 - 2.05	0.97 ± 0.59a	0.14 - 1.42	0.62 ± 0.36a	0.30 - 1.24	0.82 ± 0.29a
TDN (ppm)	**0.19 - 0.27**	**0.22 ± 0.02a**	**0.19 - 0.38**	**0.31 ± 0.07b**	**0.20 - 0.52**	**0.38 ± 0.13b**
TDP (ppm)	0.00 - 0.09	0.02 ± 0.03a	0.00 - 0.04	0.02 ± 0.01a	0.00 - 0.04	0.02 ± 0.01a

*Values in bold indicates parameters with significant differences between sampling sites (p-value < 0.05).

Chlorophyll-a and TDN concentration of *H. malayana* were statistically different than *P. helicopus* and non-vegetated area ($p < 0.05$). The highest concentration of Chlorophyll-a was observed in *H. malayana* dominated area (0.02mg/L) followed by *P. helicopus* dominated area (0.02mg/L) and non-vegetated area (0.01mg/L). It was observed that *H. malayana* dominated area has highest concentration of chlorophyll a but lowest TDN concentration (0.22 ppm) compared to *P. helicopus* dominated area (0.31ppm) and non-vegetated area (0.38 ppm). The mean TSS was the highest in *P. helicopus* dominated area (8.60 mg/L), followed by *H. malayana* dominated area (6.09 mg/L) and non-vegetated area (3.67 mg/L). There are significant differences found between all three locations ($p < 0.001$).

This study found that the concentration of chlorophyll-a was higher in *H. malayana* dominated area, which contradicts the findings of earlier studies. Although density of macrophytes was not assessed, based on field observation, coverage of *H. malayana* was higher than *P. helicopus*, which potentially indicates a higher biomass (Figure 4.2).

Figure 4.2 The coverage of *H. malayana* (yellow line indication) at both side of the lake in Tasik Berombak.

Previous studies shown that chlorophyll-a concentration reduces with increased macrophyte density. Chlorophyll-a content increases as phytoplankton population grow. During nutrient competition as macrophytes outcompete phytoplankton, it depletes the nutrient essential for phytoplankton growth, thus reducing its populations and chlorophyll-a concentration (Albertoni *et al*., 2014; Lawniczak-Malinska *et al*., 2018; Mowe *et al*., 2019). Allelopathy may be a possible explanation of high chlorophyll-a concentration in the high biomass of *H. malayana* area. This was shown in the allelopathic effect from an emergent macrophytes (*Ludwigia adscendens*), where this plant releases inhibiting chemicals that deter phytoplankton growth, further altering chlorophyll-a concentration regardless of macrophyte density (Mowe *et al*., 2019). Study by Mulderij *et al*. (2007) shown that the effect of allelopathy is species dependent.

Such mechanisms might be the reason of reduced chlorophyll-a concentration even when macrophyte density is low. Research on these aspects is currently lacking in this study, further research needed to better understand factors influencing chlorophyll a concentration in Tasik Berombak.

This study found that both vegetated areas have higher TSS concentration compared to non-vegetated area. Previous studies have demonstrated the efficacy of

TSS removal by macrophytes, thereby reducing TSS concentration. This finding contradicts with previous studies (Karathanasis *et al*., 2003; Dhote, 2007; Al-Kenzawi & Al-Rawi, 2009; Ng & Chan, 2021). Dense and complex root structures of macrophytes, with associated microbial metabolic activities (Ng & Chan, 2021) can effectively filter and trap suspended particles, thereby reducing resuspension from wind and waves, and lowering TSS in the water column (Al-Kenzawi & Al-Rawi, 2009).

Correlation analysis showed that temperature is strongly influencing the TSS content in *P. helicopus* dominated area (Figure 4.4). Temperatures has a direct and indirect link towards TSS content. High temperature decreases water viscosity, making it easier for suspended particles to remain suspended, potentially leading to short-term TSS elevations (Wetzel, 2001). However, the indirect effects of high temperature often play a more significant role. Warmer water increases biological activity, leading to increased organic matter production from algae and other organisms, which contributes to TSS (Kosten *et al*., 2010). It's crucial to acknowledge that the effect of temperature on TSS depends on few factors such as the initial TSS concentration and lake characteristics. Further research with increased sampling size and consideration of other environmental factors influencing TSS accumulation is necessary to fully understand these dynamics.

Previous studies found that macrophytes reduces concentration of TDN in water column (Ng & Chan, 2021). In this study, similar trend was observed. The observed lower TDN in the *H. malayana* area could be attributed to several factors such as efficient nutrient uptake and assimilation. Nutrients can be absorbed passively through diffusion by root and actively by cell membrane transporter membrane (Ng & Chan, 2021) for plant growth. *Hanguana malayana* might be more efficient at utilizing TDN for its own growth, leading to lower TDN levels in the surrounding water compared to the other areas. Besides, the root structure of *H. malayana* and its microbial communities might promote denitrification, where nitrate were being converted and removed from water column, thus reducing TDN concentration (Seitzinger *et al*., 2006). Further investigations on the nitrogen uptake rates, activity of nitrogen-fixing bacteria and denitrification rates were needed to comprehend TDN dynamics in relation to different plant communities of this lake.

Both the carbon groups and TDP data shows no significant differences among all three sites. But the observed value in *H. malayana* dominated area was higher than the other two sites. As shown in Table 4.1, the average value of in-situ water parameters including temperature, total dissolved solids, dissolved oxygen, pH shows no significant differences between all locations.

The lack of significant differences in most parameters between the three locations suggests that the presence of different plant communities does not exert a major influence on these water parameters under the conditions of this study. It is important to note that this study was conducted at a single point in time and at a limited number of locations. Further monitoring over time would be necessary to draw more definitive conclusions about the potential effects of vegetation on water parameters in this ecosystem.

Heatmap is a graphical presentation of data in two-dimensional form using different colours where the colour of each cell indicates the value of the main variable in the corresponding cell range. The intensity of the colour and (*) symbol reflects the strength of the relationship between variables, whether positive or negative. Darker shades indicate a stronger relationship. Brown signifies a negative correlation between parameters, while blue represents a positive correlation.

Figure 4.3, 4.4 and 4.5 present heatmaps for the respective sampling sites: *H. malayana* dominated area (Figure 4.3), *P. helicopus* dominated area (Figure 4.4), and the non-vegetated area (Figure 4.5), for comparative visualization of data across different environments.

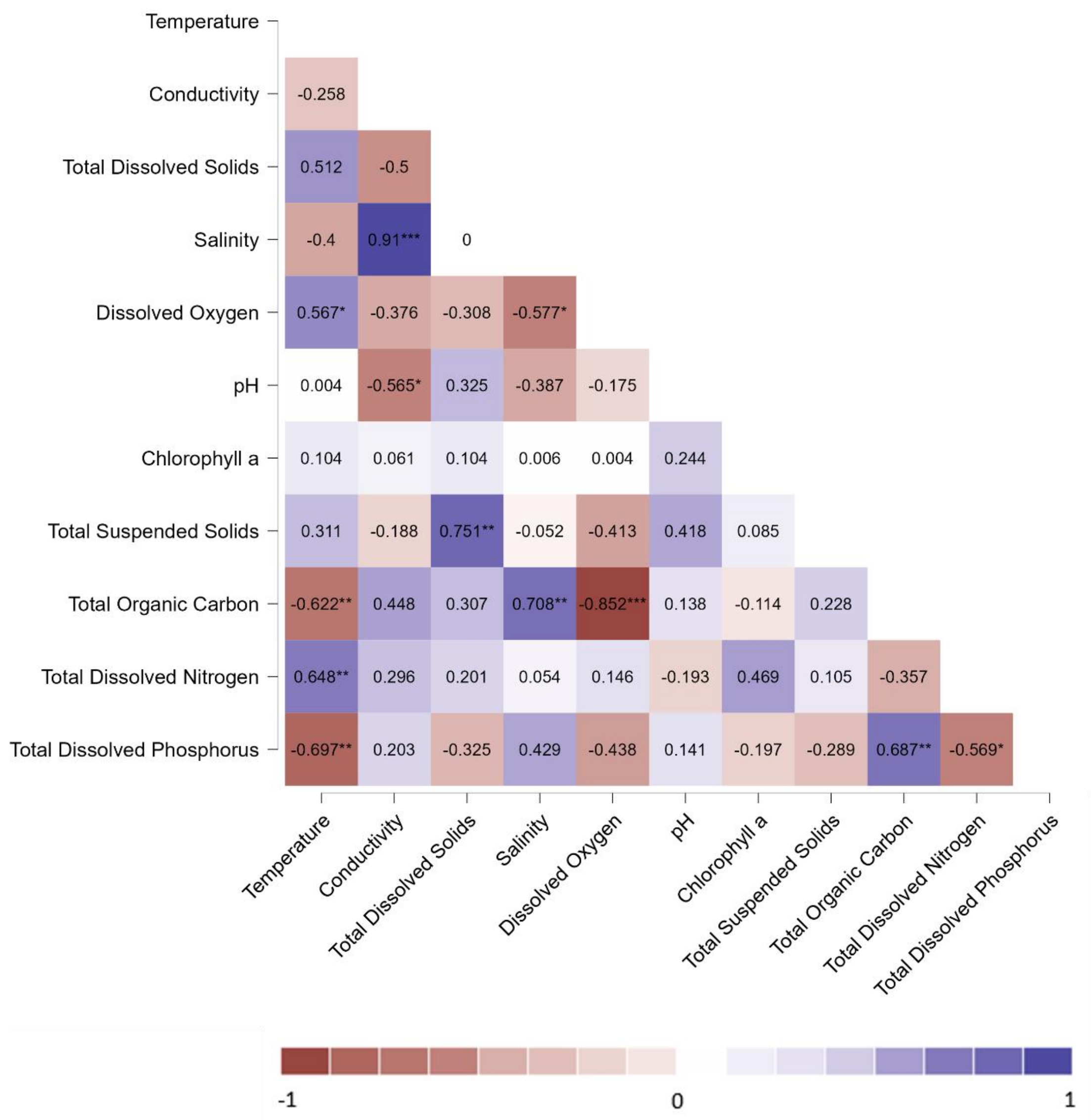

Figure 4.3 The Spearman rank correlation coefficients illustrate the relationship between each parameter recorded from *H. malayana* dominated area in Tasik Berombak.

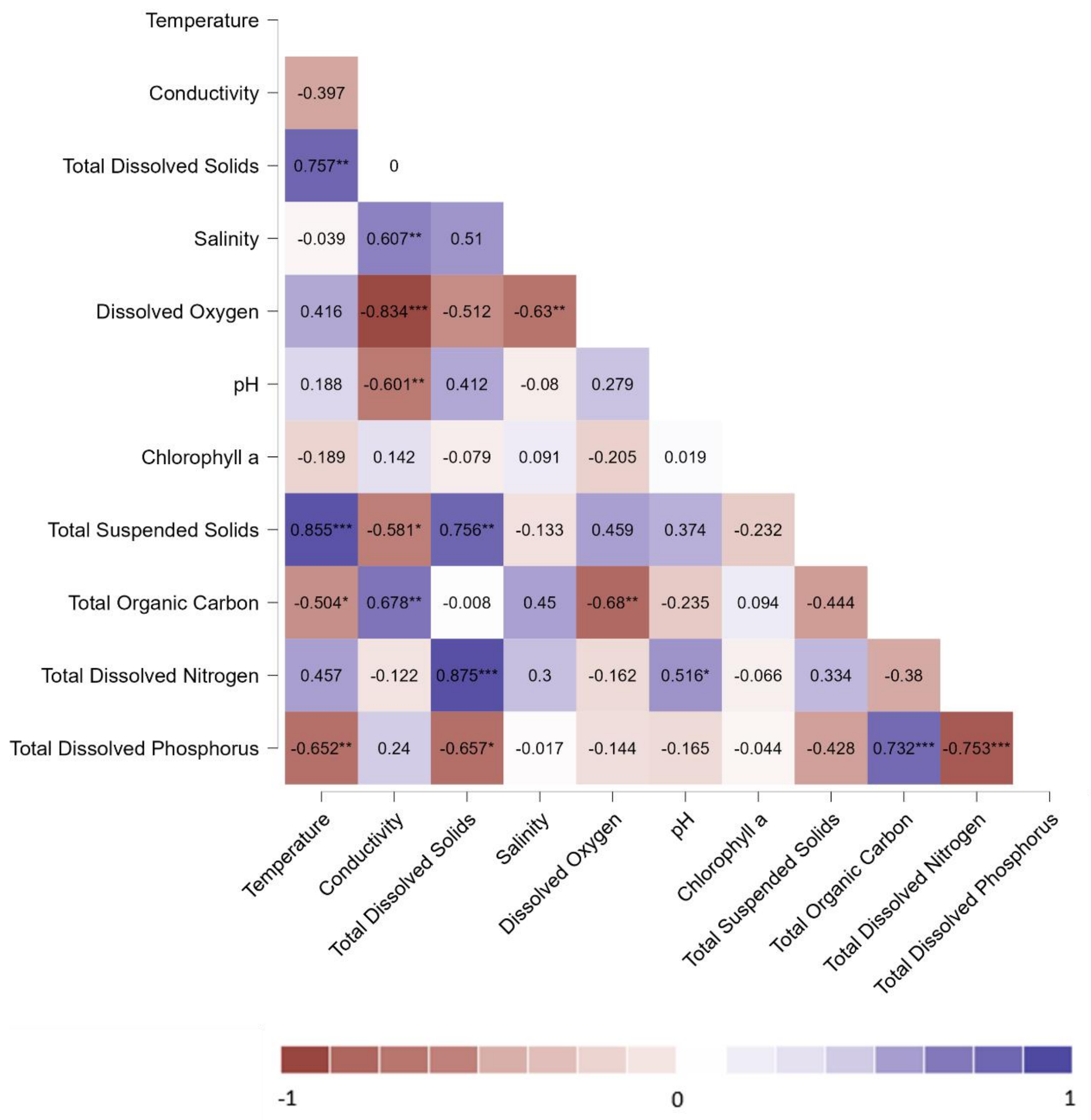

Figure 4.4 The Spearman rank correlation coefficients illustrate the relationship between each parameter recorded from *P. helicopus* dominated area in Tasik Berombak.

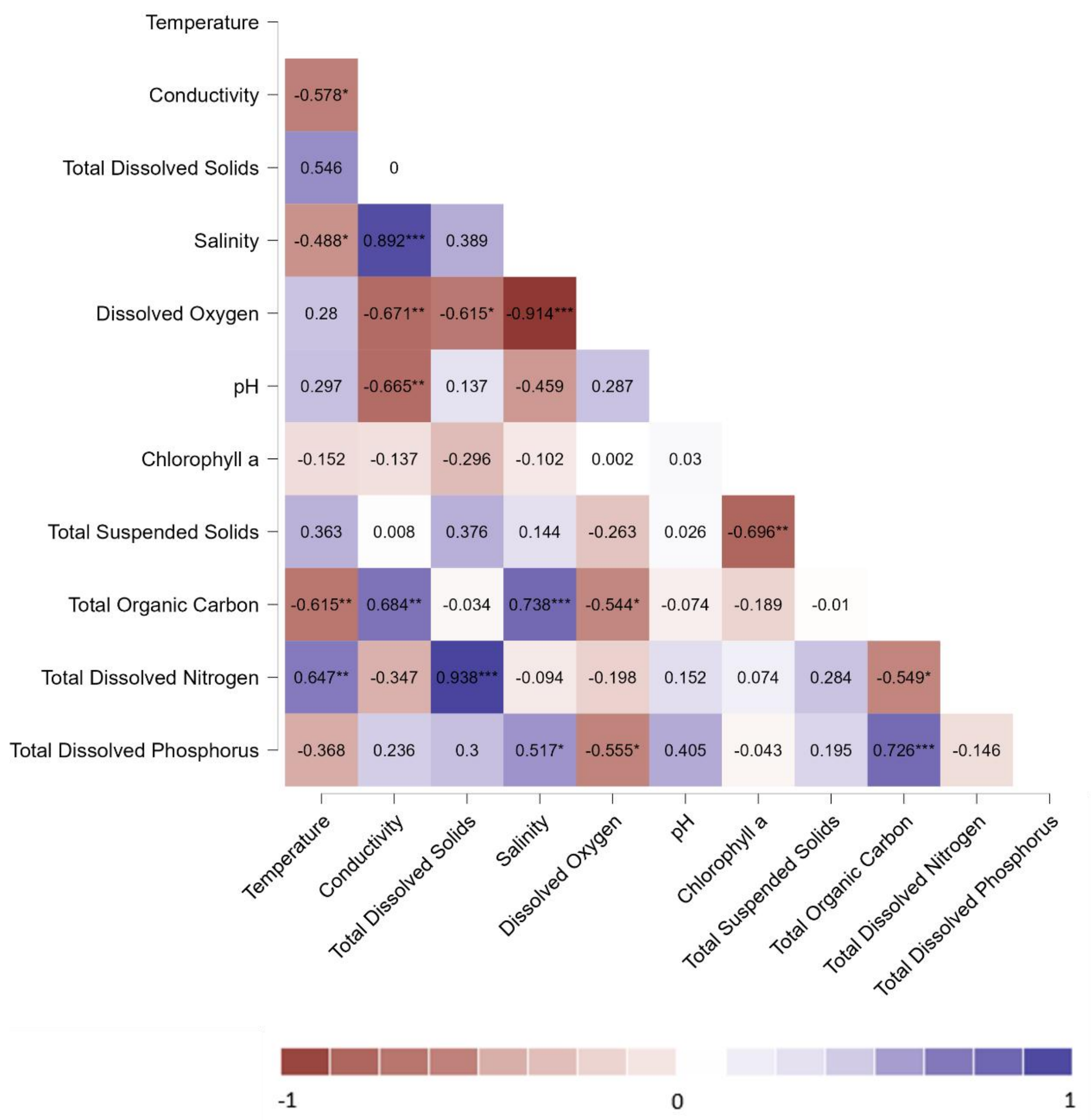

Figure 4.5 The Spearman rank correlation coefficient illustrates the relationship between each parameter recorded from non-vegetated area in Tasik Berombak.

Although most physico-chemical variables assessed in this study did not exhibit significant differences between vegetated and non-vegetated areas, three parameters which were Chlorophyll a, TSS, and TDS did show notable significance. Among these, areas dominated by *H. malayana* demonstrated significant differences compared to the other two sampling sites.

CHAPTER 5

THE EFFECTS OF EMERGENT MACROPHYTES TOWARDS THE SEDIMENTATION RATE OF TASIK BEROMBAK

5.1 Introduction

Sediment are particulate matters that were deposited into the water bodies, suspended, and settled to the bottom of the ecosystem. Sediment is a mixture of two types of particulate matters, the organic and inorganic, and that their sizes vary greatly (Rutledge *et al*., 2024). These particulate matters originate from different sources, can it be of allochthonous or autochthonous input. Allochthonous particulate matters derived from other places into where it was settled, whereas autochthonous particulate matters derived within the same lake where sediment formation occurred (Bloesch, 2003).

Sedimentation is a natural process of lake ecosystem whereby inorganic, organic matter and other suspended particles in the water bodies sink to the lakebed. Not only do sedimentation contributes to the forming of beaches, estuaries, deliver nutrients and minerals to the downstream ecosystems, it is also an essential element for some of the living organisms, as they rely on the sediment as their habitat (Byers & Grabowski, 2014). The amount of sedimentation inevitably affects the condition and function of the ecosystem, for example the quality of water. Water quality may be affected by high sedimentation rate which leads to reduced water clarity and the habitat of living organisms (Tundu *et al*., 2018; Teagasc, 2020).

Emergent macrophytes are aquatic plants that have roots anchored to the sediment and other vegetative parts protruding out of the water. Presence of emergent macrophytes tends to influence the sedimentation of the ecosystem (Li *et al*., 2016). The process of sedimentation and its patterns could be correlated with the sediment capture and stabilization, influence on hydrodynamics of the lake (Madsen *et al*., 2001; Horppila & Nurminen, 2003; Horppila *et al*., 2013). Emergent macrophytes have dense and complex matrix root systems that extend into the sediment that acts as a physical barrier, effectively capture and retain suspended sediments, slowing down water flow and allowing sediment particles to settle, reducing their transport downstream (Kaitaranta *et al*., 2013). By stabilizing the sediments, they prevent erosion and helps to maintain the overall stability of the aquatic environment.

The presence of emergent macrophytes can alter the hydrodynamics of aquatic systems. Plants affect water flow patterns and velocity distribution. This altered flow patterns and velocity distribution further influence sedimentation dynamics by promoting sediment deposition in specific areas (Horppila & Nurminen, 2003; Horppila *et al*., 2013; Zhu *et al*., 2015). It is important to note that the effects of emergent macrophytes on sedimentation dynamics can vary depending on species composition, plant density, hydrological conditions, and other factors specific to the ecosystem. The presence or absence of macrophytes can have both positive and negative impacts on sedimentation, depending on the context and specific goals of management or conservation efforts.

The rate of sedimentation does not show a constant pattern whether it be in the same lake or different. There are numerous aspects and circumstances that influence the amount and rate of sedimentation. Apart from the characteristics of sediment, such as particle size, density, shape, charge and orientation, there are few other factors that affects the sedimentation of water bodies. The presence of macrophytes such as its density and coverage, the morphological characteristics of macrophytes, environmental factors also possess impacts towards the load and rate of sedimentation (Zhu *et al*., 2015). Water temperature, wind, precipitation, currents, velocity of water, input of particles, land use and the characteristics of the ecosystem are to be taken into consideration when determining the rate of sedimentation (Fojutowski *et al*., 2021).

The lake was mostly covered with vegetation, especially *H. malayana*, which is a type of emergent macrophytes that is dominating the lake and is still growing rapidly, causing the issue of “disappearance” of the lake. Not to mention the overgrowth of emergent macrophytes may gradually covering up the lake surface, emergent macrophytes was also claimed to have notable effect on sedimentation rate (Li *et al*., 2016). The structure of emergent macrophytes can function as a barrier trapping particles and slowing water flow. Yet, overgrowth of macrophytes also causes serious implications towards the lake’s integrity. Consequently, the lake will eventually be covered up by macrophytes and vanished, results in loss of biodiversity. Understanding the sedimentation dynamics may provide prospect on the potential ecological and management implications towards the lake restoration and protection. Thus, the objective of this study was to investigate the effects of emergent macrophytes towards the sedimentation rate in freshwater lake ecosystems. The assumption made regarding sedimentation rate of vegetated areas and non-vegetated area will be different.

5.2 Methodology

5.2.1 Sampling Design

At each sampling location, three sediment traps were deployed and retrieved during each sampling event. Each sediment trap was constructed from aluminium and designed as a single unit (Figure 5.1). The unit had four cylindrical tubes, each 50 cm long and 6 cm wide (Figure 5.2). Sediment traps were retrieved every two months, and the content accumulated in the traps were transferred into a 5-L HDPE bottle to be brought back to the laboratory. The sediment in the bottle were then transferred into measuring cylinder and let settle for a week. The height of the settling was recorded, dried at 60°C on aluminium foil and recorded in grams.

The sedimentation rate of was calculated as $g/m^2/day$ (Anisah *et al.*, 2011), which

W = dry weight of settling,

A = surface area of the measuring cylinder

D = number of days the sediment trap deployed per sampling session

$$\text{Sedimentation} = \frac{\text{W (g)}}{\text{A (m}^2\text{) / D (day)}}$$

(Equation 5.1)

Figure 5.1 The single unit of the trap with four cylinder tubes used for sediment settling experiment.

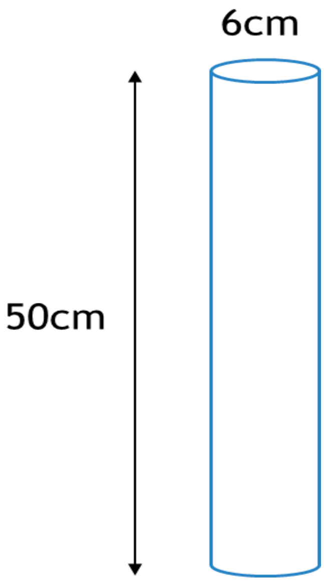

Figure 5.2 The dimension of the cylinder tube used in this study.

5.2.2 Statistical Analysis

Normality test was conducted to determine the distribution of data. The data from the sediment traps were processed using non-parametric Kruskal-Wallis and Dunn's Post-hoc test. The Kruskal-Wallis test was used to determine whether the comparison of two or more groups of variables showed any significant differences. After determination, variables that were significantly different were further analysed using Dunn's Post-hoc test. Best Fit Model was used as a predictor to indicate the relationship of all data. Best Fit Model approach was used to develop sedimentation rate equations for each sampling site based on the selection of most significant factors.

5.3 Results and Discussion

Table 5.1 presents the mean sedimentation rate for all sampling locations. Overall, the sedimentation rate of both vegetated areas was lower as compared to non-vegetated area. In the *H. malayana* dominated area, the sedimentation rate remained steady at 0.04 $g/m^2/day$ from February to July, increasing to 0.06 $g/m^2/day$ from July to September and further to 0.07 $g/m^2/day$ through January. In contrast, the *P. helicopus* area showed variability, beginning at 0.03 $g/m^2/day$ from February to April, peaking at 0.07 $g/m^2/day$ from July to September, and fluctuating to 0.02–0.04 $g/m^2/day$ in later months. The non-vegetated area displayed the most pronounced changes, with values decreasing from 0.13 $g/m^2/day$ in early months to 0.05 $g/m^2/day$ by April to May, reaching a peak of 0.21 $g/m^2/day$ from July to September, and stabilizing around 0.12 – 0.14 $g/m^2/day$ from September to January.The observed mean data with high standard deviation (0.21 ± 0.25) as of July to September was due to the dislocation of the traps during the two months period. One of the traps was tilted when it was retrieved, which caused the high loading of sediment in the tubes.

Table 5.1 Average value of sediment accumulation during sampling period (February 2019 to January 2020) of Tasik Berombak.

Locations	Sampling period	Sedimentation rate (g m^{-2} day^{-1})	
		Mean	S.D.
Hanguana malayana	Feb – Apr	0.04	0.01
	Apr – May	0.04	0.01
	May – July	0.04	0.01
	July – Sept	0.06	0.01
	Sept – Nov	0.07	0.02
	Nov – Jan	0.07	0.01
Pandanus helicopus	Feb – Apr	0.03	0.00
	Apr – May	0.05	0.02
	May – July	0.04	0.03
	July – Sept	0.07	0.00
	Sept – Nov	0.02	0.01
	Nov – Jan	0.04	0.01
Non-vegetated area	Feb – Apr	0.13	0.10
	Apr – May	0.05	0.05
	May – July	0.07	0.00
	July – Sept	0.21	0.25
	Sept – Nov	0.12	0.13
	Nov – Jan	0.14	0.07

Kruskal-Wallis test was performed on the sedimentation rate dataset of all sampling area. The outcome showed that there are significant differences in sedimentation rate (p-value < 0.05) between location. Post-hoc test was done on each location. The analysis indicates a statistically significant disparity solely between locations of *H. malayana* and non-vegetated area (p = 0.018) and *P. helicopus* and non-vegetated (p < 0.001). The sedimentation rate between the two vegetated area does not show significant difference. Nevertheless, no significant differences observed between north-east monsoon (November to February) and non-monsoon (March to October) periods across all locations.

Although each sampling area either with vegetation or unvegetated have different rate of sedimentation, but overall, the rate of sedimentation is lower in vegetated areas as compared to non-vegetated area (Figure 5.3). The study suggests that the sedimentation rate do differs between vegetated and non-vegetated area. The obtained result contradicts with previous results (Li *et al*., 2016; Lawniczak-Malinska *et al*, 2018). It was suggested that macrophytes slow down water current and waves, reducing resuspension and increases sedimentation (Madsen *et al*., 2001), promoting lake shallowing (Lawniczak-Malinska *et al*, 2018).

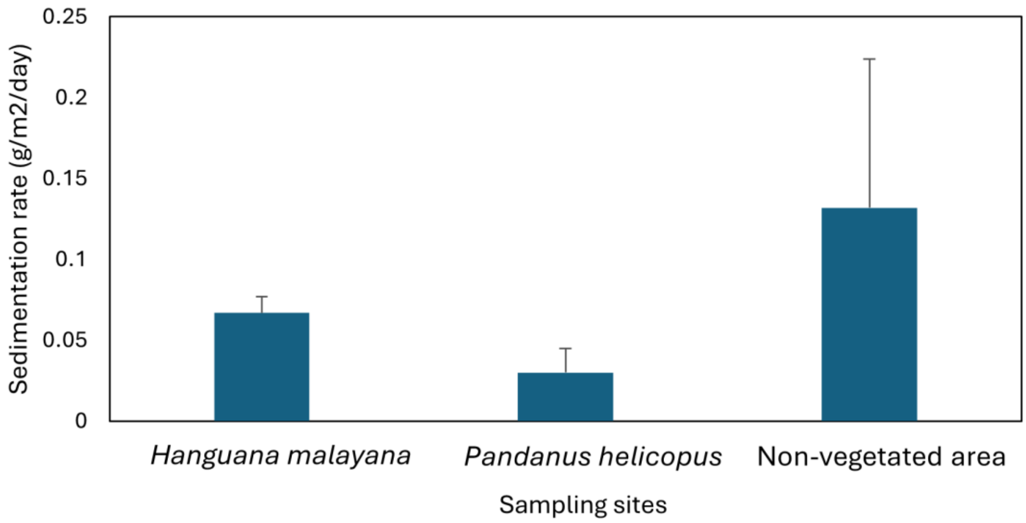

Figure 5.3 The sedimentation rate of three different sampling sites.

The adjusted R^2 value of Goodness-of-Fit for sedimentation rate of all sampling sites were obtained as of 0.454, 0.352 and 0.125 for *H. malayana*, *P. helicopus* and non-vegetated area respectively. The R^2 value of non-vegetated area was comparatively lower than the vegetated area. Input variables for this sampling site might have less significant effect on the improvement in the model of the sedimentation rate by chance by looking at the stated value. However, the error could be caused by other factors such as the sampling sessions, number of samples collected.

5.3.1 Factors controlling sedimentation rate

Among all parameters recorded, the two variables which are IC (*p*-value = 0.017) and TDP (*p*-value < 0.0001) were considered having significant positive influences on the sedimentation rate of *H. malayana* covered area. In *P. helicopus* covered area, the two variables having the most influential adverse effects towards the sedimentation rate were pH and TDP (*p*-value = 0.004 and *p*-value = 0.000 respectively) (Table 5.2). TDP is the variables that affect significantly on the sedimentation rate at both vegetated locations, despite in each vegetated area having positive and negative effects. TDP is one of the essential nutrients that boost the growth of plants by increasing photosynthesis. Thus, promoting the production of organic matter when they decay. The only parameter significantly affecting the sedimentation rate of non-vegetated area was pH with *p*-value of 0.047 (Table 5.2).

TDP has a crucial role as predictor of chlorophyll *a* via phytoplankton biomass and plant growth (Søndergaard *et al*., 2017). Thus, result in rapid algal and plant growth and increased sedimentation rate. TDP can be influenced by pH and IC proportionately. High level of IC influence pH which in turn affects the solubility of phosphorus (Wetzel, 2001; Pagano & Titus, 2007; Cerozi & Fitzsimmons, 2016). Increase in IC concentration then promotes growth rate of macrophytes (Pagano & Titus, 2007), increase in biomass thus resulting in higher sedimentation rate.

Inorganic carbon (IC) is responsible for the alteration freshwater lakes pH. Low IC concentration reduces the water pH which in turn reduces the sedimentation rate, as a result of cation dissolution, interrupt calcium carbonate formation which can accelerate sedimentation rate (Wang *et al*., 2019). These studies suggested that liming and monitoring the concentration of IC can be effective in managing sedimentation.

Table 5.2 Statistical factors controlling the sedimentation rate for each sampling locations in Tasik Berombak.

Sampling locations	Factors controlling sedimentation rate
Hanguana malayana	Inorganic carbon and Total Dissolved Phosphorus
Pandanus helicopus	pH and Total Dissolved Phosphorus
Non-vegetated area	pH

5.3.2. Sedimentation Rate Modelling

Sedimentation rate modelling allow others to understand certain variable as a water quality indicator, the productivity and the long-term ecological processes. Application of the modelling can forecast the impact of human-induced activities on the sedimentation rate, nutrient dynamics of the ecosystems. Then, the data obtained can be referred when development planning and management take place, restoration, ideally to lessen adverse effects towards the ecosystem (Wang *et al*., 2018).

Best Model variable selection method was used to identify the dominant variables that display the best prediction of the sedimentation rate by developing a model. All three sampling sites have different variables that influence its sedimentation rate. According to the most prominent parameters influencing the sedimentation rate of each site, three models were presented (Equation 5.2, 5.3 and 5.4) as a prediction of sedimentation rate for each site and other lake area with similar characteristics. Sedimentation rate prediction model is described by the equation below.

Equation of model for sedimentation rate in *H. malayana* dominated area:

Sed. rate = -0.99+0.14***IC**+0.14***TDP** (Equation 5.2)

The model suggests that sedimentation rate increases as IC and TDP increases, meaning that if the IC and TDP concentration increases, the sediment settling rate increases (Figure 5.4). This is due to the influence of IC on pH which will then influence the solubility of TDP. As TDP induces plant growth rate, higher biomass results in higher sedimentation.

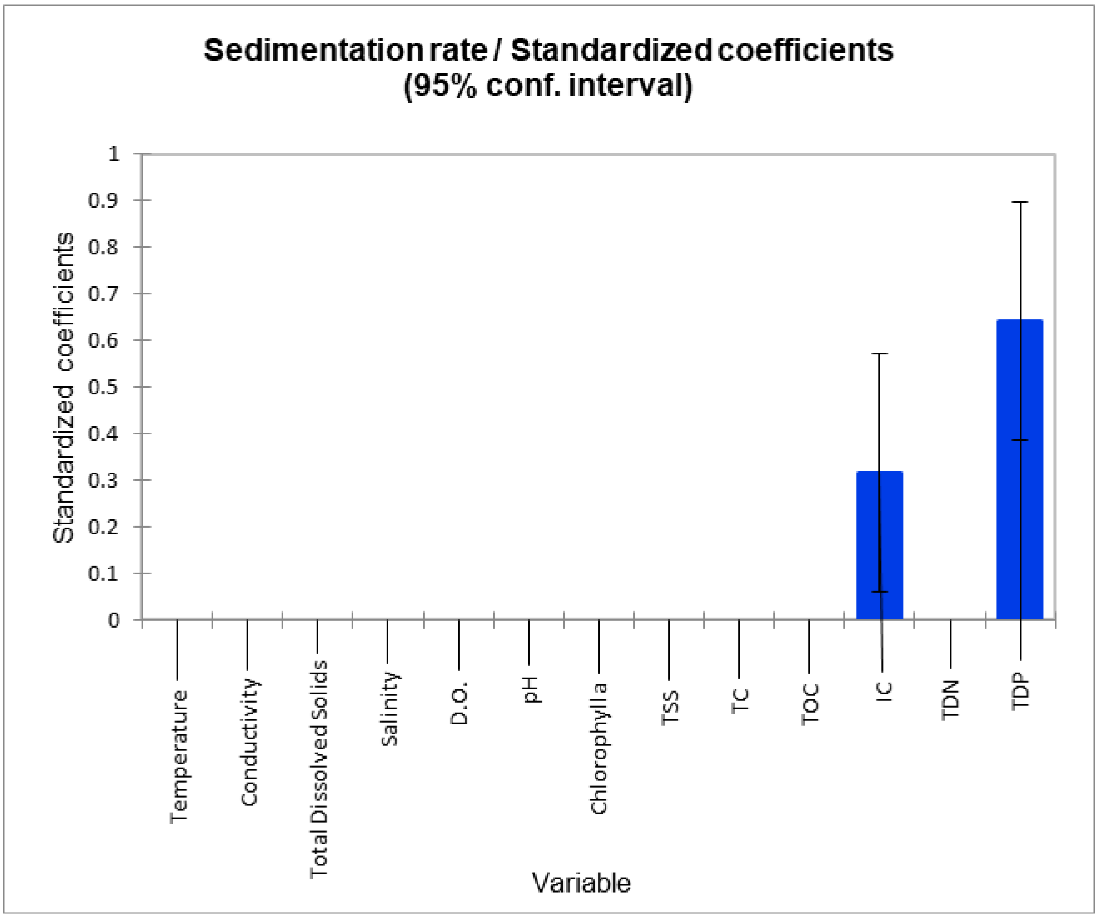

Figure 5.4 Predicted variables (IC and TDP) based on forward selection and backward elimination that contributed the most to the sedimentation rate in *H. malayana* dominated area.

Equation of model for sedimentation rate in *P. helicopus* dominated area):

Sed. rate = -1.18-1.24***pH**-0.41***TDP** (Equation 5.3)

The model suggests that sedimentation rate reduces when pH and TDP concentrations decrease, implying that as pH and TDP concentrations fall, so does sediment settling rate (Figure 5.5). This is due to pH's impact on TDP solubility. Because TDP is tied to plant growth rate, the biomass will impact the sedimentation of a particular area.

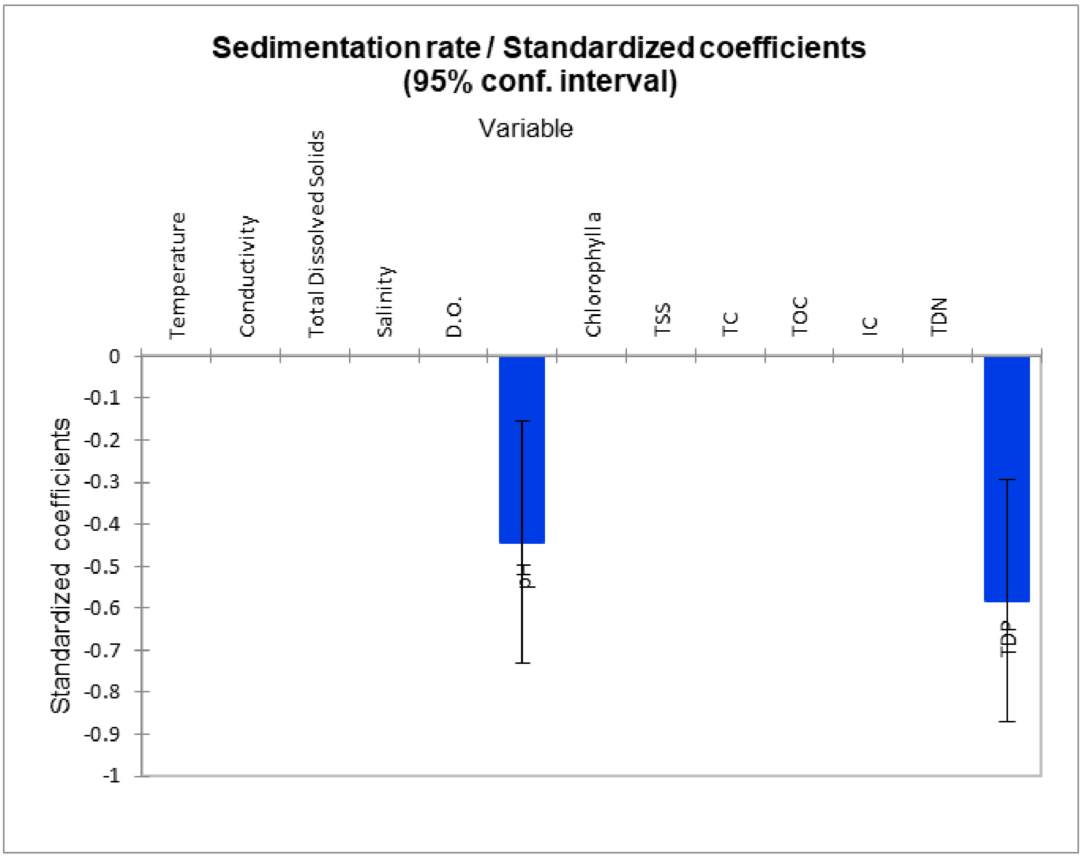

Figure 5.5 Predicted variables (pH and TDP) based on forward selection and backward elimination that contributed the most to the sedimentation rate in *P. helicopus* dominated area.

Equation of model for sedimentation rate in non-vegetated area:

Sed. rate = 1.01-1.37***pH**+0.51***Chlorophyll-*a*** (Equation 5.4)

According to the model, the rate at which sedimentation occurs in the non-vegetated region rises when the pH level lowers, while the concentration of Chlorophyll-a increases (Figure 5.6). However, it is worth noting that the increase in Chlorophyll-a was not statistically significant.

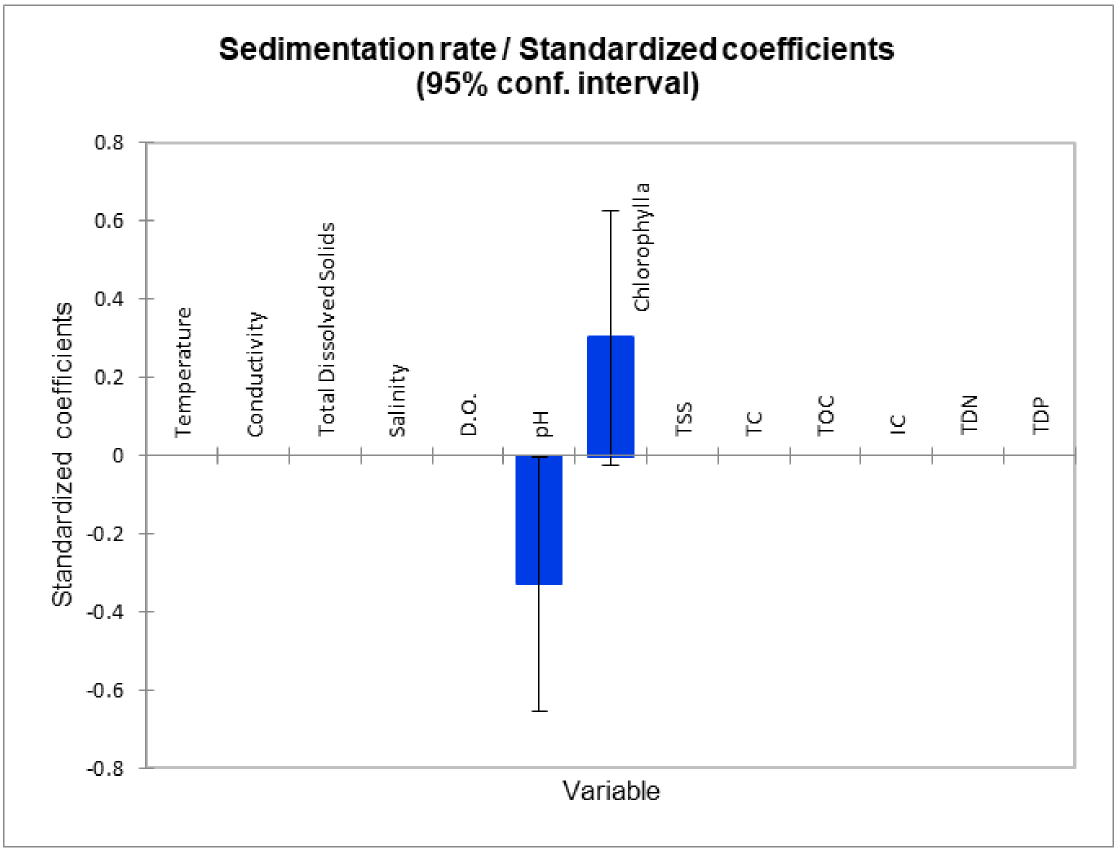

Figure 5.6 Predicted variables (pH) based on forward selection and backward elimination that contributed the most to the sedimentation rate in non-vegetated area.

The presence of macrophytes reduces the lake's sedimentation rate through their physical structures, such as roots and shoots, which trap particles originating either from within the lake or from adjacent land inputs. In Tasik Berombak, specific factors were found to influence sedimentation rates across different sites: in the *H. malayana*-dominated area, inorganic carbon (IC) and total dissolved phosphorus (TDP) were key determinants; in the *P. helicopus*-dominated area, pH and TDP played significant roles; while in non-vegetated areas, pH was the sole factor affecting sedimentation rate.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Emergent macrophytes are considered a valued component of freshwater lake ecosystem. This is due to their role in regulating all physical, chemical and biological property of the ecosystem and showing significant impact towards the shaping of ecological community and sedimentation in particular. Therefore, this study was conducted to investigate the influence of emergent macrophytes on water parameters and sedimentation rate.

Although much of the physico-chemical variables tested in this study does not show significant differences between vegetated and non-vegetated area, the only three parameters that showed significance were Chlorophyll a, total suspended solids and total dissolved nitrogen. And, among all three parameters, *H. malayana* dominated area showed significant differences with the other two sampling areas. The presence of macrophytes helps reduce the sedimentation rate of the lake thanks to its physical structure such as the roots and shoots which traps the particles whether it be originated from the lake or input from the adjacent land. It was found that in Tasik Berombak, the factors that determined the sedimentation rate of each site were IC and TDP for *H. malayana* dominated area, pH and TDP for *P. helicopus* dominated area, whereas for non-vegetated, only one factor which is pH was affecting the sedimentation rate.

As much as other studies suggested that the existence of macrophytes do help in maintaining water clarity and quality, overgrowth of macrophytes will then bring adverse effects towards the lake ecosystem. Overgrowth of macrophytes contribute to lake shallowing and shrinking of lake surface area, inevitably causing the lake to disappear. Such phenomena are of great lost to earth's biodiversity, and impacting the livelihoods of people who depend on the ecosystem, which is positively impacted by studies shedding light on the complex interactions of crucial ecosystems that avoid biodiversity or ecosystem imbalance. Thus, maintaining moderate coverage of macrophytes and appropriate development programme are of utmost importance where one can enjoy benefits the ecosystem brought while still protecting and preserving the ecosystem and other connected ecosystems.

To enhance the findings,

a. Study on parameters such as COD, BOD, heavy metals to obtain a more comprehensive understanding of the influence of emergent macrophytes on water quality.
b. Study on hydrological characteristics (for example water flow velocity, water level) should be considered. Tasik Berombak is undergoing channelization which might have impact on sedimentation patterns, water quality and habitat alteration for restoration purpose.

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APPENDICES

Appendix 1

Detailed methodology for nutrient analysis

Total Dissolved Nitrate Analysis

Preparation of mix reagent

1) Sulfanilamide:

   1 mL of 12 N HCl were prepared and 0.1 g of sulfanilamide were dissolved in the solution, deionized water were then added to obtain the volume of 10 mL and let cool to room temperature.

2) N-(1-napthyl)-ethylenediamine dihydrochloride (NED):

   0.01 g of NED were dissolved in 10 mL of deionized water.

3) Vanadium (III) chloride:

   250 mL of 6 N HCl were prepared and stored in opaque bottle. 5 g of VCl_3 were dissolved in the solution and let rest for approximately 1 h for dissolution. The solution was then filtered through 0.7 µm pore size GF/F and stored in 4°C.

4) Order of mixing reagents (100 mL):

   10 mL of each reagent prepared were added into 70 mL of deionized water.

Total Dissolved Phosphorus Analysis

Preparation of combined reagent

1) Sulphuric acid:

14 mL concentrated sulphuric acid were diluted to reach the volume of 90 mL with deionized water. The solution is then let cool to room temperature before mixing with other reagents.

2) Potassium antimonyl tartrate solution:

0.034 g of potassium antimonyl tartrate were dissolved with 25 mL deionized water in glass bottle.

3) Ammonium molybdate solution:

0.6 g of ammonium molybdate were dissolved with 20 mL deionized water in glass bottle.

4) Ascorbic acid:

1.08 g ascorbic acid were dissolved with 20 mL of deionized water every time before experiment.

5) Order of mixing all reagents (100 mL):

50 mL of sulphuric acid were added into glass container. Then, 20 mL of ammonium molybdate solution were added into the container, followed by 20 mL of ascorbic acid and top up with 10 mL of potassium antimonyl tartrate solution. The turbid solution was shaken and let stand until it becomes bluish transparent. Combined reagents were prepared freshly every time as it is stable for 4 hours after mixing.

Appendix 2

Kruskal-Wallis and Post-Hoc test on significant results for water parameters

Kruskal-Wallis Test – Chlorophyll a (mg/L)

Factor	Statistic	df	p
Plant	8.346	2	0.015

Dunn's Post Hoc Comparisons – Chlorophyll a (mg/L)

Comparison	z	W_i	W_j	p	p_{bonf}	p_{holm}
HM - Non vege	2.672	32.000	19.875	0.004	0.011	0.011
HM - Pandan	2.287	32.000	21.625	0.011	0.033	0.022
Non vege - Pandan	-0.386	19.875	21.625	0.350	1.000	0.350

Kruskal-Wallis Test – Total suspended solids (mg/L)

Factor	Statistic	df	p
Plant	22.997	2	< .001

Dunn's Post Hoc Comparisons – Total suspended solids (mg/L)

Comparison	z	W_i	W_j	p	p_{bonf}	p_{holm}
HM - Non vege	3.020	29.778	13.944	0.001	0.004	0.003
HM - Pandan	-1.716	29.778	38.778	0.043	0.129	0.043
Non vege - Pandan	-4.736	13.944	38.778	< .001	< .001	< .001

Kruskal-Wallis Test – Total dissolved nitrogen (ppm)

Factor	Statistic	df	p
Plant	15.746	2	< .001

Dunn's Post Hoc Comparisons – Total dissolved nitrogen (ppm)

Comparison	z	W_i	W_j	p	p_{bonf}	p_{holm}
HM - Non vege	-3.808	15.889	35.750	< .001	< .001	< .001
HM - Pandan	-2.871	15.889	30.861	0.002	0.006	0.004
Non vege - Pandan	0.937	35.750	30.861	0.174	0.523	0.174

Appendix 3

Kruskal-Wallis and Post-Hoc test on significant results for sedimentation rate

Kruskal-Wallis Test – Sedimentation rate ($g/m^2/day$)

Factor	Statistic	df	p
Monsoon	0.304	1	0.582
Location	15.027	2	< .001

Dunn's Post Hoc Comparisons – Sedimentation rate ($g/m^2/day$)

Comparison	z	W_i	W_j	p	p_{bonf}	p_{holm}
hm - nv	-2.369	25.324	37.556	0.009 **	0.027 *	0.018 *
hm - ph	1.413	25.324	18.028	0.079	0.236	0.079
nv - ph	3.837	37.556	18.028	< .001 ***	< .001 ***	< .001 ***

* p < .05, ** p < .01, *** p < .001

LIST OF PUBLICATIONS

Choe, J.Y., Ku Yusof, K.M.K, and Rohani, S. (2023). A raw data on the physico- chemical water parameters and sedimentation rates of two different aquatic macrophytes in Tasik Berombak, Malaysia. *Data in Brief*, *49*. DOI: 10.1016/j.dib.2023.109397 (Published)

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