SEAGRASS CONDITIONING IN HUSBANDRY TANKS AND TRANSPLANTING AT GAYA ISLAND, KOTA KINABALU, SABAH

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THESIS SUBMITTED IN FULFILLMENT FOR THE DEGREE OF MASTER OF SCIENCE

BORNEO MARINE RESEARCH INSTITUTE

UNIVERSITI MALAYSIA SABAH

2019

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ACKNOWLEDGEMENT

Firstly, I would like to thank Universiti Malaysia Sabah for accepting my application to continue my master study in Borneo Marine Research Institute. Secondly, I would like to extend my appreciation and gratitude to both supervisors, Assoc Prof Dr John Barry Gallagher and Assoc Prof Dr Ejria Saleh for the opportunity to work in this project. Thank you for the guidance, knowledge and experience sharing to improve my research skills and writing. Additional, my appreciation to Mr Muhammad Ali and Dr Zarinah Waheed for the constructive suggestions in my research, Assoc Prof Dr B.A. Venmathi Maran for suggestions in this thesis and finally staff of Borneo Marine Research Institute for providing support. Not forgeting some national and international researchers in terms of advice, knowledge sharing and research collaboration, they are Dr Reuben Shipway, Dr Aileen Tan Shau Hwai, Dr Mohammad Rozaini and Dr Ekkalak Rattanachot.

Besides that, I would like to extend my appreciation to Datuk Robert Tan and Mr Alvin Wong from Marine Ecology Research Centre for the providing the support in facilities, financial and manpower in the seagrass transplanting project. Furthermore, thank you Vienna Anastasia Admodisastro, Vanessa Rose Marie Stephens, Gan Sze Hoon, Sidi, Asri and some supporting staffs from Marine Ecology Research Centre for the assistance provided during this project.

I would like to reiterate my thanks to fellow postgraduate and undergraduate who have supported me along the way and provided aid in my field sampling, data analyses, writing and moral support. They are Gwen Chew Swee Theng, Cheong Kai Ching, Alyn, Azureen Binti Murshidi, Yang Shahida, Wydia, Chen Nuo Geng, Mohammad Aiman, Muhammed Fauzan, Muhammad Shazwan and many more. Lastly, to fellow advocacy members in ClimatEducate, Seagrass Guardians and friends who have been very supportive and motivating throughout the whole journey. Lorrayne Isidoro, Juan Carlo Alongsagay, Nurrul Fazlina, Gorfreey Moey, LowTzer Yang, Sheikh Syaqil and many more, thank you very much.

Yap Tzuen Kiat

08 July 2019

ABSTRACT

Seagrass meadows are recognised as one of the productive coastal ecosystems. Unfortunately, unsustainable coastal development and climate change had caused seagrass degradation at the rate of 2-7% annual globally. Seagrass transplantation has been introduced since the 1970s as part of the solutions to facilitate restoration of degraded meadows. Seagrass meadows in Gaya Island, Kota Kinabalu had been declining since 2001 and this raises the urgency to restore its ecosystem. This study aims to (1) determine percent survival of different seagrass species (*Cymodocea rotundata*, *Cymodocea serrulata, Halodule uninervis* and *Halophila ovalis*) and growth rate of *Enhalus acoroides*; (2) identify organisms associated with seagrass in husbandry tanks and transplanting site; (3) determine which method and species suitable for seagrass transplanting. The seagrass was collected from Gaya Bay and transferred to husbandry tanks (Marine Ecology Research Centre) at Malohom Bay, Gaya Island. The percentage of seagrass survival was determined by the number of surviving planting units, while the growth rate by leaf elongation rate. Transplanting methods were tested at four different approaches: (i) sprig, (ii) plug, (iii) mono- and mixed-species, and (iv) different combination of mixed-species. Percent coverage of seagrass for each approach was recorded to determine the success of transplanting. Associated organisms in husbandry tanks and transplanting site were identified to the lowest taxon. Percentage of survival in husbandry was 83% and the growth rate of *Enhalus* was 0.69±0.04 cm day^{-1}. Mixed-species transplanting recorded high percent cover, which is ranging from 50 to 100% compared to mono-species. Total of 16 and 30 species organisms identified associated with seagrass in husbandry tanks and transplanting site, respectively. This study concluded mixed-species transplanting, while *C. serrulata* and *H. ovalis* are suitable for transplanting.

ABSTRAK

PENJAGAAN RUMPUT LAUT DI TANGKI SEMAIAN DAN PEMINDAHAN DI PULAU GAYA, KOTA KINABALU, SABAH

Hamparan rumput laut telah dikenalpasti sebagai salah satu ekosistem persisiran pantai yang produktif. Malangnya, pembangunan pantai yang tidak lestari dan perubahan iklim telah menyebabkan kemerosotan rumput laut pada kadar tahunan 2-7% di seluruh dunia. Pemindahan rumput laut telah diperkenalkan semenjak 1970-an sebagai sebahagian penyelesaian untuk pemuliharaan hamparan yang terdegradasi. Hamparan rumput laut di Pulau Gaya, Kota Kinabalu telah merosot sejak tahun 2001 dan memerlukan pemuliharaan ekosistem dengan kadar segera. Sasaran kajian ini adalah untuk (1) menentukan peratusan kelangsungan hidup spesies rumput laut (Cymodocea rotundata, Cymodocea serrulata, Halodule uninervis dan Halophila ovalis) dan kadar pertumbuhan Enhalus acoroides, (2) mengenal pasti organisma dalam tangki semaian dan tapak pemindahan (3) menentukan kaedah dan spesies rumput laut yang sesuai untuk pemindahan. Rumput laut diperolehi dari Teluk Gaya dan dipindahkan ke tangki semaian (Marine Ecology Research Centre) di Teluk Malohom, Pulau Gaya. Peratus kelangsungan hidup ditentukan dengan jumlah unit rumput laut yang hidup, manakala kadar pertumbuhan pulak ditentukan dengan kadar pemanjangan daun. Kaedah pemindahan diuji dengan empat pendekatan: (i) tangkai (ii) palam (iii) spesies mono dan campuran dan (iv) combinasi campuran spesies yang berlainan. Peratus litupan rumput laut untuk setiap kaedah direkod untuk menentukan kejayaan pemindahan. Organisma dalam tangki semaian dan tapak pemindahan dikenal pasti sehingga taksifran terendah. Peratus kelangsungan hidup rumput laut dalam tangki semaian adalah 83% dan kadar pertumbuhan Enhalus adalah 0.69 ± 0.04 cm hari^{-1}. Pendekatan tranplantasi menggunakan spesies campuran mencatatkan peratus litupan yang tinggi, iaitu antara 50 hingga 100 % berbanding dengan spesies mono. Sebanyak 16 dan 30 spesies organisma dikenal pasti di dalam tangki semaian dan tapak permindahan. Kajian ini menyimpulkan kaedah campuran manakala spesies C. serrulata dan H. ovalis adalah sesuai untuk pemindahan rumput laut.

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CHAPTER 1

INTRODUCTION

1.1 Seagrass

Seagrass is the only monocotyledonous flowering plant (Angiosperm) thriving in the marine environment. They had evolved from freshwater macrophytes between 100 to 70 million years ago (Orth *et al*., 2006; Short *et al*., 2011). There are 62 species of seagrass has so far been described and reported across the globe. They belong to six families, namely Posidoniaceae, Zosteraceae, Hydrocharitaceae, Cymodoceae, Ruppiaceae and Zannichelliaceae (Short *et al*., 2016). The family Zosteraceae is distributed in the temperate and subtropical regions, Posidoniaceae is found in Mediterranean and South coast of Australia, while Hydrocharitaceae and Cymodoceae have wider distribution, mainly in the tropical region. There are only three genera (*Enhalus*, *Halophila* and *Thalassia*) belonging to the family Hydrocharitaceae. Tropical tape grass (*Enhalus acoroides*) is the largest seagrass species with low growth rate but has high biomass. This widespread species is commonly found in most of the seagrass meadows in Southeast Asia (Short & Waycott, 2015).

Like their terrestrial counterparts, seagrass produces leaves, vertical stems, rhizome, roots, flowers, fruits and seeds but in the underwater environment. Leafy structures are responsible for plant photosynthesis (Beer & Koch, 1996), whereas a complex network of rhizomes and roots absorb and store nutrients (Terrados *et al.*, 1999) and help to stabilize sediments (Christianen *et al.*, 2013). Seagrass reproduces both sexually and asexually. In sexual reproduction, both pollination and seed dispersal are influenced by water currents (Ackerman, 2006). More recently, it has been found that zooplankton plays a role as a pollinator

(Tussenbroek *et al.*, 2016), analogous to a niche that bees occupy by pollinating terrestrial flowers. Nevertheless, seagrass primarily reproduces vegetatively through budding new clonal shoots or sexual propagules from a horizontal rhizome extension (Olesen *et al.*, 2004). Clonal propagation allows rapid colonization, either in a new area or gap resulted from disturbances. This development is faster than sexual propagation (Rasheed, 2004). Another possible mode of colonization, viviparous propagules, which has the potential in long-distance dispersal, contributes to seagrass population expansion (Thomson *et al.*, 2015). This kind of dispersal is influenced by wind and currents.

1.2 Use of Seagrass in Sabah

Seagrass is poorly understood and often mistaken as seaweed. This is due to lack of awareness and less visually attractive compared to the colourful and charismatic coral reefs (Yaakub *et al.*, 2018). It is noted that the coastal community, especially fishermen, are aware of the importance of seagrass as habitat for commercially important fisheries. In Sabah, coastal villagers harvest various resources such as fish, sea cucumbers, bivalves, shrimps (Bujang *et al.*, 2006; Unsworth *et al.*, 2018a), crabs and sea urchins (Gumpil *et al.*, 2006) from seagrass meadows. The local fishermen in Salut Mengkabong believed that the declines in fish catch and size over the last 10 years are linked to the decline in seagrass habitats and pollutant discharge from nearby industries.

The coastal communities use seagrass beds for mariculture or sea ranching. In Kudat (Sabah), a few coastal communities are known to ranch sea cucumbers (*Holothuria scabra*) within seagrass beds. Sea cucumber raised in seagrass meadows is capable of reaching the market size faster than those raised in non-vegetated sediment (Tri, 2008; Hair *et al.*, 2016). For instance, juvenile sea cucumbers have always been observed in the seagrass beds of Gaya Island, indicating that sea cucumber larvae prefer to settle and develop on seagrass leaves (Mercier *et al.*, 2000). This further demonstrates the potential of seagrass meadows as both settlement and nursery grounds for commercially important sea cucumber in Sabah.

Seagrass has been used as food and ethnomedicine in some coastal communities. The largest seagrass *Enhalus* produce sizeable fruits and seeds, locally known as "green rambutan", which are eaten by some communities (Montano *et al.*, 1999; Green & Short, 2003; Bujang *et al.*, 2006). Villagers in Salut-Mengkabong (Tuaran, Sabah) enjoy these fruits as snacks during the flowering season. Its texture is similar to water chestnut and can be turned into flour (Montano *et al.*, 1999) to make other delicacies. Some "Bajau Laut" communities in Sabah use the rhizome of *Enhalus* seagrass as food and medicine to treat stonefish sting injuries. Similar to other indigenous communities elsewhere, seagrass also has been used for ailment treatment or to maintain good health (Newmaster *et al.*, 2011) through the medicinally active ingredients still remain unclear. Nevertheless, a recent study has confirmed that the rhizome of *Enhalus* contains antifeedant, antibacterial and antilarval properties (Qi *et al.*, 2008).

1.3 Status of Seagrass in Sabah

Currently, it is still unclear how climate change and natural variability contribute to the decline of seagrass meadows in Sabah. Nonetheless, several authors (Bujang *et al.*, 2006; Freeman *et al.*, 2008) reported that local human activities are believed to be the main cause of the seagrass decline. These activities include anchor damage from fishing boats and tour operators, unregulated coastal development, destructive fishing practices in shallow water, and overfishing. Rapid coastal development such as reclamation and dredging contribute to the loss of seagrass meadow (Erftemeijer & Lewis III, 2006). The seagrass meadows are either removed physically or buried by the sediment. High suspended sediment particles from river runoff due to unsustainable land use change (Freeman *et al.*, 2008) increase the turbidity, which affect the seagrass through reduction in light availability for photosynthesis. A fall in photosynthesis leads to an increase in shoot mortality and eventual loss of meadow (Burkholder *et al.*, 2007; Freeman *et al.*, 2008).

There are other activities that contribute to the seagrass decline across Sabah. Trawling, fish bombing, over-fishing and seaweed farming contribute to seagrass degradation (Unsworth *et al.*, 2018a). Seagrass damaged or uprooted by boat propellers are fragmented and possibly become less resilient (Vermaat *et al.*, 2004). So far, there are no national or state policies that address the seagrass protection and conservation (Fortes *et al.*, 2018; Unsworth *et al.*, 2018a). Lack of integrated coastal resources management leads to further seagrass degradation (Unsworth *et al.*, 2018a).

Gaya Island is one of the biggest islands in Kota Kinabalu, Sabah, Malaysia. This island was reported to have the most diverse seagrass meadows consists of 11 out of 12 species found in Sabah (Bujang *et al.*, 2006). However, seagrass coverage has been declining since 2002, and some species have disappeared from certain parts of the island (Freeman *et al.*, 2008). A survey conducted on 5 March 2016 revealed that some patches of seagrass adjacent to Gayana Eco Resort in Malohom Bay recorded by Tan (2008) have disappeared. This is possibly due to tramping from increased tourism activities in the shallow area (Tri, 2008). Meanwhile, *E. acoroides* and *Halodule pinifolia* located in deeper water and farther from the tourism activities area survived. Another factor for the disappearance of seagrass patches at shallow area might be the intensity and frequency of storms, which are usually prevalent during Northeast Monsoon (Gallagher, 2015).

1.4 Urgency for Seagrass Restoration

Under ideal growing conditions, seagrass meadow is able to rejuvenate from small-scale disturbances, by replenishing lost shoots through sexual reproduction and clonal growth (Bell *et al.*, 1999). Seeds of seagrass can replenish lost shoots both within and across other meadows, depending on local currents (Ruiz-Montoya *et al.*, 2012; Thomson *et al.*, 2015) and seasonal monsoon changes (Lacap *et al.*, 2002). Seagrass rhizome fragments and viviparous propagules can remain healthy before settling in a new area far away from parent meadows (Thomson *et al.*, 2015). Mass long-distance dispersal of seagrass vegetative fragment has the potential to increase population connectivity and genetic diversity, as well as aid in intermeadow repair. On the other hand, clonal growth allows a faster recovery to compensate lost from grazing or disturbances. Unfortunately, the rapid decline of seagrass meadows due to various factors has pushed these seagrass meadows beyond the self-sustaining threshold to produce sufficient healthy shoot to recolonize the area (van der Heide *et al.*, 2011).

The decline of seagrass has raised the concern about the consequences of the loss in biodiversity and ecosystem services (Yaakub *et al.*, 2018). Without seagrass meadows to provide physical protection, juvenile fish would become easy prey to predators. This may reduce the biodiversity, thus the loss of local fisheries resources and abundance. Other than the loss of nursery ground, endangered species such as dugong and green turtles may either starve or migrate to another area, leading to further reduction and changes in community composition. Such losses from apex grazers may lead to a shift in dominance or collapse of the ecosystem (Jackson, 2001). Losing seagrass meadows has other physical and biological consequences. For example, loss of coastal protection capacity against shoreline erosion (Christianen *et al.*, 2013), loss of filtering capacity to protect adjacent coral reefs from smothering (Guannel *et al.*, 2016), and export of organic matter as a subsidy to other adjacent coastal ecosystems (Gillis *et al.*, 2014).

Loss of seagrass can be mitigated through rehabilitation (passive) and restoration (active) approaches. These approaches play important roles in protecting seagrass meadow from further degradation. Rehabilitation involves the modification of environment condition through eco-engineering or removing stressors. This helps to improve the growing condition for seagrass survival (Fortes *et al.*, 2018). Eco-engineering may create a suitable habitat for natural recruitment and formation of new seagrass bed. Restoration, on the other hand, is to transplant seedlings or vegetative fragments to encourage re-colonization in a degraded or disappeared seagrass bed. The term 'husbandry' is used to describe the period of conditioning seagrass shoots before transplanting. Few researchers transplanted seagrass indoor under controlled environment to study seagrass reproduction and physiological responses (Bujang *et al.*, 2008), but not for restoration purpose.

There have been many attempts to restore seagrass in temperate or subtropical countries (Ganassin & Gibbs, 2008; Paling *et al.*, 2009; Bourque & Fourqurean, 2014; Infantes *et al.*, 2016; van Katwijk *et al.*, 2016) but less so in tropical regions due to lack of awareness (Yaakub *et al.*, 2018). Several tropical countries such as Vietnam (Tri, 2008), Indonesia (Asriani, 2014; Lanuru *et al.*, 2013), Philippines (van Katwijk *et al.*, 2016) and Thailand (Rattanachot *et al.*, 2018) have attempted seagrass transplanting with varying degree of success. Some of the challenges faced in those transplanting were seasonal changes, herbivore grazing, suitability of transplanting methods and lack of long-term monitoring. In Malaysia, no seagrass transplanting or husbandry approach has been formally reported so far. In general, there is still a large gap in knowledge and lack of publications on seagrass husbandry and transplanting across Asian countries, as well in Sabah (Southeast Asia Seagrass Restoration publication in preparation).

In order to promote seagrass conservation and restoration, various approaches are required to raise awareness (Keulen *et al.*, 2018) and stimulate behaviour changes. During Southeast Asia Seagrass Restoration Workshop in conjunction with 13th International Seagrass Biology Workshop, Singapore on 15 June 2018, several approaches been suggested: (i) education, (ii) market success stories, (iii) present seagrass ecosystem services in monetary value, and (iv) universal toolkits for education. Education plays vital roles in promoting the value and importance of seagrass, especially to the children, who would be the future leaders and policymakers.

Several questions are highlighted for the seagrass husbandry and transplanting in this study:

1. Can the controlled environment in husbandry condition seagrass planting units, in the manner of terrestrial plant nurseries? In other words, to remove potential stresses associated with extraction from the donor area, i.e., root damage/loss, and reductions in epiphyte growth, all of which that could be reasonably inferred to affect the survival after transplanting in the open sea.

2. Could a husbandry approach provide an answer to whether there is a necessity for quarantine of seagrass shoots before transplantation?
3. Would mixed seagrass species transplanting have better success of restoration compared to mono-species transplanting, for the chosen site at Malohom Bay, Gaya Island?
4. Can small-scale seagrass transplanting provide habitat for colonization of fish and invertebrates?

1.5 Adaptive Management in Seagrass Restoration

Adaptive management, also known as adaptive environmental assessment and management is a structure, iterative process of robust decision making in the face of uncertainty, with an aim to reducing uncertainty over time via systematic monitoring. This approach was chosen to address the questions stated in this seagrass transplanting project. The advantages of this approach become apparent for a natural open system, in this case, the donor and transplanting sites, where the knowledge of ecology, as well as physical and chemical stresses, e.g., storm events and nefarious fishing activities, are relatively unknown or unknowable. These factors lead to uncertainties and can be more confounding compared to controlled experimental design by reacting to events. The adaptive management allows re-evaluation and adjustment of approaches from time to time to suit local need and challenges.

It is believed that adaptive management is capable of countering uncertainties in seagrass conservation and restoration. Seagrass ecosystem is a complex interaction of feedbacks between seagrass, associated organisms and abiotic conditions. Different range of feedback strength, either positive or negative, play an important role in the stability and resilience of the ecosystem (Thorn, 1997; Maxwell *et al.*, 2016). Unfortunately, disruption in one or multiple feedbacks can alter the whole structure and functioning of the ecosystems. The disruption in the feedbacks can be disastrous and ecosystem recovery may be difficult, which fluctuate and shift back and forth between different alternative stages of development. This alternative stage development is site-specific, scale-dependent, morphologies and life traits history of seagrass, and gradients of prevailing environmental condition (Maxwell *et al.*, 2016).

For effective management of seagrass conservation and restoration, it is important to assess changes in the feedback, re-evaluate, and readjust approaches in restoration effort (Thorn, 1997). Small-scale transplantation might not sufficient to encourage or assist natural recovery when the feedback had been disrupted (Maxwell *et al.*, 2016). The information gained through the monitoring process during restoration must be translated into project redesign as part of adaptive planning and management (Thorn, 1997). In relation to that, Maxwell *et al.* (2016) proposed five important steps in adaptive management in seagrass restoration: (1) formulate objectives and goals, (2) recognize feedbacks that might or would affect the restoration success, (3) formulate actions to address identified feedbacks permanently or temporarily, (4) monitor and assess feedback dynamic in the restoration program, and (5) re-assess and modify goals if needed.

1.6 Objectives

Objectives of this study consist of two parts. The first part focused on seagrass in husbandry (objectives 1 and 2) and the second part focused on transplanting seagrass at the site (objectives 3 and 4). The objectives are:

1) To determine the survival rate of different seagrass species and growth rate of *Enhalus acoroides* in husbandry tanks.
2) To identify associated organisms in husbandry tanks, together with their potential impacts on seagrass.
3) To restore seagrass bed through different methods and determine which method and species are suitable for transplantation.
4) To identify organisms associated with seagrass after transplantation and their potential relationship with seagrass.

1.7 Significance of the Research

This study would offer a foundation and guidelines for long term seagrass restoration. It will provide technical support to local seagrass conservation and restoration effort. In addition, seagrass transplanting or relocation can be proposed as mitigation measures to habitat loss by coastal development, especially coastal reclamation project. This would to some degree compensate for the degradation of seagrass meadows. Establishment of seagrass husbandry not only conditions seagrass shoots but also rehabilitates uprooted shoots and propagate new vegetative shoots or seedlings. This would provide additional seagrass for transplanting and reduce the pressure on donor meadows. Furthermore, husbandry provides an opportunity to study seagrass and its associated organisms in a controlled environment compared to a dynamic open system.

Restored seagrass habitat would improve and restore ecosystem functions and services, such as coastal protection, nursery for fishery species, and blue carbon storage. Healthy seagrass meadows provide protection and food for commercially important fishes, which are important protein source and provide livelihoods for the local communities. Mariculture such as sea cucumber ranching and seagrass eco-tourism can be established to provide sustainable livelihood opportunities.