TEMPORAL AND SPATIAL CHANGES OF SEAGRESS DISTRIBUTION IN LAWAS, SARAWAK, EAST MALAYSIA

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CHAPTER ONE

INTRODUCTION

1.1 Seagrasses

Seagrasses are flowering plants that have adapted to life under marine constraints. The term seagrass refers to the grass-like habit of most of its representatives (den Hartog & Kuo, 2006). Similar to the terrestrial grasses, seagrasses possess leafy shoots, rhizomes, roots, flowers and fruits. The leaves are distinct characteristic of the seagrass and can be use for species identification. It can vary in length, number of veins and shapes (such as spoon-like, ribbon-like, scythe-shaped or spinulose) depending on species (den Hartog, 1970; Lanyon, 1986; Japar Sidik et al., 1999; Phang, 2000; Gumpil & de Silva, 2007).

Seagrasses are different from other plants based on four characteristics as described by Arber (1920). Firstly, it must be able to tolerate saline medium. Seagrasses usually occurs in marine or estuarine environment (Spalding et al., 2003). Secondly, it must have the power to vegetate while being wholly submerged underwater. Seagrasses are found growing at intertidal or subtidal area (Hogarth, 2007). The subtidal species are permanently submerged in seawater and creates extensive seagrass meadow. Meanwhile, seagrasses that grow at intertidal areas are exposed to the risk of desiccation during low tide but will be fully submerged during high tide (Erftemeijer & Herman, 1994; de Iongh et al., 1995). Thirdly, seagrasses have roots that provide sufficient anchoring system to withstand waves and tidal currents (Cruz-Palacios & Tussenbroek, 2005). Seagrasses possess horizontal branching rhizomes with anchoring roots at frequent interval. This is effective in binding to the sediments and reducing sediment mobility (Hogarth, 2007). Lastly, the marine flowering plants need to be capable of hydrophilous pollination. Hydrophilous pollination refers to pollination while being fully submerged underwater (den Hartog & Kuo, 2006). All seagrass species except for *Enhalus acoroides* satisfy this requirement. *Enhalus acoroides* shows aerial surface pollination (den Hartog, 1970) where the pollen were released during high tide and pollinates the female flowers during low tide (Pettitt, 1984; Hemminga & Duarte, 2000). Another characteristic of seagrass, i.e. the ability to compete with other organism in marine environment (Phillips & Menez, 1988; Spalding et al., 2003).

Seagrasses form an ecological group, not a taxonomic group. This means, various families of seagrass are not necessarily closely related (den Hartog & Kuo, 2006). Previously, there were only two families of seagrasses recognized; Potamogetonaceae and Hydrocharitaceae with six subfamilies; Zosteroideae, Posidonioideae, Cymodoceoideae, Vallisnerioideae, Thalassioideae, Halophiloideae; which were classified based on their morphology (Arber, 1920; den Hartog, 1970; Duarte, 2001 (in Hogarth, 2007)). In comparison to Arber (1920) and den Hartog (1970), Duarte, 2001 (in Hogarth, 2007) renamed the subfamily Vallisnerioideae as Hydrocharitoideae. However, recent advances of molecular analysis suggested that these subfamilies should be upgraded into full family status. Further phylogenetic analysis suggested that four families of seagrass should be established. These are Zosteraceae, Posidoniaceae, Cymodoceaceae and Hydrocharitaceae (Duarte, 2001 in Hogarth, 2007). Twelve genera of seagrasses have been identified. These are *Enhalus, Thalassia, Halophila, Syringodium, Cymodocea, Thalassodendron* and *Halodule* which inhabit tropical areas while *Zostera, Heterozostera, Posidonia, Phyllospadix* and *Amphibolis* can be found in temperate areas (Refer Table 1.1).

Table 1.1: Classification of seagrasses (family from molecular evidence)

Kingdom:	Plantae		
Phylum:	Magnoliophyta (Angiosperms)		
Class:	Liliopsida		
Subclass:	Alismatanae		
Superorder:	Alismatiflorae (Monocotyledonae) = Helobiae		
Order:	Alismatales		
Family:		Hydrocharitaceae	
			Enhalus
			Thalassia
			Halophila
		Zosteraceae	
			Zostera
			Phyllospadix
			Heterozostera
		Posidoniaceae	
			Posidonia
		Cymodoceaceae	
			Halodule
			Cymodocea
			Syringodium
			Thalassodendron
			Amphibolis

1.2 Seagrass distribution in Malaysia

The occurrence of seagrasses in Malaysia is restricted to sheltered areas of shallow intertidal associated ecosystem, semi-enclosed lagoons and also in the subtidal zones (Bujang & Zakaria, 2003). Major seagrass locations in Malaysia are located at estuaries (Zakaria & Bujang, 2004; Bali, 2005; Japar Sidik et al., 2006), bays (Zakaria et al., 1999; Gumpil & de Silva, 2007) and offshore islands sheltered from strong winds (Ooi et al., 2011). Sg. Pulai (Southern Johor) (Japar Sidik et al., 2006), offshore islands of Johor (Affendi et al., 2005; Ooi et al., 2011), Tunku Abdul Rahman Marine Park (Freeman et al., 2008; Gumpil & de Silva, 2007) and Lawas, Sarawak (Bali, 2005; Bali Per. Obse.) are known as major seagrass location in Malaysia.

Fourteen species of seagrasses (belong to eight genera) found in Malaysia (Phang, 2000). However, only twelve species (belong to six genera, i.e.,*Cymodocea, Halodule, Syringodium, Enhalus, Thalassia* and *Halophila*) are taken in further consideration since they are commonly recorded (Phang, 2000; Japar Sidik et al, 2006; Gumpil & de Silva, 2007). The remaining two species, i.e. *Ruppia maritima* and *Thalassodendron ciliatum* are rarely recorded (Bujang & Zakaria, 2006; Japar Sidik et al., 2006). *Ruppia maritima* was the earliest seagrass species recorded in Malaysia. It was recorded in a paddy field in the Province of Wellesley, Prai (Ridley, 1924 in Bujang, 1994). However, *Ruppia* is yet to be universally accepted as seagrass (Spalding et al., 2003) due to its occurrence both in marine and freshwater environments. The plant is considered as a seagrass only when occurring in marine or estuarine environment. Meanwhile, the occurrence of *Thalassodendron ciliatum* was recorded once in Tanjung Kaitan, Kota Kinabalu (Phang, 2000). Table 1.2 shows historical and recent distribution of seagrasses in Peninsular Malaysia, Sabah and Sarawak.

Table 1.2: Historical and recent distribution of seagrasses in Malaysia

Location	HU	HP	CR	CS	TH	EA	HO	HB	HM	HD	HS	SI	RM	TC	Total
Kedah															
Tanjung Rhu							x		x						2
Teluk Ewa	x	x					x								3
Pulau Langkawi	x						x								2
Kuah							x								1
Wellesley													x		1
Perak															
Beting Tengah						x	x		x						3
Pulau Pangkor	x						x								2
Selangor															
Teluk Nipah	x								x						2
Negeri Sembilan															
Port Dickson	x	x	x							x					4
Batu Empat		x			x	x									3
Batu Tujuh				x		x	x								3
Telok Kemang	x	x		x	x	x	x			x		x			8
Pantai Dickson	x				x										2

Table 1.2, continued

Location	HU	HP	CR	CS	TH	EA	HO	HB	HM	HD	HS	SI	RM	TC	Total
Cape Rachado	x				x	x	x								4
Melaka															
Pulau Besar	x			x	x	x									4
Pulau Serimbun	x				x	x									3
Johor															
Sg. Pulai				x		x	x				x	x			5
Tanjung Andang-Merambong	x	x	x	x	x	x	x		x		x	x			10
Pulau Besar	x		x	x			x				x	x			6
Pulau Sibu	x		x	x		x	x					x			6
Pulau Sibu Tengah	x				x										2
Pulau Tinggi	x		x	x	x		x		x	x	x	x			9
Pulau Tengah	x	x		x			x								4
Terengganu															
Telaga Simpul		x						x							2
Paka		x						x							2
Pulau Kapas							x								1
Sg. Redang Estuary	x						x					x			3
Kuala Setiu	x	x					x		x						4

Table 1.2, continued

Location	HU	HP	CR	CS	TH	EA	HO	HB	HM	HD	HS	SI	RM	TC	Total
Pulau Redang	x	x					x		x	x		x			6
Pulau Perhentian		x				x	x		x	x					5
Pangkalan Nangka		x						x							2
Sarawak															
Pulau Talang-talang										x					1
Sg. Bintulu								x							1
Lawas	x	x	x		x	x	x	x	x						8
Sabah															
Pulau Layang-layang	x				x		x								3
Pulau Gaya	x	x	x	x	x	x	x		x	x	x				10
Pulau Manukan	x								x						2
Pulau Sulug			x												1
Tunku Abdul Rahman Marine Park												x			1
Tanjung Kaitan					x									x	2
Sepangar Bay	x	x	x	x	x		x		x	x	x				9
Pulau Sepangar	x										x				2
Pulau Mantanani	x		x		x	x	x								5
Tanjung Mengayau	x		x	x	x	x	x								6

Table 1.2, continued

Location	HU	HP	CR	CS	TH	EA	HO	HB	HM	HD	HS	SI	RM	TC	Total
Bak-Bak	x	x	x	x		x	x					x			6
Pulau Banggi	x		x	x	x	x	x			x	x	x			9
Pulau Selinggaan, Pulau Bakungan Kecil		x					x		x	x		x			5
Nunuyan Laut					x										1
Sandakan						x						x			2
Bagahak					x	x	x								3
Pulau Meganting	x				x		x		x						4
Pulau Tabawan	x		x				x		x						4
Pulau Sibuan							x								1
Pulau Bohay Dulang	x				x	x	x								4
Pulau Bum-bum	x														1
Semporna					x	x									2
Kunak						x									1
Pulau Mabul	x				x		x								3
Pulau Sipadan	x	x	x		x		x								5
Sg. Salut & Mengkabung	x	x	x	x	x	x	x								7
Pulau Bai											x				1

Table 1.2, continued:

Location	HU	HP	CR	CS	TH	EA	HO	HB	HM	HD	HS	SI	RM	TC	Total
Wilayah Persekutuan Labuan															
Batu Manikar			x												1
Labuan					x	x									2
Pulau Papan					x	x									2
Pulau Rusukan Kecil & Besar		x*				x									2
Pulau Daat		x*				x									2

HU – *Halodule uninervis,* HP – *Halodule pinifolia,* CR – *Cymodocea rotundata,* CS – *Cymodocea serrulata,* TH – *Thalassia hemprichii,* EA – *Enhalus acoroides,* HO – *Halophila ovalis,* HB – *Halophila beccarii,* HM – *Halophila minor*, HD,- *Halophila decipiens,* HS – *Halophila spinulosa*, SI – *Syringodium isoetifolium*, RM – *Ruppia maritima,* TC – *Thalassodendron ciliatum,* * - *Halodule* sp. (Bujang, 1994; Phang, 2000; Zakaria & Bujang, 2004; Bali, 2005; Japar Sidik et al., 2006; Gumpil & de Silva, 2007; Japar Sidik et al., 2008; Rajamani, 2009; Ooi et al., 2011)

1.3 Significance of study

In Malaysia, residential areas near seagrass meadows are commonly inhabited by fishermen (Japar Sidik et al., 2006). Human habitation relies on seagrass ecosystem for food and source of income. Dense seagrass meadows contribute to a high number of fishes and prawns that were found in the middle reaches of Sg. Pulai, Johor (Sasekumar et al., 1989). Similarly, fishermen in Chwaka, East Africa, noted that all their fishing grounds (except one) have seagrass (de la Torre-Castro & Ronnback, 2004). Previously, many surveys of fish species in seagrass habitats have been done. For example, Coles et al. (1993) listed 134 taxa of fishes from a tropical estuary, Cairns Harbour, Australia. Bali (2005) recorded 60 fishes species of 35 families from Lawas estuary and Aziz et al. (2006) observed 27 species or 18 fish families of fishes in Merchang Lagoon. Despite different methods and fishing gears used in these researches, all researches noted that catches from the seagrass meadows were mostly juvenile. This indicates the importance of seagrass as a nursery and nesting grounds for fish species (Kwak & Klumpp, 2004; Dorenbosch et al., 2006). Besides fish, juvenile penaeid prawns (which are commercially important), crabs, horseshoe crabs, gastropods, bivalves, sea-cucumber and echinoderms can also be found in seagrass habitat (Perkins-Visser et al., 1996; Loneragan et al., 1998; Bali, 2005; Japar Sidik et al., 2006).

Seagrass habitat also supports charismatic marine animals such as the green turtles and dugongs. Through necropsies, dugong was found to feed on seagrasses (Erftemeijer et al., 1993; Nakaoka & Aioi, 1999; Yamamuro & Chirapart, 2005; Lanyon & Sanson, 2006; Nakanishi et al., 2006). Green turtle has been observed to feed on seagrass species such as *Thalassia testudinum* (Aragones et al., 2006). Besides turtles and dugongs, nineteen from thirty-three species of seahorse were observed to inhabit seagrass areas (Foster & Vincent, 2004). In Malaysia, locations that support dugongs and seagrass are designated as Marine Protected Area (MPA) except two locations; i.e. Lawas and Tanjung Adang-Merambong (Japar Sidik et al., 2006; Ahmad-Kamil et al., 2008; Jaaman et al., 2010). Although not protected, both locations support huge seagrass area and green turtles and dugong population.

Despite the roles and functions of seagrasses, studies on the importance of seagrasses are rarely conducted compared to mangroves and coral (de la Torre-Castro & Ronnback, 2004). Perhaps the physical characteristic of seagrasses is less appealing than other marine organism. In Malaysia, seagrasses are not given any protection against any risk of threats unless it occur in a Marine Park. There are several seagrass locations in Malaysia (Teluk Kemang, Tanjung Adang-Merambong, Pulau Tinggi, Pulau Besar, Pulau Tengah, Pulau Sibu, Telaga Simpul, Paka, Merchang, Gong Batu, Pulau Redang, Pulau Perhentian, Pengkalan Nangka, Pulau Gaya, Pulau Manukan, Pulau Mamutik, Pulau Sapi, Sepangar Bay, Pulau Selinggaan, Pulau Bakungan Kecil, Punang-Sari-Lawas) but only nine are gazetted as marine parks (Japar Sidik et al., 2006). Currently, even the largest and most diverse meadows in Malaysia (i.e. Tanjung Adang-Merambong and Lawas) are not protected (Japar Sidik et al., 2006).

1.4 Seagrass studies in Malaysia

Seagrass research in Malaysia has been concentrated on documenting the distribution of seagrasses along Malaysian waters (Ismail, 1993;Bujang, 1994;Japar Sidik et al., 1999; Phang, 2000; Zakaria & Bujang, 2004; Bali, 2005; Zakaria et al., 2003; Gumpil & de Silva, 2007; Rajamani, 2009; Muta Harah & Japar Sidik, 2013). Detailed information on all species occurring in Malaysia has not been documented except for a few. Thorough examination of *Halophila beccarii* flowers, fruits and seedlings occurring in Malaysia has been recorded by Zakaria et al. (1999). Morphological description of

Halophila decipiens, Halophila minor and *Halodule pinifolia* occurring in Pulau Redang, Malaysia were studied by Zakaria et al. (2003). It was later concluded that *Halodule* shows morphological plasticity as an adaptation towards different environmental condition in Malaysia (Bujang et al., 2008). In addition to this, *Halophila ovalis* were also observed to show morphological variation towards photoacclimation (Jamaludin et al., 2005). The productivity of seagrasses in Malaysia remains unknown except for *Thalassia hemprichii* (Abu Hena et al., 2001a) and *Cymodocea serrulata* (Abu Hena et al., 2001b).

1.5 Objective of study:

This study aims to:

- record seagrass percentage cover and seagrass species distribution at the study site
- measure pH, temperature, turbidity, salinity, dissolved oxygen (DO) and determine the type of sediments at the study site
- investigate the temporal variation of seagrass percentage cover at the study site
- study the correlation between seagrass percentage cover and monthly water parameter measurements (pH, temperature, turbidity, salinity and DO)
- assess spatial relationship between seagrass distribution and abundance with different water parameters

1.6 Hypothesis

The study expects seagrass percentage cover to change monthly. The changes can be affected by temporal and/or spatial variation. In order to verify this, the study estimated seagrass percentage cover at various sampling stations monthly. In addition to this, water parameter such as pH, temperature, salinity, DO and turbidity were measured monthly. The type of sediment were determined as it is expected to also have variations that may affect seagrass population and distribution at a number of sampling stations established.

1.7 Literature review

1.7.1 Temporal changes of seagrass distribution

In tropical countries, seagrasses exhibit temporal changes of percentage cover, above and below ground biomass, species composition and morphological changes caused by environmental factors such as disturbance (Agawin et al., 2001; Hedge et al., 2009), anthropogenic effect (Freeman et al., 2008), tidal effects (Erftemeijer & Herman, 1994), cyclone (Kwak & Klumpp, 2004) and monsoon (Ooi et al., 2011).

The coastline of South East Asia were exposed to heavy rain and tropical thunderstorms during wet season or monsoon. Prathep (2003) recorded that there are temporal interactions between seagrass percentage cover and species distribution during different seasons (dry and wet). The distribution of *Cymodocea rotundata* and *Thalassia hemprichii* was affected by wave exposure, shore levels and seasonal variation. Ooi et al. (2011) also observed that seagrass leaf length increased after the monsoon season. Similar weather conditions of the monsoon and its effects on seagrass population was studied in other tropical areas such as Queensland, Australia, where temporal changes of seagrass cover after flood and cyclone related event have been observed (Preen et al., 1995; Campbell & McKenzie, 2004). Seagrass population was devastated by these natural events due to uprooting of the plants, low light condition due to elevated turbidity and seagrass seed burial (Preen et al., 1995). In the event of seagrass burial and sediment removal, effect on seagrasses is depending on the condition of the rhizome and root system of the seagrass species. For example, Cruz-Palacios & Tussenbroek (2005) observed that uprooting and burial of *Syringodium filiforme* which had delicate rhizome and root system, while the population of *Thalassia testudinum* which has robust rhizome and root system was unaffected by hurricane. In temperate waters, Steward et al. (2006) and Carlson et al. (2010) observed seagrass loss was resulted from physical damage as well as reducing water quality caused by the cyclone. Seagrass population was recovered after three years of the event. Full recovery was facilitated by improved water quality (Campbell & McKenzie, 2004). In Florida, the recovery of seagrasses in deeper area was dependent on improved water quality such as decrease turbidity and increase of light availability (Carlson et al., 2010).

The fluctuations of tide within a day has been observed to effect seagrasses in tropical waters (de Iongh et al., 1995). If low tide occurred during daytime, seagrasses will be exposed to direct sunlight and higher irradiance will result in the increase of water temperature especially at tidal pools. *Cymodocea rotundata* and *Thalassia hemprichii* were observed in tidal pool with water temperature up to 42ºC in Yap, Micronesia (Bridges & McMillan, 1986). Campbell et al. (2006) observed thermal stress on tropical seagrass species at 40ºC. Different tropical seagrass species has different thermal tolerance as an adaptive response towards high temperature. For example, *Cymodocea rotundata, Cymodocea serrulata* and *Halodule uninervis* are tolerant to temperature ranges from 26ºC to 40ºC. *Syringodium isoetifolium, Zostera capricorni* and *Halophila ovalis* showed thermal stress at 40ºC while *Thalassia testudinum* was observed to be tolerant to temperature up to 33ºC (de Iongh et al., 1995). Seagrasses respond to thermal stress by releasing chlorophyll from damaged cells and tissue (de Iongh et al., 1995) and leaf reddening (Novak & Short, 2010). Generally, seagrasses have morphological adaptation towards high temperature. Thin and flexible stems are adaptation of *Halophila ovalis* which allows them to lie on the moist sediment when exposed during the low tide (Beer et al., 2006). Thermal stress will affect seagrass by discoloration of seagrass leaves due to damage in enzymatic pathways that will lead to chlorophyll release (Erftemeijer & Herman, 1994; de Iongh et al., 1995; Novak & Short, 2010) and leave drying (de Iongh et al., 1995) which will finally resulted in decreasing seagrass percentage cover. Thermal stress on seagrasses also affects photosynthetic pathways of seagrasses which results in decrease of above ground biomass (Campbell et al., 2006). Several studies have observed that tropical seagrass species such as *Thalassia testudinum* able to tolerate high temperature, but addition of toxins, such as sulphide, reduced their tolerance towards increasing temperature (Koch & Erskine, 2001; Koch et al., 2007). The tolerance to various temperature had affected seagrasses in terms of species distribution at both tropical and temperate waters (Bridges & McMillan, 1986; Masini et al., 1995; Masini & Manning, 1997).

1.7.2 Spatial changes of seagrass distribution

Seagrasses in Malaysia responds to spatial and environmental changes (Japar Sidik et al., 1999; Bujang et al., 2008 and Gan et al., 2011). Spatial variation refers to the variation of coastlines in Malaysia such as sheltered bay, long cape, wave exposed beach and many more. Meanwhile, environmental changes refer to weather changes and threats (natural and human-induced) at a particular place.

The occurrence of seagrasses in Malaysia is restricted to sheltered areas of shallow intertidal associated ecosystem, semi-enclosed lagoons and also in the subtidal zones (Bujang & Zakaria, 2003). Major seagrass locations in Malaysia are located at estuaries (Zakaria & Bujang, 2004; Bali, 2005; Bujang et al., 2006), bays (Zakaria et al., 1999; Gumpil & de Silva, 2007) and offshore islands sheltered from strong winds (Ooi et al., 2011). Depending on species, seagrasses are able to adapt to different locations and geographical attributes. For example, highest percentage cover of *Thalassia hemprichii* was recorded at wave exposed area while highest percentage cover of *Cymodocea rotundata* was recorded mainly in sheltered shore area of Thailand (Prathep, 2003). The anchoring system of seagrasses (root and rhizome) determine the distribution of seagrasses in sheltered or wave exposed area. Cruz-Palacios & Tussenbroek (2005) showed that seagrasses with robust rhizome (such as *Thalassia testudinum*) is able to withstand simulated hurricane than seagrasses with delicate rhizome (such as *Syringodium isoetifolium*) and root system.

Seagrasses are sedentary organism. It need to stay rooted for stabilization and nutrient intake. In Malaysia, seagrasses have been found growing on various types of substrates in coastal zone such as sandy, coral, sandy-coral, sandy-muddy, sand covered coral, sandy rocky, shallow water and sand coral rubble (den Hartog, 1970; Ismail, 1993; Zakaria et al., 1999; Phang, 2000; Gumpil & de Silva, 2007). *Thalassia hemprichii,* for example, has been found growing on coral patches and coarse sand (Ismail, 1993) and on muddy substrates (Zakaria & Bujang, 2004). While *Halodule pinifolia* and *Halophila ovalis* grew on a wide ranges of sediment type; from sandy to muddy substrates (Zakaria & Bujang, 2004). Changes in sediment includes siltation resulted from deforestation (Jakobsen et al., 2007; Freeman et al., 2008), accretion and erosion (de Boer, 2007; van Katwijk et al., 2010). The occurrence of seagrass species also depending on the sensitivity of the seagrasses towards siltation (Terrados et al., 1998; Bach et al., 1998). Besides species richness, leaf biomass also declined with increased siltation (Terrados et al., 1998). Two scales of seagrass sensitivity towards siltation were suggested. Bach et al. (1998) suggested sequence of seagrass species from least to most sensitive as follows: *Enhalus acoroides* > *Cymodocea rotundata* > *Halodule uninervis* > *Thalassia hemprichii* > *Halophila ovalis* > *Cymodocea rotundata* > *Syringodium* *isoetifolium.* Terrados et al. (1998), on the other hand, suggested a slightly different model with the least to most sensitive to siltation; *Enhalus acoroides* > *Halophila ovalis* > *Halodule uninervis* > *Cymodocea serrulata* > *Thalassia hemprichii* > *Cymodocea rotundata* > *Syringodium isoetifolium*. Due to siltation, seagrasses are also prone to sediment burial and and smothering which will reduce seagrass productivity (Cabaco et al., 2008).

Changes of seagrass distribution were caused by natural and anthropogenic threats (Short & Wylie-Echeverria, 1996). Natural threats such as tsunami (Nakaoka et al., 2006) and flood (Birch & Brich, 1984; Preen et al., 1995; Campbell & McKenzie, 2004) have caused seagrass loss at large scale (Birch & Brich, 1984; Preen et al., 1995; Campbell & McKenzie, 2004). Siltation and sedimentation have caused seagrass loss in Talibong Island (largest seagrass area in Thailand) immediately after the tsunami (McKenzie et al., 2012). It is well noted that seagrass species diversity and percentage cover were declined due to the tsunami (UNEP, 2006). Extensive seagrass loss has been observed in Queensland during flood due to increased in turbidity and nutrient concentration (Campbell & McKenzie, 2004). Spatial differences of seagrass death at shallow and deep water have been observed. Seagrasses in deep water died due to light limitation while seagrasses in shallow water were died due to uprooting by the heavy water currents during the flood (Preen et al., 1995). The variation in seagrass diversity after disturbance (i.e. flood or tsunami) was affected by high growth rate characteristics of the seagrass species. For example, *Halophila decipiens* was observed dominating the recovery sites in Queensland (Preen et al., 1995). Other study indicated that *Halophila ovalis* was recorded after strong physical disturbance by the tsunami in Thailand but other seagrass species was wiped out (Nakaoka et al., 2006). However, the same study showed that the distribution of two seagrass species showed no differences after the tsunami. The differences of seagrass occurrence after similar event proved that spatial differences contributed to the survival of seagrass population.

1.7.3 Seagrasses response towards environmental changes

Combination of environmental changes such as physical parameter (temperature, salinity and pH), natural phenomena (nutrient input, epiphytic algae and diseases) and anthropogenic effects limit or encourage seagrass growth. However, when certain parameter become limiting factor, the increase of this parameter cause seagrass population at a specific location to fluctuate (Short et al., 2001). Basic requirements for seagrass growth are light, inorganic carbon and nutrients (Hemminga & Duarte, 2000; Lee et al., 2007). Ruiz & Romero (2003) suggested that there are more complex interactions that causes seagrass mortality such as water quality, grazers and nutrients.

Seagrasses need light for photosynthesis. Increasing depth will limit light penetration. Furthermore, the amount of light reaching the bottom is also affected by increasing turbidity which affects the water clarity. Increasing turbidity affects the clarity of water due to changes of water colour caused by pollution and increase of suspended solid. Increased turbidity was resulted from coastal development (Ruiz & Romero, 2003), deforestation (Freeman et al., 2008) and natural events such as flood and hurricane (Preen et al., 1995; Campbell & McKenzie, 2004; Steward et al., 2006; Carlson et al., 2010). Living submerged underwater, seagrasses need to overcome light limitation problem. Depending on species, some seagrasses have photo-acclimation to low light condition (Ruiz & Romero, 2003). For example, tropical seagrass species, *Halophila* sp. has morphological characteristics such as petiolate, elliptic or ovate leave shapes that are more efficient in harvesting light than linear or lanceolate leave shapes. Consequently, *Halophila* sp. can survive to the maximum depth limit with minimum light requirement (Lee et al., 2007). *Halophila* sp. was found at 58 m of depth in a very clear water of Great Barrier Reef (Lee Long *et al.,*1999 (in Short et al., 2001)). During the condition of light deprivation due to increased turbidity, *Halophila ovalis* was observed to exhibit physiological changes such as biomass and sugar concentration decline and finally plant death after 30 days of light deprivation (Longstaff et al., 1999). However, *Halodule pinifolia* was observed to be more tolerant towards extended increased turbidity than *Halophila ovalis* by exhibiting no biomass loss up to 38 days and death only occurs after 100 days (Longstaff & Dennison, 1999).

As described earlier, seagrasses in marine environment have adapted to saline environment (Arber, 2010). Unlike subtidal seagrasses, intertidal seagrasses are exposed to decrease salinity as a direct result of freshwater influx. Therefore, the distribution of intertidal seagrass species will be affected by the degree of its tolerance towards salinity fluctuations. Bridges & McMillan (1986) observed the distribution of *Cymodocea rotundata, Thalassia hemprichii* and *Enhalus acoroides* at shallow waters due to its tolerance towards lower salinity condition in Yap, Micronesia. Similar condition has been observed for temperate seagrass species, where decrease of *Thalassia testudinum* growth rate with decrease salinity will ultimately replaced by *Halodule wrightii* which has better tolerance towards low salinity condition (Lirman & Cropper, 2003). Benjamin et al. (1999) found that marine *Halophila ovalis* was less tolerant towards low salinity than estuarine *Halophila ovalis.* Different response of marine and estuarine *Halophila ovalis* towards hyposalinity condition (such as swollen chloroplasts, visible vacuoles on cells, leaf senescence, cell surface area, leaf and internode length, rhizome diameter) was postulated to be a result of acclimation and ecotype emergent (Benjamin et al., 1999). On the other hand, Bujang et al. (2008) observed *Halodule* species in Malaysia is having morphological plasticity (such as leaf length, leaf width, erect stem length, rhizome growth pattern and leaf tip morphology) as a response towards lower salinity and other environmental condition but not as a result of ecotype emergent. Besides responding to decrease salinity, seagrasses also respond to hypersalinity. Hypersalinity is a condition where salinity of the marine environment increases more than its normal threshold. Hypersalinity is caused by brine effluents from desalination plant (Sanchez-Lizaso et al., 2008) and reduced freshwater input to the estuary/bay (Kelble et al., 2007). Hypersalinity has been observed to change seagrass composition (Lirman & Cropper, 2003), decreased growth rate (Fernandez-Torquemada & Sanchez-Lizaso, 2011) and decreased seagrass productivity (Murphy et al., 2003).

pH is affecting the photosynthetic pathways of seagrasses (Beer et al., 2006). Invers et al. (1997) showed that seagrass photosynthesis depends on the species tolerance/efficiency to take up carbonate ion (HCO_3^-) due to low concentration of carbon dioxide (CO_2). The photosynthetic rate of *Cymodocea nodosa* and *Posidonia oceanica* is linearly decrease with the increase of pH. However, the increase of pH do not effect the photosynthetic rate of *Zostera noltii.* This species maintains a high photosynthetic rate up to pH 8.8 and started to show reduction whenever pH reach 9.0. There were differences between intertidal and the subtidal *Cymodocea serrulata* and *Halophila ovalis* photosynthetic efficiency at high pH (Swarz *et al.* (2002) in Marba et al., 2006). On contrary to Invers et al. (1997) findings, Jiang et al. (2010) observed that the increase in photosynthetic rate do not present any limiting effects on *Thalassia hemprichii* and increase of the leaf growth in high CO_2 condition. Therefore, Jiang et al. (2010) suggested that seagrasses are able to absorbed direct CO_2 and strive in high pCO_2 environment and tend to dominate the community. Hall-Spencer et al. (2008) observed enhanced seagrass production and higher shoot density at high pCO_2 and low pH in Ischia, Italy where seawater were acidified from volcanic CO_2 vents. At a local scale, fluctuations of pH may be caused by increasing ammonia/ammonium ion (NH_3-NH_4^+) ratio (van der Heide (2008) in Christianen et al., 2011) due to runoff from human activities such as aquaculture, land clearing, palm oil plantations and human habitation near river mouths. Increase of photosynthetic rate will cause pH to increase and it is expected to increase seagrass percentage cover. Although no dedicated study on the effect of pH towards seagrass percentage cover was done, correlation between seagrass percentage cover and pH has been observed by Balaji (2009) and Adajar et al. (2010).

Dissolved gasses such as oxygen (O_2) and carbon dioxide (CO_2) are important for respiration and photosynthesis of underwater seagrasses (Davies, 1991) and therefore influence their distribution. Dissolved oxygen (DO) is added into the ocean at the water surface through exchange with the atmosphere or as a by-product of photosynthesis (Sverdrup et al., 2006). It is measured to determine the suitability for marine life survival (Saleh et al., 2007). Plants (such as phytoplankton, algae and seagrasses) and and plant-like organisms (e.g. *Euglena*), which holds the photosynthetic organelles (chlorophyll) are responsible for producing oxygen for the ocean environment (Davies, 1991). Seagrass communities support respiration rates close to their gross primary production (Hemminga & Duarte, 2000) resulting in intense gas changes in the water column (Gacia et al., 2005). Respiration rate for *Thalassia hemprichii* ranges from 0.115 ± 0.005 to 0.164 ± 0.021 mg O_2/hr/g of fresh weight while for *Cymodocea serrulata* is 0.189 ± 0.017 to 0.214 ± 0.014 mg O_2/hr/g of fresh weight (Abu Hena et al., 2001a,b). Normal oxygen requirement that has been recorded by other tropical species is 0.34 ± 0.13 mg O_2/hr/g and 0.92 ± 0.13 mg O_2/hr/g for *Halodule uninervis* and *Halophila ovalis* respectively (Wahbeh (1983) in Abu Hena et al., 2001b). Daby (2003) postulated that high value of DO can be used as an indicator of seagrass productivity which was measured by standing biomass, shoot density and shoot length. It is expected that the increase of seagrass productivity will lead to the increase of seagrass percentage cover and the increase of dissolved oxygen in seawater.

In Malaysia, changes in water quality of the coastal areas were influenced by various activities such as recreation, shipping, coastal development, untreated sewage (Praveena et al., 2011), dredging (Sabri, 2009), refinery, power station (Baharuddin Pallan, 2011), agricultural (Katimon et al., 2004; Saleh et al., 2007) and aquacultural waste (Alongi et al., 2003; Saleh et al., 2007). The anthropogenic activities influenced seagrasses population by affecting water turbidity (Saleh et al., 2007), nutrient (Alongi et al., 2003) and heavy metal accumulation (Sabri, 2009). The increase of turbidity will limit the light from reaching seagrasses which effects the seagrass morphological and physiological changes (Longstaff & Dennison, 1999; Longstaff et al., 1999). Increase of nutrient will affect the seagrass-seaweed competition (Davis & Fourqurean, 2001) and seagrass metabolism (Udy & Dennison, 1997). Meanwhile, long term exposure to heavy metal will affect leaf growth rate and size of seagrasses (Ambo-Rappe et al., 2011).

Changes of other water parameter such as salinity, pH, temperature and DO due to anthropogenic threats have been recorded. For example, desalination activities produced hypersaline brine which is discharged to the sea. This activity has increased salinity which affect structure and vitality of *Posidonia oceanica* (Sanchez-Lizaso et al., 2008). Land-use and water-use in Florida Bay have reduced freshwater delivery resulted in hypersalinity of the Bay (Herbert et al., 2011). Proposal for Florida Bay habitat restoration include to increase the freshwater input into the Bay. Herbert et al. (2011) and Lirman & Cropper (2003) have predicted changes of seagrass species distribution as a respond to changes in salinity. Increased of water temperature had affected physiological (Masini et al., 1995; Masini & Manning, 1997; Campbell et al., 2006) and morphological (Novak & Short, 2010; Erftemeijer & Herman, 1994) changes of seagrasses. In a tropical country like Malaysia, small fluctuation of temperature is observed compared to temperate countries. Therefore, differences of temperature within the same study area in Malaysia will be minimal and it is not expected to foresee any direct differences on seagrass percentage cover. Besides these parameters, pH is also influenced by aquaculture and agriculture wastes. Decreased pH values correspond to human activities such as aquaculture (Tovar et al., 2000; Anh et al., 2010). Aquaculture activities bring about nitrogenous, sulphurous (Bjork & Beer, 2009) and phosphorous (Anh et al., 2010) emission. Tovar et al. (2000) explains that low pH were also resulted from increased ammonium (NH_4^+) ion as well as acidic character of faeces and fish foods. Changes of pH has been observed to cause changes in seagrass physiological processes such as photosynthesis (Invers et al., 1997).

DO has been used as a tool to measure productivity of primary producers in the ecosystem (Abu Hena et al., 2001a, b). Fluctuation of DO value at coastal areas was contributed by continuous mixing of coastal water with the open sea water (Saleh et al., 2007). Mixing of coastal waters and open sea water increases DO due to the exchange of gas between the atmosphere and the water. Decreasing DO value was recorded during the event of pollution (O'Boyle et al., 2009) and nutrient loading (Shanmugam et al., 2006). O'Boyle et al. (2009) and Shanmugam et al. (2006) observed that the improved value of DO corresponded to the decreasing freshwater runoffs which brings pollution and nutrients to the coastal areas.

CHAPTER TWO

MATERIALS AND METHODS

2.1 Study site

This study was conducted in Lawas, Sarawak. The waters of Lawas are located within the Brunei Bay which faces the South China Sea. Brunei Bay is a semi enclosed body of water shared by Brunei, Sabah and Sarawak (Mustafa, 2007). It is sheltered from the Southwest and the Northeast monsoon seasonal winds (Bali, 2005). Figure 2.1 and 2.2 show the location of Lawas which is a part of the Borneo mainland. Mangrove fringing forests, sandy beaches, rocky shores, mudflats and seagrass meadow contribute to the coastal profile of Lawas (Figure 2.3). Approximately 500-1000 ha of seagrass area were discovered in Lawas in 2002 (Bali, *Pers. Comm.*). This area supports sixty species of fish including commercially important species and vulnerable marine animals such as dugongs and turtles (Bali, 2005).

An aerial survey in 2001 had confirmed sighting of dugongs and turtles in Brunei Bay (Jaaman & Lah-Anyi, 2003; Bali et al., 2008). Satellite tracking study in 1999 and 2001 revealed that there are 11 green turtles and a hawksbill turtle in Sarawak Turtle Islands. The turtles were observed to spend some time in Lawas waters before continuing their journey to their feeding ground in Sabah, Indonesia and the Philippines. In another aerial survey in 2007, nine sightings of marine turtle and 14 individuals of dugong were sighted at Lawas (Bali et al., 2008).

There are coastal villages along the coastline of Lawas. Most of the villagers are fishermen that practice traditional fishing methods such as small mesh seine, hock-and-line and gill net (Bali, 2005). Trawling is illegal in Lawas. Bali (2005) listed 60 species of fish (belong to 35 families) in the area. These include commercially important

Figure 2.1: Location of Lawas situated in Borneo, East Malaysia

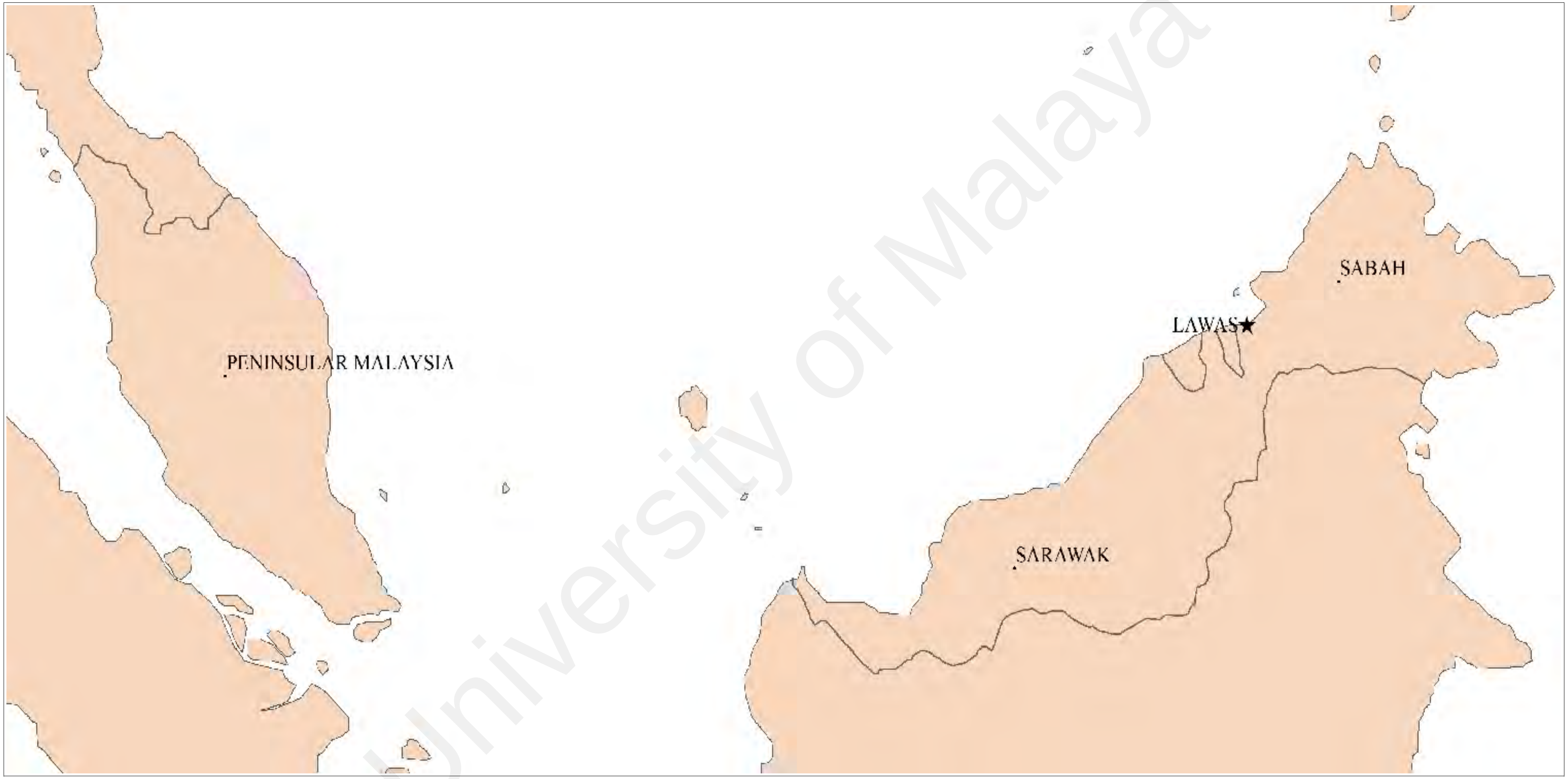

Figure 2.2: Location of Lawas, Sarawak, sandwiched between the border of Sabah and Brunei.

Figure 2.3: Coastal profile of Lawas coastline includes sandy beach, rocky shores, mangrove fringing forest and coral patches (clockwise)

species such as grouper, trevally, anchovy, mullet as well as the endangered seahorse. Beside fishes, the coastal community also harvests edible invertebrates such as lobster, sea cucumber, shellfish and crabs for trading. Lawas supports brackish water aquaculture at river mouths that breeds commercial fish species such as seabass and grouper (Bali, 2005). This small scale fish culture can be found in the coastal villages along the river mouth of Sg. Sangkurum, Sg. Kuku Karu, Sg. Punang, Sg. Awat-Awat and Batang Lawas. Besides fisheries, some parts of the land in Lawas are cleared for agriculture and this also contributes to Lawas economy. Further inland in Ba' Kelalan, logging activity is still active and being supervised by the respective government agency. Figure 2.4 shows the information land-usage and human activities took place in Lawas based on map of Pekan Sundar (Pekan Sundar, 2007) acquired from Jabatan Ukur dan Pemetaan Malaysia (JUPEM).

Lawas was selected as the study site because:

- It's uniqueness as a seagrass-mangrove-coral ecosystem is unexplored
- No baseline data on temporal distribution of seagrasses and basic water physico-chemical parameters at Lawas
- Detail information on spatial and temporal distributions of seagrasses have never been published
- A better conservation strategy for marine mammals and marine turtles in Lawas can be formulated through the understanding of seagrass ecology

2.2 Sampling stations

Estimation of seagrass percentage cover and water parameter measurements were conducted at various sampling stations established along the 32.2 km of coastline from Sg. Bangkulit (4° 59' 3.5016" N, 115° 27' 4.3992" E) to Awat-awat (4° 55' 59.8002"N, 115° 14' 37.899" E) were visited monthly during the first neap tide from June 2009 to May 2010 (Figure 2.4). The coastline of Lawas extends until the international border of Sarawak-Brunei. However, preliminary survey observed no seagrass presence near the border. Due to this, the sampling stations were only established from Sg. Bangkulit to Awat-Awat. Sampling points were marked using GARMIN GPSMAP 60CSx fixed with WGS1984 Geographic Coordinate System. The sampling stations established were located at shallow areas (depth between 0.4 m to 3.1 m during high tide).

Twenty-eight sampling stations were established along the coastline (Figure 2.4). Each sampling stations is located 1 km apart. Another set of 28 sampling stations were located 500 m perpendicular to the coastline stations. These sampling stations were at the maximum depth of 3.1 m during high tide of the neap tide. Stations which are located 500 m from the coastline are called “open water stations” and stations that are located along the coastline are known as “coastal stations”. At areas with higher abundance of seagrasses, additional sampling stations were established. Here, the sampling stations are located 250 m from each other bringing the total number of sampling stations along the coastline to 56 stations. Therefore, the total number of sampling stations established at the study area is 84. The sampling stations were exposed to different environmental disturbances and human activities (Table 2.1).

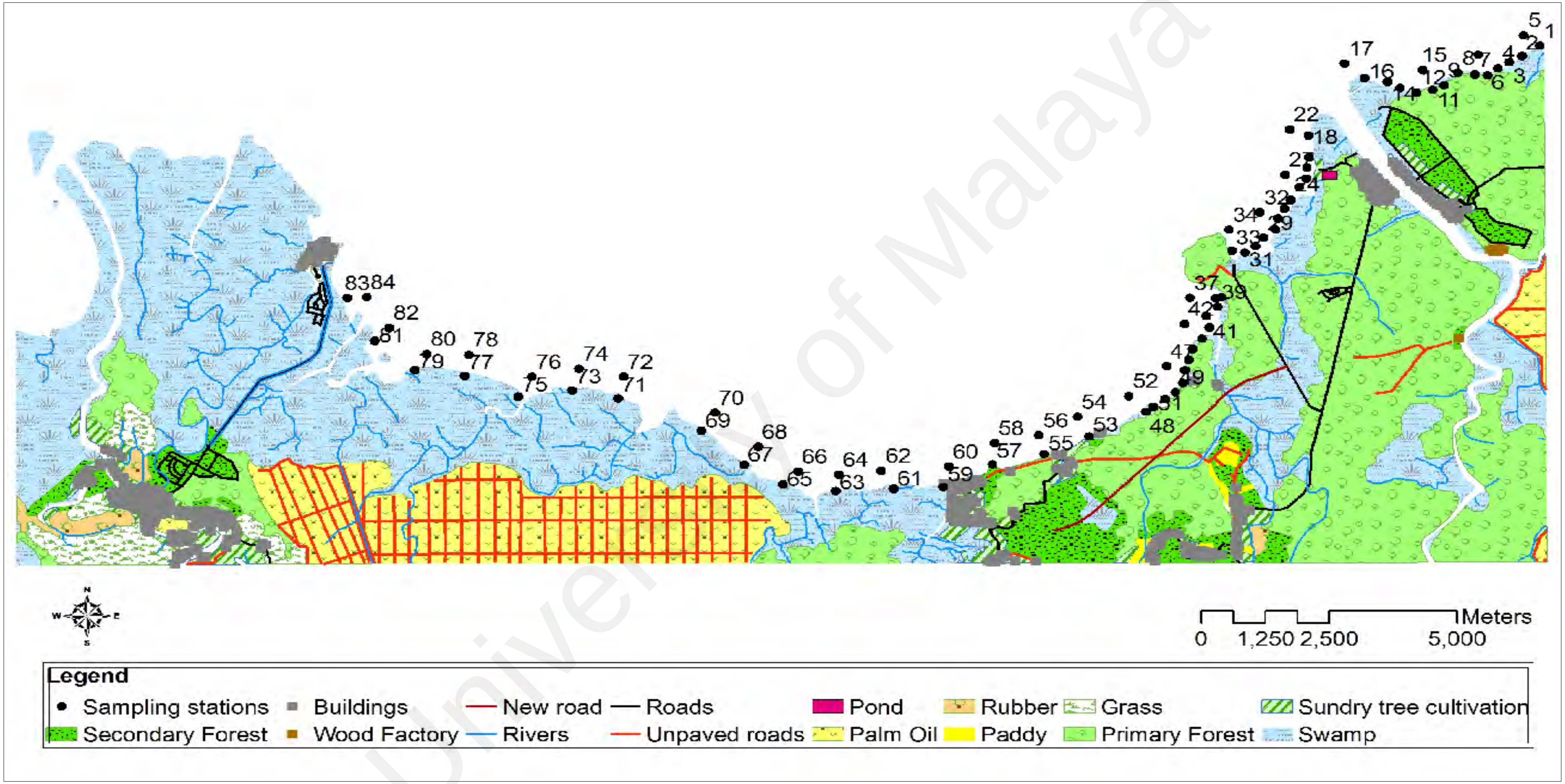

Figure 2.4: Information on land-use and location of sampling stations (numbered) established in Lawas

Table 2.1: Classification of sampling stations based on localities and disturbances

Station	Sampling location	Locality	Disturbance / Human activities
1 – 13	1	Bangkulit	Sediment plume, runoffs from Sg. Bangkulit
14 – 18 and 22	2	Batang Lawas	runoffs from Batang Lawas, coastal village along Batang Lawas and small scale aquaculture from the coastal village
19 – 34	3	Tanjung	Runoffs from Sg. Kuku-Karu, gleaning activities (shellfish)
35 – 52	4	Sg. Cina	Runoffs from Sg. Cina and Labik-labik gleaning activities (shellfish)
53 – 62	5	Punang	Runoffs from Sg. Punang, coastal village along Sg. Punang and small scale aquaculture from the coastal village
63 – 84	6	Awat-awat	Oil palm plantation

2.3 Seagrass sampling

Seagrass population were observed at each sampling station by wadding or snorkelling depending on the water depth. At each sampling stations, three 50 cm x 50 cm quadrat (Figure 2.5) were randomly thrown within 5 m radius of the sampling stations. Total seagrass cover within the quadrat were visually estimated using the percent cover standards (Figure 2.6). Seagrass species within the quadrats were identified and the percent contribution of each species to the total coverage were determined. Data obtained from three quadrats at each sampling station was averaged. Seagrass sampling method in this study was based on the method used by Nakanishi et al. (2006). Meanwhile, seagrass species was identified based on identification guide from den Hartog (1970), Japar Sidik et al. (1999) and Gumpil & de Silva (2007).

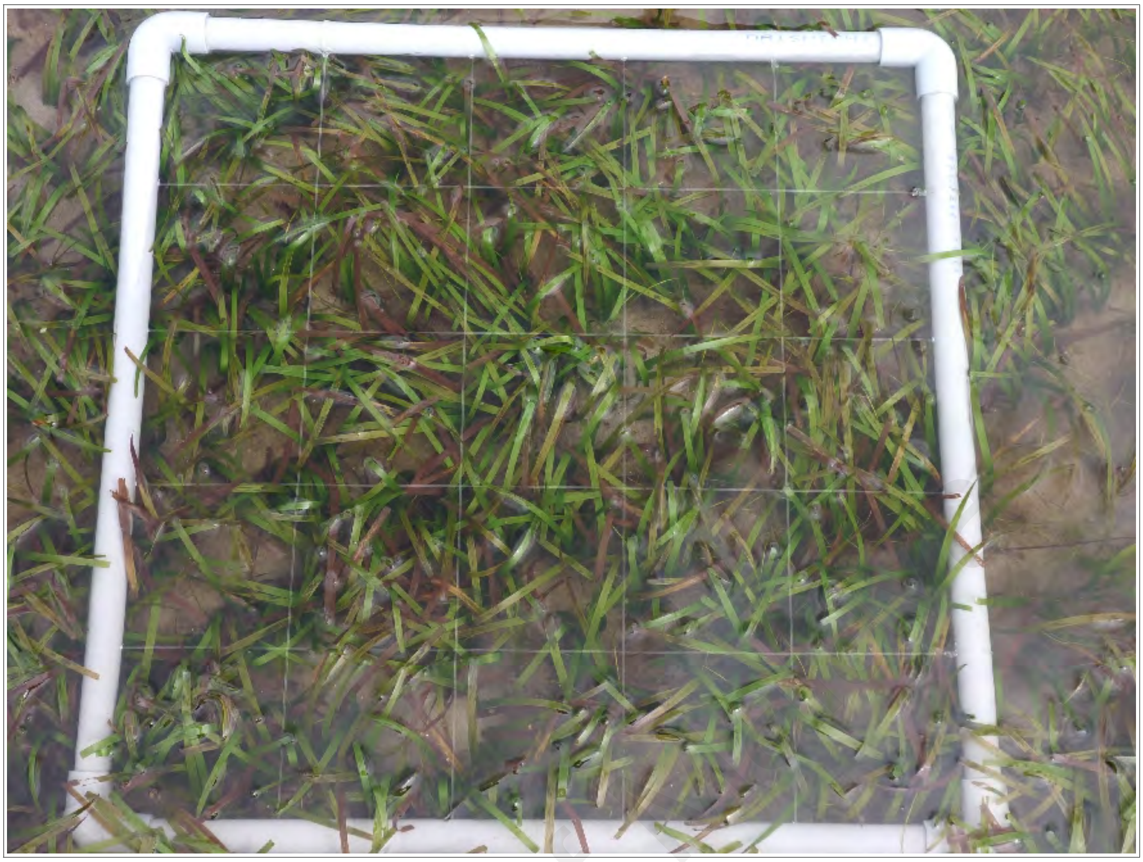

Figure 2.5: 50 cm x 50 cm quadrat used to visually estimate the seagrass percentage cover

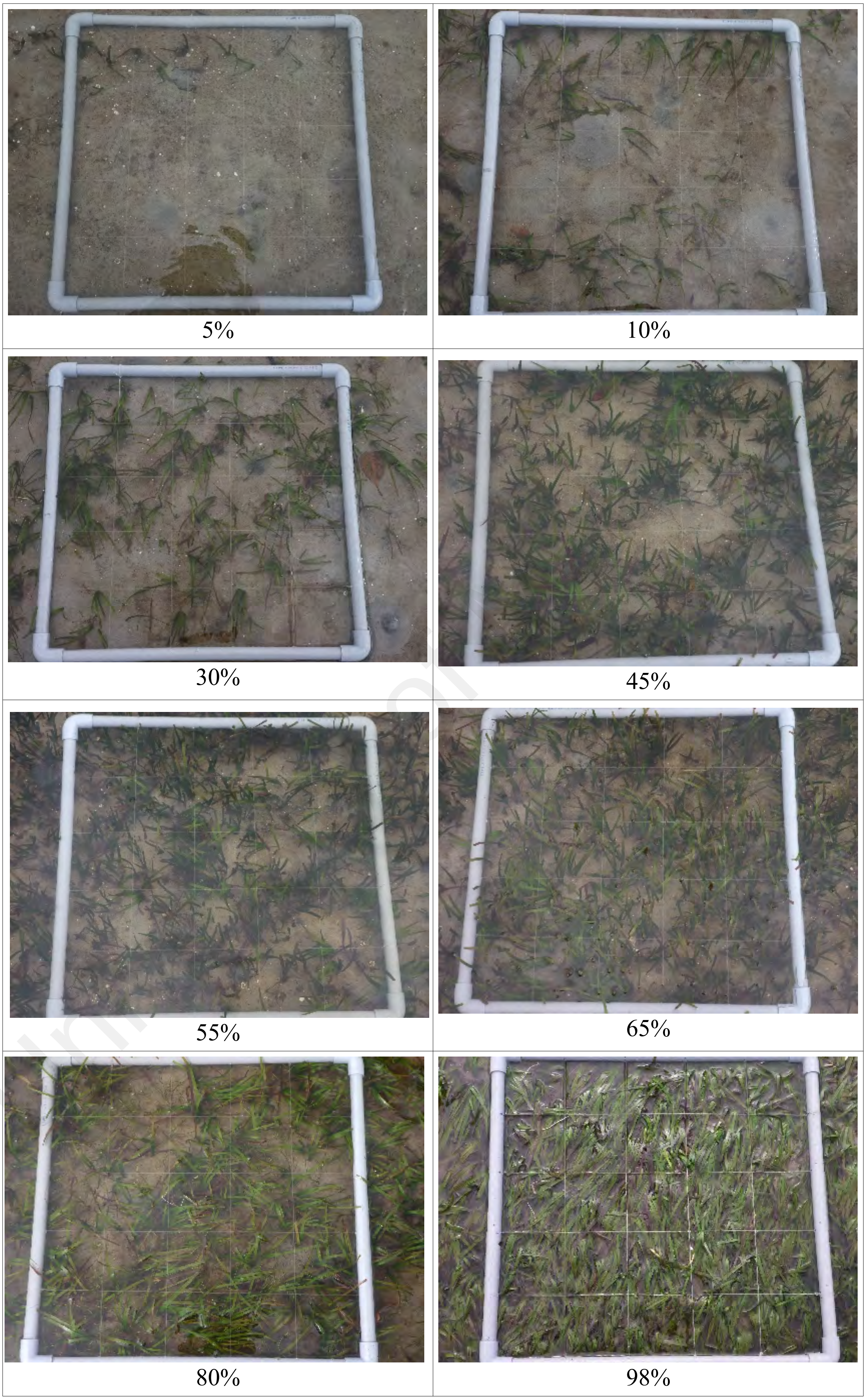

Figure 2.6: Seagrass percentage cover standards

2.4 Temporal data analysis

Mean seagrass percentage cover (mean ± SE) was plotted against month. In deducing correlation between seagrass percentage cover and water physico-chemical parameter, only 49 out of 84 (58.3%) sampling stations were considered for this study. This is because only these stations recorded seagrass presence throughout the year. Seagrass percentage cover were converted into ordinal data (grouped seagrass percentage cover as seen in section 3.2.4.1) because the seagrass percentage cover and water parameter value do not conformed to normal distribution. The temporal changes of grouped seagrass percentage cover was analyzed using non-parametric statistical analysis, Friedman test. This non-parametric test measures the differences between several related groups when assumptions for repeated measures ANOVA is violated and when data is ordinal (Field, 2005).

2.4.1 Grouped seagrass percentage cover

The differences of monthly seagrass percentage cover were analyzed by grouping the stations based on modified Braun-Blanquet scale (Braun-Blanquet, 1972). The modified Braun-Blanquet (B-B) scale was based on Braun-Blanquet and Participatory Coastal Resource Assessment (PCRA) Scale (Deguit et al., 2004). Table 2.2 shows the comparison of Braun-Blanquet scale based on Braun-Blanquet, PCRA Scale and the modified Braun-Blanquet Scale used in this study.

Braun-Blanquet Score was widely used in seagrass monitoring which estimates seagrass density based on the number of seagrass shoots and assign a value from the scale of 0 to 0.5. Meanwhile, PCRA developed a scale to to assess the health of mangrove ecosystem based on crown cover, average tree height and measurements of regeneration. Instead of giving score, PCRA scale gave names to the condition of the mangrove as Excellent, Good, Fair and Poor.

The Braun-Blanquet Scale was not suitable for the current study because the study does not take into account solitary shoots as < 5% cover. The current study was also unable to adopt PCRA scale because the PCRA Scale gathered all plant covers from 0% to 25% as one classification. This study disagreed with PCRA Scale and added “absent” and “occasional” to the modified B-B Scale.

Table 2.2: Interpretation and comparison of Braun-Blanquet Scale, PCRA Scale and the modified Braun-Blanquet Scale used in this study

Braun-Blanquet Scale		PCRA Scale		Modified B-B Scale	
0	No vegetation	Poor	0 - 25%	Absent	No seagrass found in quadrat (0% cover)
0.1	Solitary shoot, < 5% cover			Sparse	< 5%
0.5	Few (<5) short shoots, < 5% cover				
1	Many (>5) short shoots, < 5% cover				
2	Many (>5) short shoots, 5-25% cover			Occasional	5-25%
3	Many (>5) short shoots, 25-50% cover	Fair	26% - 50%	Frequent	26-50%
4	Many (>5) short shoots, 50-75% cover	Good	51% - 75%	Common	51-75 %
5	Many (>5) short shoots, 75-100% cover	Excellent	76% - 100%	Abundant	76-100%

2.4.2 Seagrass species composition

The percentage of seagrass species composition that was present at the study area from June 2009 to May 2010 was presented in a graph. Temporal changes of three seagrasses species that were most commonly found were analyzed using Friedman's test.

2.4.3 Meteorological data

Rainfall data for Limbang station (4° 48’ N, 115° 0’ E) in Sarawak were obtained from Malaysian Meteorological Department. Sampling were conducted during El-Nino period (Malaysian Meteorology Department, 2013). The stage of El-Nino events can be determined based on Southern Oscillation Index (SOI), which were obtained from Australian Government Bureau of Meteorology.

2.5 Water parameter measurements

DO (mg/l), temperature (ºC), pH and salinity (PSU) were measured using HI9828 HANNA Instrument Multimeter. Turbidity was measured using HI93703 Hanna Instrument Microprocessor Turbidity meter. Each water parameter was measured every month during high tide (of neap tide) at all sampling stations established along the coastline of Sg. Bangkulit (4° 59' 3.5016" N, 115° 27' 4.3992" E) to Awat-awat (4° 55' 59.8002"N, 115° 14' 37.899" E).

2.5.1 Correlation of water parameter and grouped seagrass percentage cover

The correlation of water parameter with grouped seagrass percentage cover were evaluated using non-parametric Spearman Rho correlation which can be used to find relationship between variables because the data was not normally distributed.

2.6 Spatial distribution of seagrasses

2.6.1 Sediment type

The type of sediment at each sampling station were assessed by digging into the sediment using fingers into the top centimeter of the substrate. The texture for the sediment were felt and described. Sediments were categorized as Muddy, Mix of Sand and Mud and Sandy. Table 2.3 refers to the description of the sediment.

2.6.2 Spatial data analysis

2.6.2.1 Geographic Information System (GIS)

Information on seagrass distribution including its abundance, species distribution, sediment type and water parameter measurements were mapped according to sampling locations using Borneo RSO (m) map projection with ArcGIS 9.3 software.

2.6.2.2 Statistical analysis

The non parametric Kruskal-Wallis test was used to compare the mean ranks of two or more samples whether they are independent or not. This test was used to study the differences of seagrass percentage cover at different sampling location, evaluate seagrass species distribution on different sediment type, as well as to test the differences of water parameter at different sampling location. This non-parametric test was used to correct abnormality.

Table 2.3: Description of sediment type (based on McKenzie & Campbell, 2002)

Sediment type	Description
Sandy	Coarse, grainy or fine sand texture. Particles are clearly apparent or loose particles. Grain size 63 µm to 1 mm.
Muddy	Soft, silty , elastic/sticky texture. Grain sizes less than 63 µm
Mix of mud and sand	A mixture of sand and mud as described above.

CHAPTER THREE

RESULTS

3.1 Seagrass abundance

A total of seven species of seagrass were recorded in the study area. *Thalassia hemprichii, Cymodocea rotundata, Halodule pinifolia, Halodule uninervis, Enhalus acoroides, Halophila minor* and *Halophila ovalis* were found at coastal stations on sandy, muddy, mix of sand and mud, mix of sand and coral rubble substrate at the intertidal zone which was exposed during low tide. Figure 3.1 to 3.3 are images of different seagrass species at the study area.

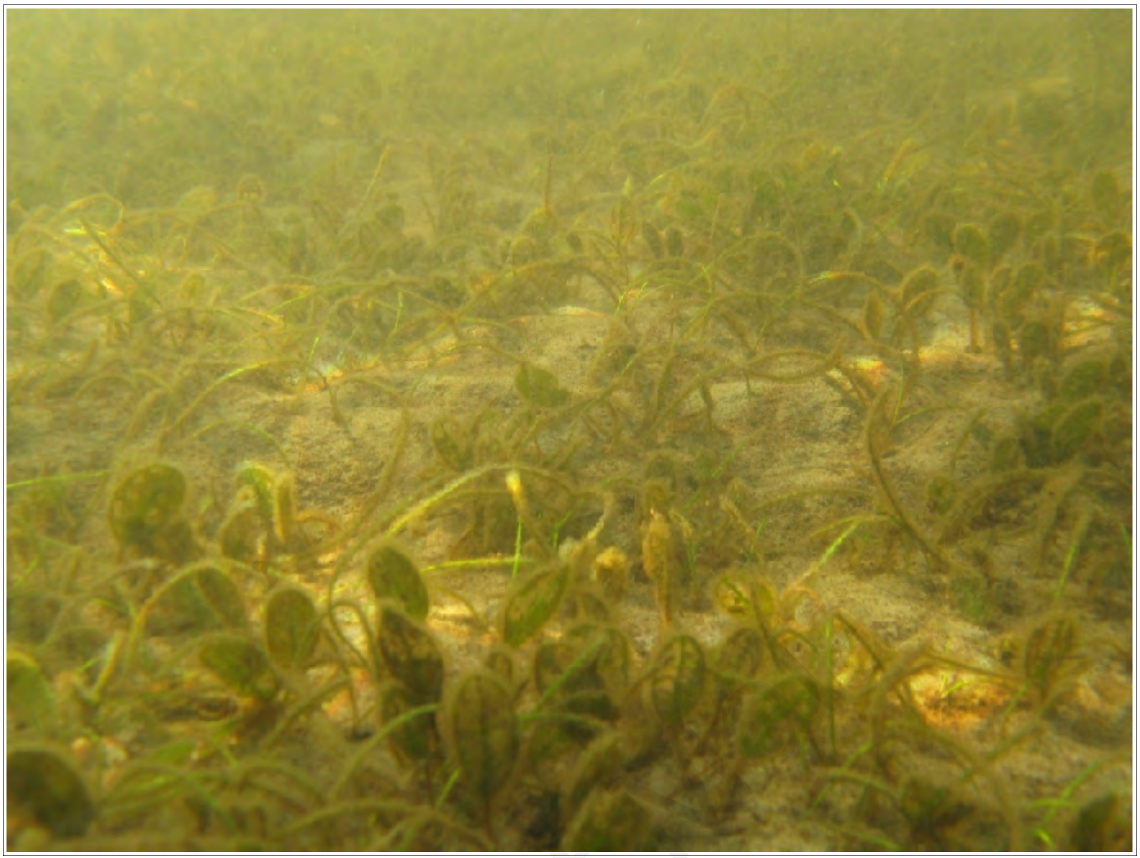

Figure 3.1: Mixed vegetation of *Halodule pinifolia* and *Halophila ovalis*

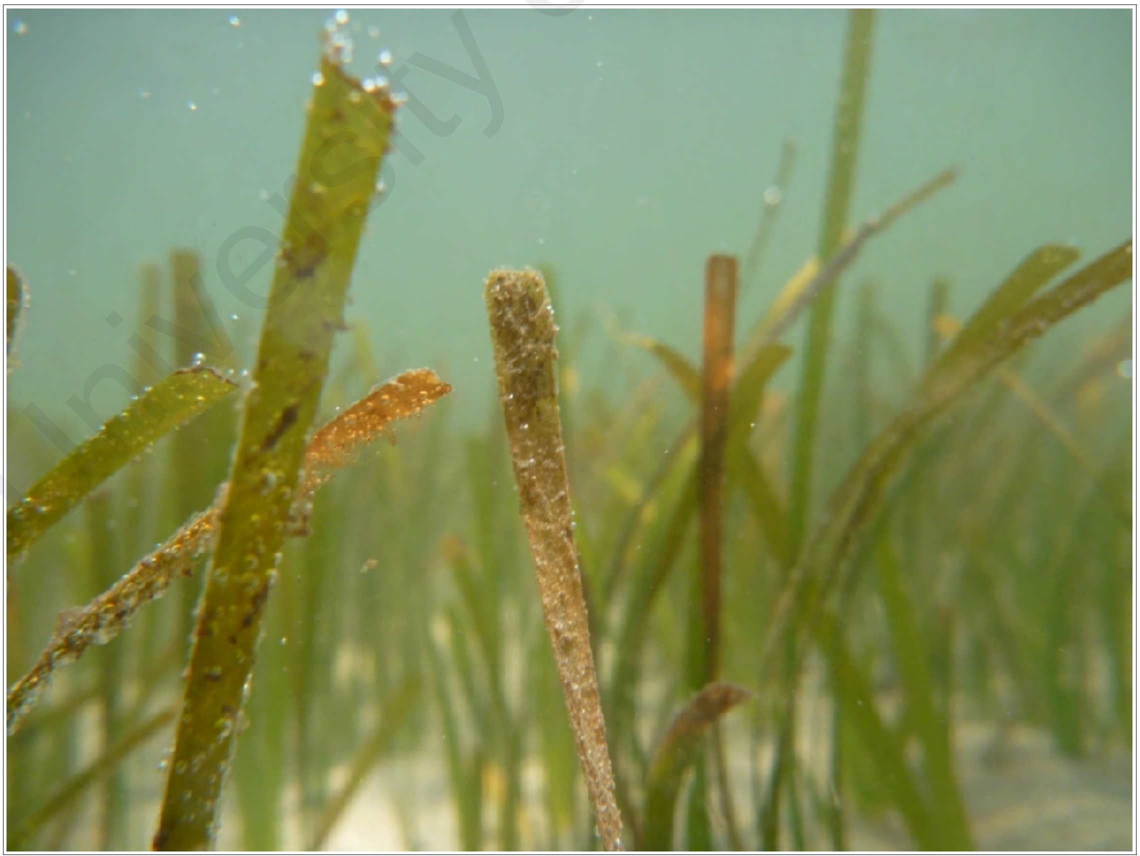

Figure 3.2: Meadow of *Cymodocea rotundata*

Figure 3.3: Male inflorescence of *Enhalus acoroides*

3.2 Temporal changes of seagrass percentage cover

The total seagrass percentage cover at all stations ranged from less than 5% to 95%. Figure 3.4 shows monthly fluctuations of mean percentage cover of total seagrass (all species pooled) from June 2009 to May 2010. Mean of seagrass percentage cover was observed to be stable from June to August 2009. Seagrass decline was observed in August 2009 but recovered in September 2009. However, from October 2009, mean seagrass percentage cover was devastated until recovery was observed in February 2009. Recovery of mean seagrass percentage cover continued and reached maximum in May 2010 .

Figure 3.5 shows number of stations classified according to the scale for each month. The monthly changes of grouped seagrass percentage cover was highly significant ($\chi^2_{(11, N = 49)} = 88.260$, $p < 0.001$). The fluctuations of seagrass percentage cover during the sampling period can be observed by the variation of the number of stations classified in a specific group scale each month. For example, in November 2009, when mean seagrass percentage cover decreased, the number of stations exhibiting higher percentage cover with group scale (such as common and abundant) reduces and the number of stations exhibiting lower percentage cover with sparse increases. The increase on the number of station classified as sparse indicated that loss of seagrass percentage cover was observed during this time. The recovery of seagrass percentage cover were observed in February 2010 when the number of stations classified as absent decreased. This means, less sampling stations were recorded without seagrass. During this time, there was an increased number of sampling stations having as frequent and common seagrass distribution.

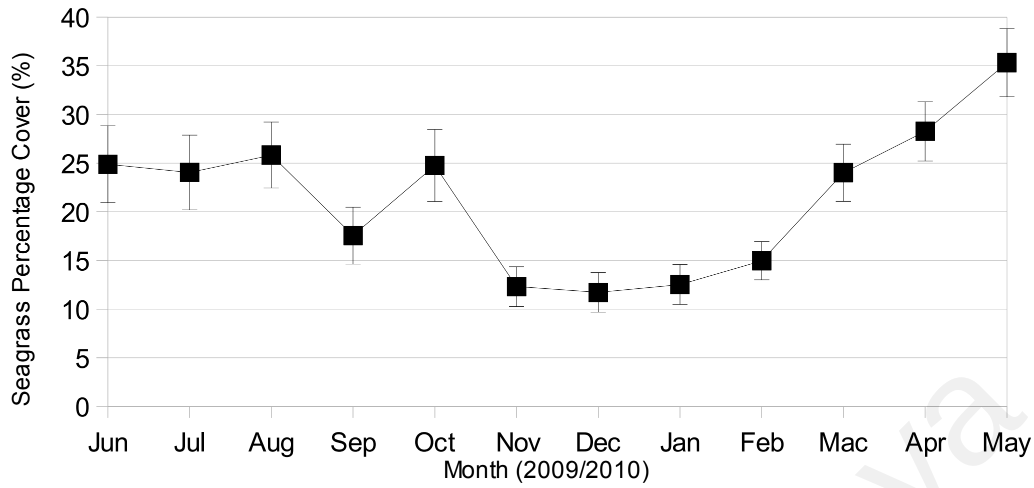

Figure 3.4: Mean seagrass percentage cover (%) from June 2009 to May 2010.

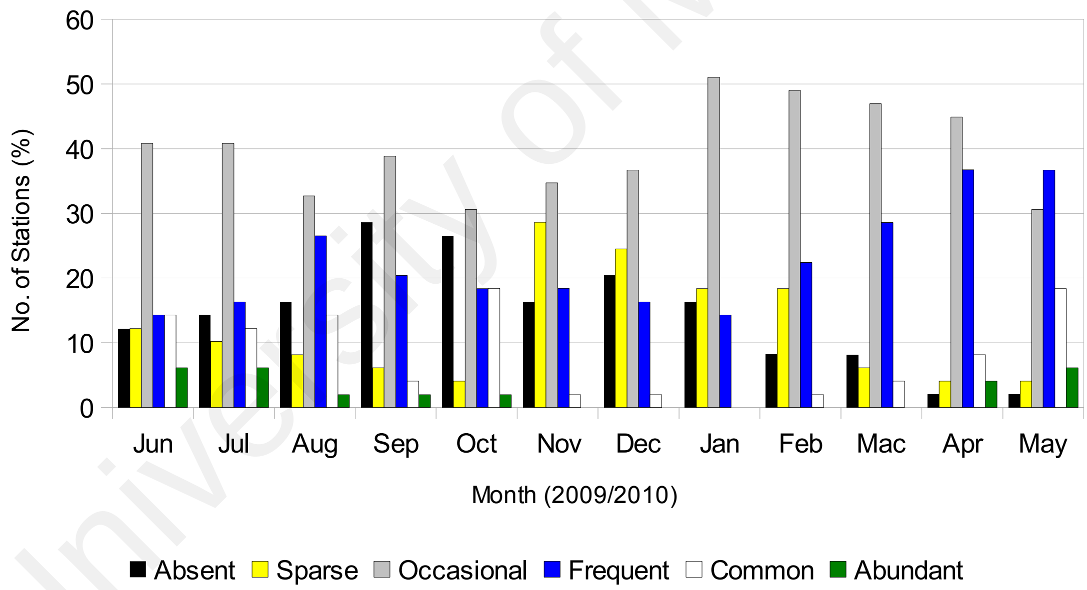

Figure 3.5: Number of stations classified based on modified B-B Scale from June 2009 to May 2010

3.3 Temporal changes of seagrass composition

The percentage cover of *Halodule pinifolia* ranged between 1% - 90% at all stations throughout sampling period. The difference of monthly grouped percentage cover for *Halodule pinifolia* was significant, $\chi^2_{(11, N = 35)} = 59.941$, $p < 0.01$. The percentage cover of *Halodule uninervis* at all stations ranged between 1% - 74% throughout the sampling period. Although the lowest percentage cover for this species was recorded in November, it was recovered two months later. The monthly differences of grouped percentage cover for *Halodule uninervis* was significant, $\chi^2_{(11, N = 17)} = 31.400$, $p < 0.05$. The percentage cover of *Cymodocea rotundata* ranged between 1.83% - 60% throughout the sampling period, indicating the percentage cover was unstable. There was a competition between *Cymodocea rotundata, Halodule uninervis* and *Halodule pinifolia* which can be clearly observed at Station 28, 39, 44, 46, 53 and 54. However, the difference of the grouped percentage cover of *Cymodocea rotundata* for each month was not significant, $\chi^2_{(11, N = 7)} = 16.949$, $p > 0.05$. In August 2009, there was an event of *Cymodocea rotundata* succession over *Halodule pinifolia* in Labik-labik. During this event, *H. pinifolia* leaves becomes red and new shoots of *Cymodocea rotundata* protruded from the sediment. Succession of other seagrass species was not clearly observed as the abundance was low.

The species composition of seagrasses found in the study area is shown in Figure 3.6.

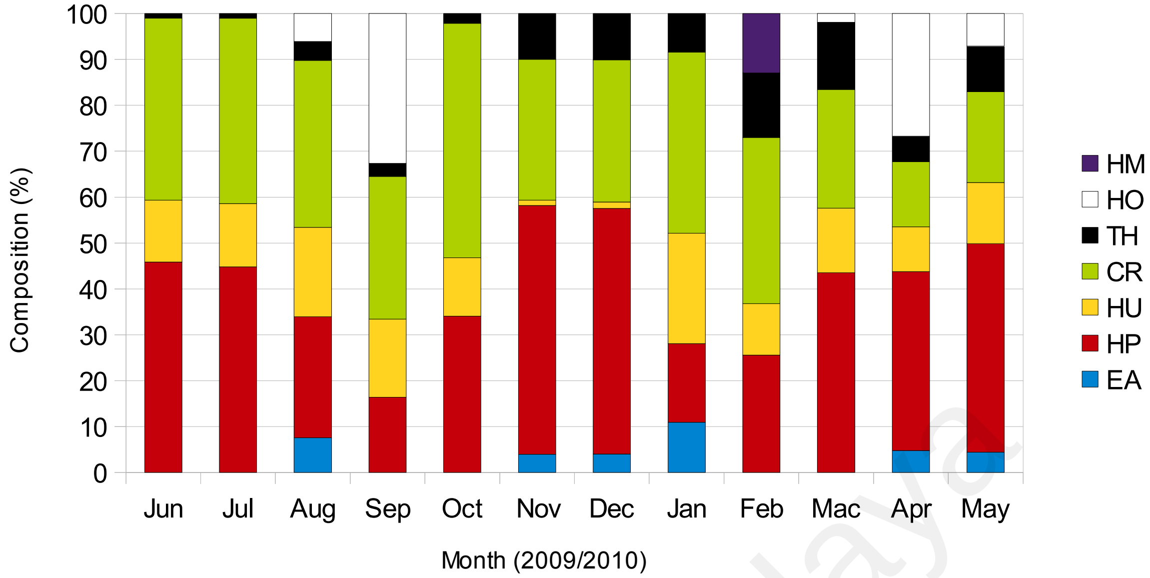

Figure 3.6: Temporal changes of species composition from June 2009 to May 2010 (HM – *Halophila minor,* HO – *Halophila ovalis,* TH – *Thalassia hemprichii,* CR – *Cymodocea rotundata,* HU – *Halodule uninervis,* HP – *Halodule pinifolia,* EA – *Enhalus acoroides*)

3.4 Meteorological data

Lawas observed abundant rainfall during the monsoon season (wet season) which was observed from November 2009 to January 2010. Least rain were observed in February 2010. However, the amount of rain gradually increases from March 2010 to May 2010 (Refer Figure 3.7). Least amount of rain in February 2010 were coupled with high air temperature. During this time, Lawas experienced drought season. In addition to these conditions, Southern Oscillation Index (SOI) observed negative SOI values from October 2009 to March 2010 (Figure 3.8).

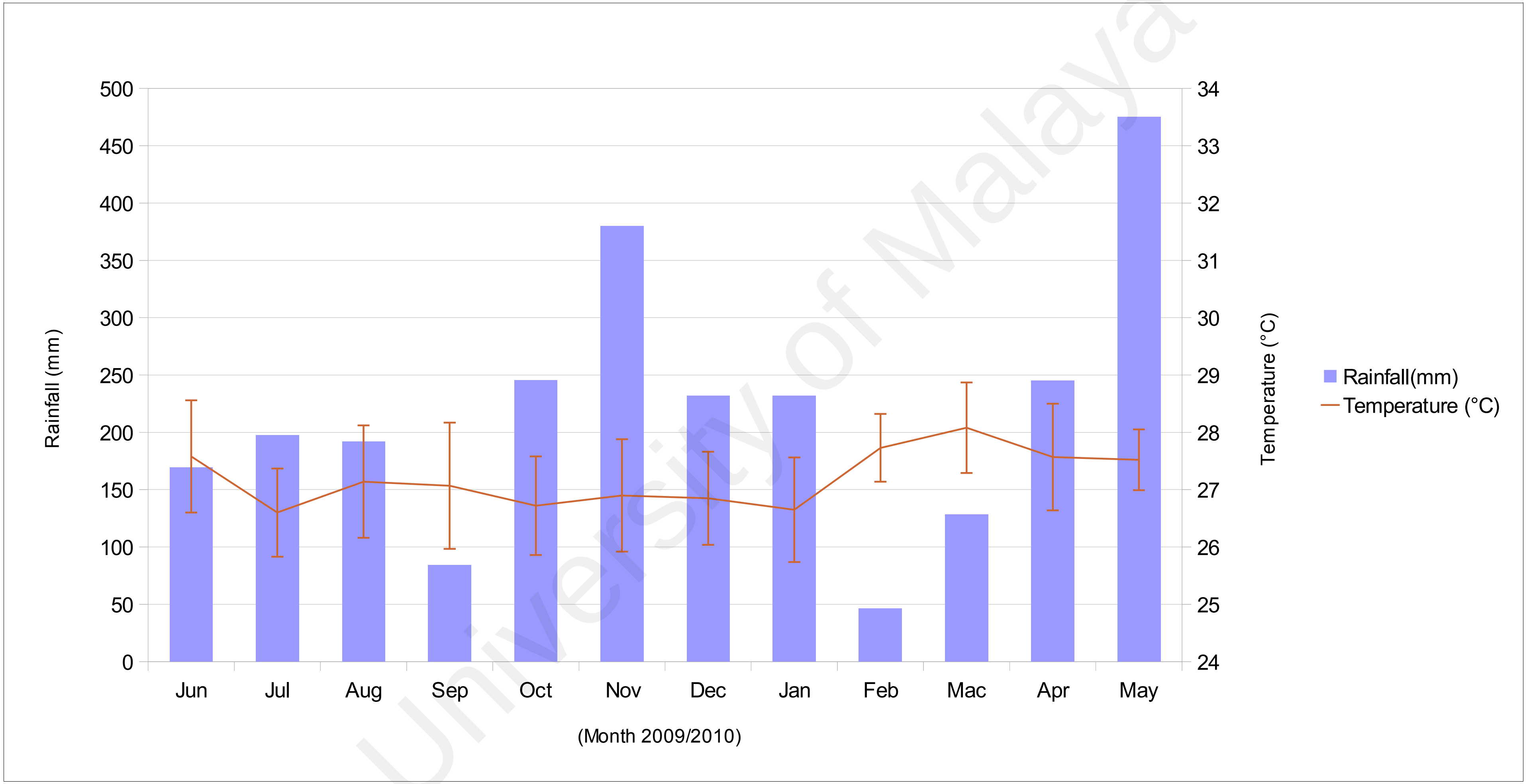

Figure 3.7: Total rainfall (mm) and average of monthly air temperature (Malaysian Meteorology Department, 2011)

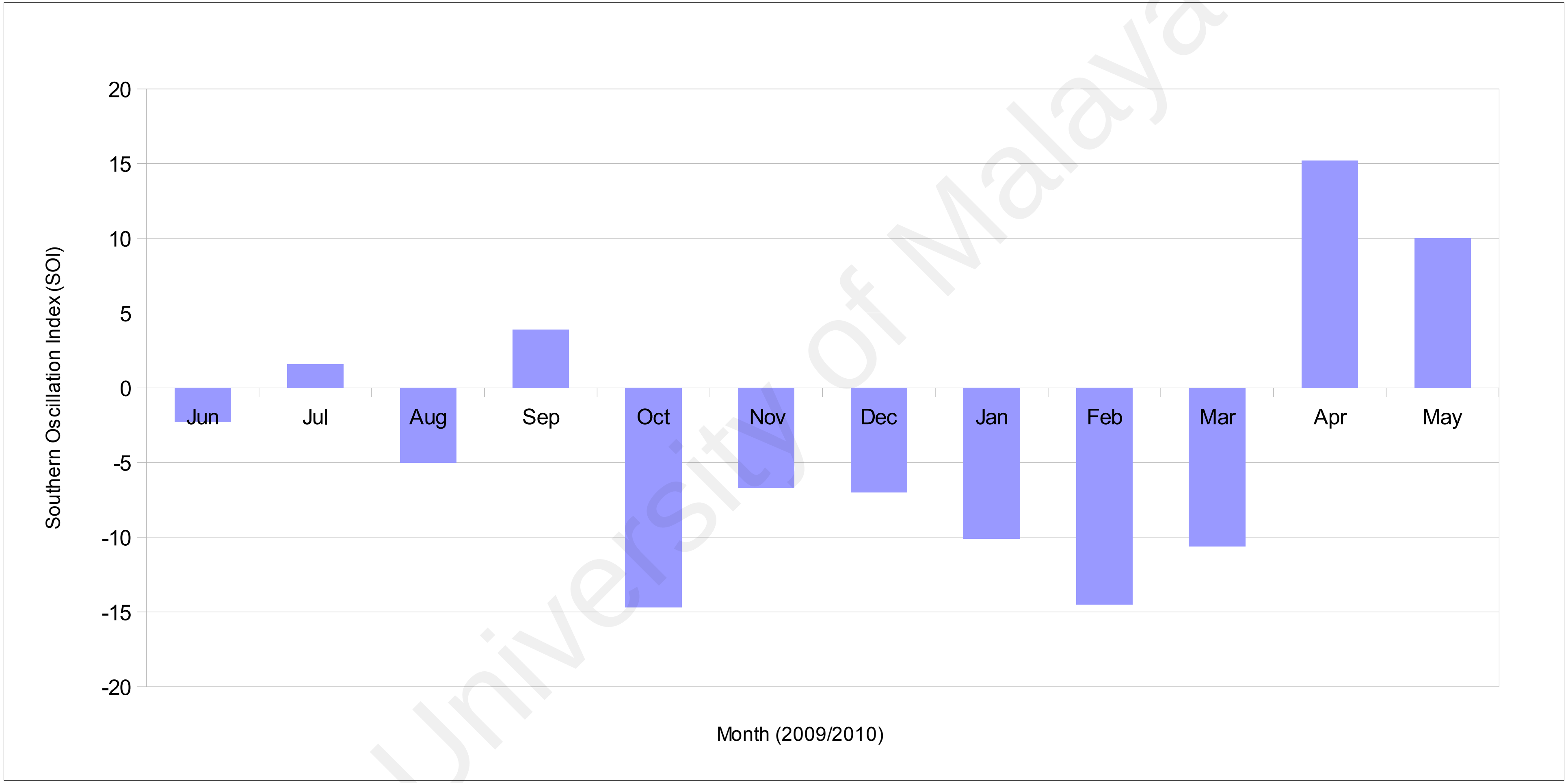

Figure 3.8: Southern Oscillation Index (SOI) from June 2009 to May 2010 (Australian Government Bureau of Meteorology, 2013).

3.5 Basic water parameter measurement

All water parameter measurements are within the Primary Water Quality Criteria for Class SW-II Waters (SW-II) and Class E Malaysian Marine Water Quality Criteria and Standard (MMWQC) except for temperature (Refer Table 3.1). Based on Malaysian Marine Water Quality Criteria and Standard (Class E), acceptable range of water temperature is less or equal to 2ºC increase over maximum ambient. The average ambient temperature throughout the sampling period as measured by Malaysian Meteorological Department is 27.21ºC. Thus, the acceptable range of water temperature should be within 25 – 29ºC. The average water temperature measured throughout the sampling period is 31.29 ± 0.06, more than the acceptable range based on MMWQC.

3..5.1 Correlation between grouped seagrass percentage cover and basic water parameter

3.5.1.1 Temperature

Based on Figure 3.9, lowest water temperature was recorded in October 2009 and the highest water temperature was recorded in March 2010. There were two peaks of maximum temperature observed during the study period , i.e. August 2009 and March 2010. After the first peak, seagrass percentage cover was observed to decrease with the increasing number of stations grouped as Absent and decrease number stations grouped as Sparse, Frequent and Common. However, after the second peak, increased in seagrass percentage cover was observed together with the decreasing number of stations recorded seagrass absence and increasing number of stations recorded with higher group scale. During this time, recovery of seagrass coverage was recorded. Despite these observations, there was no significant correlation between grouped seagrass percentage cover and temperature, $r_{(588)} = 0.030$, $p > 0.05$.

Table 3.1: Mean of basic water parameter measurements and comparison with SWII and MMWQC Class E

Water Parameter	Mean	SWII standards	MMWQC Class E
Temperature (°C)	31.29 ± 0.06		2°C increase over maximum ambient
Salinity (PSU)	27.68 ± 0.12		
Dissolved Oxygen (DO)	5.36 ± 0.03	(4.0 mg/l - Not less than 3.5 mg/l	4
PH	7.98 ± 0.10	6.5-8.5	
Turbidity	7.99 ± 0.33	30 NTU	20 NTU

*SW II – Primary Water Quality Criteria for Class SW-II Waters (For bathing, contact water sports and commercial fishing); MMWQC Class E - Malaysia Marine Water Quality Criteria and Standard – Class E (Mangrove estuarine and River-mouth water).

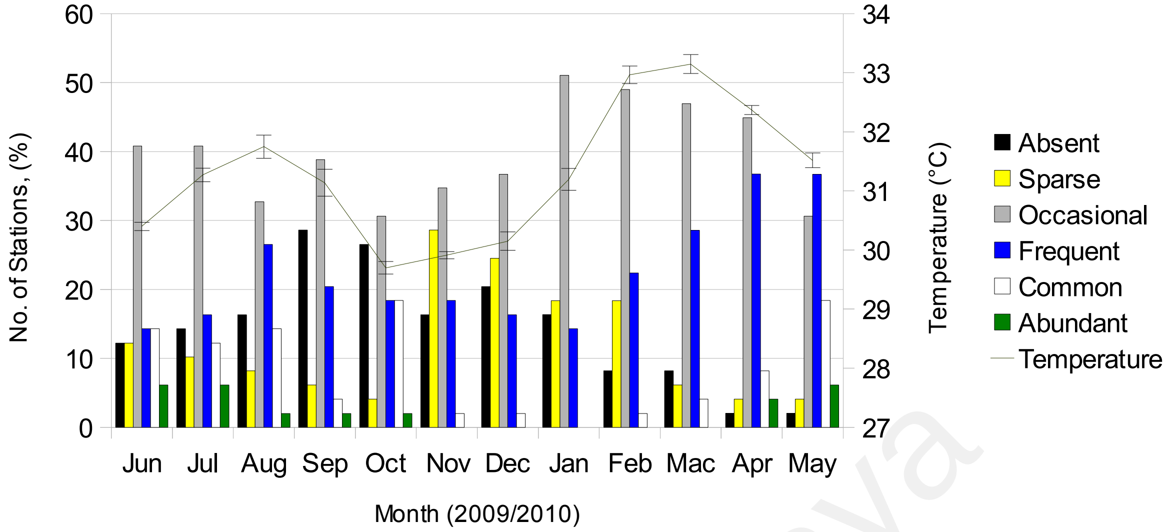

Figure 3.9: The changes of number of stations classified based on modified B-B Scale and monthly fluctuations of temperature

3..5.1.2 pH

Based on Figure 3.10, pH was measured lower than 8.0 in June, July and November 2009. After initial drop of pH during the first two months of study, increase of pH was recorded starting in August 2009. However, seagrass percentage cover decreases (number of stations classified at higher B-B scale decreases). After the maximum pH value was measured in April 2009, seagrass coverage was observed to recover (number of stations classified at higher B-B scale decreased). This correlation was not significant, $r_{(588)} = 0.041$, $p > 0.05$.

3..5.1.3 DO

Based on Figure 3.11, DO was almost constant from June 2009 until March 2010. In April, there was a drop on the value of DO measured. This coincides with seagrass reaching its maximum percentage cover (low in the number of stations with absent and increase number of stations recorded with higher B-B scale). However, the correlation between grouped seagrass percentage cover and DO was not significant, $r_{(588)} = 0.013$, $p > 0.05$.

3..5.1.4 Salinity

Based on Figure 3.12, when the lowest salinity was recorded in November 2009, the seagrass percentage cover decreased (none of the stations grouped as abundant and the number of stations recorded as frequent or common decreased). In March 2010, when highest salinity was measured, the seagrass coverage improved (increase number of stations recorded as frequent and common). However, this correlation was not significant, $r_{(588)} = 0.033$, $p > 0.05$.

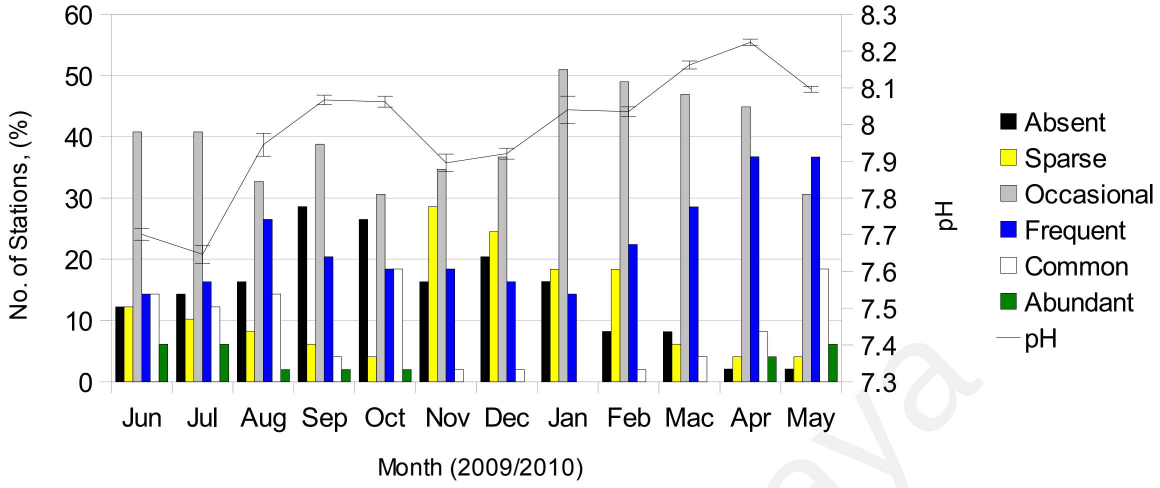

Figure 3.10: The changes of number of stations classified based on modified B-B Scale and monthly fluctuations of pH

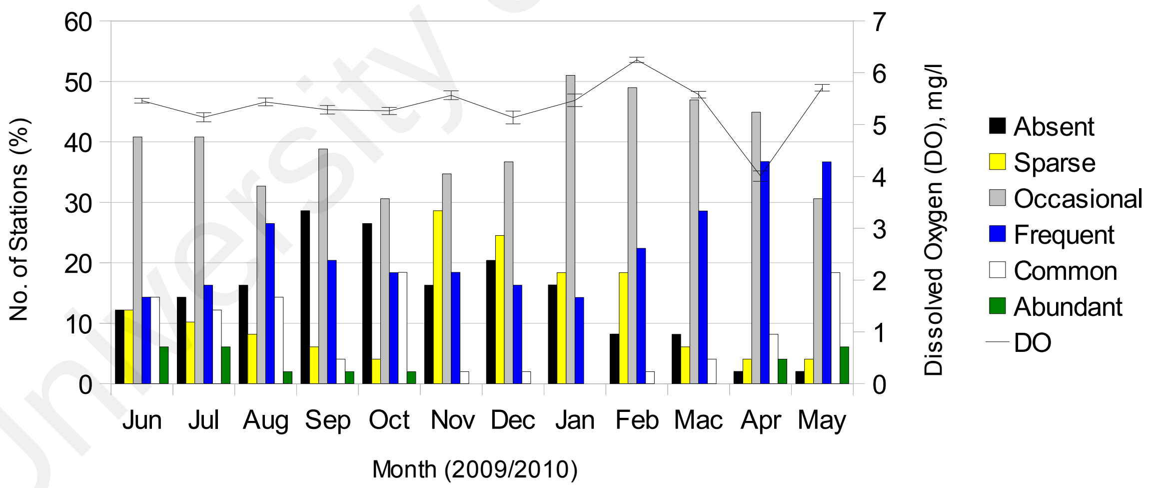

Figure 3.11: The changes of number of stations classified based on modified B-B Scale and monthly fluctuations of DO

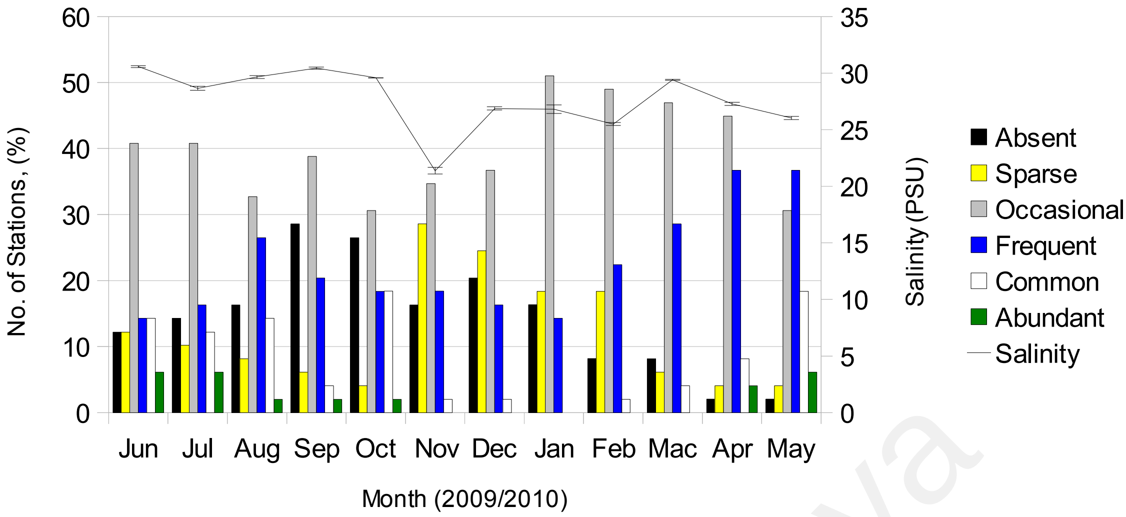

Figure 3.12: The changes of number of stations classified based on modified B-B Scale and monthly fluctuations of salinity.

3.5.1.5 Turbidity

A large fluctuation was observed on monthly turbidity compared to other water parameter (Refer Figure 3.13). During the earlier period of the study, high turbidity was recorded. Water clarity increased at later period of the study. Two peaks of turbidity measurements were observed (July and November 2009). After the event of high turbidity recorded in July 2009, seagrass percentage cover was decreased in August (due to decreased number of stations recorded as abundant). Seagrass percentage cover continued to decrease in September 2009 (Number of stations classified as frequent also decreased). In December 2009 (after high turbidity event in November 2009), seagrass coverage was also observed to be devastated with the number of stations classified as abundant, frequent and common have decreased). However, when low turbidity was measured (starting from January 2010 to May 2010), seagrass coverage improves (number of stations classified as abundant, frequent and common increases). The correlation between grouped seagrass percentage cover and turbidity is significant, $r_{(588)} = -0.235$, $p < 0.05$.

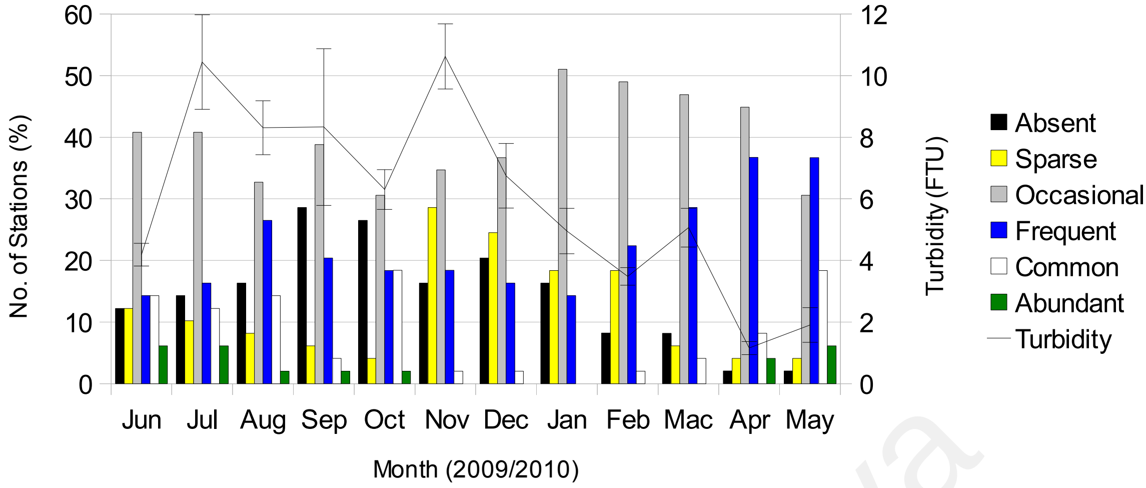

Figure 3.13: The changes of number of stations classified based on modified B-B Scale and monthly fluctuations of turbidity

3.6 Spatial distribution of seagrass

3.6.1 Seagrass abundance

Figure 3.14 shows the number (in percentage) of stations which recorded seagrass presence according to B-B scale at different location. Locations 1, 2 3 and 4 have higher seagrass abundance as less stations recorded seagrass absence and more stations have common and abundant seagrass distribution based on the B-B Scale. Location 6 has less seagrass cover as the percentage of stations that do not have any seagrass are highest. Figure 3.15 shows the distribution of seagrass abundance. Seagrasses were abundantly found at coastal stations except at location 5 and 6, where more seagrass were observed at open water stations. Kruskal-Wallis showed significant differences of seagrass percentage cover at different location, $\chi^2 = 39.892$, $p < 0.01$. This indicates a strong relationship between seagrass percentage cover and sampling location.

3. 6.2 Spatial distribution of seagrass species

Thalassia hemprichii, Cymodocea rotundata, Halodule pinifolia, Halodule uninervis, Enhalus acoroides, Halophila minor and *Halophila ovalis* were found at coastal stations on sandy, muddy, mix of sand and mud, mix of sand and coral rubble substrate at the intertidal zone which was exposed during low tide. *Halodule pinifolia* is most abundant at the study area. Location 4 recorded the highest number of seagrass species while Location 6 has the least number of seagrass species. Figure 3.16 shows the species composition of seagrasses at each location. Both *Halodule uninervis* and *Halodule pinifolia* have largest distribution range in the study area where these species were found at all sampling locations. On contrary, *Halophila minor* was observed only at Location 4. *Thalassia hemprichii* and *Enhalus acoroides* were always found together in Location 1 and Location 5 (Refer Figure 3.17 to 3.20).

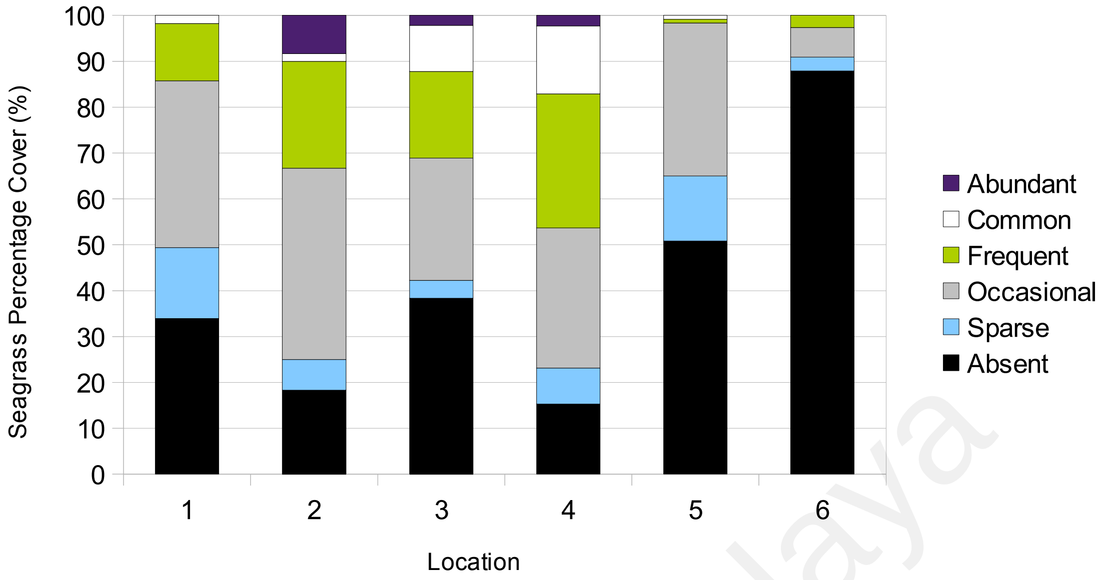

Figure 3.14: Number of stations (in percentage) classified based on B-B Scale at different locations

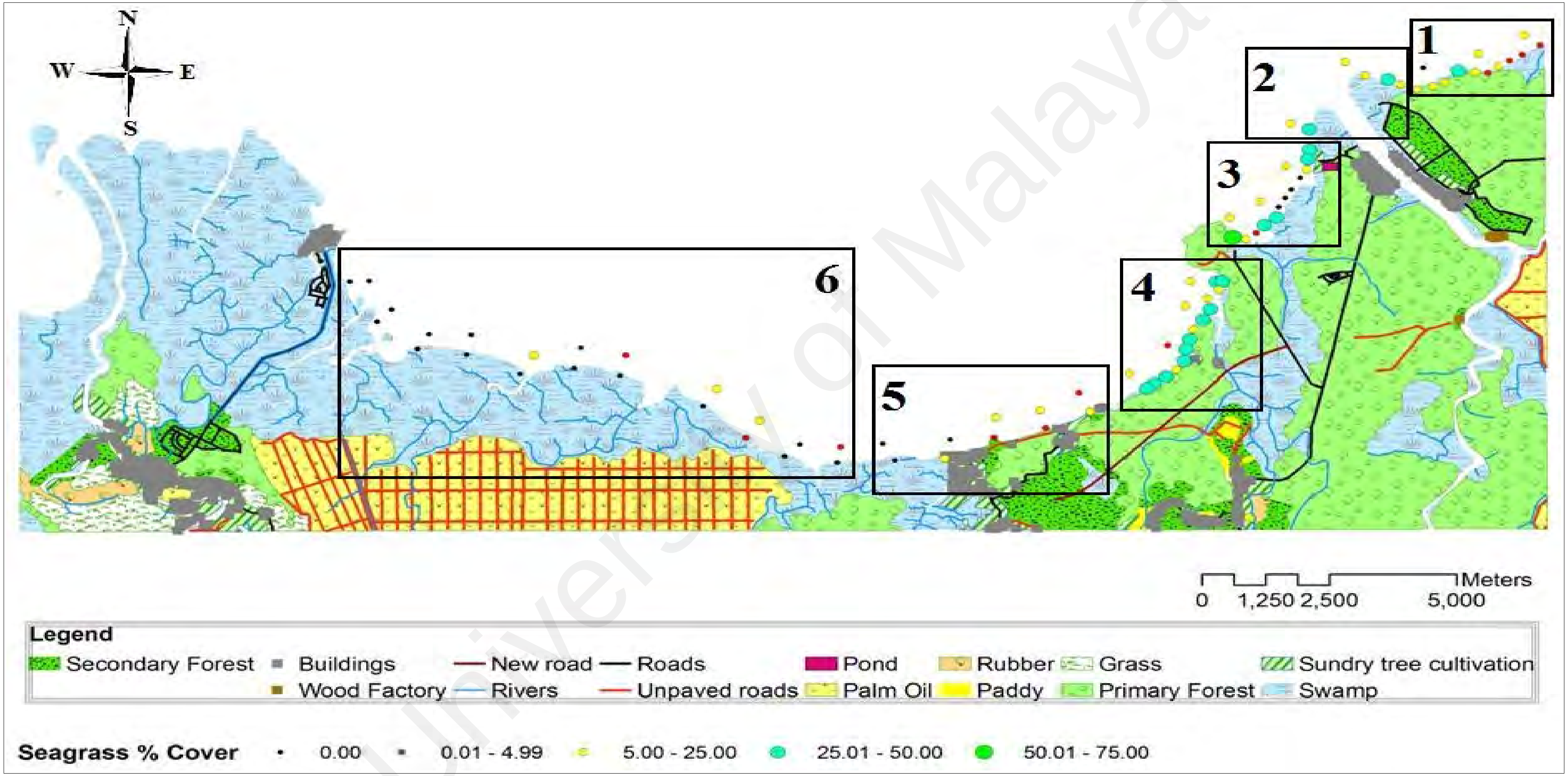

Figure 3.15: Spatial distribution of seagrass abundance

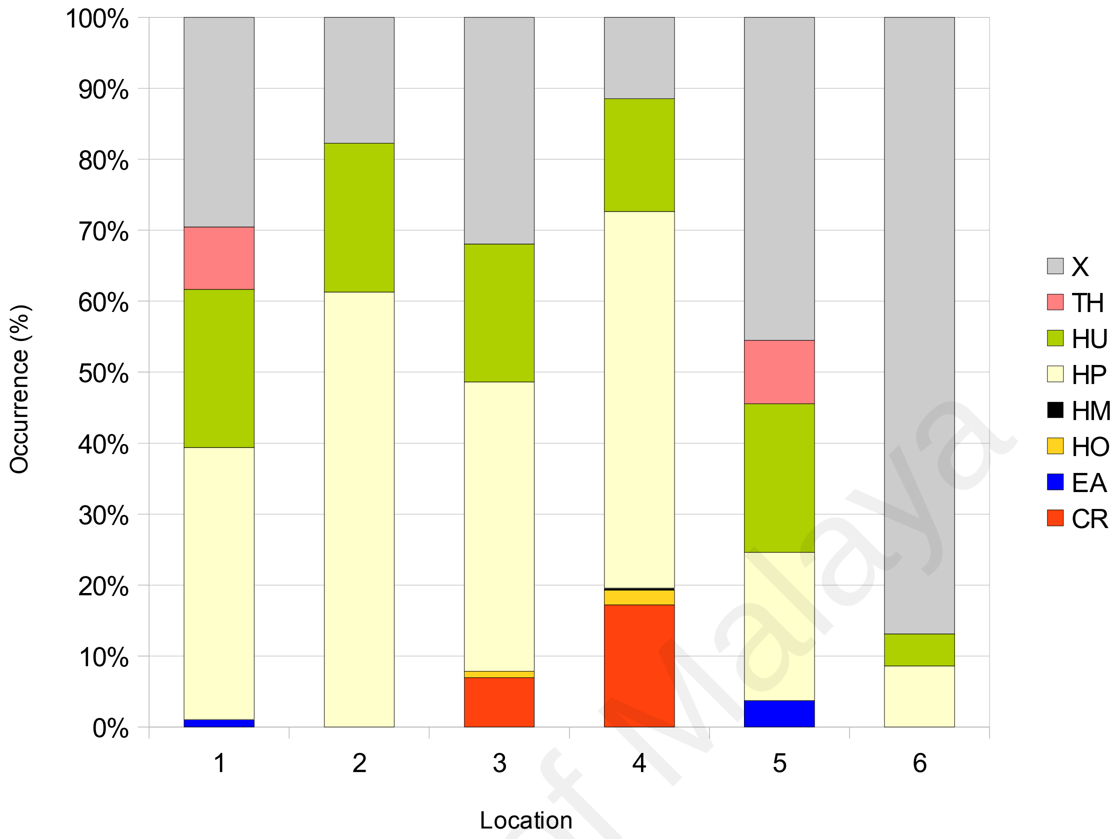

Figure 3.16: Species composition at different locations

(HM – *Halophila minor,* HO – *Halophila ovalis,* TH – *Thalassia hemprichii,* CR – *Cymodocea rotundata,* HU – *Halodule uninervis,* HP – *Halodule pinifolia,* EA – *Enhalus acoroides,* X – No seagrass recorded)

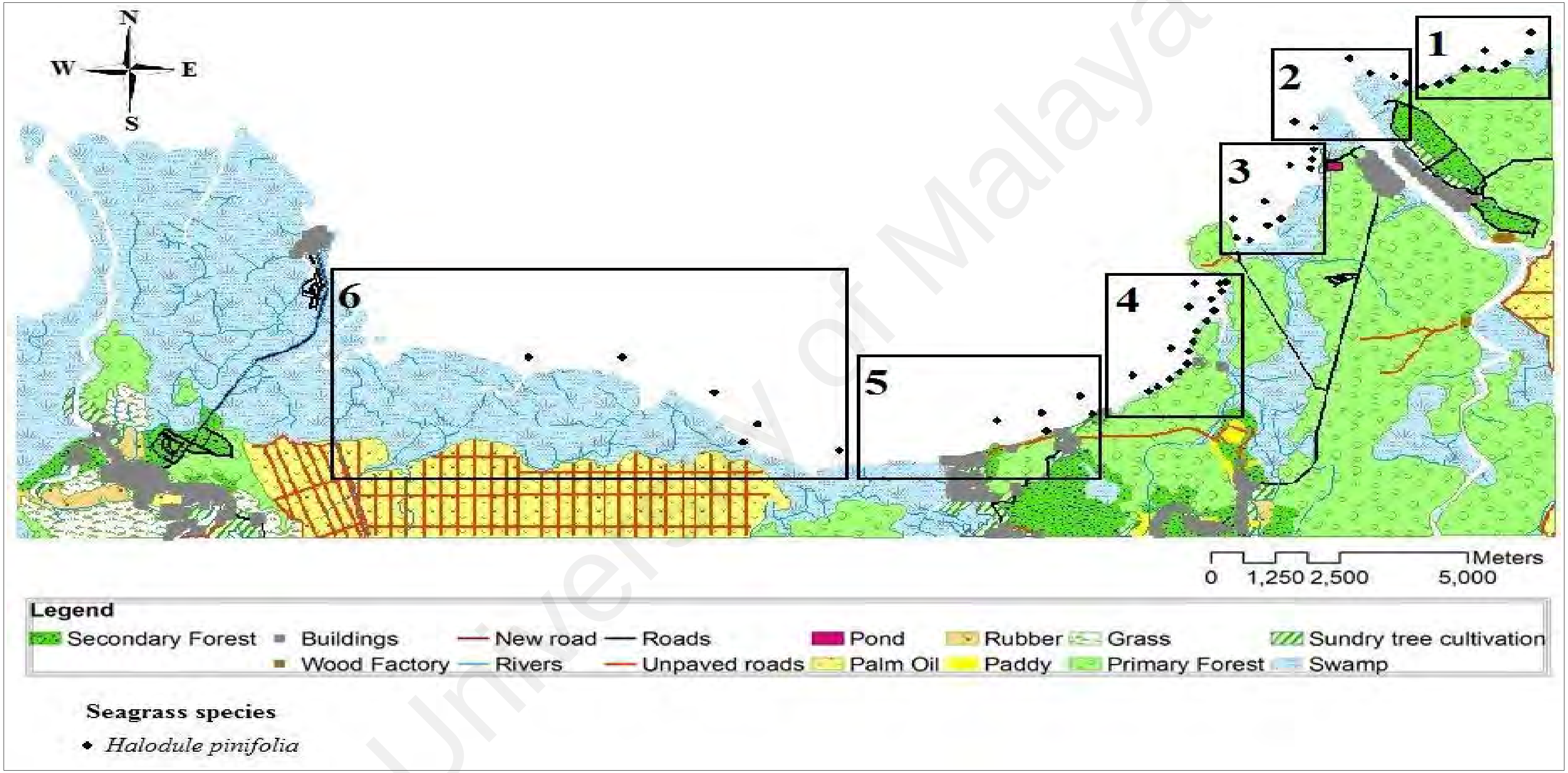

Figure 3.17: Distribution of *Halodule pinifolia*

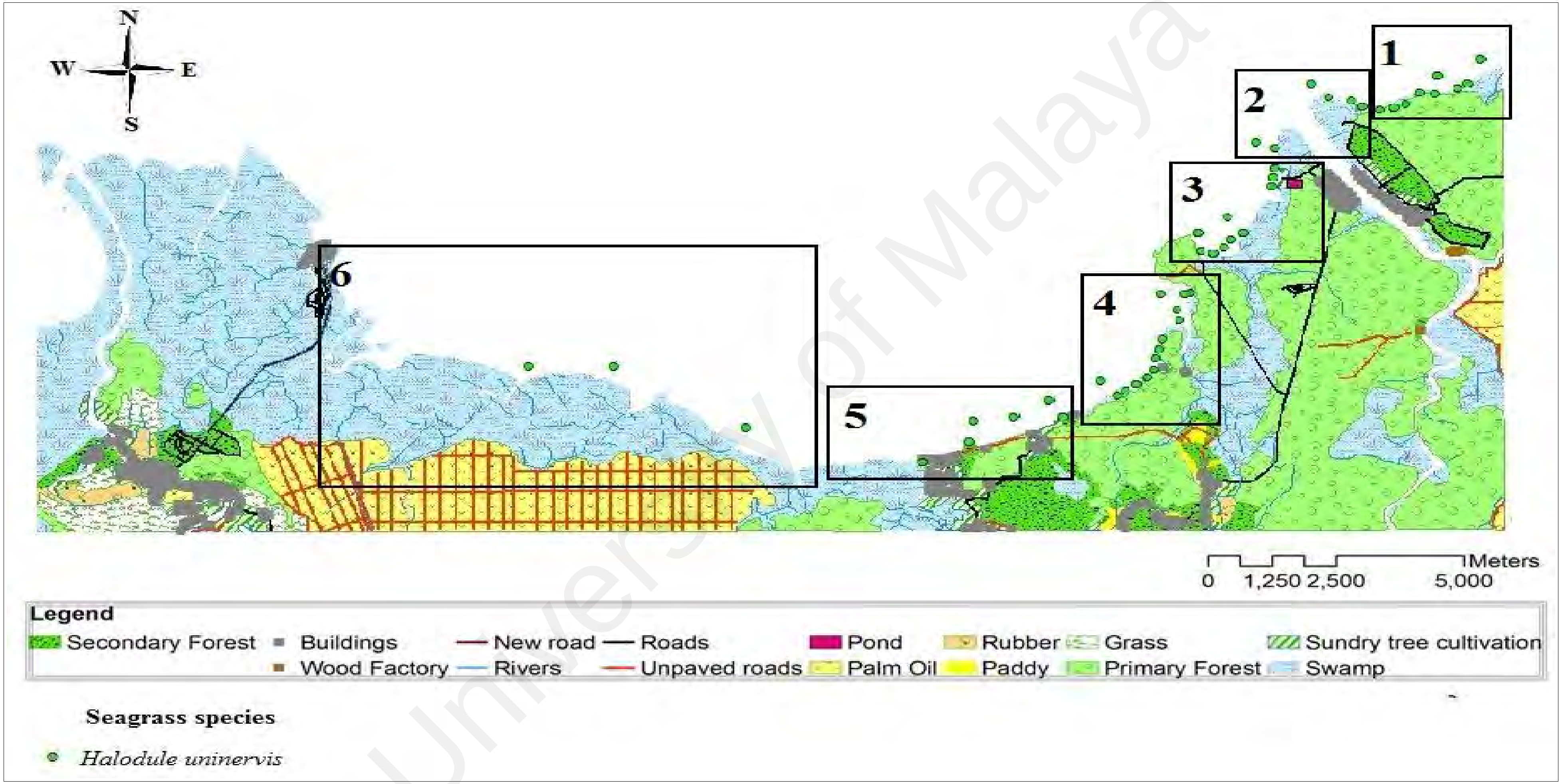

Figure 3.18: Distribution of *Halodule uninervis*

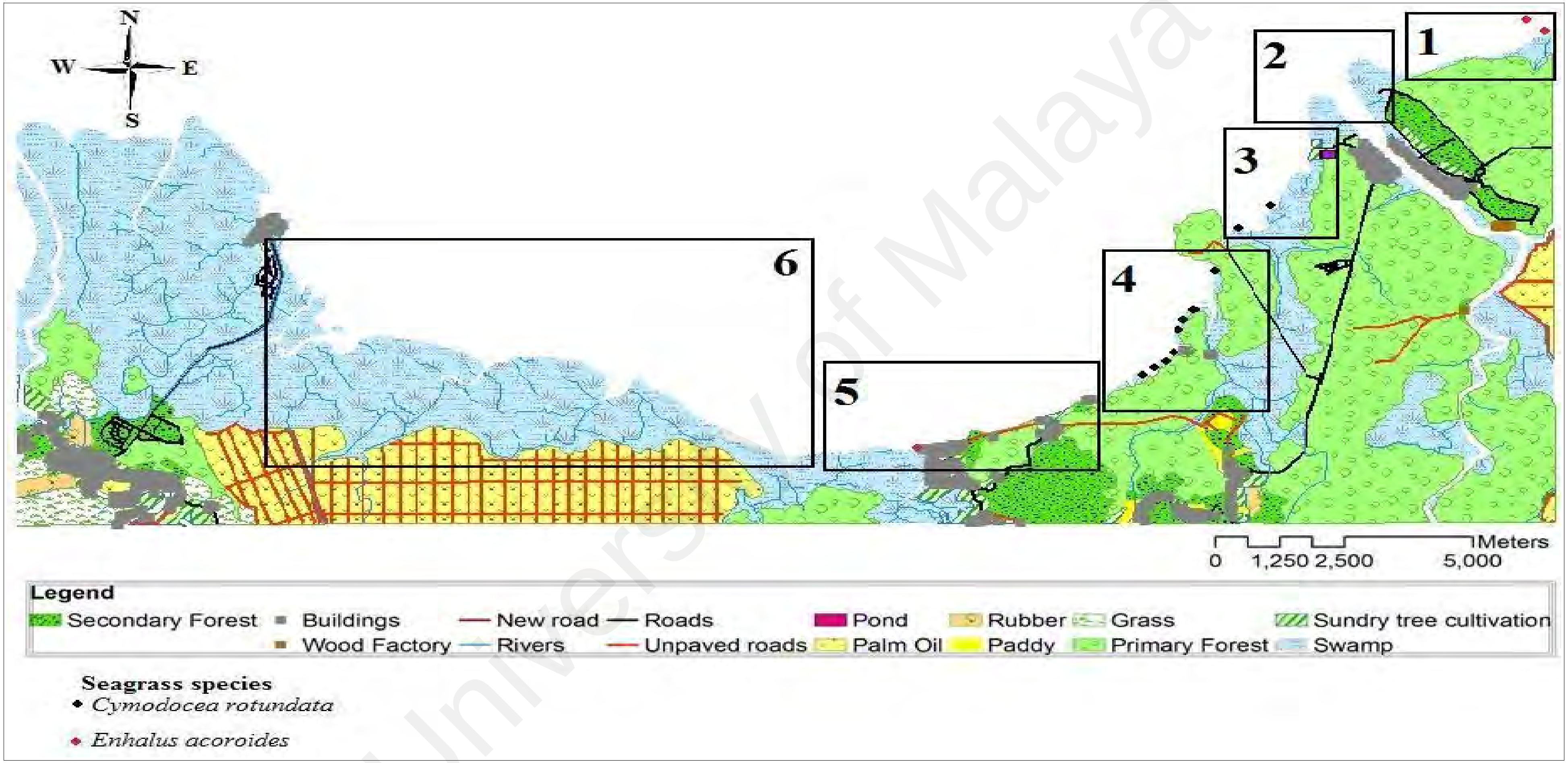

Figure 3.19: Distribution of *Cymodocea rotundata* and *Enhalus acoroides*

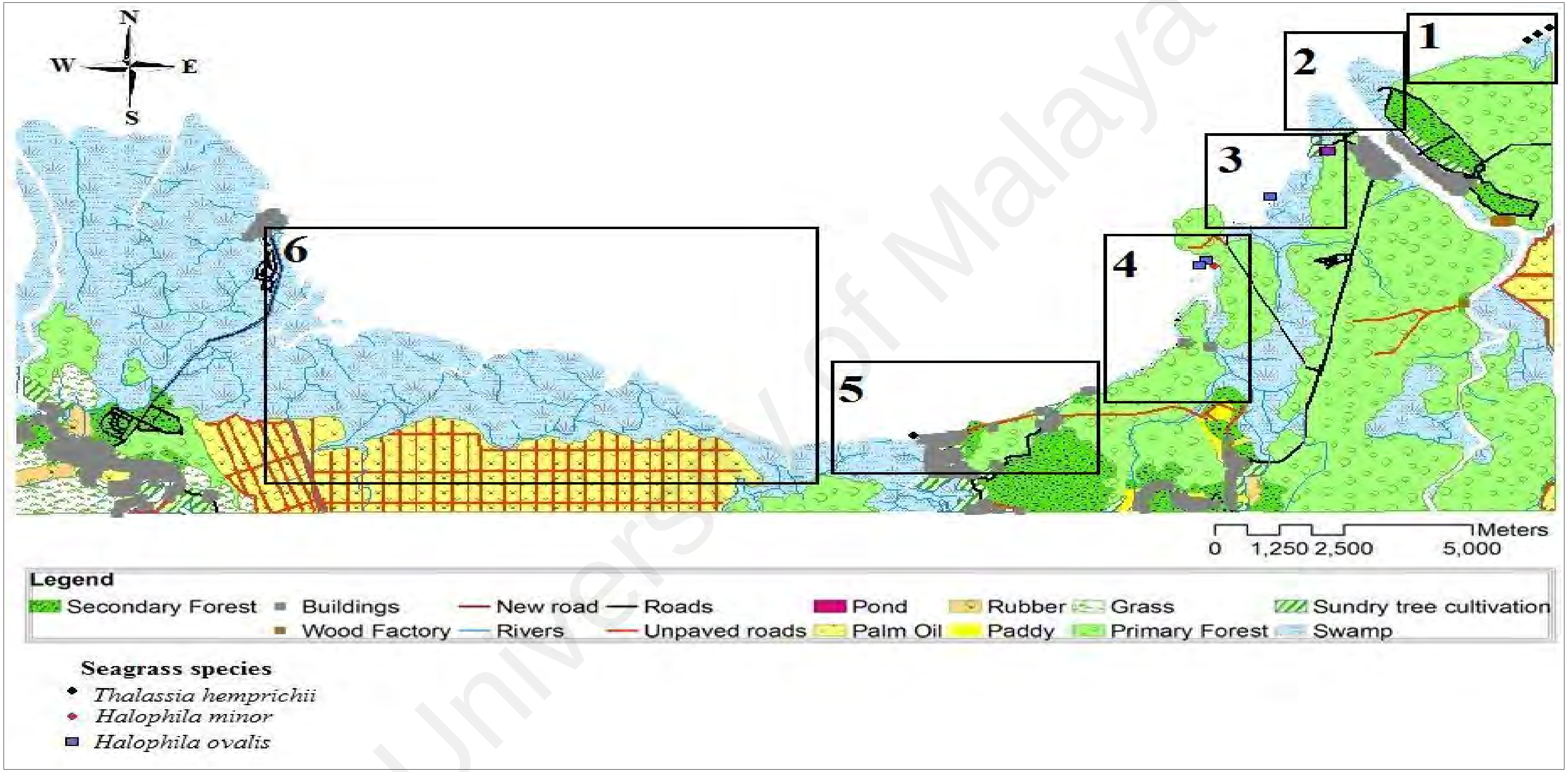

Figure 3.20: Distribution of *Thalassia hemprichii, Halophila minor* and *Halophila ovalis*

3.6.3 Sediment distribution

Sediment distribution at the study site has been observed as sandy, muddy and mix of mud and sand. Most sampling stations were classified as sandy. Meanwhile, least sampling stations were classified as muddy (Figure 3.21). The occurrence of sea gasses were associated with sediment type. Table 3.2 indicated that 81.86% of sampling stations with muddy sediment do not have any seagrass while most of the stations that have seagrass occurred in mixed of muddy and sandy sediment. Kruskal-Wallis test showed significant differences of seagrass species occurrence in different sediment type, $\chi^2 = 222.214$, df = 2, $p < 0.01$. *Halodule pinifolia, Halodule uninervis* and *Cymodocea rotundata* were observed in all types of sediment (mixed of mud and sand, sandy and muddy). However, their occurrence are more abundant on mix of sandy and muddy sediment type. *Thalassia hemprichii* and *Enhalus acoroides* were observed at muddy substrate while *Halophila ovalis* and *Halophila minor* were observed in sandy substrate. Table 3.3 shows the occurrence of different seagrass species on different sediment type. A strong relationship between seagrass percentage cover and different sediment type was observed, $\chi^2 = 245.985$, df = 2, $p < 0.01$. The relationship are presented in Table 4.4.

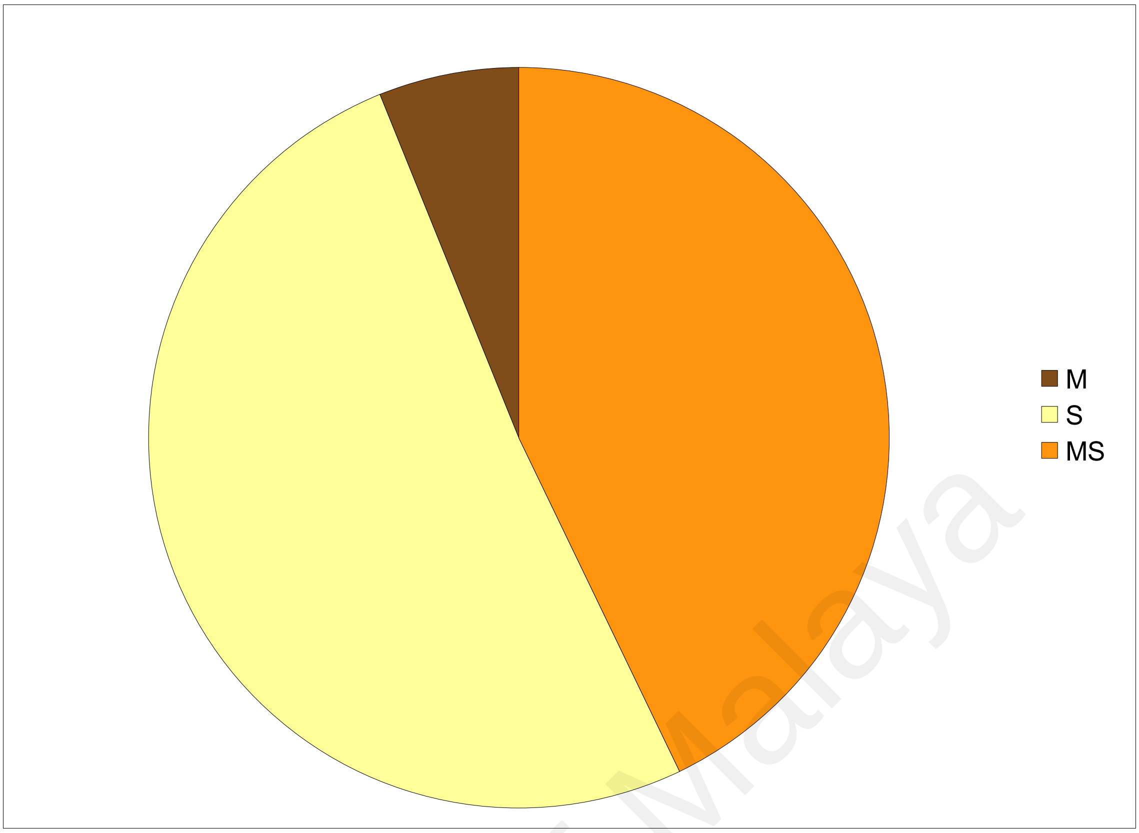

Figure 3.21: Occurrence of different sediment type

Table 3.2: Seagrass species occurrence on different sediment type

Sediment/ Species	CR	EA	HO	HP	HU	TH	HM	X
M	0.98%	0.50%	0.50%	6.86%	1.96%	7.35%	0.00%	81.86%
S	5.35%	0.00%	0.57%	35.37%	15.87%	0.00%	0.19%	42.64%
MS	8.16%	1.36%	0.91%	47.39%	22.22%	3.17%	0.00%	16.78%

CR - *Cymodocea rotundata;* EA – *Enhalus acoroides;* HO – *Halophila ovalis;* HP – *Halodule pinifolia;* HU – *Halodule uninervis;* TH – *Thalassia hemprichii;* HM – *Halophila minor;* X – no seagrass found; M – Muddy, S – Sandy; MS – Mix of mud and sand

Table 3.3: Sediment type, species association and vegetation form of seagrasses found at Lawas.

Species	Sediment type	Associated species	Monospecific or mixed vegetation	Open water or coastal station
Halodule pinifolia	sandy, muddy, mix of sand and mud, mix of sand and coral rubble substrate	Often found mixing with *Halodule uninervis, Halophila ovalis*, *Cymodocea rotundata*, *Enhalus acoroides*, *Halophila beccarii*	Formed dense monospecific bed or mixed vegetation.	Can be found at both open water and coastal station
Halodule uninervis	sandy, mix of sand and mud and muddy	*Halodule pinifolia*, *Cymodocea rotundata*, *Halophila ovalis*	Rarely forming a meadow. Often found in small patches. Has been found near the *Avicennia* sp. pneumatophors	Can be found at both open water and coastal station
Cymodocea rotundata	muddy, mix of sand and mud, sandy substrate and coral rubble substrate	*Halodule uninervis*, *Halophila ovalis*, *Halodule pinifolia*	Formed monospecific and mixed meadows in tidal pools Has been found near the *Avicennia* sp. pneumatophors	Were only found at coastal stations
Thalassia hemprichii	muddy	Rarely associates with other species. However, *Enhalus acoroides* were always found nearby but never mixed	Monospecific	Coastal stations only. Only found near river mouth

Table 3.3, continued

Species	Sediment type	Associated species	Monospecific or mixed vegetation	Open water or coastal station
Enhalus acoroides	muddy, sandy and mix of sand and mud	*Halodule pinifolia*	Monospecific, rarely mixing with other species	Coastal stations only. Can be found near river mouth
Halophila minor	sandy	Patches were found next to *Halodule pinifolia* meadow	Monospecific patch	Coastal station

Table 3.4: Seagrass abundance on different sediment type

Sediment / Seagrass abundance	Absent	Sparse	Occasional	Frequent	Common	Abundant
M	81.86%	2.45%	11.76%	1.47%	0.00%	1.47%
S	42.45%	9.18%	27.15%	14.15%	5.74%	1.34%
MS	16.78%	8.16%	32.20%	26.3	13.61%	2.95%

M – Muddy; S – Sandy; MS – Mix of mud and sand

3.6.4 Water parameter measurements at different sampling locations

A number of sampling stations recorded values of pH, turbidity, DO and water temperature values exceeding or less than the MMWQC Class E and SW II standards (Figure 3.22 to 3.26).

Different sampling location recorded various water parameter measurements. For example, highest temperature and turbidity were measured at Location 1. Highest pH, DO, were recorded at Location 2 while highest salinity value was recorded at Location 6. Figure 3.26 to 3.40 show differences in water parameter measurements at different locations.

Kruskal-Wallis test showed significant differences between all water parameter measurements at different sampling locations (pH: $\chi^2 = 17.461$, df = 5, $p < 0.05$; temperature: $\chi^2 = 40.829$, df = 5, $p < 0.01$, salinity: $\chi^2 = 35.935$, df = 5, $p < 0.01$; turbidity: $\chi^2 = 39.236$, df = 5, $p < 0.01$ and dissolved oxygen: $\chi^2 = 29.656$, df = 5, $p < 0.01$). This indicate a strong relationship between water parameter and sampling locations.

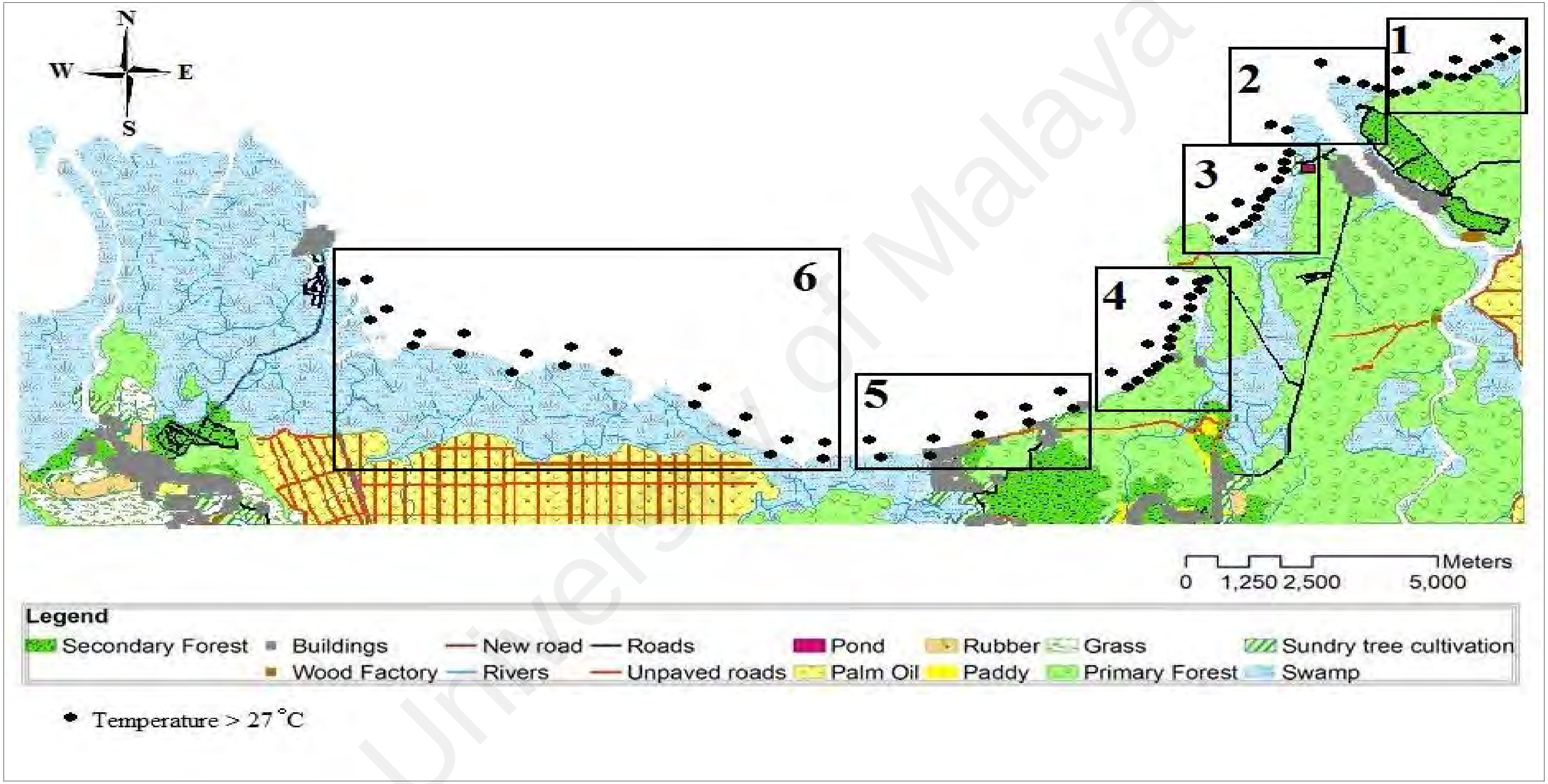

Figure 3.22: Distribution of sampling location with water temperature measurements which exceed the normal standard of MMWQC (> 27°C)

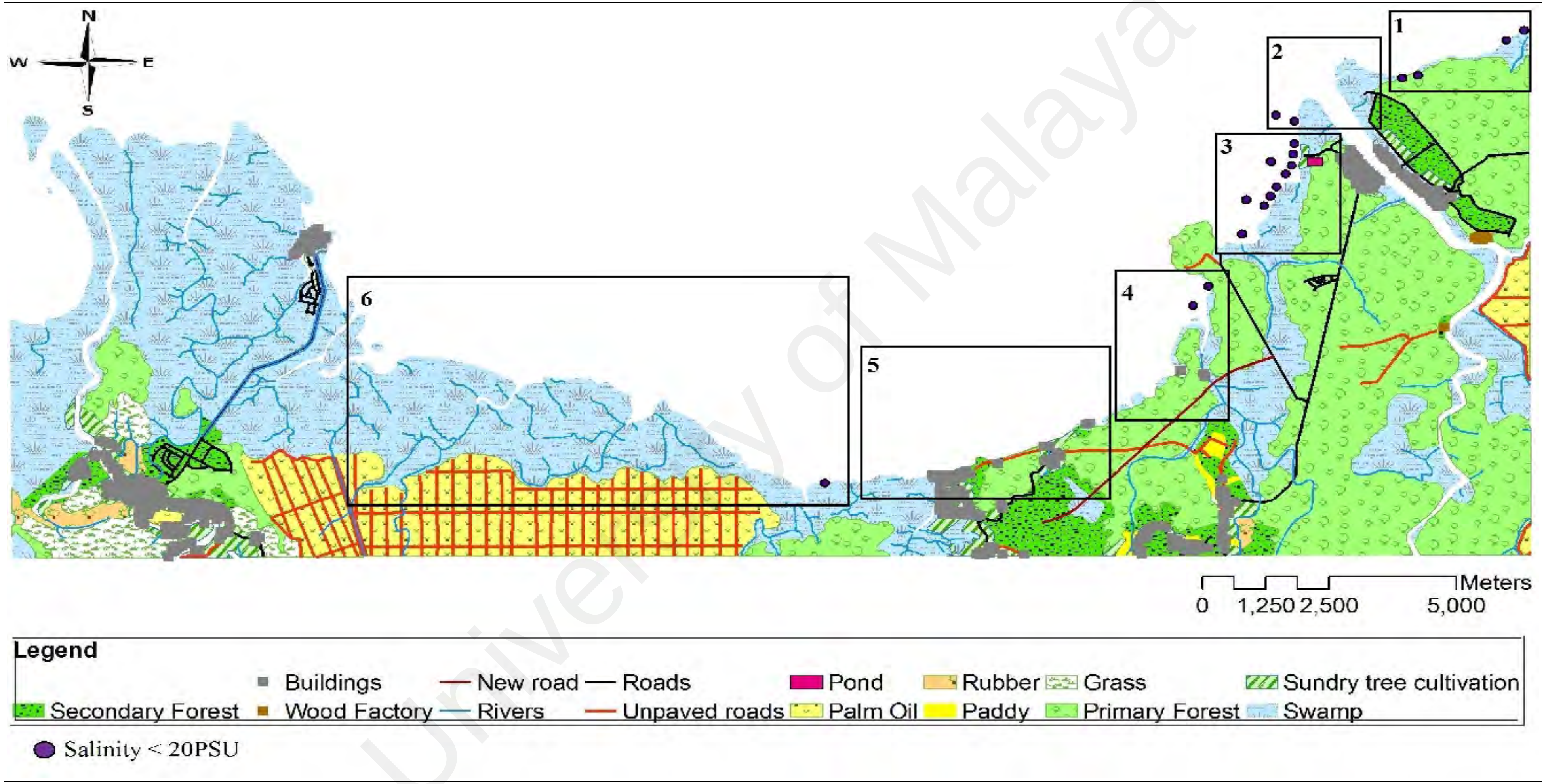

Figure 3.23: Distribution of sampling location with salinity measurements lower than 20 PSU.

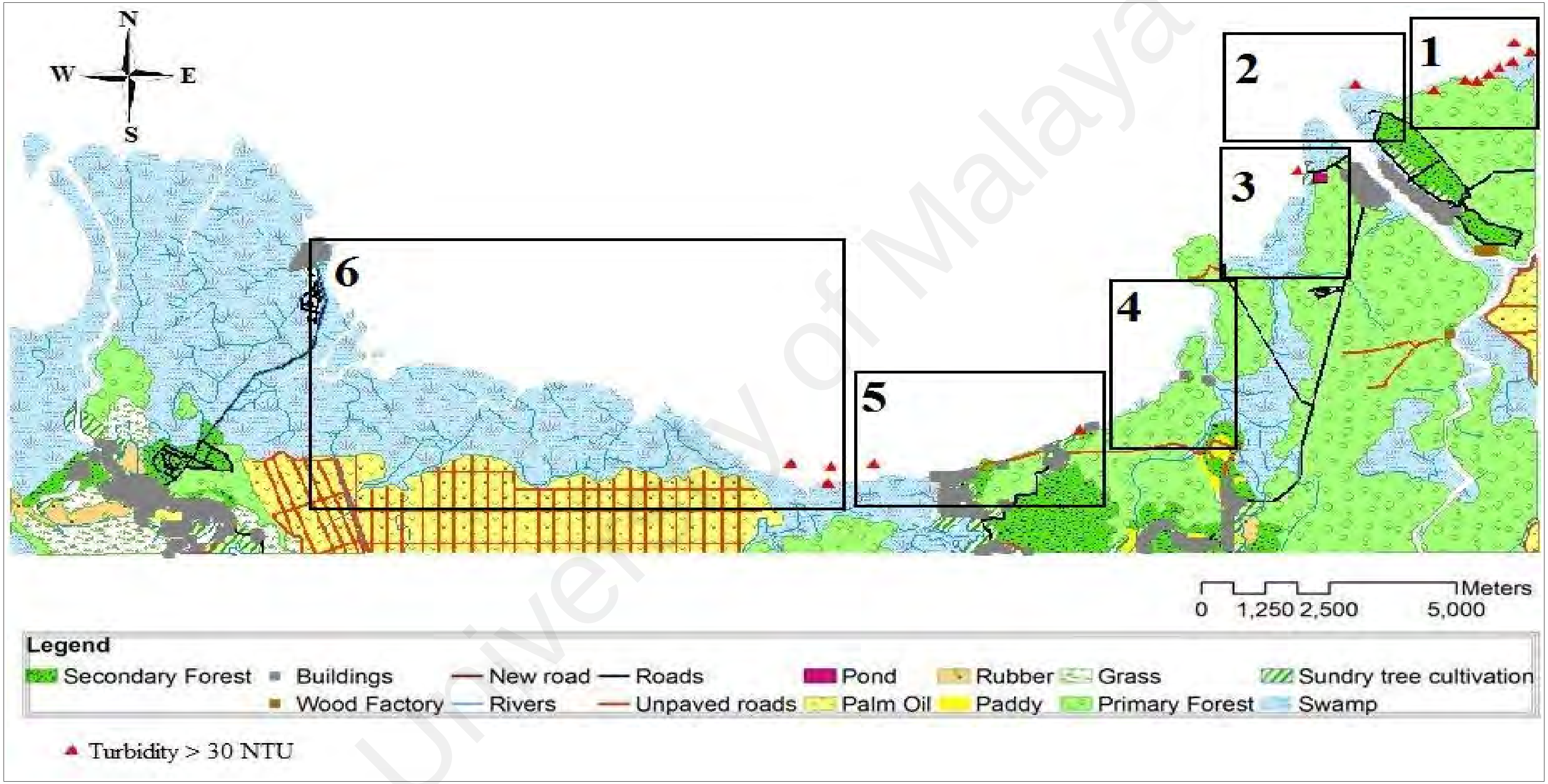

Figure 3.24: Distribution of sampling location with water turbidity measurements which exceed the normal standard of SW-II (> 30 NTU)

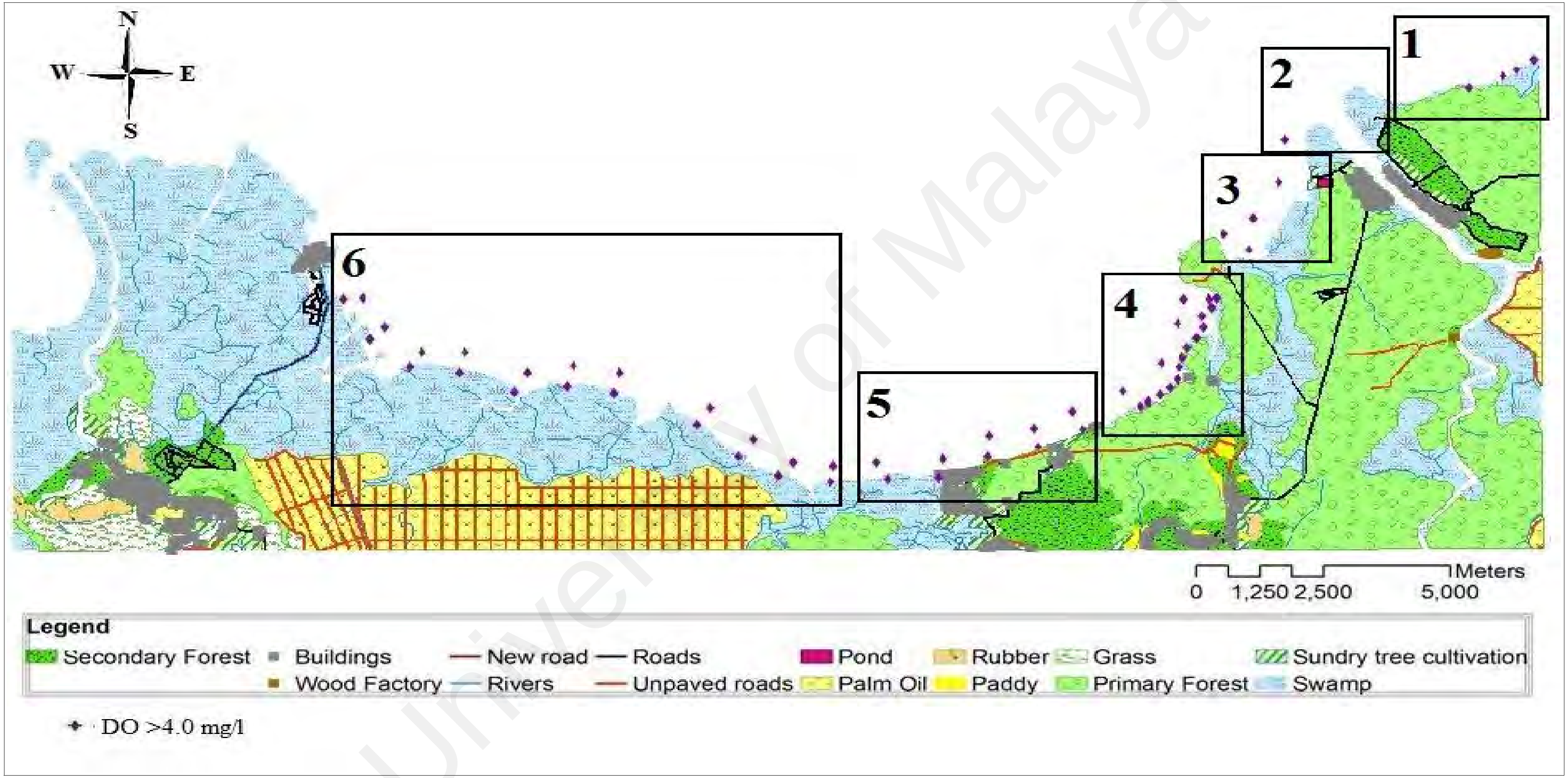

Figure 3.25: Distribution of sampling location with DO values which exceed the normal standard of SW-II and MMWQC (< 4.0 mg/l)

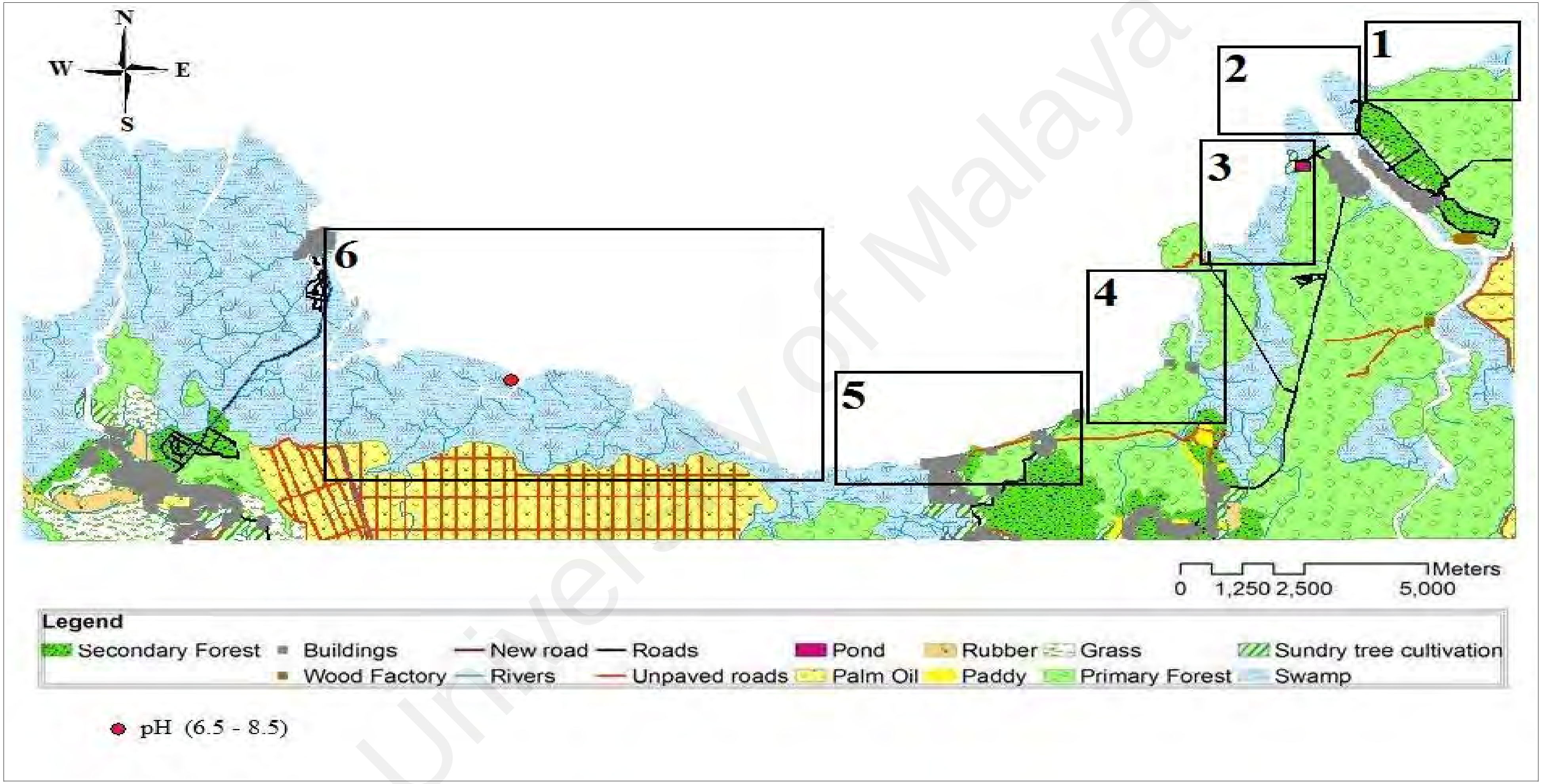

Figure 3.26: Distribution of sampling location with pH values which exceed the normal standard of SW-II (6.5-8.5)

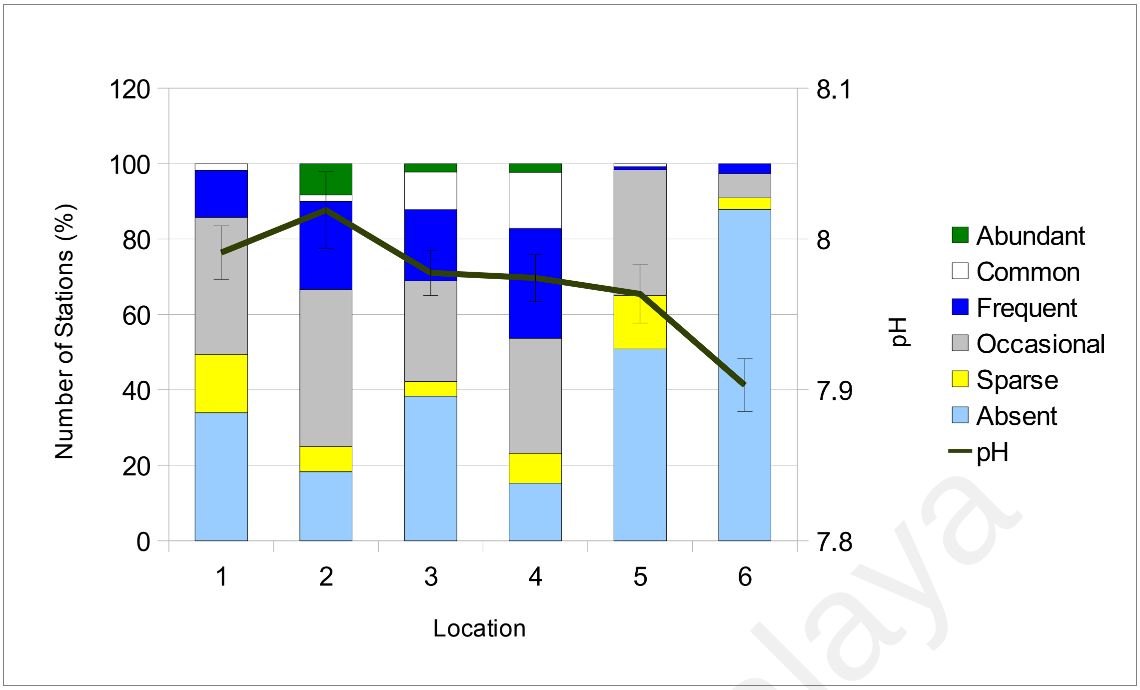

Figure 3.27: Differences of average pH values recorded at different location

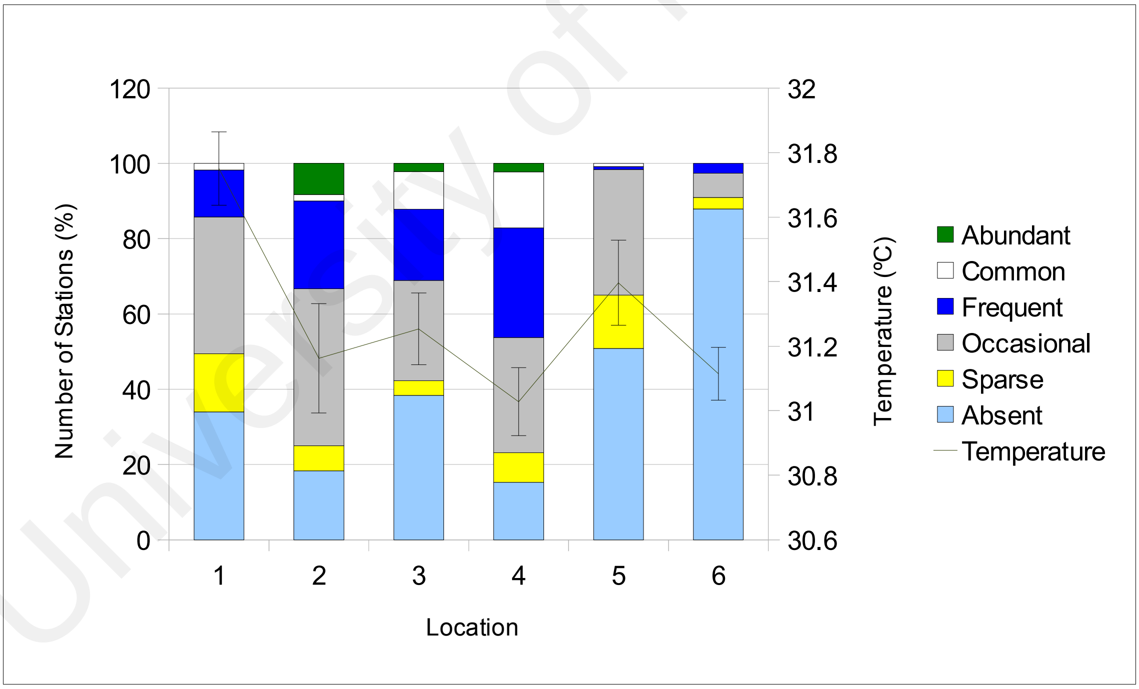

Figure 3.28: Differences of average water temperature values recorded at different location

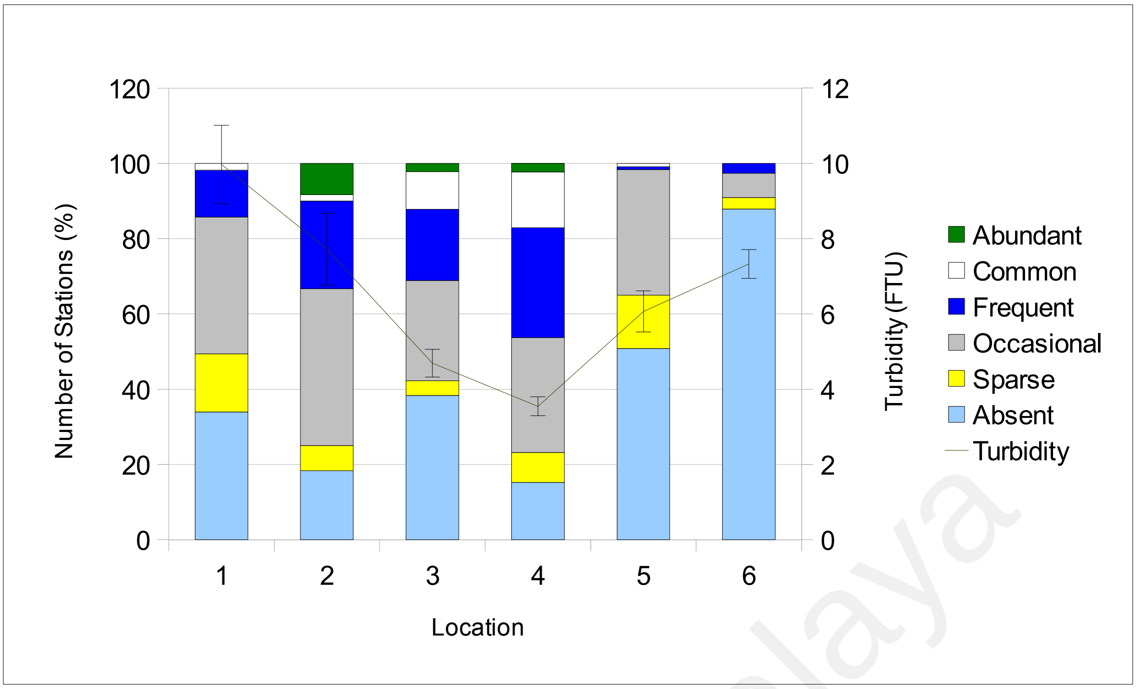

Figure 3.29: Differences of average turbidity values recorded at different location

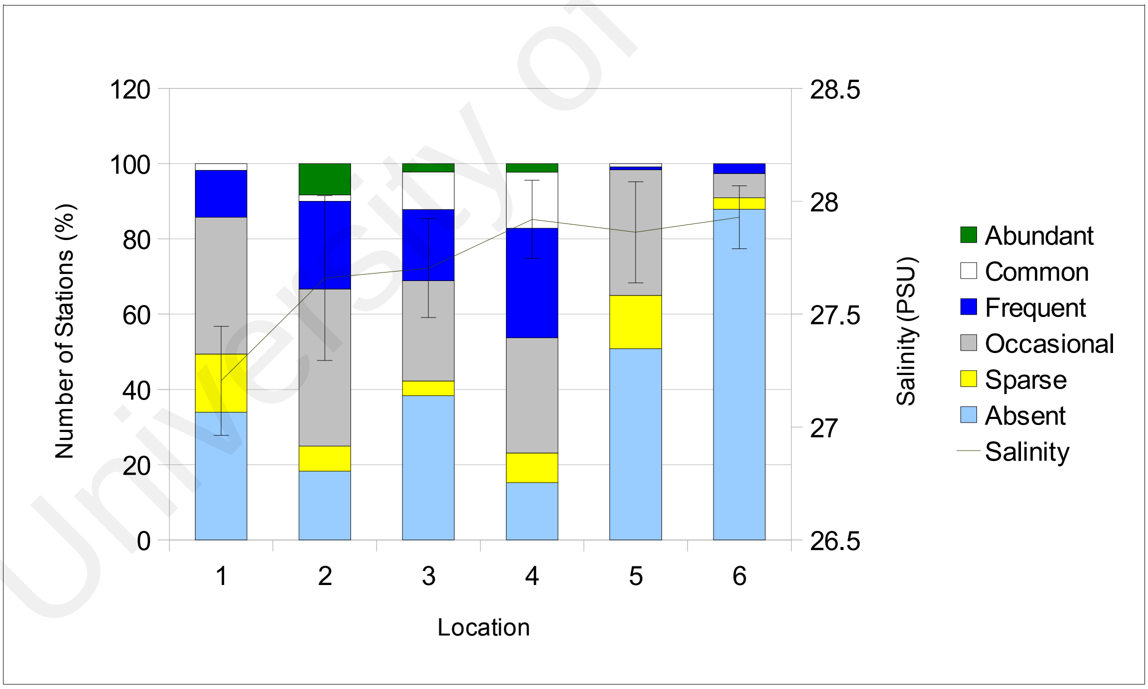

Figure 3.30: Differences of average salinity values recorded at different location

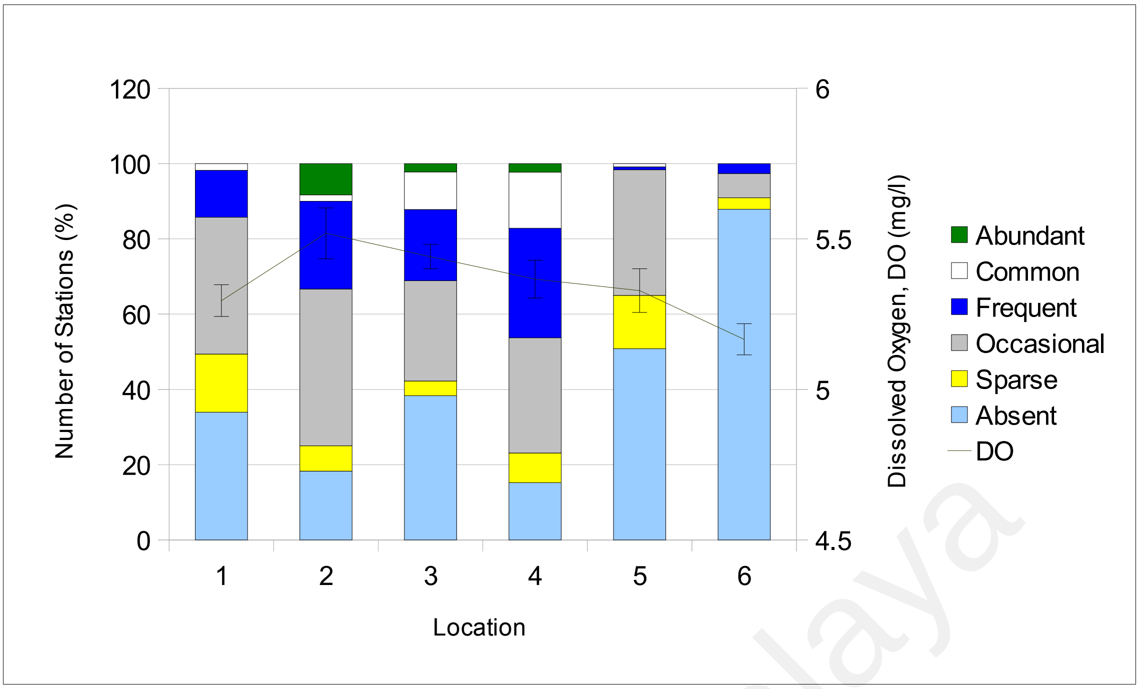

Figure 3.31: Differences of average dissolved oxygen (DO) values recorded at different location

CHAPTER FOUR

DISCUSSION

4.1 Seagrass abundance

Seven seagrass species (*Thalassia hemprichii, Enhalus acoroides, Halophila ovalis, Halophila minor, Halodule uninervis, Halodule pinifolia* and *Cymodocea rotundata*) were recorded in the study area. These species were also recorded in previous study in Lawas by Zakaria & Bujang (2004), Bali (2005), Bali (*pers comm.,* 2010). It is worth noting that another species, *Halophila beccarii,* was also recorded in this study but was not included in the analysis because it was found outside established sampling station. The occurrence of *Halophila beccarii* at the study site is important because the species is listed as Vulnerable according to the IUCN redlist (Short et al., 2012). The population of this species is declining globally due to coastal habitat conversion for aquacultural practices aside from other major threats such as storm, mining, dredging and pollution. Therefore, the occurrence of this species at the study area should serve as a conservation importance to coastal managers for protecting the coastal habitats of Lawas.

4.2 Temporal distribution of seagrasses

The current study showed significant monthly fluctuations of seagrass percentage cover. Mean seagrass percentage cover declined in September and November 2009. Meanwhile, seagrass population recovery were observed in February 2010 with the increased of mean seagrass percentage cover. The decline of seagrass population in this study is similar to many findings in all parts of the world. For example, de Iongh et al., (1995) recorded above ground biomass of *Halodule uninervis* was declined in Indonesia. Seagrass percentage cover and biomass of *Halodule uninervis, Thalassia hemprichii* and *Halophila ovalis* were declined in Pulau Gaya, Sabah (Freeman et al., 2008). Similar findings were recorded in Townsville, Australia where percentage cover of *Halodule uninervis, Halodule* sp. and *Halophila ovalis* were also observed to be declined (Lanyon & Marsh, 1995). In this study, the decline of mean seagrass percentage cover was observed in September 2009 possibly corresponding to the daytime low tide which started August 2009. Discoloration (i.e. leaves turning yellow and reddening) and drying of seagrass leaves are typical respond of intertidal seagrasses when exposed to heat stress or direct sunlight (Erftemeijer & Herman, 1994; Novak & Short, 2010). In November 2009, further decline of seagrass percentage cover were observed to coincide with the northeast monsoon season. The northeast monsoon season in Borneo is characterized by heavy rainfall coupled with thunderstorm and rough sea conditions (heavy waves upon reaching shallow water). The northeast monsoon normally occurring from November to February (Malaysian Meteorological Department, 2012). Heavy rain increases the volume of freshwater runoff from the rivers which causes increased turbidity and sedimentation in coastal waters (Latrubesse et al., 2005; Saleh et al., 2007). Previous observations by Preen et al. (1995), Campbell & McKenzie (2004) and Steward et al. (2006) have recorded similar weather conditions which also causing decline on seagrass percentage cover. Seagrass population was devastated by these natural events due to the uprooting of the plants, low light condition due to elevated turbidity and seagrass burial (Preen et al., 1995).

Seagrasses have the capability to recolonize disturbed meadow by the extension of its rhizomes and the presence of seagrass seed bank (Rollon et al., 2003).Seagrass population in Lawas were observed to recover immediately after the rainy season in February 2010. This finding is not surprising as seagrass in many parts of the world had recovered/recolonized after extreme weather conditions and disturbances (Preen et al., 1995; Ooi et al., 2011; Campbell & McKenzie, 2004; Carlson et al., 2010). However, the result of this study showed increase in the seagrass percentage cover during the 2009/2010 El-Nino phenomenon. The finding of this study is contradictory with Campbell et al. (2002), Connolly (2009) and Tomasko et al. (2005). Seagrass percentage cover found to be decreased in subtropical area such as northern Australia during the El-Nino phenomenon (Campbell et al., 2002; Connolly, 2009. Results from El-Nino that occurred between 1997–98 had caused more than 2,000 acres of seagrass in the southwest part of Florida (Tomasko et al., 2005). There are few possible answers to explain the recovery of seagrass in observed in this study. Additional nutrient from the land may contribute to the recovery of seagrass percentage cover (Ooi et al., 2011). Nutrients such as phosphate and nitrate have been observed to increase growth and cover of *Thalassia hemprichii* (Miller & Sluka, 1999) and *Halodule uninervis* (Udy & Dennison, 1997). The recovery of seagrass percentage cover took place during the drought season which is immediately after the rainy season ends. Therefore, improved water clarity could be the driver on seagrass population recovery in Lawas. As the Southern Hemisphere experience summer, dry winds from the South Pacific limits humidity in Borneo and causes few parts of Borneo including Lawas to experience several weeks of drought. Less rain limits the amount of freshwater input to the coastal area resulting in improved water clarity. In addition to this, El-Nino phenomenon in Malaysia is characterized by high air and seawater temperature which affects directly in reducing cloud cover and limits total rainfall (Malaysian Meteorology Department, 2013). During this period, it could be possible that the amount of available light is sufficient for seagrass growth which leads to population recovery. Seagrass recovery in Lawas persisted until the end of the sampling period in May 2010 may be contributed by the nature of the fast growing *Halodule pinifolia* (Nakanishi et al., 2006; Waycott et al., 2007) which was abundant at the study area.

The current study, which indicated that *Halodule pinifolia* and *Halodule uninervis* showed significant changes over time while no significant changes were recorded by *Cymodocea rotundata* population, agreed with findings of Lanyon & Marsh (1995). *Halodule pinifolia* and *Halodule uninervis* have delicate root system while the root system for *Cymodocea rotundata* is more robust (den Hartog, 1970; Phang, 2000; Gumpil & de Silva, 2007). The delicate root system is prone to seagrass uprooting and burial during unfavourable weather condition while the robust root system able to withstand extreme condition. This observation was proved accurate by Cruz-Palacios & Tussenbroek (2005). Although not studied in details, dugong feeding trail were observed on *Halodule uninervis* and *Halodule pinifolia* meadow. Dugong feeding strategy is to graze the whole plant which include leaves, root and rhizome (Aragones et al., 2006). Thus, dugong feeding behaviour will obviously affect the percentage cover of seagrasses. Meanwhile, there were no dugong feeding trails on *Cymodocea rotundata* but clipping marks were evident on the leaves. This feeding strategy was adopted by marine turtles (Aragones et al., 2006). Although evident turtle clipping marks on *Cymodocea rotundata* leaves, it do not influence changes of seagrass percentage cover.

4.3 Correlation between seagrass percentage cover and basic water parameter

Turbidity has always been found to affect seagrass population (Freeman et al., 2008). This study indicates that the increase in seagrass percentage cover is corresponding to the decrease in turbidity measurements. This finding agree with Longstaff & Dennison (1999) which observed turbidity had caused *Halophila ovalis* and *Halodule pinifolia* mortality in Australia. Bach et al. (1998) recorded decline in shoot density of seagrasses with increase of suspended material and light attenuation at Cape Bolinao, Philippines. Increasing turbidity also affected productivity and abundance of *Posidonia oceanica* in Spain (Ruiz & Romero, 2003). There are several possibilities which can explain mean seagrass percentage cover declined with elevated turbidity. Increase in turbidity was caused by the increase of suspended solids especially from the inland due to deforestation, sedimentation and erosion processes (Saleh et al., 2007; Freeman et al., 2008). This condition limit light from reaching the leaves for photosynthetic processes which will decrease seagrass productivity (Ruiz & Romero, 2003). In addition, the decline of seagrass population during increased turbidity event can also be explained by the shading of old shoots (resulting in reduced percentage cover) and formation of new shoots which will improve better light harvesting for photosynthesis (Bach et al., 1998). Other than that, the increase of mean seagrass percentage cover was observed when turbidity decreased due to ability of seagrass leaves to modify water movement (Madsen et al., 2001). Reduced water movement had resulted in enhanced deposition of suspended particles (Marba et al., 2006). Decreased in suspended particles resulted in improved water clarity which was preferred by the seagrasses for light harvesting.

Seagrass metabolism and its maintenance of positive carbon balance always affected by increasing water temperature (Short & Neckles, 1999). The current study revealed high average water temperatures. Another study conducted in Brunei Bay (which was located north-east of the study area) had recorded lower average of water temperature (Saleh et al., 2007). The differences inbasic the value of the temperature measured were contributed by the sampling stations' locality. Study indicated that variation in temperature value was contributed by the locality of the sampling stations. In current study, water temperature was measured only at shallow areas (depth between 0.4 m to 3.0 m during high tide) where the sampling stations were exposed to higher irradiance which resulted in higher water temperature. Whereas in Saleh et al. (2007), the sampling stations were extended to the whole Brunei Bay. Moreover, the sampling period coincides with negatives values of Southern Oscillation Index (SOI) recorded for the year 2009/2010 (Australian Government Bureau of Meteorology, 2013). Based on the data observed from October 2009 to March 2010, El-Nino was observed. El-Nino phenomenon in Malaysia is characterized by high air and seawater temperature which affects directly in reducing cloud cover and limits total rainfall (Malaysian Meteorology Department, 2013). Although high water temperature were observed during the study period, this study revealed that seagrass percentage cover did not correlate significantly with water temperature. The result differs from Lanyon & Marsh (1995), which showed correlation between water temperature and seagrass standing crop in tropical waters. The contrasting result is possibly due to different sampling method used. Lanyon & Marsh (1995) studied seagrasses at areas with maximum depth of 15 m while the current study observed seagrasses along the coastline with maximum depths of only 3 m. Sampling stations which are located at shallow water area will be exposed to sunlight irradiance which will increase the water temperature. The effect of sunlight irradiance will be less at deeper waters. This study also indicated that variation in temperature value was contributed by the locality of the sampling stations. In current study, seagrass distribution was affected by variation in temperature. This is because tropical seagrass species such as *Thalassia hemprichii, Halophila ovalis* and *Cymodocea rotundata* are able to tolerate high temperature of up to 40ºC (Campbell et al., 2006).

Salinity has been observed to affect seagrass distribution (Lirman & Cropper, 2003; Bridges & McMillan, 1986). Interestingly, no correlation was observed between seagrass percentage cover and salinity because seagrasses such as *Halodule pinifolia* and *Halophila ovalis,* are estuarine species. Seagrasses in estuaries are able to adapt to changes in salinity due to freshwater run-off from nearby rivers (Touchette, 2007). Other species that were found in this study, such as *Cymodocea rotundata, Thalassia* *hemprichii* and *Enhalus acoroides* have also been observed to tolerate estuarine conditions (Bridges & McMillan, 1986). Although the relationship is not significant, it is worth noting that during dry season, salinity measurement is higher than during rainy season and the value of mean seagrass percentage cover started to increase during this time. This finding indicated that the possibility of these estuarine seagrasses prefers higher salinity for optimum seagrass growth and production. Other studies had indicated this preference. For instance, Fernandez-Torquemada & Sanchez-Lizaso (2005) had observed that the leaf of *Cymodocea rotundata* and *Zostera noltii* was growing with the increase in salinity value. Increase in leaf growth will ultimately lead to increasing seagrass percentage cover. However, Fernandez-Torquemada & Sanchez-Lizaso (2005) studied seagrass species in the Mediterranean Seas, where the environmental condition is different from tropical waters.

pH influences seagrass photosynthetic rate (Invers et al., 1997) by affecting the photosynthetic pathways (Beer et al., 2006). pH was observed to have no significant correlation with seagrass percentage cover in this study. This is in contrary to Adajar *et al.* (2009) which discovered high correlation between seagrass population and pH in The Philippines. The percentage cover of *Syringodium isoetifolium* also correlates significantly with pH in India (Balaji, 2009). However, Daby (2003) did not observe any correlation between *Halodule uninervis* and *Syringodium isoetifolium* biomass and pH in Mauritius due to minimal pH variation. Although fluctuations of pH is apparent (ranging from 7.06 to 8.43), no correlation between seagrass percentage cover and pH was detected. pH value is heavily influenced by other environmental factors such as river discharge (Latrubesse et al., 2005; Saleh et al., 2007; Steward et al., 2006; Seddon et al., 2000). The river discharges of Brunei Bay River includes acidic humus and low contents of carbonate and bicarbonate ions that lowers the pH in the area (Saleh et al., 2007). Due to this, the value of the pH will not remain constant to facilitate high photosynthesis activity for the seagrass. Although no correlation with seagrass percentage cover was observed in this study, pH has been observed to influence the photosynthetic performance and abundance of *Cymodocea nodosa* and *Posidonia oceanica* (Invers et al., 1997; Hall-Spencer et al., 2008).

This study revealed that DO do not significantly correlate with seagrass percentage cover. This is different from Abu Hena et al. (2001a, b) which discovered that *Cymodocea serrulata* and *Thalassia hemprichii* produced 0.189 ± 0.017 – 0.214 ± 0.014 mg O_2/hr/g fresh weight and 0.429 ± 0.086 – 0.289 ± 0.034 mg O_2/hr/g fresh weight respectively. In contrast to Abu Hena et al. (2001a, b) the value of DO measured in this study was recorded in the field and not in the laboratory. When DO was measured in the field, it is exposed to many uncontrolled external factors. For example, respiration process of the seagrasses and its community such as fishes, crustaceans and zooplanktons will affect the concentration of measured DO. Moreover, seagrasses were not the only primary producer in the area. Mangrove and phytoplankton can contribute to the concentration of DO. DO was also seen to significantly correlated with pH and temperature. Similar findings was observed by Daby (2003). This indicates that, although pH and temperature do not significantly correlate with group seagrass percentage cover, they were seen to influence the productivity of the ecosystem.

4.4 Spatial distribution of seagrass abundance

The current study shows significant changes of seagrass abundance at different sampling location. This finding is similar to Prathep (2003) which discovered that spatial changes of *Cymodocea rotundata* percentage cover was affected by the degree of exposure to the waves. Fourqurean et al. (2001) also observed spatial changes of *Thalassia testudinum* at different sampling site are influenced by intense intraspecific competition between seagrass ecosystem. The difference of seagrass abundance that was observed in current study was contributed by the shape of the coastline, i.e. long cape and hill. Seagrasses were mostly abundant at location 3 and 4. Location 3 was characterized by a long cape (Tanjung Lawas) while location 4 was characterized by a hill (Bukit Sari), which shelters the shoreline from currents and heavy waves. This condition is preferred by seagrasses as seen in few other locations in Malaysia such as Pulau Tinggi (Ooi et al., 2011), Sg. Salut and Sepanggar Bay (Ismail, 1993). At location 1, seagrasses were sparsely recorded. The location of sampling stations in this area makes them vulnerable to riverine sediment plume of Sg. Padas. As a result, muddy sediment smothered the coastal line of this area and became the characteristic of this area and affected seagrasses percentage cover (Freeman et al., 2008) and distribution (Terrados et al. 1998). Other sampling locations recorded rare occurrence of seagrasses as sampling stations were exposed to the waves and currents from the South China Sea. The exposure had caused smaller seagrass species to be uprooted (Cruz-Palacios & Tussenbroek, 2005) or buried (Preen et al., 1995).

4.5 Spatial distribution of seagrass species

Seagrasses species that were recorded in this study have different distribution pattern. *Halodule pinifolia* was observed to dominate the study area. Similar finding was recorded by Zakaria & Bujang (2004) which discovered *Halodule pinifolia* is abundantly distributed in Lawas. This species dominated the area since 2004 to 2009-2010 sampling. This indicated that although *Halodule pinifolia* is known as a pioneering species (den Hartog, 1970), it can also be considered as a climax species in Lawas. This means, the population of *Halodule pinifolia* in Lawas is stable. Pioneering species such as *Halodule uninervis, Halophila ovalis* and *Halodule pinifolia* were also recorded as a climax species in Rowes Bay, Australia (Lanyon & Marsh, 1995). Presence of herbivors such as the dugongs (*Dugong dugon*) can explain the dominance of *Halodule pinifolia* in Lawas. Dugongs have been found to feed dominantly on *Halophila* and *Halodule* (Erftemeijer & Herman, 1994; Preen, 1993 in de Iongh et al., 1995). The current study observed the evidence of dugong feeding trail on *Halodule pinifolia* meadow. Aerial surveys also confirmed the sightings of dugongs in Lawas (Jaaman & Lah-Anyi, 2003; Bali et al, 2008). When feeding on these small species, dugongs removed the entire plant, including the rhizomes and root system (Preen, 1995). Fortunately, these small seagrass species has high growth rate (Nakaoka & Aioi, 1999). Therefore, even if the population is reduced by herbivory or any other disturbance, it is able to recover to the previous state within shorter period (Preen, 1995; Nakaoka & Aioi, 1999). This prevents interspecific competition and maintains the same seagrass species that is preferred by the dugongs (Aragones et al., 2006).

Although *Halodule pinifolia* was a dominant species in this study, it was observed to co-exist with other seagrass species. For example, it was commonly seen associating with *Halodule uninervis*. The co-existence of these species is normal and has been recorded by previous studies (Ismail, 1993; Japar Sidik et al., 1999). These species were always found occurring together possibly because both species have similar ecological preferences (den Hartog, 1970). Besides *Halodule uninervis*, *Halodule pinifolia* was always seen to associate with *Halophila ovalis* and *Cymodocea rotundata* on sandy and mix of sand and mud substrates. This association was also been observed previously (Ismail, 1993; Zakaria & Bujang, 2004; den Hartog, 1970). *Halophila ovalis* is a colonizing species and was observed as the first species to occur after a meadow received disturbances (Rasheed, 2004; Nakaoka & Aioi, 1999). However, it was easily displaced by other species that has better generative strategy (Rasheed, 2004). The success rate of reproductive strategy (sexual or asexual) will determine the occurrence of the seagrass in a specific location. This explain why more than one species can be found in a particular meadow.

All species that were recorded in the study area are normally found in tropical intertidal areas. This is similar to previous findings that recorded *Cymodocea rotundata, Thalassia hemprichii* and *Enhalus acoroides* on shallow coral areas in Yap, Micronesia (Bridges & McMillan, 1986). *Halophila ovalis, Cymodocea rotundata* and *Thalassia hemprichii* were also observed in intertidal area of Zanzibar, Tanzania (Beer et al., 2006). In addition, Baron et al. (1993) also observed *Thalassia hemprichii* in New Caledonia. Two conditions must be tolerated by intertidal seagrasses. Firstly, seagrasses must be able to cope with the increase of temperature and desiccation when exposed to direct sunlight during low tide. Secondly, seagrasses are prone to salinity decrease due to the increase of freshwater runoffs during heavy rainfall. *Halophila* sp. prevent desiccation during low tide by laying flat on the wet sediment (Beer et al., 2006). *Cymodocea rotundata* adapted to low tide condition by occurring in tidal pools (Zakaria & Bujang, 2004). Both strategies prevent seagrass from desiccation during low tide.

4.6 Sediment distribution

Seagrasses anchor on the sediment for support and nutrient intake (Stapel et al., 1996). The current study indicated that different seagrass species was growing on different sediment type. This finding is similar to Gacia et al. (2002), Bach et al. (1998) and Terrados et al. (1998) where they observed *Enhalus acoroides* to be least sensitive towards siltation and high sediment deposition while smaller seagrass species such as

Sryingodium isoetifolium and *Halodule uninervis* were more sensitive towards siltation and were only found at sites with low to medium sediment deposition. This is probably due to the fact that, in the event of sediment burial and shading, seagrass species with large leaf area are still capable of conducting photosynthesis than smaller leaf species (Duarte et al., 1997).

Halodule pinifolia and *Halodule uninervis* were recorded on a wide range of sediments (i.e. sandy, muddy and mix of mud and sand). This finding is in accordance to Phang (2000), den Hartog (1970), Gumpil & de Silva (2007) and Kiswara (1996). Fast growing *Halodule* sp. dominate new locations rapidly and eventually stabilizes any type of sediment with its delicate root system. This ability allows the species to occupy various habitats along the coastline and has been speculated to function as coastal stabilizer (Japar Sidik et al., 1999; Zakaria & Bujang, 2004).

4.7 Water parameter measurements at different sampling locations

Seagrass occurrence are affected by spatial changes due to environmental parameter (Biber & Irlandi, 2006). The current study showed that different sampling locations contribute significantly by changes in water parameter (turbidity, salinity, pH, temperature and DO). Differences in water parameter measurements at different sampling locations were also observed along the coastline of Sabah. The differences in water parameter measurements were contributed by geographical attribute of the study area (semi-enclosed bays), population concentration, agricultural activities and industrial loads (Jakobsen et al., 2007).

Higher turbidity was recorded at locations 1, 2 and 5. Elevated turbidity in sampling location 1 was contributed by the proximity of the sampling stations with Sg. Padas.

Increase in suspended solids in Sg. Padas was associated with upstream deforestation. This has been observed to effect Brunei Bay with the increase of turbidity and siltation (Saleh et al., 2007; Freeman et al., 2008). Sampling stations in locations 2 and 5 were also experienced increase turbidity and siltation due to the fact that sampling points were located near to rivermouths. Location 2 is located close to main river in Lawas (i.e. Batang Lawas) while, location 5 is located near to Sg. Punang. Freshwater runoffs had contributed to the increased in sedimentation and turbidity which brought by heavy rain from land development and human activities further inland (Latrubesse et al., 2005; Saleh et al., 2007). This study recorded *Enhalus acoroides* and *Thalassia hemprichii* on muddy sediment near rivermouths as discovered by Gacia et al. (2002), Bach et al. (1998) and Terrados et al. (1998). Previous studies recorded *Enhalus acoroides* to be least sensitive towards siltation and sediment deposition. This species is more tolerant than *Thalassia hemprichii* and usually occurs near rivermouths with silt and muddy sediment types. Both species were also observed at sampling locations which were polluted by coastal villages along the rivers. These coastal villages do not have proper sanitation system and many of the coastal villagers practising brackish water aquaculture along the rivers. Aquaculture waste was washed to the coastal areas and contained elevated nutrient such as phosphate and nitrate (Tovar et al., 2000; Anh et al., 2010). The occurrence of seagrasses such as *Thalassia hemprichii* and *Enhalus acoroides* near rivermouths could be contributed by nutrients such as phosphate brought by the rivers (Miller & Sluka, 1999).

Waste water from aquacultural and agricultural activities can change pH value (Tovar et al., 2000; Anh et al., 2010; Obire et al., 2010). All sampling locations recorded pH values within the standard of SWII and MMWQC except one sampling station (in location 6). The decrease of pH at this sampling station was possibly affected by oil palm plantation located nearby. Similar observation has been observed by Obire et al. (2010) in Nigeria. Effluents from palm oil mills is acidic because organic acid was produced during production of palm oil which include the process of fermentation (Rupani et al., 2010). Therefore, the runoffs from agricultural practices and palm oil effluents through three streams/rivers into the sea is decreasing the pH value. Agricultural activities in oil palm plantation also include the use of herbicides like diuron and hexazinone (Ikuenobe & Ayeni, 1998). Herbicides (diuron, simazine, atrazine, hexazinone and/or flumeturon) from agricultural practices have been detected with higher concentration after rainfall (McMahon et al., 2005; Shaw & Muller, 2005) at all inshore reef and rivermouth. Diuron and other herbicides were known to affect coastal plant species and had caused the dieback of mangrove species, *Avicennia marina* (Duke et al., 2001). Photosynthesis of tropical seagrasses is inhibited even at low concentrations of diuron (0.1 to 1.0 µg/l) (Haynes et al. 2000). Seagrass occurrence at this sampling location is very sparse and was only found at open water stations. van Katwijk et al. (2011) and Cabaco et al. (2008) also recorded higher total biomass and seagrass cover at locations further from the rivermouth in area polluted with diuron. It is also worth noting that although seagrass was sparsely present at sampling location 6, only *Halodule pinifolia* and *Halodule uninervis* were recorded. The presence of *Halodule pinifolia* and *Halodule uninervis* could be associated by its capability of growing rapidly which allow it to quickly colonizes an area and stabilizes the bottom sediment (den Hartog, 1970; den Hartog & Zong-Dai, 1988 in Japar Sidik et al., 1999).

The study also revealed that there was differences in salinity value at different sampling locations. The differences in salinity value recorded from this study were contributed by the location of the sampling stations. Similar observation was made by Biber & Irlandi (2006) where a range of salinity was recorded in their sampling site within

Biscayne Bay, Florida. Salinity value of less than 20 PSU was recorded at sampling location near to rivermouths of Batang Lawas, Sg. Punang, Sg. Cina, Sg. Kuku Karu and Sg. Bangkulit. However, low salinity measurements was only recorded during the rainy season. It is also worth mentioning that the study area is an estuary that experienced freshwater run-off from Batang Lawas. The same situation was also seen in Brunei Bay (Sabah), where low salinity was measured (Saleh et al., 2007). Although decrease in salinity value was recorded along the coastline where coastal stations were located, seagrasses were more abundant at coastal stations than open water stations. This showed that seagrasses were able to tolerate decreased in salinity of the estuarine ecosystem.

Dissolved oxygen produced by primary producers including seagrasses and mangroves species is important to the marine ecosystem for respiration and metabolism processes. In this study, different DO values were recorded at different sampling locations. Kruskal-Wallis statistics used in this study showed that sampling location 6 has the lowest mean rank of DO values. Sampling location 6 is exposed to the effluents of oil palm plantation. Similar observation was made by Rupani et al. (2010) and Obire et al. (2010). The fluctuation of DO value can be explained by natural biological processes such as photosynthesis and respiration. Low levels of DO value coincides with increased bacterial counts (Obire et al., 2010) or nutrient degradation (Tovar et al., 2000). The variation of DO value was contributed by the timing of the measurements. In this study, all water parameters (including DO) was measured during high tide regardless of the timing of the day. Higher DO value will be recorded in the afternoon and lower pH value will be recorded in the early morning or late afternoon as a result of higher photosynthetic activities in the afternoon. Higher DO during midday is contributed by the physiological characteristic of the seagrasses which increases electron rate and the maintenance of electron transport rate during the midday (Campbell et al., 2008).

4.8 Appraisals

There are a number of method that can be used to assess seagrass population. For example, SeagrassNet provides a useful manual for rapid assessment of seagrass abundance (Short et al., 2004). Meanwhile, another popular and rapid assessment method that can be used was developed by SeagrassWatch (McKenzie & Campbell, 2002). In both methodology, line transect and quadrat method was used to estimate seagrass population status. The same protocol was used by Prathep (2003) and Freeman et al. (2008) to record spatial and temporal changes of seagrass occurrence. The current study adopted only the quadrat method. The line transect was not used in this study as the study aimed to record the distribution/occurrence and the estimation of seagrass percentage cover at sampling stations established and not the size of seagrass meadow. However, the size of the seagrass meadow at the study area should be studied as an indication of declining health of the seagrass ecosystem either naturally or caused by anthropogenic threat.

In the effort to study temporal and spatial changes of seagrass percentage cover, the current study sampled seagrass using 0.25 m^2 quadrat with three replicates at 84 sampling stations established along 34.4 km coastline of Lawas. According to Kirkman (1996), the number of replication and size of quadrat chosen for a study needs to be determined based on the smallest number of coefficients of variations for the lowest cost benefit. However, the current study followed the standard method conducted by Nakanishi et al., 2006 which also assessed seagrass distribution using similar quadrat size and number of replicate. Moreover, as the sampling stations spreads along 34.4km of coastline, time and logistic factors limits the number of replicates to three and to a small quadrat size.

It is important to note that only the effect of water parameter on seagrass percentage cover was studied. In the event of other disturbance such as nutrient load, increased turbidity or pollution, seagrasses have been observed to change the physiological processes. The physiological responds of *Halophila ovalis* include declined sugar concentration and biomass. This was recorded as early as two days and complete death of the plant was observed after 30 days during light deprivation period (Longstaff et al., 1999). The fluctuation of seagrass photosynthesis can be used to measure the changes of pH water. Invers et al. (1997) proved that the fluctuation of pH affect the daily photosynthesis value for seagrasses. van Katwijk et al. (2011) suggested using parameter such as seagrass cover, above/below ground biomass, occurrence of different seagrass species, number of leafs per seagrass shoot and seagrass leaf length as an indicator to detect changes of seagrass ecosystem.

Due to lack of baseline water parameter data on the study area, the need of values on water parameters relevant to seagrass distribution, economical constraints and logistic constraints, only DO, temperature, pH, turbidity and salinity were measured. Moreover, the availability and simplicity of HI9828 HANNA Instrument Multimeter and HI93703 Hanna Instrument Microprocessor Turbidity meter were helpful to gather necessary data for the study. However, as the coastal area of Lawas are being explored, more land are being cleared for human activities such as brackish water aquaculture practices and oil palm plantation, other water parameter such as phosphates, nitrates will be more useful to assess the health of seagrass ecosystem in Lawas. The Malaysian Marine Water Quality Criteria and Standards used by Department of Environment Malaysia gave standards for other water parameter such as oil and grease, metals (arsenic, chromium, copper, lead, zinc, cyanide, mercury, etc), phosphate and nitrate that can be used for future monitoring of the study area.

Although the present study were successful in proving that seagrass percentage cover was influenced by water parameter measurements (i.e. turbidity), it is important to understand that the water parameters were only measured during high tide. The variation of water parameters due to tidal effects were unable to be studied due to time and logistic constraints. Water parameters measurement were conducted during high tide only because samplings stations were established along an intertidal area which is shallow. The sampling stations were easily accessible during high tide and not during low tide. To minimize the variation of tidal effect, water parameters were measured during high tide (of neap tide). This is because, during the neap tide, seawater level increases and decreases gradually. As measurements were conducted during high tide, there were monthly variation on the timing of the water parameter measured. However, the study was conducted with the assumption that time of water parameter do not influence the monthly measurements. Therefore, the result of this study may be regarded as providing a baseline data on basic water parameters and the correlation with seagrass percentage cover at intertidal areas during high tide.

4.9 Recommendation

Much information has been collected from this study about the temporal and spatial variation of seagrass distribution in Lawas waters. Detailed study need to be conducted to explore the relationship between oil palm plantation and seagrass species distribution. The study has indicated that there was no seagrass occurring at sampling stations near the oil palm plantation. In Australia, herbicides and pesticides usage from agricultural plantations has affect coastal plant species (Duke et al., 2001; McMahon et al., 2005). Therefore, it is expected herbicides and pesticides that is being used in oil palm plantation near the coastline is affecting the seagrass meadow at shallow waters in Lawas. To date, more land-clearing were observed near the coastline to support the demand of palm oil. Seagrasses parameters such as tissue content and morphological changes can be used for future studies to detect detrimental changes to the environment and to predict the changes of coastal seagrass population. Moreover, these biotic parameters should be used to assess the vulnerability and adaptation response towards environmental changes due to agricultural practices.

The current study had successfully display the spatial difference on seagrass percent coverage of the study area. The spatial differences were observed based on land-usage near established sampling stations. However, further studies should be conducted to examined the differences between seagrass population at coastal stations and open water stations. Differences in seagrass population are expected as seagrasses at coastal stations are exposed directly to freshwater runoffs from nearby river system. Moreover, coastal seagrasses may experience desiccation due to direct exposure to heat/sunlight during low tide.

In 2010, Sarawak Forestry Corporation has pledged to gazette Lawas as a Marine Protected Area (MPA). The current study serves as a baseline data on the occurrence and changes of seagrass percentage cover and its relationship with water parameters to support the gazettement of Lawas as an MPA. Lawas has been known to support a huge population of green turtles and dugongs (Jaaman & Lah-Anyi, 2003; Bali et al, 2008). Further study on dugong population and behaviour is needed. In addition to aerial survey by Jaaman & Lah-Anyi (2003) and Bali et al. (2008), there is another study on the occurrence and distribution of dugongs and its associated threats in Lawas which is currently on-going (Redzwan, unpublished). Other than that, studies also shown that juvenile fishes and prawns can be found in seagrass area (Coles et al., 1993; Bali, 2005; Aziz et al., 2006). Therefore, the gazettement of Lawas as an MPA will also benefit the fishery stock in the area. This has been observed in Wakatobi National Park where the MPA supported higher fishery stock than the other sites.

CHAPTER FIVE

SUMMARY

This study examined monthly changes of basic water parameters (i.e. temperature, pH, salinity, turbidity and dissolved oxygen) and their effects on the distribution and abundance of seagrasses. This study was conducted over a span of 12 months, consisted of 84 sampling stations across 34.4 km of Lawas coastline. This study is the first to investigate the relationship between water parameters and spatial/temporal distribution of seagrasses in Malaysia. It was an attempt to create a baseline data for long term ecological monitoring at Lawas, Sarawak. The result from this study indicated that:

- a total of eight species of seagrasses were observed along the coastline of Lawas. Seagrass population, which was measured by the percentage cover, displayed temporal variation. Temporal variation was discussed to be the result of tidal exposure, weather conditions and physical characteristics of the seagrasses such as possession of robust rhizome and root system which aided in recovery of seagrass .
- only the changes of turbidity is significantly correlated with seagrass percentage cover. This shows that seagrasses are sensitive to light limitation and low light condition (Longstaff et al., 1999; Longstaff & Dennison, 1999; Ruiz & Romero, 2003). The sampling stations were established along the coastline of Lawas. Therefore, the sampling stations are exposed to freshwater runoffs from nearby rivers which brings effluents from anthropogenic impact (agricultural, human habitation and aquacultural) and soil erosion (Jakobsen et al., 2007) which increases turbidity, siltation and nutrient. In addition to these, freshwater runoffs causes increased siltation along the coastal area (Freeman et al., 2008). The

condition worsens during the monsoon season as heavy rain had increases the volume of freshwater discharge to the sea.

- Spatial variation of seagrass distribution in Lawas were contributed by sediment type, river runoffs, geographical features of the study area and human activities.

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