SPATIAL AND TEMPORAL DISTRIBUTION OF MACROPHYTES IN RELATION TO WATER QUALITY PARAMETERS IN CHENDEROH RESERVOIR, PERAK

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by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF SYMBOLS AND ABBREVIATIONS

°C	Degree celcius
a.s.l	Above sea level
cm	Centimeter
g	Gram
ha	Hectare
Hz	Hertz
km	Kilometer
L	Liter
nm	Nanometers
m	Meter
mg	Milligram
ml	Mililiter
mm	Millimeter
rpm	Revolutions per minute
R^2	Regression coefficient
s.d.	Standard deviation
S	Siemens
SPSS	Statistical Package for Social Science

SEBARAN MAKROFIT SECARA SPATIAL DAN TEMPORAL BERKAIT DENGAN PARAMETER KUALITI AIR DI EMPANGAN CHENDEROH, PERAK

ABSTRAK

Satu kajian mengenai variasi spatial dan temporal faktor persekitaran terhadap sebaran makrofit di Empangan Chenderoh telah dijalankan dari Jun 2015 hingga Mei 2016. Kajian ini bertujuan untuk menganalisis kepelbagaian dan corak sebaran spesies makrofit berdasarkan faktor spatial dan temporal yang berhubung kait dengan parameter kualiti air dan morfometri takungan. Kajian ini telah dilakukan di 18 titik persampelan yang meliputi kawasan teluk dan saluran utama sungai pada selang 1 km. Tinjauan mengenai sebaran dan peratusan liputan spesies makrofit dilakukan berdasarkan kaedah garisan transek dan kuadrat. Beberapa parameter kualiti air dari tiga kedalaman yang berbeza (permukaan air, kedalaman Secchi dan bawah) diukur secara *in-situ* dan sampel air dikumpulkan untuk analisis selanjutnya. Di makmal, analisis jumlah pepejal terampai (TSS), klorofil *a* (Chl *a*), ortofosfat (PO_4), nitrit-nitrogen (NO_2), nitrat-nitrogen (NO_3) dan ammonia-nitrogen (NH_3) telah dijalankan. Tinjauan batimetrik dilakukan pada Februari 2016 dan April 2017 menggunakan kaedah pemeruman gema. Dalam kajian ini, spesies makrofit disebarkan mengikut kecerunan takungan. Sejumlah 34 spesies makrofit yang terdiri daripada empat jenis; muncul, daun terapung, tenggelam dan terapung bebas telah direkodkan. *Eichhornia crassipes* dan *Salvinia adnata* direkodkan di semua titik persampelan dan SP5 dengan keputusan bilangan spesies tertinggi iaitu sebanyak 29 spesies. Variasi temporal yang mempengaruhi turun naik paras air dalam takungan telah menunjukkan bahawa jumlah kekerapan makrofit berbeza secara signifikan antara titik persampelan dan bulan persampelan. Ciri morfometrik, terutamanya kedalaman air menghasilkan pengezonan makrofit mengikut jenis yang mana ianya ditentukan oleh ketersediaan cahaya dan ciri hidrologi berdasarkan analisis kluster yang dijalankan. ANOVA dua hala menunjukkan perbezaan yang signifikan ($p<0.05$) secara spatial dan temporal antara parameter kualiti air dan sebaran makrofit. Parameter yang menyusun komuniti makrofit di Empangan Chenderoh adalah ketelusan air (kedalaman Secchi; SD) (59.49 ± 0.55 cm hingga 186.94 ± 0.64 cm), suhu (28.46 ± 0.06 °C hingga 30.27 ± 0.07 °C), oksigen terlarut (3.29 ± 0.13 mg/L hingga 4.74 ± 0.14 mg/L), PO_4 (0.025 ± 0.001 mg/L hingga 0.029 ± 0.001 mg/L), NO_2 (0.006 ± 0.002 mg/L hingga 0.038 ± 0.007 mg/L), NO_3 (0.025 ± 0.001 mg/L hingga 0.089 ± 0.009 mg/L), NH_3 (0.498 ± 0.087 mg/L hingga 1.393 ± 0.073 mg/L) dan Chl *a* (0.004 ± 0.000 mg/L hingga 0.014 ± 0.001 mg/L). Manakala, keadaan trofik semasa berdasarkan kepekatan Chl *a* (TSI_{Chl}) menunjukkan titik persampelan yang terletak di ekosistem lotik berada dalam status mesotrofik awal (39.29 ± 0.97) dan titik persampelan di ekosistem lentik menunjukkan status mesotrofik sederhana hingga tinggi (44.50 ± 1.07). Kajian ini menunjukkan bahawa sebaran makrofit di semua titik persampelan di Empangan Chenderoh ditentukan oleh ciri morfometrik dan parameter kualiti air yang dipengaruhi oleh perubahan musim dan pengawalan paras air empangan. Pengaturan ciri kualiti air oleh komuniti makrofit mengurangkan kebarangkalian eutrofikasi dalam takungan dan dapat bertindak sebagai penapis semula jadi dan bioakumulator. Hasil kajian ini membantu dalam pemahaman yang lebih baik mengenai dinamik kepelbagaian dan sebaran makrofit bersama dengan skala spatial dan temporal dalam takungan tropika yang cetek (<100 m kedalaman).

SPATIAL AND TEMPORAL DISTRIBUTION OF MACROPHYTES IN RELATION TO WATER QUALITY PARAMETERS IN CHENDEROH RESERVOIR, PERAK

ABSTRACT

A study on the spatial and temporal variations of environmental factors and the distribution of macrophytes at Chenderoh Reservoir was carried out from June 2015 until May 2016. This study was aimed to analyze the diversity and distribution pattern of macrophyte species based on spatial and temporal factors in relation to water quality parameters and reservoirs morphometry. The field sampling was conducted at 18 sampling points covering the embayments and main river channel of the reservoir with an interval of 1 km. Surveys on the macrophyte species distribution and cover percentage were conducted based on line transect and quadrat methods. Several parameters of water quality from three different depths (surface, Secchi depth and bottom) were measured *in-situ* and water samples were collected for further analysis. In the laboratory, the analysis of total suspended solids (TSS), chlorophyll *a* (Chl *a*), orthophosphate (PO_4), nitrite-nitrogen (NO_2), nitrate-nitrogen (NO_3) and ammonia-nitrogen (NH_3) were carried out. Bathymetric survey was conducted in February 2016 and April 2017 using echo sounding method. In this study, macrophyte species was distributed according to the slope of the reservoir. A total of 34 macrophyte species from four different types; emergent, floating-leaved, submerged and free-floating were recorded. *Eichhornia crassipes* and *Salvinia adnata* were recorded at all sampling points and SP5 resulted in the highest species number with 29 species. Temporal variations affecting water level fluctuation in the reservoir showed that the macrophytes total frequency was significantly different between sampling points and sampling months. The morphometric characteristic, particularly water depth resulted in the zoning of macrophytes according to their types, which is determined by the availability of light and hydrological attributes based on cluster analysis conducted. Two-way ANOVA showed significant differences ($p<0.05$) spatially and temporally between water quality parameters and macrophytes distribution. Parameters that structured the macrophytes community at Chenderoh Reservoir were water transparency (Secchi depth; SD) (59.49 ± 0.55 cm to 186.94 ± 0.64 cm), temperature (28.46 ± 0.06 °C to 30.27 ± 0.07 °C), dissolved oxygen (3.29 ± 0.13 mg/L to 4.74 ± 0.14 mg/L), PO_4 (0.025 ± 0.001 mg/L to 0.029 ± 0.001 mg/L), NO_2 (0.006 ± 0.002 mg/L to 0.038 ± 0.007 mg/L), NO_3 (0.025 ± 0.001 mg/L to 0.089 ± 0.009 mg/L), NH_3 (0.498 ± 0.087 mg/L to 1.393 ± 0.073 mg/L) and Chl *a* (0.004 ± 0.000 mg/L to 0.014 ± 0.001 mg/L). Whereas, the existing trophic state based on Chl *a* concentration (TSI_{Chl}) showed the sampling points located at lotic ecosystem were in early mesotrophic status (39.29 ± 0.97) and the sampling points at lentic ecosystem showed moderate to high mesotrophic status (44.50 ± 1.07). This study indicated that the macrophytes distribution at all sampling points in Chenderoh Reservoir was determined by morphometric characteristics and water quality parameters which were influenced by seasonality and water level fluctuations of the dam operation. The regulation of water quality attributes by macrophytes communities reduced the probability towards eutrophication in the reservoir and could act as a natural filter and bioaccumulator. These results help in a better understanding of the dynamic of macrophytes diversity and distribution along with spatial and temporal scales in a shallow tropical reservoir (<100 m depth).

CHAPTER 1

GENERAL INTRODUCTION

Plants in the wetland ecosystem are different from those on terrestrial. The ability of the plant to adapt to wet and damp conditions is one of the characteristics of aquatic plants, also known as macrophytes. Freshwater macrophytes are found all over the world, particularly at the lakes margin, rivers and streams, marshes and swamps (Lukács *et al*., 2013; Murphy *et al*., 2019). It is usually the most visible component of the ecosystem. There are four main types of macrophytes namely emergent, floating-leaved, submerged and free-floating (Cronk & Fennessy, 2016).

Generally, macrophytes have many possible methods to be established in new locations. Colonisation can be initiated by the vegetative structures of macrophytes which originated from other locality, subsequently regenerate and conquer new areas (Vári & Tóth, 2017). Macrophytes introduction, dispersal and succession are related to a few factors such as the seed production and dispersal, ecosystem types and nutrient enrichments (untreated domestic waste, agricultural nutrient leaching and industrial pollutant discharge) (Narasimha & Benarjee, 2016). Habitat disturbance or fragmentation of the wetland ecosystem facilitates macrophytes colonisation such as damming of large rivers. The dam construction interrupted the connection of river flow and resulted in vast standing water habitats. Thus, it will lead to the alteration of the hydrology, ecology and physico-chemical status of the system (Beck *et al*., 2012; Shivers *et al*., 2018).

Most of the reservoirs especially in the tropics were subjected to periodic fluctuations of water levels, affected by rainfall and dam operation. The regulated flow of water is a significant result of changing a natural river ecosystem (lotic) into a man-made reservoir or lake (lentic) (Wetzel, 2001; Gangstad, 2018). The regulations of matter transport and water flow accumulate the inorganic nutrients such as phosphorus and ammonia and also maneuver the suspended particles towards hypolimnion layer and bottom sediment in a lentic environment. The continuous nutrient loading into the reservoir will raise the eutrophication problem. Eutrophication or enrichment of nutrients increases the aquatic organism populations, particularly the macrophytes community (Poff & Zimmerman, 2010; Salameh & Harahsheh, 2010; Beck *et al*., 2012; Shivers *et al*., 2018; Asmaliza & Sidek, 2019).

Macrophytes distribution is also determined by water depth, slope and morphometry, soil characteristics and wind direction of lakes and reservoirs (Joanna *et al*., 2020). The variations of water depth influence the underwater light intensity which had a strong relationship with macrophytes growth and zonation (Roznere & Titus, 2017; Jin *et al*., 2020). Macrophytes zonation varied depending on types (emergent, floating-leaved, submerged and free-floating) and species with the successful seedling establishment and inundation tolerance (Thomaz *et al*., 2015; Ye *et al*., 2018). Subsequently, soil substrates in fine particles and frequently nutrient-rich will stimulate the growth of macrophytes (Gillefalk *et al*., 2019).

Alien species that are accidentally or purposefully introduced by humans would subsequently be established and colonised in a nutrient-rich environment such as reservoirs. The interactions of introduced species in a new location in terms of competition and displacement of the native species, lack of predations and special species morphology and physiology would lead to species invasiveness (Louback-Franco *et al*., 2019). For example, the establishment of water hyacinth (*Eichhornia crassipes*) caused trouble throughout the tropics by impeding the irrigation canals, blocking transportation and accelerating habitat deterioration (Degaga, 2018). This South American native species had spread worldwide and became invasive through rapid reproduction upon introduction in a new habitat (Yigermal & Assefa, 2019). Ecological invasion studies have shown that the increase in invasive species colonisation is the consequence of environmental changes (Grzybkowska *et al*., 2017). Introduced species will multiply in number when the environmental requirements are met through seed dispersal or offspring reproduction, either sexually or non-sexually; and lacks in competition, thus make them invasive without limiting factors (Brainard *et al*., 2021).

1.1 An overview of macrophytes distribution in Malaysia

The macrophytes growth is often cause problems and interfere with humans activities. Perhaps, Cheam (1974) was the first local scientists to highlight the aquatic weed problem in Malaysia. Studies focused on the macrophytes distribution, influenced by nutrient enrichment and seasonal variation in this country were conducted at natural lakes such as Bera Lake and Chini Lake (Lim & Furtado, 1975; Furtado & Verghese, 1981; Sharip *et al*., 2012). The absence of volcanic activities and a stable geological formation hinder the formation of deep natural lakes in Malaysia. Chini Lake and Bera Lake in Peninsular Malaysia and Loagan Bunut in Sarawak are Malaysian natural lakes. Chini Lake primarily consists of water-bodies that merged and forming a combination of small lakes (Gasim *et al*., 2017), while Bera Lake is more of a freshwater swamp than a true lake, covered with stands of littoral, emergent, floating-leaved, submerged and floating macrophytes such as *Lepironia articulata* and *Pandanus helicopus* and very few truly open water spaces (Furtado & Mori, 2012). A few literatures concerning macrophytes and macrophytes related issues from various aspects such as ecological and socio-economic impact, productivity and also species diversity were reported in several wetland types in Malaysia (Anwar, 1978; Chin & Fong, 1978; Ho, 1981; Baki, 1982; Mashhor *et al*., 1983; Nather Khan, 1990; Nather Khan, 1991; Arumugam, 1994; Mashhor & Masnadi, 1994; Ali, 1996; Mashhor, 1996; Muta Harah *et al*., 2005; Sharip *et al*., 2014).

A study on macrophytes recorded massive infestation of water hyacinth in Perak River, the second-longest river in Peninsular Malaysia (Mashhor *et al*., 1983). The infestation of noxious macrophytes or weeds affects the natural and man-made water bodies, choking the irrigation canals by forming a dense mat on the water surface (Mashhor, 1996). Reservoirs in Malaysia were constructed for irrigation, water supply, flood control and hydropower generation since the 1930s (Sharip *et al*., 2016). Dam construction affects the lotic system which subjects to the relative stabilization of water levels, generating habitats preferable for macrophytes community succession, increasing underwater illumination after the conversion of a river into a reservoir determine the growth of submerged macrophytes (Cunha-Santino *et al*., 2016; Shivers *et al*., 2018). A study by Sharip *et al*. (2014) on 15 selected lakes and reservoirs in Malaysia had shown that almost all the studied sites recorded high nutrient levels and classified as eutrophic. The studied sites with prevailing eutrophication issues were Sembrong Reservoir in Johor, Bukit Merah Reservoir in Perak, Chini Lake in Pahang and Aman Lake in Selangor. Therefore, the information on macrophytes diversity and environmental interactions after the dam construction are crucial, especially in the tropical shallow reservoir.

1.2 Importance of study

Macrophyte infestations have been reported in reservoirs such as the colonisation of *Hydrilla verticillata*, *Ceratophyllum demersum*, *Nymphaea* sp., *Phragmites australis*, *Pandanus* sp. in Chenderoh Reservoir, Perak (Ali, 1996; TNBR, 2013), *Eichhornia crassipes* in Sembrong Reservoir, Johor (NAHRIM, 2012; Hashim *et al*., 2018) and *Hanguana malayana* in Bukit Merah Reservoir, Perak (Akademi Sains Malaysia, 2010). Subsequently, the aforementioned studies suggested that a few reservoirs were subjected to high productivity due to higher cultural eutrophication by the surrounding human settlements coupled with shallowness, slow water moving and extensive littoral zone. Anthropogenic nutrient enrichment results in excessive biological products such as the development of phytoplankton which are deposited at the bottom of the lake, contributing to the shallowness of the reservoir and possibly increasing the macrophytes development rate in the long term (Rhodes *et al*., 2017). Sharip *et al*. (2014) addressed the issues on the excessive growth of macrophytes and algae that reduce the water quality of a lake and threaten the ecosystem services and functions that have not been studied well, especially in the tropical region.

Considering the high number of macrophytes colonisation in Chenderoh Reservoir, this study was conducted to further understand the macrophyte distribution associated with water quality parameters. This man-made lake is accessible by road and renowned for its natural beauty, high productivity and rich diversity of fish and plant populations comparable to the other natural ecosystem such as Chini Lake and Bera Lake (Ali, 1996; Rafidah *et al*., 2010; Sharip *et al*., 2012). The Chenderoh Hydroelectric Power Station operated since 1930, had been considered a multi-purpose reservoir in the Perak Hydro scheme river system (Lee *et al*., 2018). Almost 70 to 80% of the embayments in this reservoir such as Kampung Beng, Kampung Cherakoh, Raban Lake and Kampung Jenalik are affected by human-related activities such as homesteading oil palm plantations, rubber plantations and fruit orchards (TNBR, 2013). Ground verification of 1981 map indicated changes at the margin and littoral zone of the reservoir due to shoreline sedimentation and growth of littoral macrophytes (TNBR, 2013).

The previous studies at Chenderoh Reservoir were concentrated on the fisheries (Nather Khan *et al.*, 1990; Ali & Lee, 1995; Ali & Kadir, 1996; Ali, 1996; Kah-Wai & Ali, 2000), zooplankton (Meor Hussain *et al*., 2002) and ecotourism potential (Aziz *et al*., 2014; Hassan *et al*., 2017) but less is known about macrophytes except for Mashhor *et al*. (1988) and Mashhor (1996) on the invasion of water hyacinth in Raban Lake. Based on personal communication with a local fisherman in Chenderoh Reservoir, they are facing problems with the rapid growth of nelumbo at Kampung Jenalik that has hindered the fishing activity. Slash-and-burn was practiced to reduce the massive growth of macrophytes due to limited supplementary information (species guide and control measure). The updated information on macrophytes establishment and distribution is crucial to face the rapid development of climate crisis that catalyst plant invasion (Rai, 2015).

Distributions of macrophytes subjected to seasonal variation mainly dependent upon hydrological changes of the reservoir. This process is particularly intense in tropical shallow reservoirs that are subjected to periodic water level fluctuations. Water loss via evapotranspiration was the most highlighted problems in the reservoir and requires maintenance such as weed removal programs to reduce water losses (Ali & Khedr, 2018). It was reported the reservoir operation decreases multiyear average hydropower generation by 10% under the macrophytes diversity conservation program (Xu *et al*., 2020). Water level fluctuation is a major concern by the dam operator concerning the function of dam operation with any declining trend in water level beyond a critical level can cause the degradation of the reservoir. Massive macrophytes cover may cause gradual conversion of the reservoir into the land due to evapotranspiration, but on the other hand, macrophytes may contribute to the improvement of water quality due to nutrient assimilation (Lu *et al*., 2018). Others such as sustainable riparian land use, protection of riverbanks and littoral zones, and management of watershed areas are also important in conserving the biodiversity and production of the fishery as a significant source of protein for the local community (Ali & Lee, 1995; TNBR, 2013).

The site specific morphometry would affect the macrophyte species distribution and colonisation that are depending on light exposure (Shivers *et al*., 2018; Schneider *et al*., 2018). Thus, it is a need to construct the contour map based on echo sounding data to a better understanding of water quality parameters that structures the macrophytes communities. The importance of this study is to investigate macrophyte species distribution and diversity based on spatial and temporal factors in relation to water quality parameters which are influence by seasonal patterns and morphometry of Chenderoh Reservoir.

1.3 Research objectives

The objectives of this study are:

1. To study the macrophytes zonation at Chenderoh Reservoir by constructing a bathymetric survey.
2. To determine the relationship between macrophyte and physico-chemical parameters of water quality at Chenderoh Reservoir.
3. To determine the spatial and temporal macrophyte species diversity and distribution at Chenderoh Reservoir.

CHAPTER 2

LITERATURE REVIEW

2.1 Aquatic macrophytes

The term ‘aquatic macrophytes’ is referring to a diverse group of aquatic photosynthetic organisms, that all large enough and visible with the naked eye. Macrophytes possess the vegetative parts of which actively grow either permanently or periodically (for at least several weeks each year) growing up, submerged below, or floating on the water surface (Cook, 1996; Chambers *et al*., 2007; Murphy *et al*., 2019). Macrophytes have varied shapes so that they can be classified into different structural groups based on morphology, orientation and arrangement of stems, leaves or branches (Grzybkowska *et al*., 2017). The types of macrophyte are emergent (plants that are rooted in submerged soils or soils that are periodically inundated, with foliage extending into the air), floating-leaved (plants rooted to the lake or stream bottom with leaves that float on the surface of the water), submerged (plants that grow completely submerged under the water, with roots buried in, attached to, or closely associated with the substrate) and free-floating (plants that commonly float on the water surface) (Figure 2.1) (Chambers *et al*., 2007; Chambers *et al*., 2008; Cronk & Fennessy, 2016; Murphy *et al*., 2019).

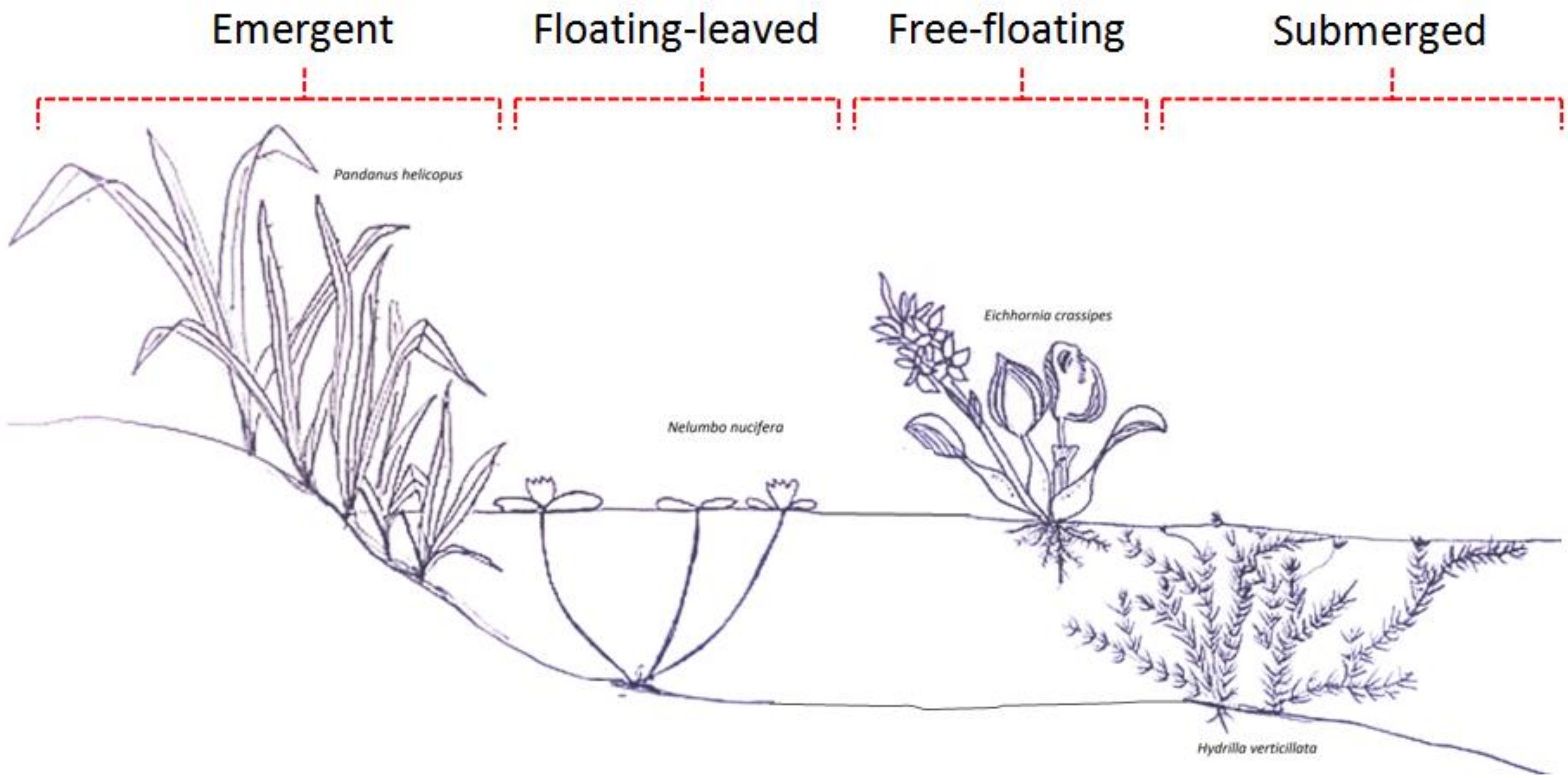

Figure 2.1: Types of macrophytes based on their growth form; emergent, floating-leaved, free-floating and submerged macrophytes (Cook, 1996)

Macrophytes are producers in the aquatic environment which positioned at the first trophic level in a food chain. Throughout the process of photosynthesis, it provides oxygen and food and also serves as shelters for fish, gastropods, aquatic insects, periphyton and epiphytic bacteria (Carpenter & Lodge, 1986; Wiegleb, 1988; Cronk & Fennessy, 2016). The habitats that cover with emergent macrophytes such as common reed and softstem bulrush provide better protection for macroinvertebrates and zooplankton populations compared to open water habitats (Stahr & Kaemingk, 2017). Free-floating macrophyte species such as water hyacinth, duckweeds and water lettuce possess great potential for phytoremediation (bioremediation) of polluted or wastewater due to their natural ability to remove toxicants effectively (Ting *et al*., 2018; Abdul Aziz *et al*., 2020). Besides, exudate production by submerged macrophytes improves bacteria and microorganism activities and modifies microbial mediated processes, such as denitrification (Wetzel, 1969; Xu *et al*., 2020). Extensive colonization and diversity of this species also increase surface area for microbial biofilms and periphyton growth by several orders of magnitude. Macrophytes and associated microbiota are the main supply of food for small fishes and invertebrates, forming the fundamental food webs in the reservoir and sustaining the adult fish populations (Zhou *et al*., 2018; Shivers *et al*., 2018). Moreover, O'Hare *et al*. (2018) suggested high macrophytes diversity and richness leads to effective service delivery to surrounding communities such as sustainable food resources, greater productivity, recreation freedom, efficient removal of contaminants and sediment retention in the aquatic ecosystem.

Whereas aquatic weeds are the term used for undesirable macrophytes in ponds, lakes, reservoirs and other consistent water bodies prevailing on the loss of ecology as well as economy by negatively affecting the aquatic ecosystem, irrigation, navigation, public health and last but not the least, the fisheries industry of any country. Intensive utilization of natural water resources (formation of dams and canals), increased nutrient load and pollution (due to domestic sewage and industrial pollutant discharge) and introduction of aggressive exotic plants have made aquatic weed a threat globally (Narasimha & Benarjee, 2016). Areas of high temperature, particularly the tropical and subtropical regions are promoting prolific growth and multiplication of weed species where Malaysia is no exception. Many of the invasive weed species are not native to Malaysia, however, they have adapted and colonized the local habitats, thereby impacts on socio-economic of farming and non-farming communities (Bakar, 2004; Fraser *et al*., 2016; Hassan & Nawchoo, 2020). The aquatic weed problems in Malaysia have been addressed (Mashhor, 1988; Mashhor, 1996; Mashhor *et al*., 2012) as it has a warm equatorial climate and receives continuous rainfall throughout the year. Eradication of weeds has proved as almost impossible and even control measure is effortful. The population spread of emergent species such as common reed (*Phragmites australis*) has been recorded since 2000 until present (Baki *et al*., 2000; Bakar, 2004; Ismail *et al*., 2019). In addition, the submerged macrophytes such as hydrilla (*Hydrilla verticillata)* and coontail (*Ceratophyllum demersum*) increase the bottom coarseness hence increasing drag and decreasing the flow of lakes and irrigation canals (Pitlo & Dawson, 1990; Tena *et al*., 2017; Huai *et al*., 2019; Ismail *et al*., 2019) and free-floating macrophytes such as the water hyacinth (*Eichhornia crassipes*) reported being the most nuisance weed species that always clogs the waterways and triggers flash floods (UBO, 2016; DID, 2019; Che Lah, 2019). Besides, the floating macrophytes escalate water loss via evapotranspiration. A pioneering study by Brezny *et al*. (1973) shows that evapotranspiration for water hyacinth was 30 to 40% higher than evaporation from a free water surface while Ali and Khedr (2018) reported values of 92% higher than a free water surface under similar conditions. The succession of macrophytes increases the biomass and it magnified seasonally.

2.2 The distribution of macrophytes in aquatic ecosystem

The world distributional ranges of macrophytes are wide, provided with broad aquatic habitats (Cook, 1985; Santamaria, 2002; Murphy *et al*., 2019). Earlier studies conducted in the 1900s to show the importance of macrophytes diversity and assemblage (Butcher, 1933; Gessner, 1955; Sculthorpe, 1967; Haslam, 1978). Further researches were conducted on the geographical ranges (elevation above sea level: a.s.l.) for spatial-environmental drivers (Crow, 1993; Jones *et al*., 2003; Tapia Grimaldo *et al*., 2016) and other large-scale drivers are hydrological regime, including annual evapotranspiration and flood patterns, particularly flood pulse duration, size, and frequency (van Geest *et al*., 2005; Varandas Martins *et al*., 2013); also the alkalinity or acidity of the water (Vestergaard & Sand-Jensen, 2000); and land use influences especially input from agricultural nutrients and other sources influencing trophic levels in inland waters (Akasaka *et al*., 2010). Additionally, other researchers have investigated in more general macrophyte diversity and distribution drivers in different types of water bodies such as lakes and reservoirs (Rorslett, 1991; Pulido *et al*., 2015; Alahuhta *et al*., 2017), rivers and canals (Murphy & Eaton, 1983; Kennedy *et al*., 2015; Tapia Grimaldo *et al*., 2016; Tapia Grimaldo *et al*., 2017); and wetland area (Santos & Thomaz, 2007; Zhang *et al*., 2018). According to Ferreira *et al*. (2015), macrophyte distribution is influenced by spatial and temporal scales, which may determine their successful establishment and colonization. The species composition dynamic in between habitat patches correspond to a few factors, including environmental heterogeneity, connectivity, disturbance and productivity (Partanen *et al*., 2009; Cunha-Santino *et al*., 2016).

Malaysia receives a significantly high amount of precipitation throughout the year from over 1500 mm (Gopal, 2013). According to Ismail and Haghroosta (2018) a large amount of precipitation contributes to major to formation and continuation of lotic systems. Subsequently, vast areas of freshwater wetland ecosystems in Malaysia are generated including rivers and floodplains, lakes and reservoirs and also the rice agro-ecosystem area. The natural dynamic of these systems is largely affected by the seasonal variation of water level that interrelated with floodplain geomorphology and stimulates different degrees of connectivity of floodplain lakes. The spatio-temporal heterogeneity of floodplain-river systems provides habitats for large number of macrophyte species, which commonly appear in multispecific niches (Marchetti & Scarabotti, 2016).

Macrophytes are key elements in water bodies and successful macrophyte invaders have impacts on native biota. The increasing number of literature concerning macrophytes and related topics in Malaysia such as species diversity in freshwater and marine habitats (Mashhor, 1988; Chua & Fong, 1979; Mashhor & Masnadi, 1994; Mashhor, 1996; Muta Harah *et al*., 2005; Muta Harah *et al*., 2006; Mohammad-Noor *et al*., 2016), species associated with macrophytes (Ali, 1996) ecological impact (Anwar, 1978; Ho, 1981; Baki, 1982; Awing, 2008; Sharip, 2011; Sharip *et al*., 2012; Mashhor *et al*., 2012; Sharip *et al*., 2014; Ismail *et al*., 2018), socio-economic impact (Nather Khan, 1990; Nather Khan, 1991), productivity (Lim & Furtado, 1975; Chin & Fong, 1978;

Ikusima, 1978; Saupi *et al*., 2015), the biological indicator (Saidin *et al*., 2014; Othman *et al*., 2014; Othman *et al*., 2015), phytoremediation (Akhir *et al*., 2017; Ng & Chan, 2018; Abdul Aziz *et al*., 2020) and also the management (Arumugam, 1994) were reviewed. However, the knowledge on macrophytes diversity and their environmental interactions in the tropical wetland ecosystem, especially in Malaysia, is still limited after the dam construction even though they have significant contributions towards the ecosystem of an area.

Figure 2.2 and Figure 2.3 show the distribution of rivers and floodplains in Malaysia. Consequently, the dams' constructions are executed to regulate and manage the flow of rivers and mitigate the occurrence of floods (Chan *et al*., 2019).

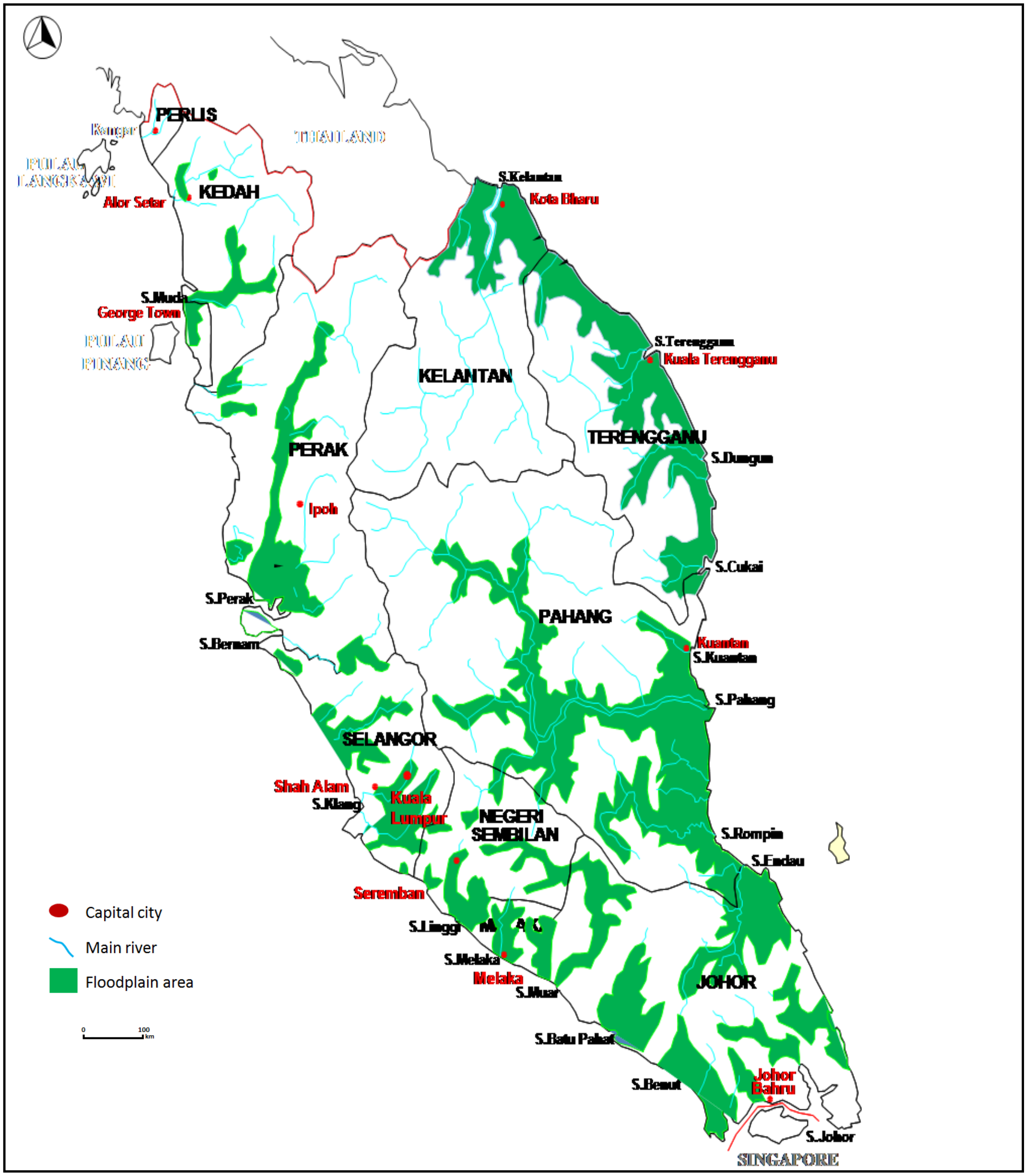

Figure 2.2: The important river and floodplain areas in Peninsular Malaysia (modified from JPS Selangor, 2019)

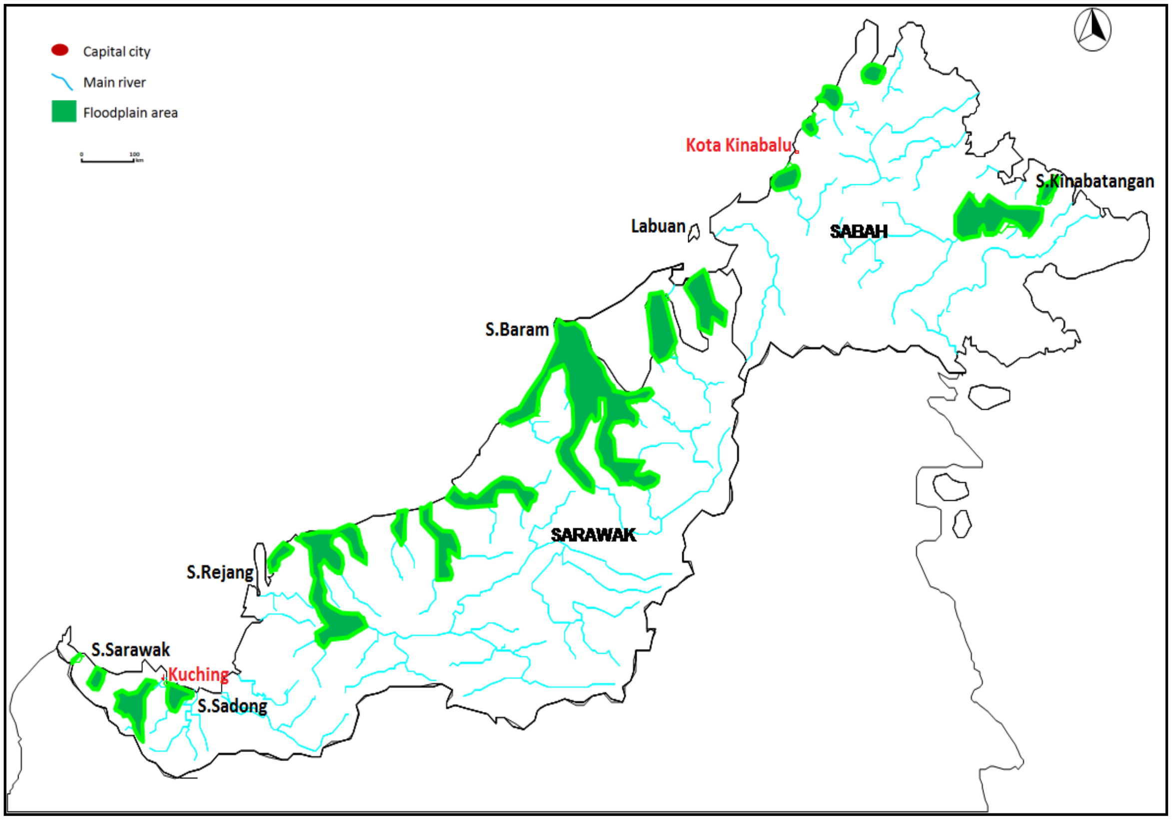

Figure 2.3: The important river and floodplain areas in East Malaysia (modified from JPS Selangor, 2019)

Perak River is the second longest river in Peninsular Malaysia, where Temengor, Bersia, Kenering and Chenderoh dams were built in cascade. The principal aim of the dams is to produce hydroelectric power and alleviate flooding (Asfaw & Hashim, 2011). Previous studies at Perak River were focused mainly on the fisheries resources (Ali & Lee, 1995; Ali & Kadir, 1996; Ali, 1996; McAdam *et al*., 1999; Jackson & Marmulla, 2001; Hashim *et al*., 2012; Hamid *et al*., 2012), hydropower feasibility (Bai & Tamjis, 2007; Choong *et al*., 2017) and water quality (Khalik & Abdullah, 2012; Rahmanian *et al*., 2015). Whereas, the reference on macrophytes species distribution and the ecological impact were provided by Mashhor *et al*. (1983), Mashhor *et al*. (1988), Mashhor (1996), Ali (1996) and Ismail *et al*. (2018).

Being considered as a new ecosystem, the reservoir could facilitate the spread of macrophytes due to the extraordinary features than any other natural aquatic habitat (Havel *et al*., 2005; Cunha-Santino *et al*., 2016). With a total estimated global surface area of 1.5 million km^2, man-made reservoirs have become novel but constitutive element of river basins (Shivers *et al*., 2018). Apart from serves as source of water supply, flood control, and hydropower generation, reservoirs are also widely used for recreational boating and fishing that can promote accidental dispersal of many non-native species (Strayer, 2010; Havel *et al*., 2015). These introductions create contemporary biotic communities within reservoirs that have unknown direct and indirect interactions as new ecosystems formed (Pereira *et al*., 2018).

Eventually, macrophytes benefit wetland stakeholders in the conservation and management of wetland areas as one of the biological indicators for ecological changes and anthropogenic impact (Hernandez *et al*., 2015; Fennessy *et al*., 2015; Jenačković *et al*., 2016). This information is potentially being used for wetland monitoring, mitigation and restoring programs. Moreover, the local authority would probably depend on the availability of macrophytes to justify the boundaries or buffer zone for better management.

2.3 Macrophytes in the reservoir

Reservoirs are contrasting with natural ecosystems due to geomorphologic changes resulting from their formation. After the damming of the lotic system, it is subject to the relative stabilization of water levels generating habitats preferable for macrophytes community succession and the increase of underwater illumination after the conversion of a river into a reservoir is an additional modification that benefits the growth of submerged species (Havel *et al*., 2005; Thomaz *et al*., 2009; Cunha-Santino *et al*., 2016; Shivers *et al*., 2018). Due to their orientation within watersheds, reservoirs being the integrator of landscape change and could be a sentinel for warning of adverse upstream effects (Schindler, 2009; Williamson *et al*., 2009; Shivers *et al*., 2018). Processes that occur in the reservoir, such as nutrient retention and export are influenced by land use, hydrology and climate factors of the surrounding area (Powers *et al*., 2014). The shape, surface area and depth of the reservoir are determined by the geography of the original valley that flooded after dam construction (Hutchinson, 1977; Messager *et al*., 2016; Shivers *et al*., 2018). The usual profile is triangular and is shallow at the river entrance and deepest adjacent to the dam.

Based on Yang *et al*. (2018), the depths of the reservoir govern the storage and modification of sediments, nutrients, and organic matter that, subsequently, can alter its water quality and affect downstream habitats. The significant features are the depths relative to the surface area, throughflow and the degree of wind activity because these factors affect the intensity of the mixing process in the reservoir. The reservoir is known to be hydrologically shallow if the water column is fully mixed by wind activity and hydrologically deep if the efficiency of mixing is not strong enough to prevent stratification (ILEC, 1999). Therefore, the size of the reservoir is important and related to the mixing process that can be categorized based on Table 2.1.

Table 2.1: Size categories of reservoirs. (ILEC, 1999)

CATEGORY	AREA (km^2)	VOLUME (m^3)
Large	10^4-10^6	10^{10}-10^{11}
Medium	10^2-10^4	10^8-10^{10}
Small	1-10^2	10^6-10^8
Very small	< 1	< 10^6

Malaysia is blessed with abundance of water sources and receives high precipitation volume per year (Yah *et al.*, 2017). Reservoirs in Malaysia were constructed continuously for irrigation, water supply, hydropower generation and flood control. Some important reservoirs in Malaysia with their surface area are listed in Table 2.2.

Table 2.2: List of major reservoirs in Malaysia (Huang *et al*., 2015).

NO.	RESERVOIR	STATE	SURFACE AREA (KM^2)	MAIN PURPOSE
1	Bakun	Sarawak	695	Hydropower
2	Kenyir	Terengganu	370	Hydropower
3	Temengor	Perak	153	Hydropower
4	Batang Ai	Sarawak	85	Hydropower
5	Bukit Merah	Perak	41	Irrigation
6	Kenering	Perak	40.5	Hydropower
7	Chenderoh	Perak	25	Hydropower
8	Sembrong	Johor	8.5	Water supply & flood control
9	Bersia	Perak	5.7	Hydropower
10	Cameron Highlands	Pahang	0.52	Hydropower

As cited in Shivers *et al*. (2018), the shallow and deep reservoirs function in different ways due to the distinct attributes such as longer nutrient residence time in the deep, density-stratified water as compared to the shallow water. However, the shallow reservoirs are affected by water-sediment interactions, such as wind mixing, and could have extensive spatial submerged macrophytes coverage. Dense macrophytes cover rapidly reduce depth penetration of wind mixing and sunlight. Impenetrable macrophyte stands can modify their environment by facilitating the build-up of steep physical-chemical parameters of water quality. This interaction has a negative impact on small lakes and reservoirs globally (Andersen *et al*., 2017).

In addition, water flow determines a successful macrophytes establishment and colonisation, stimulates macrophytes community abundance and diversity at low to moderate water velocity, but reduced growth at higher water velocity (Madsen *et al*., 2001; Biggs *et al*., 2019). Shallow reservoirs prone to monsoon flooding could carry away some submerged and free-floating macrophytes to downstream habitats by high flows that also affect nutrient budgets and interspecies dominance relationships (Shivers *et al*., 2017; Špoljar *et al*., 2017). Besides, it can also be subject to regime shifts between macrophyte-dominated clear water states to turbid, algal states water (Zhang *et al*., 2018). These two alternative ecosystem states dramatically alter ecosystem services and ecological functions (Shivers *et al*., 2018).

Report on macrophytes infestation in the reservoir that could affect water capacity is *Hanguana malayana* in Bukit Merah Reservoir (Akademi Sains Malaysia, 2010). According to Milani *et al*. (2019), the evapotranspiration rates of macrophytes in constructed wetland maybe seven to eight times higher than the evaporation in the open water area. These evapotranspiration conditions reduce the wastewater volumetric flow, leading to increasing hydraulic retention time and concentrations of non-degradable contaminants in the effluent. It was reported the reservoir operation decreases multiyear average hydropower generation by 10% under the macrophytes diversity conservation program in China (Xu *et al*., 2020). However, the water levels in the reservoir are subjected to fluctuate based on seasonal variation and dam operation. The loss in hydropower generation is relatively low during wet season (Xu *et al*., 2020). The alarming state of non-native macrophytes invasions could obstruct navigation and recreational potential include *Cabomba furcata* in Chini Lake (Sharip *et al*. 2012) and *Eichhornia crassipes* in Sembrong Reservoir (NAHRIM, 2012). In a dam surveillance report by DID (2017), mats of aquatic weed, timber and debris can be blown along with the reservoir mid cause blockage at outlets and spillways.

Furthermore, based on Moura Júnior *et al*. (2019), the limnological aspects and macrophyte species biomass are also determined by the water level fluctuations of a reservoir. Water level fluctuations based on seasonal changes would affect the growth and reproduction of submerged macrophytes and negatively impact the other biota and the ecological state of shallow reservoirs. Macrophytes play an important role in the uptake of phosphorus (P) in the water but can be a significant source of P in wet-dry cycles (Kietel *et al*., 2016). A study by Lu *et al*. (2018) stated distinct nutrient effects of submerged macrophytes compared to bare sediments during water level fluctuations. Decomposed macrophytes during low water levels would release nutrients and regrown macrophytes during high water levels have a role in assimilating the nutrients. *Cabomba* debris had a higher rate of nutrient release and resulted in higher chlorophyll *a* concentrations in the water column compared to *Hydrilla* debris. The decomposition of both species release higher P concentrations than that for nitrogen (N), and contrary, less

P was assimilated by macrophytes compared with N. This resulted in P accumulation and a decreased N:P ratio in the water column compared to bare sediments without macrophytes (Lu *et al*., 2018).

2.4 Factors determining the spatial-temporal distribution of macrophytes

Several studies have been conducted to explain the high amount of widely distributed taxa among the macrophytes. They cover the topics on aquatic environment uniformity (Avendaño & Ramírez, 2017; García-Girón *et al*., 2018), widespread clonality (Eckert *et al*., 2016) and high phenotypic plasticity (Santamaria, 2002; Fasoli *et al*., 2018). Besides, the successful growth and establishment of macrophytes correlated with physical and chemical factors of water bodies such as temperature, underwater radiation, nutrients availability, littoral slope, sediment composition, water speed, wind exposure and waves (Spence *et al*., 1973; Carr *et al*., 1997; Hudon *et al*., 2000; Thomaz *et al*., 2015; Roznere & Titus, 2017; Ye *et al*., 2018; Gillefalk *et al*., 2019). Macrophytes community integrated with spatial, temporal, physical, chemical and biological characteristics of an ecosystem. Their distribution and richness are determined by the variation of environmental conditions.

The colonisation of organisms is the outcome of species dispersal and survival in provided spaces. The importance of local factors versus regional factors controlling macrophytes species distribution and richness has been approached in lacustrine and riverine systems indicating that both scales (regional and local) are relevant (Capers *et al*., 2010; Akasaka & Takamura, 2011). Species richness is associated with various environmental factors such as trophic state (Rørslett, 1991; Akasaka *et al*., 2010; Kuczyńska-Kippen & Joniak, 2016), water transparency (Vestergaard & Sand-Jensen, 2000; Pozzobom *et al*., 2020), anthropogenic pressure (Li *et al*., 2006; Hicks & Frost, 2011; Yang *et al*., 2018), geological gradients (Noleto *et al*., 2019; He *et al*., 2019) and water body type (Sondergaard *et al*., 2005; Shivers *et al*., 2018).

The macrophytes community changes in rivers and reservoirs determined by nutrient enrichment and the presence of pollutants. Additionally, macrophytes establishment particularly submerged species would directly affect the productivity and biogeochemical cycles in the water through variable dissolved oxygen (DO), dissolved organic carbon (DOC), pH and nutrient concentrations and also indirectly slowing the flow of water and trapping sediments, which manipulate sedimentation rates and reduce internal loading of nutrients from resuspension (Carpenter & Lodge, 1986; Shivers *et al*., 2018).

Eutrophication in lakes and reservoirs is a concern across the globe, affects the water quality and ecosystem services. This problem reported with more than 60% out of 90 major lakes and reservoirs were categorized as eutrophic in Malaysia (Sharip & Yusop, 2007; Huang *et al*. 2015). The lake water quality assessments in Malaysia were based on Interim National Water Quality Standards (INWQS) (Table 2.3), involving parameters of pH, dissolved oxygen (DO), total suspended solids (TSS), ammonia-nitrogen (A-N) concentrations, biological oxygen demands (BODs) and chemical oxygen demands (CODs).

Table 2.3: Interim National Water Quality Standards (INWQS) of Water Class and Uses (DOE, 2006)

CLASS	USES
Class I	Conservation of natural environment. Water Supply I - Practically no treatment necessary. Fishery I - Very sensitive aquatic species.
Class IIA	Water Supply II - Conventional treatment. Fishery II - Sensitive aquatic species.
Class IIB	Recreational use body contact.
Class III	Water Supply III - Extensive treatment required. Fishery III - Common,of economic value and tolerant species;livestock drinking.
Class IV	Irrigation
Class V	None of the above.

While the trophic state assessments were based on Carlson's Trophic State Index (TSI) involving parameters of chlorophyll *a*, Secchi depth and total phosphorus for the lakes classification that defines the biological productivity of a water body (Carlson, 1977). There are four categories of trophic states namely oligotrophic (lowest level of productivity), mesotrophic (moderate level of productivity), eutrophic (high level of productivity) and hypereutrophic (highest level of biological productivity) (Table 2.4).

Table 2.4: Trophic State Index (TSI) classification (Carlson & Simpson, 1996)

TSI	Chl *a* (μg/L)	TP (μg/L)	SD (m)	Attributes
< 30	< 0.95	< 6	>8	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion
30 - 40	0.95 - 2.6	6 - 12	8 - 4	Hypolimnia of shallower lakes may become anoxic
40 - 50	2.6 - 7.3	12 - 24	4 - 2	Mesotrophy: Water moderately clear; increasing probability of hypolimnetic anoxia
50 - 60	7.3 - 20	24 - 48	2 - 1	Eutrophy: Anoxic hypolimnia, macrophyte problems
60 - 70	20 - 56	48 - 96	0.5 - 1	Blue-green algae dominate, algal scums and macrophyte problems
70 - 100+	56 - 155+	96—384+	0.25-0.5	Hypereutrophy: (light limited productivity). Dense algae and macrophytes