PHENOLOGY OF *Sargassum* SPECIES AT TELUK KEMANG, PORT DICKSON, MALAYSIA

BELINDA YEONG MAY LIN

MASTER OF SCIENCE

FACULTY OF ENGINEERING AND SCIENCE
UNIVERSITI TUNKU ABDUL RAHMAN
AUGUST 2011

PHENOLOGY OF *Sargassum* SPECIES AT TELUK KEMANG, PORT DICKSON, MALAYSIA

By

BELINDA YEONG MAY LIN

A thesis submitted to the Department of Science

Faculty of Engineering and Science

Universiti Tunku Abdul Rahman

in partial fulfillment of the requirements for the degree of

Master of Science

August 2011

ABSTRACT

PHENOLOGY OF *Sargassum* SPECIES AT TELUK KEMANG, PORT DICKSON, MALAYSIA

Belinda Yeong May Lin

Seasonal growth of three *Sargassum* species was studied along two reef flats of Teluk Kemang, Port Dickson from September 2009 to September 2010. Monthly non-destructive and bimonthly destructive samplings were conducted; employing systematic quadrat and line transect method. Results from destructive and non-destructive samplings revealed a bimodal pattern in mean thallus length (MTL) and biomass variation, and a biannual reproduction with three peaks within 13 months; from September 2009 to October 2009, from January to March 2010 and from July to August 2010. MTL was not significantly correlated with biomass but was correlated with fertility. Majority of harvested *Sargassum* species were in lower length classes (< 200 mm), especially in 0 - 99 mm (destructive sampling: *S. polycystum*: 71 25 %; *S. binderi*: 67.22 %; *S. siliquosum*: 71.74 %) (non-destructive sampling: *S. polycystum*: 64.20 %; *S. binderi*: 68.29 %; *S. siliquosum*: 56.80 %). Cross section on dioecious receptacles revealed a higher female to male ratio throughout the year for *S. polycystum* (88 female : 35 male) and *S. siliquosum* (29 female : 22 male). *S. binderi* and *S. siliquosum* were more abundant on the Left Reef (2° 26’ 15” N latitude; 101° 51’ 19” E longitude), while *S. polycystum* more on the Right Reef (2° 26’ 24” N latitude; 101° 51’ 18” E longitude). Redundancy analysis (RDA) was employed to test overall correlation between sample measurements and environmental parameters, of which water temperature, pH, salinity, phosphate and radiation emerged most important. In addition, cross correlations (time lag: two months) were conducted on both reefs separately, of which ammonia emerged most important, affecting all species on Right Reef positively but negatively for *S. polycystum* on Left Reef. This study reviewed the seasonality of MTL, biomass and fertility of *Sargassum* species on two reefs of Teluk Kemang.

ACKNOWLEDGEMENT

My greatest gratitude goes to my Lord above who has provided me with sufficient strength and wisdom to complete this project.

Also to my family and friends who have supported me and have been there since the beginning of this project. Without them, this journey would have been a very dull one.

Not forgetting my supervisor, Dr Wong Ching Lee who has driven me to go the extra mile, without whom I would have not been able to complete this thesis. Together with my co-supervisor, Dr Hii Siew Ling, they have been a good source of guidance and support.

Much appreciation goes to UTAR RF (6200/W08) for funding the whole research project. Lastly, to Professor Chong Ving Ching for permission to use the CANOCO programme, and to Ms. Ooi and Ms. Chew for the statistical guidance.

APPROVAL SHEET

This thesis entitled **"PHENOLOGY OF *Sargassum* SPECIES AT TELUK KEMANG, PORT DICKSON, MALAYSIA"** was prepared by BELINDA YEONG MAY LIN and submitted as partial fulfillment of the requirements for the degree Master of Science at Universiti Tunku Abdul Rahman.

Approved by:

____

Dr. WONG CHING LEE Date:…………………...
Supervisor
Department of Science
Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

____

Asst. Prof. HII SIEW LING Date:…………………...
Co-supervisor
Department of Chemical Engineering
Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

FACULTY OF ENGINEERING AND SCIENCE

UNIVERSITI TUNKU ABDUL RAHMAN

Date: ___________________

SUBMISSION OF THESIS

It is hereby certified that **Belinda Yeong May Lin** (ID No: **09UEM09089**) has completed this thesis entitled "PHENOLOGY OF *Sargassum* SPECIES AT TELUK KEMANG, PORT DICKSON, MALAYSIA" under the supervision of Dr. Wong Ching Lee from the Department of Science, Faculty of Engineering and Science and Dr Hii Siew Ling from the Department of Chemical Engineering, Faculty of Engineering and Science.

I understand that the University will upload softcopy of my thesis in pdf format into UTAR Institutional Repository, which may be made accessible to UTAR community and public.

Yours truly,

____

Belinda Yeong May Lin

DECLARATION

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

(BELINDA YEONG MAY LIN)

Date

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
DO	Dissolved Oxygen
et al.	And others
Fert	Number of fertile plants
g WW m^{-2}	Gram wet weight per meter square
g DW m^{-2}	Gram dry weight per meter square
g AFDW m^{-2}	Gram ash-free dry weight per meter square
GPS	Global Positioning System
LR	Left Reef
mg/L	Milligram per liter
mm	Millimeter
MTL	Mean thallus length
No.	Number
Q	Quadrat
r	Correlation coefficient
RDA	Redundancy Analysis
RR	Right Reef
S	*Sargassum*
Temp	Temperature
&	And

CHAPTER 1

INTRODUCTION

Marine algae is estimated to contribute about 70 % to 80 % of earth's atmospheric oxygen, amounting to about 330 billion tonnes of oxygen per year (Hall, 2008). This is an indication of how important algae are to the environment. Algae are simple, autotrophic organisms that are either microscopic or macroscopic. Specifically, seaweeds are macroscopic algae that thrive in benthic marine waters. Just like terrestrial plants, these groups of multicellular organisms are autotrophic and thus have the ability to carry out photosynthesis. However, they do not posses several distinct organs such as true leaves, roots, flowers and seeds that typify terrestrial plants (Sumich & Morrissey, 2004).

There are roughly 10000 different species of seaweeds recorded. Generally, seaweeds can be divided into three groups, namely Rhodophyceae (6000 species), Chlorophyceae (2000 species) and Phaeophyceae (2000 species) based on their colour pigment (Guiry & Guiry, 2011). The genus being studied, *Sargassum*, belongs to the group Phaeophyceae, which obtains its distinctive brown colour from the xantophyll pigment of fucoxanthin. Cell walls of these algae are mainly composed of cellulose and alginic acid, a valuable component that adds commercial value to *Sargassum* species.

In Asia, seaweeds are commonly used as fertilizers and as food for both humans and animals. Trono (1999), McHugh (2003) and Phang (2006) are among the many authors who have listed down the beneficial usages of seaweeds which include *Sargassum* as raw products for cosmetic and pharmaceutical industry. In order to adapt in harsh environments, seaweeds have to develop effective defence mechanisms, especially by means of chemical production. Hence, seaweeds are rich in bioactive compounds with structures and activities different from those found in terrestrial plants (Tierney Craft & Hayes, 2010). For instance, seaweeds contain commercially important polysaccharides, namely agar, fucoid, alginate, carrageenan, laminaran and sulphated galactan (Li, Lu, Wei & Zhao, 2008). Fucoidans commonly found in brown seaweeds are a very sought after polysaccharide in the development of new drugs due to its many biological activities such as anticoagulant, antitumor, antioxidant, etc., thus its application in the medical field (Smit, 2004). Another valued polysaccharide includes alginate, which was found to be in high yields in seaweeds of the order Fucales, including the genus *Sargassum* (Tierney et al., 2010; Zubia, Payri & Deslandes, 2008). Possessing characteristics of a polyelectrolyte, alginate is employed in food industry for their thickening and gel-forming abilities (Fenoradosoa, Ali, Delattre, Laroche, Petit, Wadouachi & Michaud, 2010), in textile printing as thickeners for dyes (Abbott, 1996) and as biosorbents in the bioremediation of contaminated water (Khorramabadi & Soltani, 2008).

There are only 42 countries globally that are involved in commercial seaweed activity (Kaur & Ang, 2009). In many parts of South East Asia where seaweeds naturally flourish, seaweed mariculture represents an important economic resource and is rapidly gaining attention (Krishnaiah, Sarbatly, Prasad & Bono, 2008). In Malaysia, seaweed cultivation is solely carried out in the state of Sabah, mainly off the coast of Semporna, Kudat and Lahad Datu (Ahemad, Ismail & Mohammad, 2006). Local cultivation focuses mainly on two seaweed species; *Kappaphycus alvarezii* (Doty) Doty ex P. C. Silva and *Euchema denticulatum* (N. L. Burman) F. S. Collins & Hervey, both cultivated and exported for carrageenan production. Since seaweed cultivation was introduced to Sabah in 1978, seaweed production has slowly increased, with two seaweed processing mills established in Sabah (Kaur & Ang, 2009; Vairappan, Anangdan, Tan & Matsunaga, 2010). In 2008, 111 300 tonnes of seaweeds were produced locally and this increased to 138 856 tonnes in 2009 (Department of Fisheries Malaysia, 2011). Currently, Malaysia is the third largest producer of carrageenan, after the Philippines and Indonesia (Vairappan et al., 2010).

Malaysia possesses a coastline of 3432 km long and a continental shelf area of 418 000 km^2 (Phang, 2006). Being a tropical country, it exhibits a fairly uniform temperature all year round, with surface waters ranging from 20-30 °C (Nybakken & Bertness, 2004). Malaysia’s climate is governed by the Northeast Monsoon from November to March and the Southwest Monsoon from June to September. Phang (2006) has reported 375 taxa of seaweeds along the coast of Malaysia. Studies done by Ismail and Go (1994) from October 1993 to April 1994 recorded 32 species of *Sargassum* in Malaysia.

Coastal shores of Teluk Kemang, Port Dickson (2° 26’ N latitude; 101° 51’ E longitude) is an inshore tidal area that is paved by sandy beaches and rocky shores. Located at a relatively secluded place, the beach is less disturbed by tourists compared to other more popular beaches in Port Dickson. Just off the shore there are coral reef flats that extend out to sea.

Abundant seaweeds have been found to naturally flourish along these reef flats, of which, *Sargassum* species dominated. Phang (1995) has so far identified 69 species of macroalgae along the coast of Cape Rachado, located 2.5 km away from the present site. Thus, Teluk Kemang is an ideal study site to monitor the seasonal environmental change and its possible effects on seasonal growth of *Sargassum* species. In this study, the focus was on three specific species found at Teluk Kemang; *S. polycystum* C. A. Agardh, *S. binderi* Sonder ex J. G. Agardh and *S. siliquosum* J. G. Agardh.

A typical life history of seaweeds involves a seasonal growth cycle caused by climatic changes occurring throughout the year. *Sargassum* in particular was shown to exhibit seasonal cycles of growth, reproduction, senescence and die back (Ang, 2006). This recurring seasonal cycle, based on climatic changes is termed as phenology.

Phenological studies are important to provide precious information for local seaweed cultivation. Studies on *Sargassum* species in particular have been extensively carried out in many countries, especially in the tropical waters of Hong Kong (Kong & Ang, 2004; Ang, 2006), Japan (Shimabukuro, Terada, Sotobayashi, Nishihara & Noro, 2007) the Philippines (Largo & Ohno, 1992), Thailand (Mayakun & Prathep, 2005; Noiraksa, Ajisaka & Kaewsuralikhit, 2006) and many more. In Malaysia, these studies are only a handful (Wong & Phang, 2004).

The objectives of this study are therefore:

1) to study the phenology of *Sargassum* species along the two reef flats of Teluk Kemang, Port Dickson.
2) to review if there is any spatial variation in *Sargassum* measurements within small distance difference (Left Reef and Right Reef).
3) to correlate seasonal growth of *Sargassum* with environmental parameters.

CHAPTER 2

LITERATURE REVIEW

2.1 *Sargassum* species

Sargassum species are macroscopic marine algae that generally dominate the shallow reefs of tropical (Ang, 2006) and temperate regions (Hwang, Park & Baek, 2006; Komatsu et al., 2007; Zhang, Li, & Pan, 2009). It is well accepted as one of the most ecologically abundant brown seaweed with high economic importance (Phang, 2006). Presence of *Sargssum* on shallow reefs form *Sargassum* beds which act as nursery ground for living organisms (Umezaki, 1984). It also acts to trap nutrients from seawater and contribute to high rates of primary production (Engelen, Breeman, Olsen, Stam & Aberg, 2005). Being a primary producer, *Sargassum* species play a vital role in marine ecosystems (Mayakun & Prathep, 2005).

Seaweeds are typically built up of a holdfast, stipe and blades (Sumich & Morrissey, 2004). *Sargassum* in particular possesses characteristic air vesicles that help keep it afloat (Trono, 1997), thus promoting photosynthesis. Due to its plasticity in morphology, certain characteristics of *Sargassum* such as average length of thallus and leaves were found to vary slightly from country to country. In the past, species identification was solely based on morphological appearance, relying on morphological descriptions from local floral books. As *Sargassum* was reported to be highly polymorphic in nature, there was a need for more accurate and consistent identification method (Mattio & Payri, 2010). In recent years, phylogenetic analysis was preferred to the more traditional method (Hodge, Buchanan & Zuccarello, 2010; Peters et al., 2010; Trobajo, Mann, Clavero, Evans, Vanormelingen & McGregor, 2011).

Up to date, records in AlgaeBase (Guiry & Guiry, 2011) listed a total of 338 species under the genus of *Sargassum*. These species belong to the group of brown algae, Phaeophyceae which obtains its distinctive brown colour from the xantophyll pigment of fucoxanthin (Trono, 1997). Generally, all groups possess a primary pigment of chlorophyll a, which result in green colouration. However, dominance of other coloured pigments in different groups may mask the effects of chlorophyll a, thus producing different coloured seaweeds. Taxonomy of *Sargassum*, is listed in Table 2.1

Table 2.1: Characteristics of *Sargassum* species in taxonomic order

Rank	Name
Empire	Eukaryota
Kingdom	Chromista
Subkingdom:	Chromobiota
Infrakingdom	Heterokonta
Phylum	Heterokontophyta
Class	Phaeophyceae
Order	Fucales
Family	Sargassaceae
Genus	*Sargassum*

Sargassum which originated in South East Asia (Wernberg, Thomson, Stæhr & Pedersen, 2001) is known to be one of the most aggressive marine invaders (Thomsen, Wernberg, Stæhr & Pedersen, 2006). Due to certain characteristics such as high growth rate, long lifespan and the fact that it is reproductively active within its first year, *Sargassum* species has been regarded as a strong competitor to potentially out-compete native macroalgae (Kraan, 2008). Thus, its introduction into many western countries such as the United States (Hewitt et al., 2004), Ireland (Kraan, 2008) and Denmark (Pedersen, Stæhr, Wernberg & Thomsen, 2005), whether intentional or unintentional, have caused an invasive replacement on native macroalgae as the dominant species. Schaffelke, Smith and Hewitt (2006) concluded that introduced species are considered one of the biggest threats to native marine biodiversity and resource values of the world's oceans.

2.2 Life History

Sargassum is a perennial plant and undergoes several stages in its life history. A typical life cycle of *Sargassum* includes growth, reproduction, senescence and die back (Ang, 2006).

Sexual reproduction produces a diploid zygote which detaches from the receptacle. It then attaches itself onto a substrate by its holdfast, whereby primary laterals begin to branch out from. The new sterile plant has to grow to a certain size before it is able to reproduce (DeWreede & Klinger, 1988). When it reaches sexual maturity, receptacle-bearing laterals begin to grow from the primary branch. At this point, growth rates would most likely decrease due to partitioning of resources.

After a peak period of reproduction, fertile laterals begin to necrose and die back (Zhang et al., 2009). The decay leaves short, primary axes attached to its perennial holdfast that will continue into the next phase of asexual reproduction. This survival strategy is crucial in order for the *Sargassum* to endure harsh seasonal environments. When conditions are ideal, primary branches arise again from the surviving thallus until the onset of reproduction again.

Ateweberhan, Bruggemann and Breeman (2008) stated that there is a strict timing for every event of seaweed life history, whereby environmental parameters act as seasonal cues. However, Engelen et al. (2005) explains that in order for organisms to survive in different and harsh environments, it is important that they be flexible in life histories. For instance, some species of *Sargassum* have been reported to show annual growth with unimodal pattern, such as *S. baccularia* (Mertens) C. Agardh and *S. binderi* Sonder ex J. G. Agardh in Port Dickson, Malaysia (Wong & Phang, 2004), while others have been forced to adapt to a bimodal pattern such as *S. autumnale* Yoshida in Maizuru Bay, Japan (Yoshida, Yoshikawa & Terawaki, 2003). The latter is advantageous in that if conditions were not ideal for zygote maturation during the first growth phase, the second phase would compensate for earlier loss.

2.3 Reproduction

Reproduction was reported to be the key to the survival of a species (Lobban & Harrison, 1994). Unlike some other seaweeds that reproduce asexually, all species of *Sargassum* reproduce only by vegetative and sexual means (Singh, Pande & Jain, 2010). In vegetative method, fragmentation of thallus occurs, whereby broken segments eventually grow into new thalli. This method is especially seen in pelagic, free floating species such as *S. natans* (Linnaeus) Gaillon and *S. hystrix* J. Agardh.

Sexual reproduction involves the fusion of male and female gametes to produce a whole new plant. Male sex organs are called antheridia while female sex organs are called oogonia. Both organs are produced inside a special cavity called conceptacle, which in turn is found inside a branchlet called receptacle. Most species of *Sargassum* were reported to be monoecious (androgynous) (Singh et al., 2010), with both sex organs found in the same conceptacle; as opposed to dioecious where both are found in separate plants each. Graham and Wilcox (2000) stated that monoecious reproduction in some *Sargassum* species, among other features, contribute to its rapid spread to new areas.

Singh et al. described in their book the details of *Sargassum* reproduction, as summarized below. In a single antheridium, 64 biflagellate sperms or antherozoids develop and are released into seawater. However, only a single ovum or oosphere develops from an oogonia. When environment is ideal, the matured ovum is released from the conceptacle, but is attached to the base through a gelatinous stalk. Brawley and Johnson (1992) reported that gamete release in *S. muticum* Yendo (Fensholt) was influenced by temperature and lunar period. At fertilization, a large number of sperms surround the ovum and attach themselves to the wall by the anterior flagellum. With the posterior flagellum still lashing, only one sperm penetrates through the wall and fuses with the haploid egg nucleus to form a diploid zygote. While still attached to the conceptacle, the zygote germinates and eventually falls off in time. Zygote then lands and attaches itself onto a hard substratum where it grows into a whole new plant.

Brawley and Johnson (1992) stated that once gametes are released, the success or failure of fertilization depends very much on the surrounding hydrodynamic environment. At low current velocities, mixing of male and female gametes is encouraged, but at high water motion, gamete concentration is diluted. In order to increase chances of fertilization, it is important that high concentrations of gametes are produced and released within a few minutes of each other. Upon release, most gametes are only viable for a brief period of time, such as in the case of *S. vestitum* (R. Brown ex Turner) C. Agardh whereby sperm motility was reported to last for only about an hour. In addition, Brawley and Johnson stated that probability of fertilization can increase when gametes are released at low tides during plant emmersion, as opposed to high tides during plant immersion.

Generally, *Sargassum* species undergo an annual reproductive cycle. This was reported in *S. thunbergii* (Mertens ex Roth) Kuntze of Bohai Bay, China that peaked during spring and summer (Zhang et al., 2009). However, depending on environmental conditions, some may resort to biannual reproduction, such as seen in the same species of *S. thunbergii* from Chiba and Nagasaki (Akira & Masafumi, 1999).

2.4 Phenology

Recurring seasonal cycle, based on climatic changes is termed as phenology. Phenological changes in *Sargassum* were shown to vary across regions. Within each region, the seasonal pattern of *Sargassum* growth has been highly predictable. De Wreede (1976) generalised that in temperate regions, *Sargassum* is most abundant during the warmest part of the year; while in tropical regions during the coolest part.

In agreement with De Wreede's observation, Gillespie and Critchley (1999) found that *S. elegans* Suhr in temperate regions of South Africa were most abundant during the hottest months of the year, but were least abundant during the coldest months. Similarly, biomass of *S. muticum* in Limfjorden, Denmark was highest in mid-summer but lowest in spring and autumn (Pedersen et al., 2005). Despite similar trends, exceptions do occur, such as seen in *Sargassum* species found along the upper Gulf of California (McCourt, 1984) and in the northwestern Pacific coast (Komatsu et al., 2007) whereby growth was highest in spring. *S. subrepandum* (Forsskål) C. Agardh in the temperate Red Sea was observed to have fast growth and reproduction in the cooler months, followed by massive shedding and hence, reduced biomass by summer (Ateweberhan et al., 2006; 2008).

As for tropical regions, studies done by Dawes (1987) in the Pacific Oceans of Florida Keys, USA showed that *S. pteropleuron* Grunow and *S. filipendula* C. Agardh have a high growth rate in summer and a degenerative rate in winter. Other studies such as done by Dar, Baig, Saifullah, Ahmad, Yasmeen and Nizamuddin (2007) verified that *S. wightii* Greville ex J. Agardh collected from sub-tropical Pakistan was found to produce the highest biomass during winter. Similarly, *Sargassum* studied in Hong Kong grew slowest during summer but began to grow fast during autumn, climaxing during the coldest months of January to March (Ang, 2006). Previous studies conducted in the tropical waters of Cape Rachado, Malaysia demonstrated how abundance of *Sargassum* peaked during the intermonsoon seasons when climate was hot and dry (Phang, 1988, 1995). Phang stated that intertidal seaweeds do not grow well during wet or rainy seasons. This is especially so during the monsoon periods experienced by Malaysia. Other studies in Cape Rachado by Wong (1997) revealed that *Sargassum* growth rate was highest in June 1995 while highest degenerative rate was from June to July.

Phenology also differs according to species. Biomass of *S. spinuligerum* var. *crispata* in the beds of South Pacific was higher during warmer seasons of spring and summer, while lower during cooler seasons of autumn and winter (Mattio, Dirberg, Payri & Andrefouet, 2008). However, when compared with *S. decurrens* (R. Brown ex Turner) C. Agardh which is of a different species in the same location, results showed that biomass was higher in spring and lower in summer, proving that seasonal variations were evident among different species.

Table 2.2 summarizes several references of phenological studies on *Sargassum* species, as represented from various locations. Period of highest growth (largest biomass, MTL or peak growth rate) and lowest growth (lowest biomass, MTL or peak degenerative rate) varied for different *Sargassum* species obtained from temperate and tropical regions.

Table 2.2: Phenological studies on *Sargassum* species

Country	Study Site	Species	Highest growth		Lowest growth		Reproductive period	Reference
			Period	MTL/biomass	Period	MTL/biomass		
Italy	Lagoon of Venice	*S. muticum*	Spring	~ 1000 $gDWm^{-2}$	-	-	-	Curiel, Bellemo, Marzocchi, Scattolin & Parisi (1998)
South Africa	Reunion Rocks, KwaZulu-Natal	*S. elegans*	Jan 97	~90 $gDWm^{-2}$	July 97	~50 $gDWm^{-2}$	Throughout the year (peak in May 97)	Gillespie & Critchley (1999)
Pakistan	Pacha, Karachi	*S. latifolium*	Jan - Feb 94	-	Jul - Aug 93	-	-	Hameed & Ahmed (1999)
		S. binderi	Jan - Feb 94	-	Jul - Aug 93	-	-	
		S. boveanum	Jan - Feb 94	-	Jul - Aug 93	-	-	
Brazil	Flamengo Bay, Ubatuba	*Sargassum* sp.	May 89	-	Nov 89	-	-	Leite & Turra (2003)
Malaysia	Cape Rachado, Port Dickson	*S. baccularia*	Jan 95	520.23 $gWWm^{-2}$, 47.88 $gDWm^{-2}$ & 13.35 $gAFDWm^{-2}$	Jan 96	76.14 $gWWm^{-2}$, 9.97 $gDWm^{-2}$ & 1.97 $gAFDWm^{-2}$	Jan-Feb 95 & June-Aug 95	Wong and Phang (2004)
			July 95	501.98 $gWWm^{-2}$, 64.92 $gDWm^{-2}$ & 14.00 $gAFDWm^{-2}$				
		S. binderi	April 96	656.13 $gWWm^{-2}$, 80.81 $gDWm^{-2}$ & 15.25 $gAFDWm^{-2}$	Sept - Oct 1995	68.21 $gWWm^{-2}$, 8.36 $gDWm^{-2}$ & 1.68 $gAFDWm^{-2}$	Jan-Mar 95, May-Oct 95 & Mar 96	
Eritrea	Sheikh Said Island, Southern Red Sea	*S. ilicifolium*	Apr 00	~600 mm	Sept 99	~150 mm	Jan-Jul 00 & Jan-Apr 01	Ateweberhan, Bruggermann & Breeman (2005)
Denmark	Limfjorden	*S. muticum*	Jul 97	~75 $gDWm^{-2}$	Nov 97	~15 $gDWm^{-2}$	-	Pedersen et al. (2005)

Table 2.2: Phenological studies on *Sargassum* species (Continued)

Country	Study Site	Species	Highest growth		Lowest growth		Reproductive period	Reference
			Period	MTL/biomass	Period	MTL/biomass		
Hong Kong	Tung Ping Chau Marine Park	*S. hemiphylum*	Feb	619 ± 199 mm	Jul-Aug	~20 mm	Feb-Mar	Ang (2006)
		S. henslowianum	Nov	783.6 ± 276.3 mm	Apr-May	~20 mm	Nov-Feb	
		S. siliquastrum	Jan	634 ± 221 mm	Apr	~50 mm	Dec-Feb	
		S. patens	Mar	1187 ± 413 mm	Apr	~50 mm	Jan-Mar	
Japan	Bandokorobana Park, Kagoshima	*S. duplicatum*	June 02	24.5 $gWWm^{-2}$ & 263.3 mm	Oct 02 - Jan 03	(Absent)	-	Shimabukuro et al. (2007)
Eritrea	Tewalet, Southern Red Sea	*S. subrepandum*	Feb 00	~1550mm & ~7 $gAFDWm^{-2}$	Aug 00	~100mm & ~0.1 $gAFDWm^{-2}$	Jan-May 00	Ateweberhan et al. (2008)
New Caledonia	South West Lagoon							Mattio et al. (2008)
	1) S01 (Rubble; 2.5m depth)	*S. howaenum*	Autumn 06	563 ± 58.9 $gDWm^{-2}$	Summer 07	170 ± 140 $gDWm^{-2}$	-	
		S. spinuligerum	Spring 06	231 ± 119 $gDWm^{-2}$	Winter 05	9 ± 18 $gDWm^{-2}$	-	
	2) S02 (Sandy rocky; 10m depth)	*S. decurrens*	Spring 06	268 ±117 $gDWm^{-2}$	Summer 07	73 ± 71 $gDWm^{-2}$	-	
		S. spinuligerum	Summer 07	285 ± 132 $gDWm^{-2}$	Winter 06	-	-	
	3) S03 (Rubble; 4.5m depth)	*S. decurrens*	Spring 06	16 ± 18 $gDWm^{-2}$	-	-	-	
		S. howaenum	Summer 07	344 ± 212 $gDWm^{-2}$	Autumn 06	124 ± 72 $gDWm^{-2}$	-	
		S. spinuligerum	Summer 06	121 ± 111 $gDWm^{-2}$	Spring 06	19 ± 38 $gDWm^{-2}$	-	
	4) S04 (Sandy rocky; 2.5m depth)	*S. spinuligerum*	Summer 06	686 ± 269 $gDWm^{-2}$	Winter 05	313 ± 194 $gDWm^{-2}$	-	
Mexico	Baja California peninsula	*S. agardhianum*	Summer	69.25 $gWWm^{-2}$	Winter	2.87 $gWWm^{-2}$	-	Fernández de Lara, Bonilla, & Zaragoza (2010)
		S. muticum	Spring	1770.31 $gWWm^{-2}$	Autumn	23.85 $gWWm^{-2}$	-	
		S. palmeri	Autumn	7.41 $gWWm^{-2}$	Summer	5.83 $gWWm^{-2}$	-	

2.5 Spatial Variation

Spatial variations can be seen across large distances or even small ones if habitat complexity is high (Araújo, Bárbara, Sousa-Pinto & Quintino, 2005). A classic example is spatial variation in the intertidal zone. Environmental factors such as salinity, temperature, desiccation etc. vary along the horizontal gradient of the shore, thus affecting seaweed zonation (Sumich & Morrissey, 2004; Villaça, Fonseca, Jensen & Knoppers, 2010). For instance, *S. thunbergii* was shown to be more abundant in an upper shore zone of southwestern Korea but as it got deeper, the abundance dropped dramatically (Choi & Kim, 2004).

Villaça et al. (2010) studied the spatial distribution of macroalgal species on the Atol das Rocas, Brazil in view of its geomorphological structure. During low tides, the inner intertidal reef flats were completely emerged and macroalgae were subjected to long periods of aerial exposure. Intense desiccation stress limited that habitat to turf-forming and crustose macroalgal species which were built to withstand such stresses. However, in some depressions and crevices, water retention during low tide protects macroalgae from intense desiccation, thus supporting a slightly richer flora. Moving on to greater depths, the reef front and outer pools were constantly submerged even during low tides. With the ideal amount of solar irradiance and lack of desiccation, this environment supported growth of a much richer flora, including species of *Sargassum*.

In the South Pacific, Mattio et al. (2008) discovered that among the same species, spatial variations were evident even in closely located sea beds of the same region. For instance, biomass of *S. howeanum* A. H. S. Lucas in a specific sea bed was highest in autumn and lowest in summer. In another sea bed located nearby, results were found to be inverted, with highest biomass in summer and lowest in autumn.

Thomsen et al. (2006) discovered variations in *Sargassum* abundance even within a relatively uniform *Sargassum* bed. The authors documented that abundance is correlated to minor differences in substratum conditions and depth. Similarly, Lapointe and Bourget (1999) concluded that substratum heterogeneity was the most important factor determining community structure. Generally, most seaweeds tend to attach themselves onto solid substrates such as hard corals, rocks and stones. Curiel et al. (1998) found that growth of *S. muticum* was restricted on tidal flats composed of silt and sand. However, between solid substrates, seaweeds did not seem to have any preferences, instead were equally found on stones, wood, mooring lines and wharves. In another study by Valdez and Ramírez (2008), seaweeds in locations of lower temperature and high quantities of hard substrates gave rise to larger seaweed biomass. Conversely, biomass obtained was much lower in a different location with higher temperature and sandy substrates present.

2.6 Environmental Factors

Benthic algae interacts and depends on their physicochemical environment for survival, with each species responding differently (Lobban & Harrison, 1994). Ateweberhan et al. (2008) stated that annual growth cycles of *Sargassum* is driven by seasonal changes in environment and/or by endogenous control. Besides affecting growth and maturation, these changes also have an impact in life activities at a molecular level. Yotsukara, Nagai, Kimura and Morimoto (2010) concluded that profiling of Japanese kelp protein expressed under certain environmental conditions can help detect environmental stress markers.

Seaweeds respond to a wide variety of ever-changing biotic and physical abiotic factors (Kraufvelin, Lindholm, Pedersen, Kirkerud & Bonsdorff, 2009). Biotic factors in benthic environment include biological interactions among seaweeds, between seaweeds and their epiphytes, of grazing from herbivores and even of impact from predators, such as during human interferences (Lobban & Harrison, 1994). Ateweberhan et al. (2006) hypothesized that competition between and within species, as well as seasonal changes in grazing pressures are partially responsible for seasonal biomass change. This was also agreed upon by Agrawal (2009), stating that in many shores, absence of green algae can be counteracted by removal of grazers. However, Thomsen et al. (2006) reasoned that competition and grazing play only a minor role in growth.

Abiotic factors constitute the external physicochemical environment surrounding seaweeds, which include temperature, pH, salinity, light, nutrient availability, water motion *etc*. (Lobban & Harrison, 1994).

2.6.1 Temperature

Temperature is an important factor that not only regulates seasonal changes in growth pattern, but also affects seaweed morphology and its geographical distribution (Chung et al., 2007). Besides that, temperature also regulates the survival and reproduction of algae (Agrawal, 2009). Agrawal reviewed that zygotes of some brown seaweeds were shown to germinate in a wide range of temperature; *Halidrys siliquosa* (Linnaeus) Lyngbye within 3 - 10 °C, *Ascophyllum nodosum* (Linnaeus) Le Jolis within 4 - 23 °C and *Spermatochnus paradoxus* (Roth) Kütz within 9 - 20 °C. For many temperate seaweeds, temperature and length of day act as seasonal cues for growth cycles (Lüning, 1990). Lüning (1993), indicated that changes in growth rate were more prominently associated with temperature, followed by water salinity and light intensity. This is in accordance with results obtained in Du-Lung Bay of southwest Taiwan whereby water temperature, together with irradiance and precipitation were the determining factors regulating macroalgal seasonality in 2001 and 2003 (Chung et al, 2007). According to Hurtado and Ragaza (1999), increase in biomass of *Sargassum* in the Philippines was positively correlated with slight seasonal variations of water temperature. However, Ateweberhan et al. (2006) reported that biomass of *Sargasuum* from the Red Sea denoted a significantly negative correlation with water temperature. Similarly, Pedersen et al. (2005) reported that growth rate of *S. muticum* in Limfjorden, Denmark was markedly correlated to surface irradiance and water temperature, rather than nutrient availability. This pattern was also seen in other seaweeds, such as in Laminarian plants (Iwao, Yamaguchi, Kurashima & Maegawa, 2010).

Light is important in the photosynthetic responses and metabolic patterns of marine algae, with its quality and quantity changing with depth (Lobban & Harrison, 1994). Raikar, Iima and Fujita (2001) noted that growth of *Gracilaria* species was not restricted by light, but generally grew well as light intensity increased. Hence, it is vital that benthic marine algae settle within the shore's intertidal zone with a depth to which sufficient light is able to penetrate through and reach the algae. However, seaweeds may experience dessication stress when exposed under the sun for too long. Damaging effects of desiccation stress can include protein denaturation and DNA strand breakage, while upon rehydration the possibility of membrane leakage (Shirkey et al., 2003). In many instances, impact of temperature and desiccation stress onto macroalgal community varies with the biogeography of a reef habitat (Villaça et al., 2010).

2.6.2 Salinity and pH

When studying salinity of water, two main components come to view; osmotic potential of water and the ionic composition (Lobban & Harrison, 1994). Osmotic potential is responsible for the flow of water in and out of the cell, thus regulating turgor pressure; while ionic composition based on Ca^{2+}

and HCO_3^- concentrations are responsible for cell membrane integrity and photosynthesis respectively.

Salinity has been well proven to be one of the primary factors that influence seaweed growth (Dawes, 1998). Raikar et al. (2001) experimented with growth rates of *Gracilaria* species from different regions at varying salinity levels. Samples from temperate Japan were shown to grow optimally at normal salinity range (20‰ to 30‰), but grew intolerant when salinity were very low (10‰ to 15‰). However, some species of *Gracilaria* from tropical India and Malaysia experienced better growth rates at lower salinities, some even surviving at salinities of 10‰. In another study along southern Scandinavian coasts, *S. muticum* that were transplanted to different sites of varying salinities experienced better growth and reproduction in water salinities of 14.7 - 27.1 ‰ than those in lower salinities of 9.5 - 17.4‰ (Steen, 2004). The author also reported that ability of *S. muticum* to tolerate hyposaline conditions vary from one life stage to another, being most intolerable during fertilization and increasing in tolerance with germling age.

According to a study by Chung et al. (2007), release of significant urban sewage waste into the reefs of Du-Lang Bay, Taiwan caused salinity levels to be lower than normal, while nutrient levels to be high in the subtidal reefs in 2001. After release of urban sewage was reduced in the following year, salinity levels were allowed to recover and return to normal levels. This shift in salinity levels caused a significant increase in *Gracilaria coronopifolia* J. Agardh biomass in 2002 and 2003. In another study by Agrawal (2009), zygospores of green algae *Spyrogyra hyalina* Cleve were shown to germinate optimally at a pH of neutral to slightly alkaline.

2.6.3 Nutrients

Generally, algae require ten essential elements; four of which are necessary for growth (Dawes, 1998). These include oxygen, carbon, nitrogen and phosphorus. It has been well accepted that phosphorus, nitrate and ammonium are three main growth-limiting nutrients that are necessary for macroalgal survival (Littler, Littler & Titlyanov, 1991; Lapointe, Littler & Littler, 1992; Lobban & Harrison, 1994). In seabeds dominated by *Sargassum* species, large inputs of detritus are contributed by the genus' relatively fast biomass turnover (Pedersen et al., 2005). In comparison to other seaweeds, the decomposition process of *Sargassum* is faster and more complete. This results in the increased turnover and regeneration of inorganic nutrients that will be added into the flow of nutrient cycles. In addition, Nishihara and Terada (2010a) stated that rate of nutrient supply was a function of two aspects; its concentration and the velocity of water movement.

High loading of these nutrients were reported to have caused macroalgae blooms (Chung et al., 2007), as seen in the blooming of *Sargassum* species in coral reefs of southern Taiwan (Hwang, Tsai & Lee, 2004). According to the relative dominance theory model by Littler and Littler (1984), cover of fleshy macroalgae increases when nutrient concentrations are high and grazing pressures are low. This is because increase in surrounding nutrient supply leads to increase in physiological processes, such as nutrient uptake and photosynthesis (Nishihara & Terada, 2010a). In application, Pang, Liu, Shan, Gao and Zhang (2009) attributed *Sargassum* on near-shore coasts to be an efficient biofilter that contributes significantly to the nutrient uptake from effluent wastes. Recognising its benefits, fish farmers have incorporated seaweed cultivation in high nutrient coastal fish farms, with intentions of reducinng dissolved nitrogen and phosphorus in the water while increasing oxygen supply (Kitadai & Kadowaki, 2007).

However, Kraufvelin et al. (2009) found that macroalgae subjected to low nutrient treatments showed higher production rates and produced standing stock larger than those in high nutrient treatments. This was especially true for bigger, long-lived macroalgae like *Sargassum*, as opposed to fast growing algae that possess different nutrient demands. Regarding species diversity, Kraufvelin et al. found that macroalgae subjected to high nutrient treatments, showed higher species diversity. Molles (1999), on the other hand, hypothesized that there is a negative relationship between nutrient availability and algal species diversity. The author explained that high nutrient concentration in the water indicates low number of limiting nutrients affecting algal growth. When this happens, other factors such as light remain the single limiting factor. Only the species of seaweeds most effective at competing for light will dominate the area, thus reducing species diversity.

Generally, the uptake rate of ammonia by seaweeds is higher than the uptake rate of nitrate (Lobban & Harrison, 1994). Some seaweeds showed saturation kinetics for ammonium uptake while others showed a linear uptake as concentrations increase. However, ammonium was shown to be toxic to certain seaweeds at very high concentrations (Brown, 1995). Hurd and Dring (1990) did a study on phosphate uptake of five species of fucoid algae by placing these algae samples in constant conditions of aerated, filtered seawater. Initially, all five species experienced a rapid uptake rate of phosphate which left the medium's phosphate content limited. This was followed by a phase of zero uptake rate and then an intermediate rate. The authors explained that initial rapid uptake of phosphate by these algae can be very useful especially for intertidal species. During low tides, algae located nearer to shore may be exposed and experience nutrient limitation. Therefore it is an advantage for these algae to be able to take up phosphate in a high rate once they are submerged in seawater.

2.6.4 Wave Action

Wave action is a physical factor that can limit distribution of seaweeds especially in the intertidal zone (Wichachucherd, Liddle & Prathep, 2009). By inflicting physical stress on the organism, it causes laterals to tear off and even whole thalli to break from its substrates. The constant water movement also reduces the chances of successful reproduction by diluting the number of spores in the water. Those that successfully fertilize into zygotes risk being swept away by the waves, thus affecting recruitment. In fact, Vadas, Johnson and Norton (1992) discovered that 90 % of *A. nodosum* zygotes that have been settled for 15 minute on pottery plates, were easily dislodged when one low-energy wave of 200 - 500 mm in height surged in. In other cases, wave action was reported to be a positive factor as it induces flow and mixing of seawater, leading to replenishment of dissolved nutrients and determent of grazing activity (Nishihara & Terada, 2010a; Villaça et al., 2010). In fact, Kraufvelin et al. (2009) observed larger biomass in autumn when macroalgae were subjected to higher wave treatments.

Zhang et al. (2009) evaluated that studies done on *S. thunbergii* located in sheltered coasts of Maizuru Bay, Japan and Bohai Bay, China underwent annual reproduction (Umezaki, 1974). On the other hand, populations of *S. thunbergii* located in more wave-exposed shores, such as those of Chiba and Nagasaki, Japan were reported to have biannual reproduction (Akira & Masafumi, 1999). From these studies, Zhang et al. concluded that flexible life history of *S. thunbergii* is attributed to wave-exposure regimes. Another study done by Wichachucherd et al. (2009) showed that recruitment of a different brown seaweed, *Padina boryana* Thivy was higher in a sheltered shore than in an exposed one. In the Lagoon of Venice, *S. muticum* colonized sheltered to moderately exposed sites and thalli produced there were more developed compared to seaweeds in exposed sites (Curiel et al., 1998).

2.6.5 Rainfall

Malaysia’s rainfall distribution pattern is determined by seasonal wind flow patterns, mainly the Northeast Monsoon (November to March) and the

Southwest Monsoon (June to September). Due to its topography, Port Dickson which is located at the coast of southwest Malaysia is subjected to maximum rainfalls from October to November while minimum rainfall in February.

Effects of rainfall onto seaweed growth was reviewed by Wong and Phang (2004), concluding that rainfall in the tropical coast of Cape Rachado, Malaysia was the most important factor controlling the biomass production of *Sargassum* species. In Tanzania, Msuya and Salum (2006) noted that *Euchema denticulatum* (N. L. Burman) F. S. Collins & Hervey and *Kappapycus alvarezii* (Doty) Doty ex P. C. Silva experienced lower growth rates during periods of long rains with hot seasons, as opposed to periods of short rains and warm seasons. Similarly, Hameed and Ahmed (1999) noted that biomass of seaweeds were highest during the pre-monsoon season.

El Niño which arises from differences in water surface temperature is an oceanic phenomenon that changes weather patterns, originating from the equatorial Pacific and spreading its abnormal effects globally (Malaysian Meteorological Department, 2011). Whenever this occurs (every three to seven years), it brings drought to the western side of the Pacific, while severe floods occur in the central and eastern Pacific. In Malaysia, El Niño results in abnormally dry conditions, often taking effect in forest fires (Suplee, 1999). On the other hand, La Niña which produces the opposite effects is characterized by large cloud formation and heavy rainfall in Malaysia. Generally, both El Niño and La Niña were noted to have minimal impact on Malaysian rainfall. Only when El Niño occurrences are strong, do Peninsular Malaysia experience below average rainfall during the southwest monsoon.

CHAPTER 3.0

MATERIALS AND METHODS

3.1 Site of Study.

The site of study, Teluk Kemang, Port Dickson (2° 26’ N latitude; 101° 51’ E longitude) is an inshore tidal area along the Straits of Malacca (Abu Hena, Misri, Japar Sidik, Hishamuddin & Hidir, 2001) (Figure 3.1). Not to be mistaken with the popular public beach of Pantai Teluk Kemang which is located only 1.6 km to the North and separated by a cape, the study site is relatively secluded and is less disturbed by tourists.

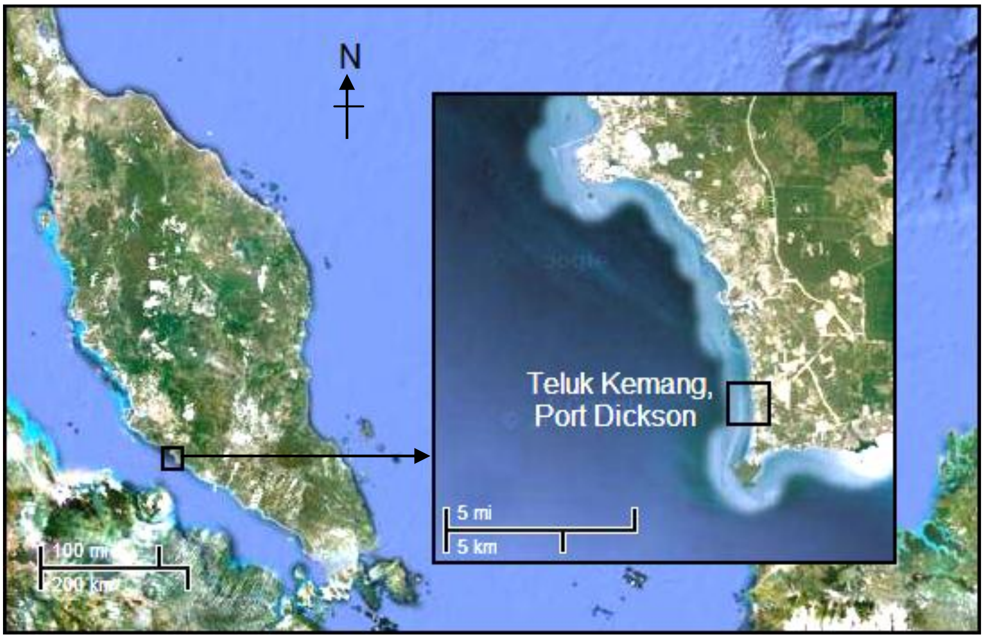


Figure 3.1: Map of Teluk Kemang, Port Dickson facing Straits of Malacca

Just off the shore, there are coral reef flats that are dominated by *Sargassum*, *Turbinaria* and *Padina*. This site is less studied compared to the nearby Cape Rachado (2° 24’ N latitude; 101° 51’ E longitude), located 2.5 km to the South. Along the coast of Cape Rachado, Phang (1995) identified 69 species of macroalgae, of which Wong (1997) reported *Sargassum*, *Turbinaria* and *Padina* to be the dominant species. Two patches of coral reefs, adjacent to each other are clearly seen from aerial view (Figure 3.5). From the shore, the reef located on the left side was labelled Left Reef (LR) (2° 26’ 15” N latitude; 101° 51’ 19” E longitude) while the reef on the right side was labelled Right Reef (RR) (2° 26’ 24” N latitude; 101° 51’ 18” E longitude). LR, fronting a resort (Kayns Resort) was measured to be estimately 100 m in width and 120 m in length, while RR was averagely 140 m in width and 930 m in length.

During the course of the study, both reef flats were relatively exposed during the daytime low tides of 0.3 m or less above sea level. According to Tide Tables Malaysia (2009, 2010), this occurred 73 times from September 2009 to September 2010. At 0.3 m or less above sea level, both reefs were exposed for roughly 3 to 4 hours, allowing safe sampling of seaweeds during this duration. Period of extreme low tides, with water levels receding down to 0.1 m or less above sea level was recorded from February 2009 to April 2009.

Although located only 80 m apart, there were many geographical differences between the LR and RR. Field observations showed that the beach facing RR consisted of rocky shore and sandy beach with slight siltation. The reef itself was made up of corals, but predominately of sand and rubble. In addition, there were large rock formations on the outer reef's edge that sheltered the inner reef from harsh wave action. During daytime low tides of the spring tide period, most part of the RR was observed to be exposed when tide levels reach 0.3 m or less above sea level (Figure 3.2B, D).

On the other hand, the beach facing the LR consisted only of sandy beach, while the reef itself was mainly made up of corals and solid boulders. Field observations showed that the LR was more exposed to wave action from the sea, unlike in the RR that received protection from large rock formations. However, when tide levels reach 0.3 m above sea level, most part of the LR was still seen to be submerged under water, only exposing random patches of large corals and boulders onto the surface (Figure 3.2A). Only when water levels reach 0.1 m or less above sea level was the LR completely exposed from the water (Figure 3.2C).

Throughout the study period, many changes occurred on the beach side that might have affected the ecosystem (Figure 3.3). From February 2010 onwards, tarred roads and parking lots were laid in front of the resort, up on shore towards the left side, while concrete-stilted balconies were constructed on the rocky beach towards the right side. In addition, the LR constantly receives effluent wastes directly from the resort. In the midst of all these changes, the Department of Fisheries Malaysia has enforced a law to protect the reef ecosystem, prohibiting anyone from collecting shells, molluscs or corals from the reefs. Despite the enforcement, it was still common to find fisherman in this area, especially on the sheltered RR.

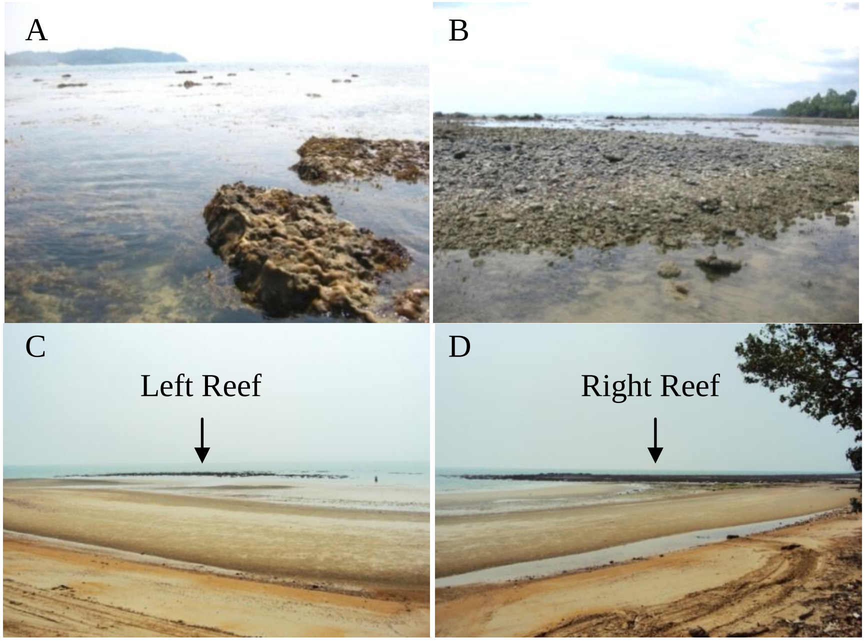


Figure 3.2: Pictures taken during daytime low tide of 0.3 m above sea level of (A) mostly submerged Left Reef and (B) mostly exposed Right Reef, and during daytime low tide of 0.1 m above sea level of completely exposed (C) Left Reef and (D) Right Reef

Figure 3.3: Changes that occurred throughout period of study. (A) Laying of tarred roads facing Left Reef, (B) building of balcony on concrete stilts facing Right Reef, (C) flow of effluent waste from resort in front of Left Reef and (D) enforcement in law to protect reefs

3.2 Preliminary Studies

The daytime low tides of the monthly spring tide periods allow only an estimate of 3 to 4 hours of safe snorkeling on the reefs of Teluk Kemang before strong currents sweep in to increase the risk of field work. With time being a limiting factor, it is crucial that the number and size of quadrats be small enough to remove unnecessary wastage of work time, as well as to prevent overharvesting of seaweeds. However, quadrat number and size have to be large enough to obtain sufficient and reliable data. Therefore efficiency tests were conducted to balance between what is ideal and practical.

Wiegert's Nested Quadrat Method, as described by Wong (1997), was used to determine ideal quadrat size for this study. In the case of Teluk Kemang reefs, a total of 12 trial samples were collected; six trial samples from LR and RR individually. Collection was done by laying 50 m line transects on both reefs, parallel to shore. Trial samples were collected every 10 m interval using a nested quadrat of three different quadrat sizes, as shown in Figure 3.4.

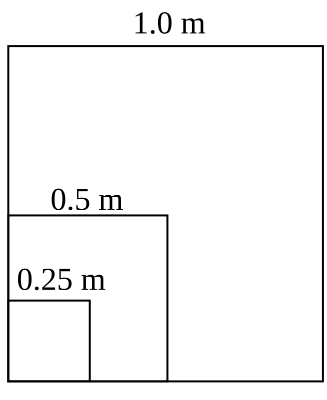


Figure 3.4: Layout of nested quadrat with three different sizes used in Wiegert's Nested Quadrat Method

An ideal quadrat size would be one that has its two main factors at a minimum; the relative cost in relation to time (C_r) and the relative variance (V_r) obtained from sampling between quadrats. Firstly, ash-free dry weight (AFDW) of trial samples were obtained for different quadrat sizes. Mean biomass per m^2 of each reef was then calculated separately, followed by its variance (V_m). Relative variance (V_r) of each quadrat size was obtained by dividing V_m of a quadrat size with V_m of the smallest quadrat size. Relative cost (C_r) was obtained from the formula below:

$$C_r = \frac{C_f + x\,C_v}{C_f + C_v}$$

Where, C_f = Fixed cost of each quadrat, time spent walking between quadrats

C_v = Time spent in sampling the smallest quadrat

x = Area of quadrat

V_rC_r were then plotted against the different quadrat areas. Quadrat area with the lowest V_rC_r were chosen as the ideal quadrat size.

3.3 Sampling Methods

3.3.1 Line Transect and Systematic Quadrat Sampling

Field trips were conducted on a monthly basis to Teluk Kemang, Port Dickson for a period of 13 months, extending from September 2009 to September 2010. Field trips were planned to coincide with the daytime low tides of the monthly spring tide periods, with reference to Tide Tables

Malaysia (2009, 2010) for Port Dickson, Negeri Sembilan Darul Khusus (Latitude 2° 31' N, Longitude 101° 47' E).

On the site of study, a 50 m line transect was haphazardly laid on the left and right reef, parallel to the shoreline (Figure 3.5). Along each line, a 0.25 m^2 (0.5 m × 0.5 m) quadrat was placed sequentially at every 10 m interval, beginning from 0 m, extending to 50 m. On the LR, quadrats were labeled from left to right as Q1 to Q6. Continuing from there, quadrats on the RR were labeled from left to right as Q7 to Q12.

Figure 3.5: Overlaying of line transect and systematic quadrat-sampling on satellite image of Left Reef and Right Reef, extracted from Google Earth

Two types of samplings were conducted throughout the research period; monthly non-destructive and bimonthly destructive sampling. Both types of samplings employed the line transect and systematic quadrat sampling method. The line transect was laid parallel to shore (horizontally) as opposed to perpendicular to shore, across intertidal zone (vertically). The latter method is advantageous if the objective of the study was to measure changes in vertical distributions to depict zonation patterns. However, this information is irrelevant in the current study, as the main objective was to measure changes over time. Thus the method of laying the line transect horizontally was chosen because it is advantageous for long-term monitoring of fixed plots. This was justified by Murray, Ambrose and Dethier (2002) who stated that “Shifts in distributions over short horizontal scales within the same vertical tidal range also may be important to document.” (p. 55).

3.3.2 Non-Destructive Sampling

The exact coordinate of each permanent quadrat was initially recorded by GPS for easy location in the monthly samplings. Within each quadrat, all *Sargassum* samples were tagged at the base using plastic cable ties, bearing labelled Dymo embossing tapes. This enabled monitoring of the exact same samples for the subsequent months. During the monthly census, additional tags were fastened onto any samples within the permanent quadrats that did not possess any tags; while previous tags that were missing were noted.

Tagged samples were identified of their species based on morphology, with references to taxonomic literature by Trono (1997). Despite reports on polymorphism, each *Sargassum* species was found to possess distinct characteristics that set it apart from one another. These were then carefully measured from the holdfast up to the apex of its longest branch to obtain the thallus length. Presence of any receptacles was also noted. These were repeated on a monthly basis for 13 months.

Thallus length measurements of each species were averaged to obtain mean thallus length (MTL) by quadrat and by month. Data for monthly thallus lengths were arranged according to length classes in order to determine the length frequency distribution. Absolute growth rate or elongation rate (mm day^{-1}) were determined by calculating the differences in thallus length between two consecutive sampling occasions, and dividing the results with the number of days in between samplings. Lastly, percentage fertility (% Fert) was obtained by dividing the number of fertile plants by total number of plants. This was done according to quadrats and months. Monthly percentage loss of tags was calculated for each species by dividing the number of missing tags in a month with total number of tags of the previous month.

3.3.3 Destructive Sampling

For destructive sampling, the first quadrat of each reef was randomly placed every bimonthly. Special notice was taken to ensure destructive quadrats do not intersect with quadrats of non-destructive sampling. Instead of tagging the samples, all *Sargassum* species within each destructive quadrat were harvested from the holdfast. These were placed in separately labelled plastic bags which were then kept in an ice box for preservation.

Back in the laboratory, seaweed samples were washed under running tap water to remove any sand, silt or epiphytes. Individual *Sargassum* species were identified based on morphology, with references to taxonomic literature by Trono (1997).

For every sample, the thallus length was measured using a 30 cm ruler. Presence of any receptacles was also noted and small parts were excised and preserved in ethanol. These reproductive parts were later examined for their sexuality using cross section technique, stained with Methylene Blue and then observed under light microscope. As for the vegetative samples, total wet weight (WW), dry weight (DW) and ash-free dry weight (AFDW) of each species were determined for each quadrat. Firstly, all samples of each species within a quadrat was blot dried with paper towels and weighed to one decimal point using an analytical balance (Adventurer™ Pro Av812, USA) to obtain the wet weight. This was followed by oven drying the samples at 105 °C for 48 hours and reweighing them to four decimals to obtain total dry weight per quadrat. These were then placed in ceramic crucibles and combusted at 550 °C for 6 hours in the muffle furnace. Combusted samples were weighed using an analytical balance (Adventurer™ Pro Av812, USA) to four decimals which were then subtracted from the initial dry weight to obtain ash-free dry weight.

Thallus length measurements of each species were averaged to obtain mean thallus length (MTL) by monthly quadrats and by overall months. Data for monthly thallus lengths were arranged according to length classes in order to determine the length frequency distribution. Weight measurements (WW, DW and AFDW) within each quadrat were divided by the area of quadrat (0.25 m^2) in order to convert to biomass of unit g m^{-2} (g WW m^{-2}, g DW m^{-2}, g AFDW m^{-2}). For every sampling occasion, biomass from Q1 to Q12 were averaged to obtain bimonthly biomass. Percentage fertility (% Fert) was also calculated by dividing the number of fertile plants by total number of plants collected and arranged according to monthly quadrats and overall months. In addition, percentage sexuality of dioecious samples per month were obtained by dividing the number of male/female plants by total number of plants.

3.4 Seawater Analysis

Environmental parameters of the study site were monitored every month on LR and RR separately. Seawater temperature was measured on the site using a portable HANNA meter (HI 9143, USA). For further analysis, seawater samples were collected into plastic bottles and kept in ice box for preservation. In the laboratory, water compositions were tested according to given standard procedures; pH using a pH meter (Sartorius, PB-11), salinity using a hand-held refractometer (Atago, Master-S/Millα) and nutrient levels (nitrate, ammonia and phosphate) using a Hach portable spectrophotometer (DR 2800, USA) (Appendix A). Parameters such as overall monthly rainfall, mean temperature and mean solar radiation, as recorded by the weather station of Malacca, were provided by the Malaysian Meteorological Department, Petaling Jaya.

3.5 Statistical Analysis

All data collected in this study were keyed into Microsoft Office Excel 2007 while all statistical analyses were conducted using SPSS 15.0 software. One way ANOVA and Post Hoc Test (Tukey HSD) were applied to test for significant changes in sample measurements (biomass, mean thallus length and percentage fertility) along quadrats and months from destructive and non-destructive samplings. Any significant differences in measurements between LR and RR were also tested. The effects of environmental parameters on *Sargassum* growth were analysed using redundancy analysis (RDA), which is a constrained form of the linear ordination method, using CANOCO Version 4.55. This multivariate analysis was conducted for log transformed data of both destructive (MTL, WW, DW, AFDW) and non-destructive samplings (MTL) of each species. In addition, cross correlation with time lag of two months were also conducted separately on both reefs among *Sargassum* measurements (Destructive sampling: MTL, WW, DW, AFDW, number of fertile plants; Non-destructive sampling: MTL, growth rate and number of fertile plants) and environmental parameters.

Before applying these statistical analyses, Levene's Test of homogeneity was employed to test for variance homogeneity, while one sample Kolmogorov-Smirnov Goodness-of-fit test employed to test normality of data. Whenever needed, data were log transformed to meet the assumptions of parametric test. Although results of ANOVA were based on transformed data, graphical figures were based on untransformed data for better clarity.

CHAPTER 4.0

RESULTS

4.1 Species Identification

Three *Sargassum* species were found in Teluk Kemang; *S. polycystum* (Figure 4.1A), *S. binderi* (Figure 4.1B) and *S. siliquosum* (Figure 4.1C). These were identified based on morphological appearances, summarised in Table 4.1.

Table 4.1: Summary of main characteristics of *Sargassum* species

Characteristics	*S. polycystum*	*S. binderi*	*S. siliquosum*
Holdfast	- Discoid with rhizoids	- Discoid	- Shield-shaped to massive and amorphous
Stem	- Brownish - Finely villose	- Short - Terete	- Terete - Warty - Finely felted
Branches	- Crowded at distal end of stem - Terete - Lumpy - Several transformed into horizontal stolons	- Distinctly compressed - Smooth	- Terete
Leaves	- Broadly lanceolate to linear-lanceolate	- Linear to linear-lanceolate	- Lanceolate to oblong
Vesicles	- Spherical-ovate to slightly elliptical	- Oblong-elliptical - Slightly compressed	- Spherical, oblong or obovate - Slightly compressed, blunt, plain, apiculate or ribbed
Receptacles	- Dioecious - Male: racemose to paniculate - Female: cymose	- Monoecious - Dense cymes	- Dioecious - Male: terete and pinched - Female: receptacular branch compressed and twisted

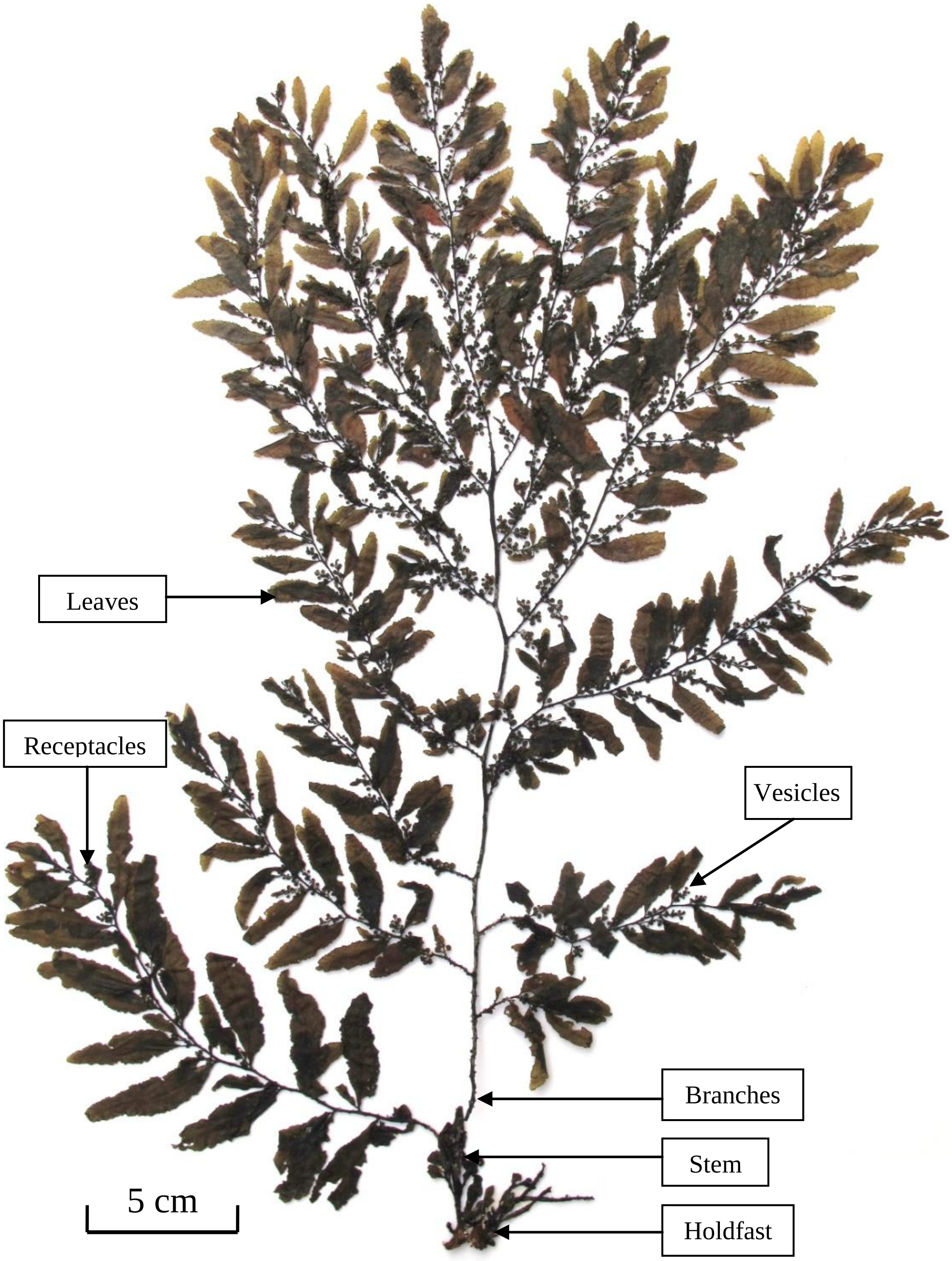


Figure 4.1: Herbarium sample of *S. polycystum*

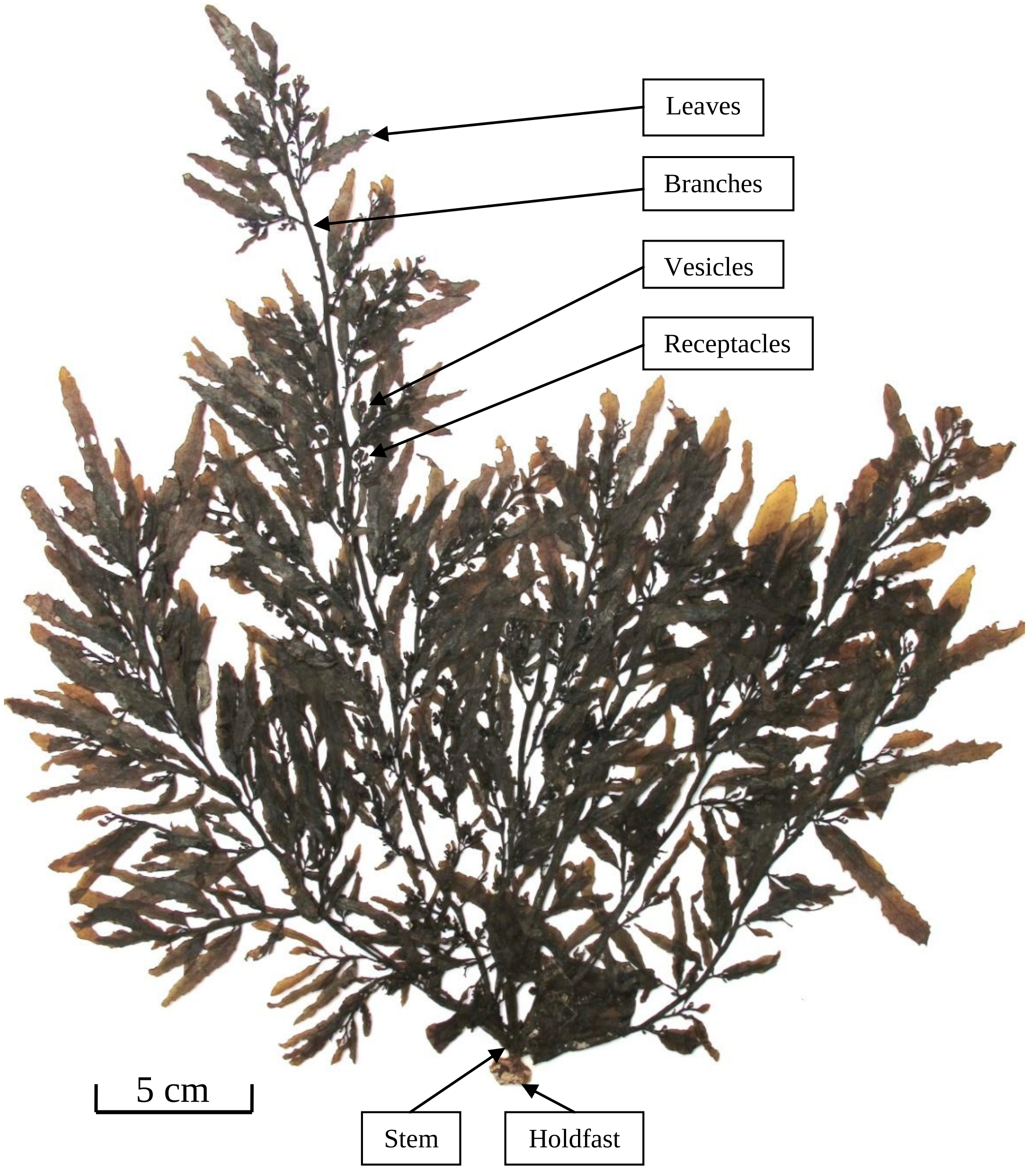


Figure 4.2: Herbarium sample of *S. binderi*

Figure 4.3: Herbarium sample of *S. siliquosum*

4.2 Preliminary Studies

Biomass (AFDW) of trial samples collected from Wiegert's nested quadrats was used to determine ideal quadrat size. Figure 4.4A shows that on the LR, quadrat size of 0.5 m was the most suitable for *S. binderi* while 1.0 m was best for both *S. polycystum* and *S. siliquosum.* However, results differed with that of the RR (Figure 4.4B), whereby quadrat size of 0.25 m was most suitable for *S. siliquosum*, while 0.5 m was for *S. polycystum* and lastly 1.0 m for *S. binderi.*

One-way ANOVA followed by Post Hoc Test (Tukey HSD) was tested for variation in biomass from different quadrat sizes. This resulted in significant difference (p < 0.05) only for trial samples of *S. siliquosum* collected from the LR, which was between quadrat size of 0.25 m and 1.0 m. Variation in biomass for *S. polycystum* and *S. binderi* were tested not significantly different (p > 0.05) between quadrat sizes for both LR and RR. Taking into consideration the lowest value of VrCr for different species and reefs, quadrat size of 0.5 m was chosen as the most suitable for this study in Teluk Kemang.

The smaller area of the LR, measuring up 120 m in length limited the number of quadrats able to be contained. In order to synchronise the methods used on LR and RR, the number of quadrats chosen for this study was 6 quadrats each. This standardization prevented overharvesting of seaweeds as well as to minimize error in calculations.

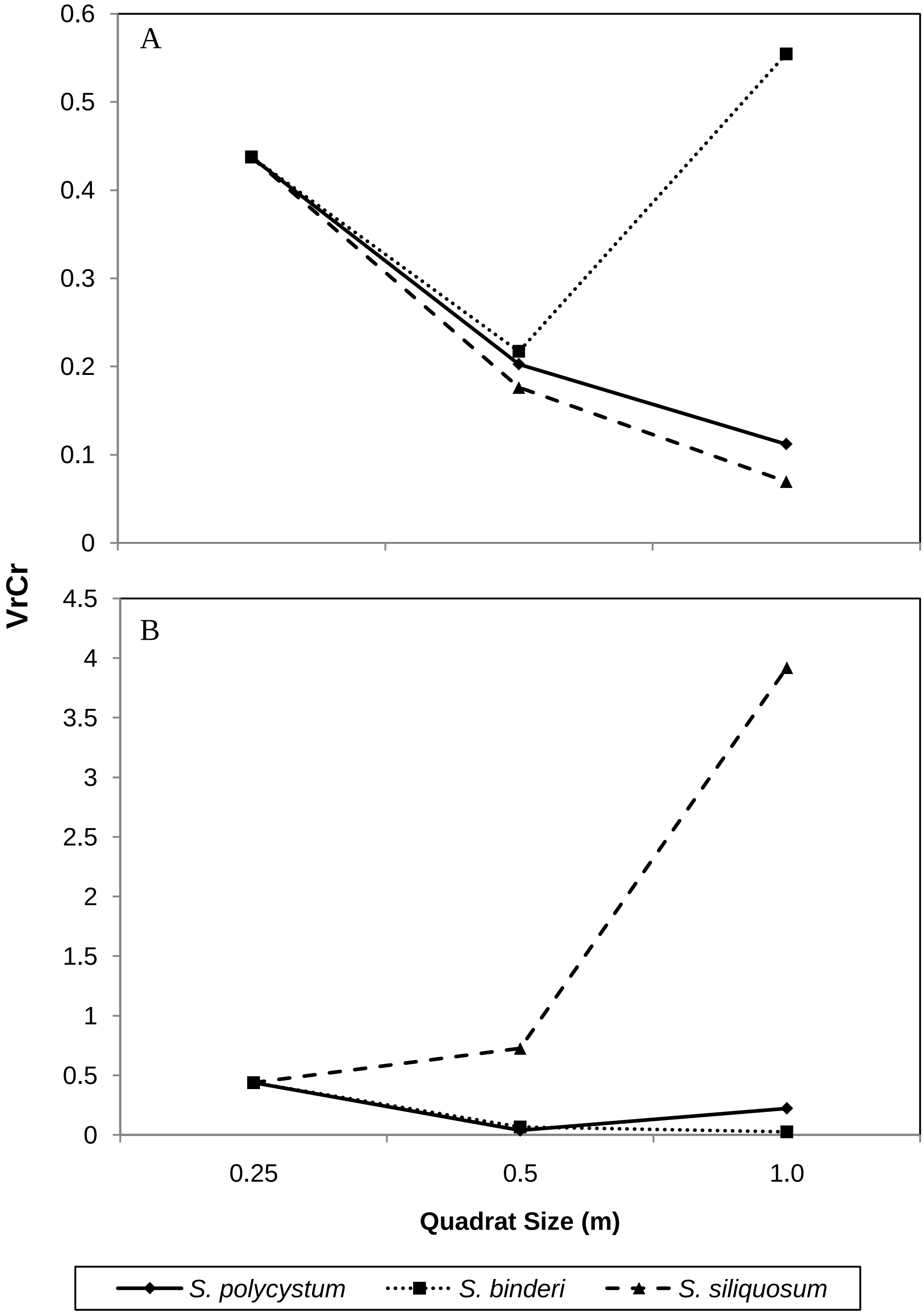


Figure 4.4: Plot of VrCr against quadrat size for *Sargassum* trial samples collected from (A) Left Reef and (B) Right Reef

4.3 Environmental Parameters

4.3.1 Seawater Composition

In this study, seawater temperature, pH and salinity were tested on the field every month using a portable HANNA meter. Technical error on the HANNA meter distorted the monthly readings of Dissolved Oxygen. Thus, for more accurate results, DO readings were not included in this study. One-way ANOVA denoted significant difference ($p < 0.05$) in seasonal changes of all seawater parameters; water temperature, salinity and pH (Appendix B).

Figure 4.5A demonstrates the seasonal changes of these parameters throughout the sampling period. Data for seawater temperature from the months of December 2009 to February 2010 were not available due to technical error on the HANNA meter used. Pearson's correlation coefficient confirmed that fluctuations in seawater temperature and pH were significantly correlated with each other ($p < 0.05$). Overall, salinity, water temperature and pH were relatively lower at the last quarter of the year (September 2009 to December 2009) which then increased in the first three quarters of the following year (January 2010 to September 2010).

4.3.2 Nutrient Levels

Nutrients tested in this study include nitrate, ammonia and phosphate (Figure 4.5B). One-way ANOVA showed that there were significant differences ($p < 0.05$) in the monthly nitrate and phosphate levels in the seawater (Appendix B). Ammonia levels were relatively stable throughout the sampling period. Pearson's correlation coefficient showed that fluctuations in nitrate levels were negatively correlated with ammonia levels ($p < 0.05$).

Nitrate levels fluctuated throughout the sampling period in a bimodal distribution, having its two peaks in December 2009 and May-June 2010. As for ammonia and phosphate levels, both were relatively higher from September 2009 to February 2010 which then decreased until September 2010.

4.3.3 Meteorological Data

Three types of meteorological data over the state of Malacca were supplied by the Malaysian Meteorological Department. These include 24 hour mean ambient temperature, mean daily global radiation and monthly rainfall. One-way ANOVA was not applicable for these parameters because data provided by the department were either in average form or in total amount without any repeated readings. Data for mean daily radiation was only provided until March 2010 due to faulty weather station in Malacca.

According to Figure 4.5C, ambient temperature remained relatively stable, with the lowest occurring in November 2009. This month also saw the lowest in mean daily radiation, which was probably due to a relatively high rainfall in that month. Monthly rainfall then dropped to its lowest in January 2010 and fluctuated to its highest in June 2010.

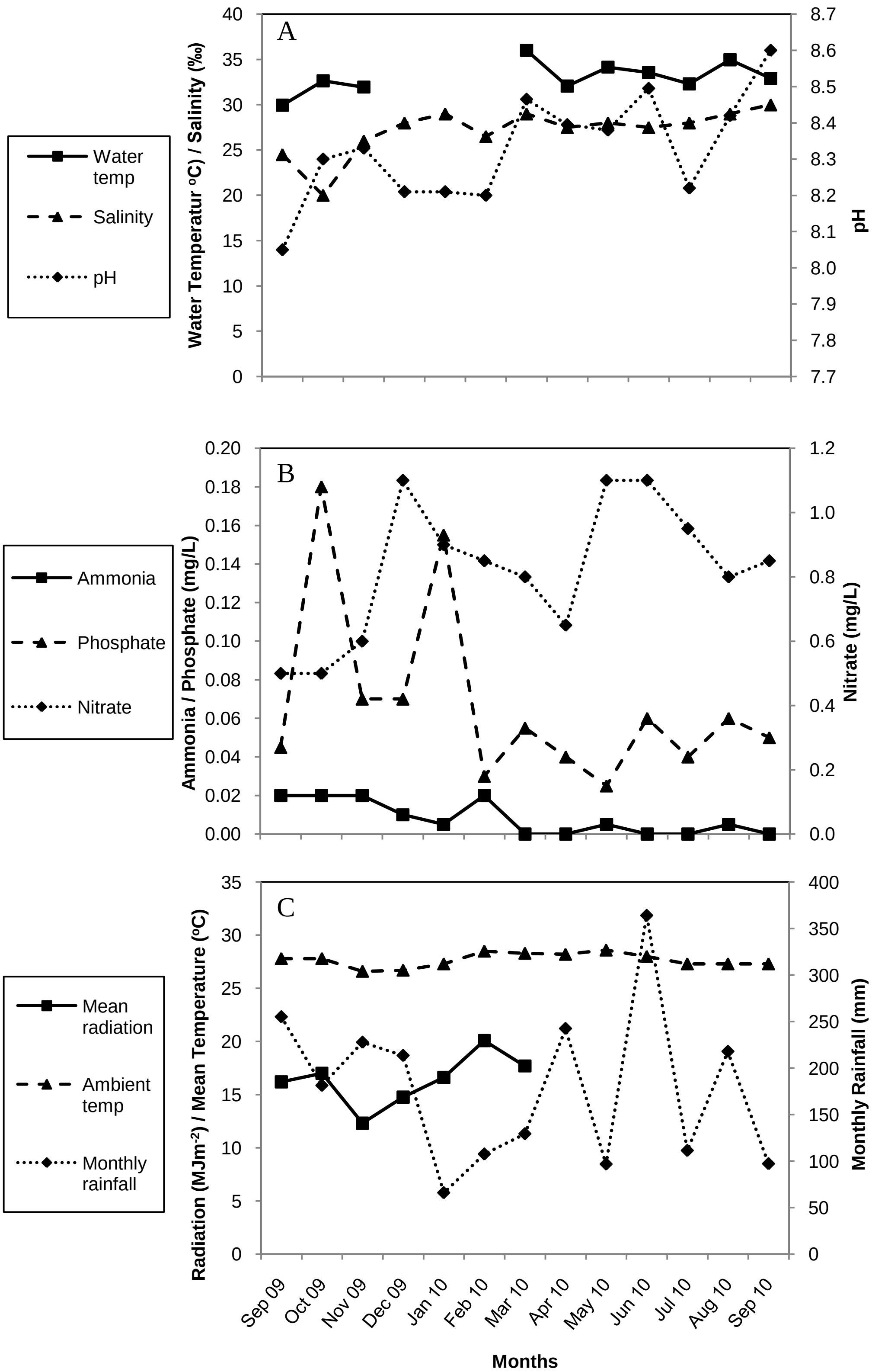


Figure 4.5: Seasonal variation in environmental parameters from September 2009 to September 2010. (A) Water temperature, salinity and pH (B) ammonia, phosphate and nitrate, and (C) mean radiation, ambient temperature and monthly rainfall

4.4 Destructive Sampling

Destructive sampling was conducted bimonthly on the 2nd September 2009, 13th November 2009, 4th January 2010, 3rd March 2010, 2nd May 2010, 26th July 2010 and 22nd September 2010. All raw data was listed in Appendix C.

4.4.1 Measurements by Quadrats

4.4.1.1 September 2009

A total of 307 plants were collected (*S. polycystum* = 134 plants; *S. binderi* = 47 plants; *S. siliquosum* = 126 plants), 176 plants from the Left Reef (LR) (*S. polycystum* = 46 plants; *S. binderi* = 31 plants; *S. siliquosum* = 99 plants) and 131 plants from the Right Reef (RR) (*S. polycystum* = 88 plants; *S. binderi* = 16 plants; *S. siliquosum* = 27 plants) (Table 4.2). On the RR, *S. polycystum* were found in every quadrat but *S. binderi* and *S. siliquosum* were found in only a few (*S. binderi*: Q7, Q9, Q10 & Q12; *S. siliquosum*: Q7 & Q8).

ANOVA on log-transformed data tested significant ($p < 0.05$) in the MTL changes of *S. polycystum* (F = 3.501) and *S. siliquosum* (F = 3.903) along quadrats (Appendix D). Generally, MTL of *Sargassum* in Q1 (*S. polycystum*: 140.75 mm; *S. binderi*: 200.82 mm; *S. siliquosum*: 92.67 mm) were shorter but increased toward Q3 (*S. polycystum*: 191.75 mm; *S. binderi*: 205.50 mm; *S. siliquosum*: 227.69 mm) and Q4 (*S. polycystum*: 272.53 mm; *S. binderi*: 191.64

mm; *S. siliquosum*: 219.25 mm), which then decreased again until Q6 (*S. binderi*: 137.50 mm; *S. siliquosum*: 99.58 mm) of the LR (Figure 4.6).

Trend of biomass along quadrats were illustrated in terms of wet weight (Figure 4.7), dry weight (Figure 4.8) and ash-free dry weight per quadrat (Figure 4.9). Biomass of *S. polycystum* on the RR was gradually increasing from Q7 (47.28 g WW m^{-2}; 8.01 g DW m^{-2}; 6.58 g AFDW m^{-2}) to Q11 (699.80 g WW m^{-2}; 76.61 g DW m^{-2}; 60.79 g AFDW m^{-2}). On the other hand, biomass of *S. siliquosum* was decreasing from Q7 (658.92 g WW m^{-2}; 84.96 g DW m^{-2}; 69.45 g AFDW m^{-2}) to Q8 (136.04 g WW m^{-2}; 24.47 g DW m^{-2}; 20.65 g AFDW m^{-2}).

MTL was not significantly correlated ($p > 0.05$) with biomass for *S. polycystum* (MTL & WW: r = 0.257; MTL & DW: r = 0.212; MTL & AFDW: r = 0.238), *S. binderi* (MTL & WW: r = 0.197; MTL & DW: r = 0.236; MTL & AFDW: r = 0.237) and *S. siliquosum* (MTL & WW: r = 0.116; MTL & DW: r = 0.076; MTL & AFDW: r = 0.001). For instance, biomass of *S. polycystum* from Q10 (300.8 g WW m^{-2}; 11.68 g DW m^{-2}; 9.95 g AFDW m^{-2}) was much lower than from Q11 (699.8 g WW m^{-2}; 76.61 g DW m^{-2}; 60.79 g AFDW m^{-2}). Despite lower biomass, MTL of the same samples in Q10 (279.09 mm) was found to be larger than that of Q11 (174.14 mm).

All three species of *Sargassum* were found to be fertile in September 2009 (Table 4.2). Overall, *S. polycystum* had a percentage fertility of 52.99 % (71 fertile plants), *S. binderi* 48.94 % (23 fertile plants) and *S. siliquosum*

38.10 % (48 fertile plants). Highest percentage was found in Q9 whereby *S. binderi* had 100.00 % fertility (2 fertile plants). Generally, fertility was higher on the left reef with almost every quadrat containing fertile plants of every species.

Pearson's correlation revealed that percentage fertility was significantly correlated ($p < 0.01$) with MTL (*S. polycytsum*: r = 0.718; *S. binderi*: r = 0.751; *S. siliquosum:* r = 0.747) but not significantly correlated ($p > 0.05$) with biomass.

Table 4.2: Percentage Fertility (%) of *Sargassum* species collected from destructive sampling on September 2009 along line transects of (A) Left Reef and (B) Right Reef

A

Quadrat (Left Reef)	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
1	4	2	50.00	11	7	63.64	18	3	16.67
2	10	7	70.00	5	2	40.00	8	4	50.00
3	4	2	50.00	2	1	50.00	13	8	61.54
4	17	13	76.47	11	5	45.45	4	2	50.00
5	11	10	90.91	0	0	0.00	30	12	40.00
6	0	0	0.00	2	1	50.00	26	6	23.08
Total	46	34	52.99	31	16	51.61	99	35	35.35

B

Quadrat (Right Reef)	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
7	7	4	57.14	1	0	0.00	20	12	60.00
8	9	4	44.44	0	0	0.00	7	1	14.29
9	2	0	0.00	2	2	100.00	0	0	0.00
10	11	6	54.55	2	0	0.00	0	0	0.00
11	36	9	25.00	0	0	0.00	0	0	0.00
12	23	14	60.87	11	5	45.45	0	0	0.00
Total	88	37	42.05	16	7	43.75	27	13	48.15

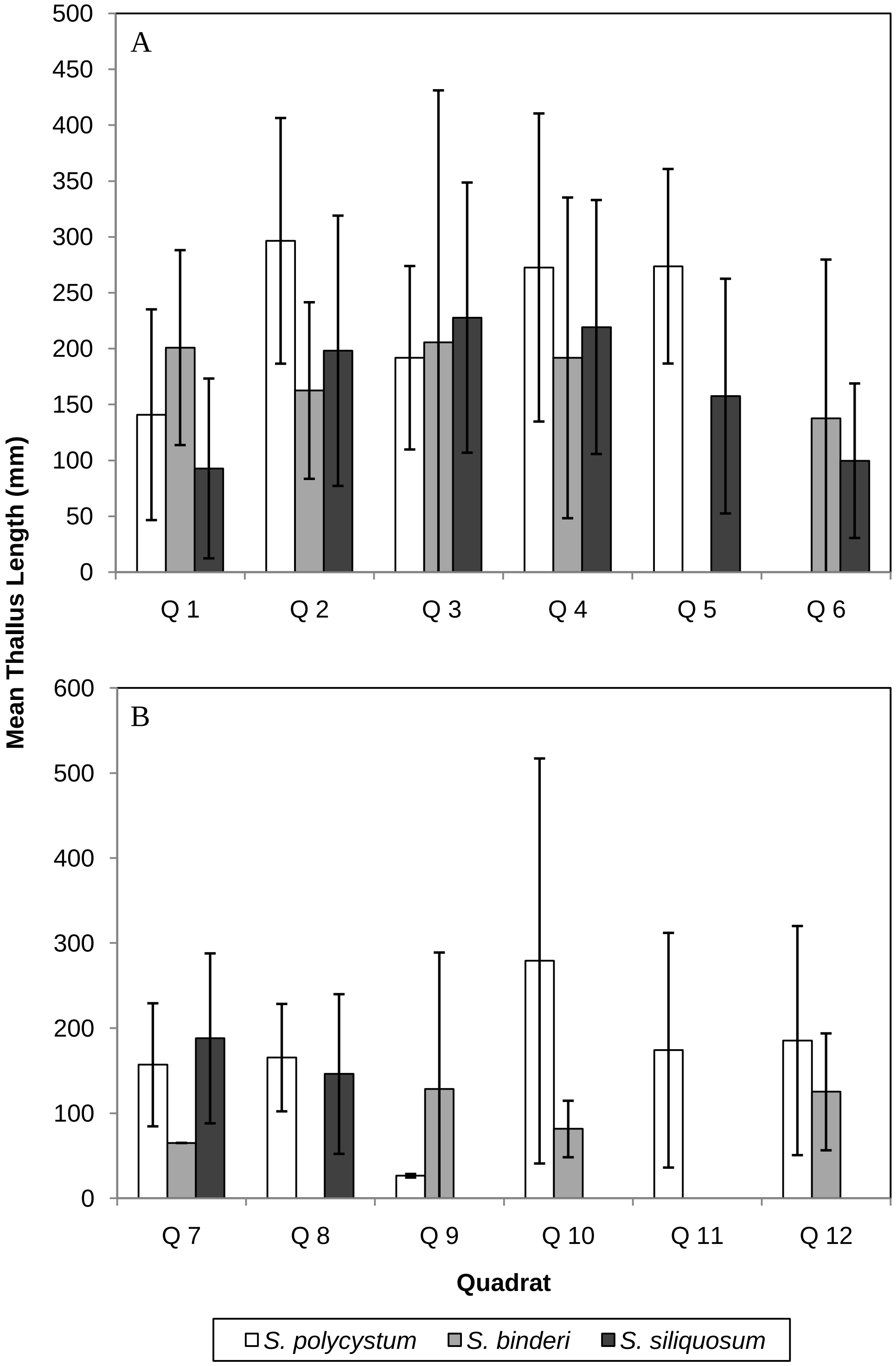


Figure 4.6: Mean thallus length (mm ± SD) of *Sargassum* species collected from destructive sampling in September 2009 along line transects of (A) Left Reef and (B) Right Reef

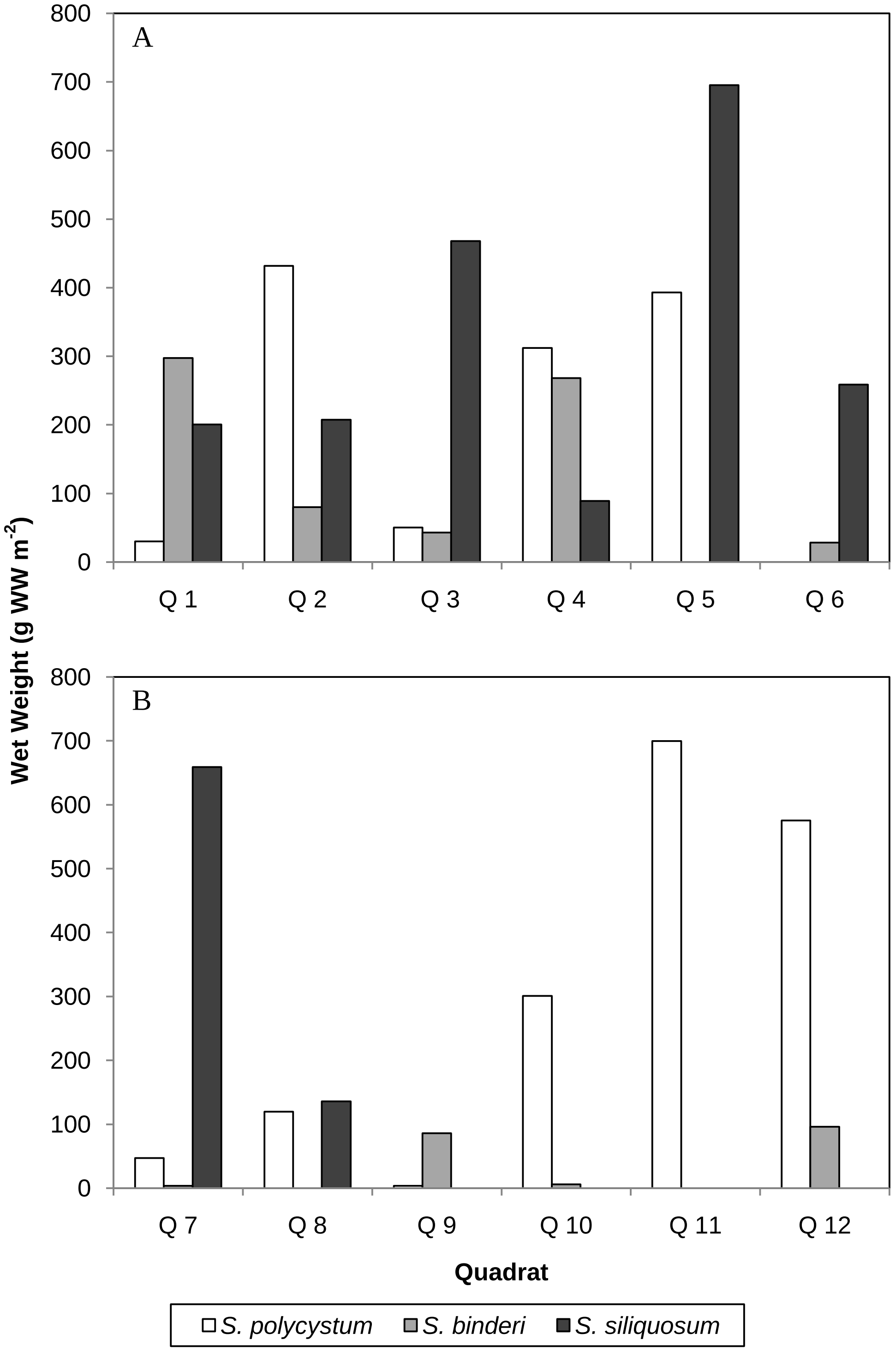


Figure 4.7: Wet weight (g WW m^{-2}) of *Sargassum* species collected from destructive sampling in September 2009 along line transects of (A) Left Reef and (B) Right Reef

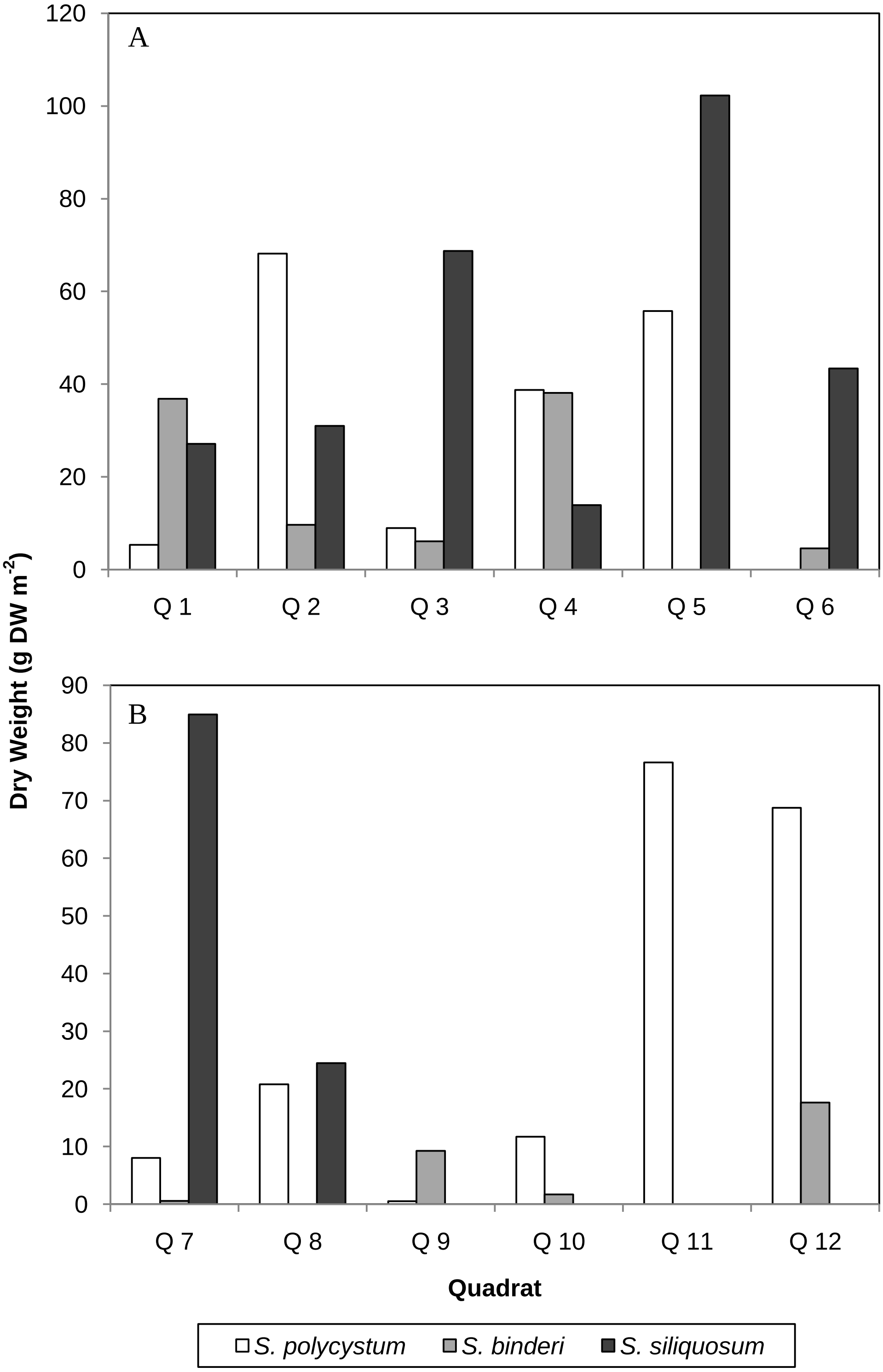


Figure 4.8: Dry weight (g DW m^{-2}) of *Sargassum* species collected from destructive sampling in September 2009 along line transects of (A) Left Reef and (B) Right Reef

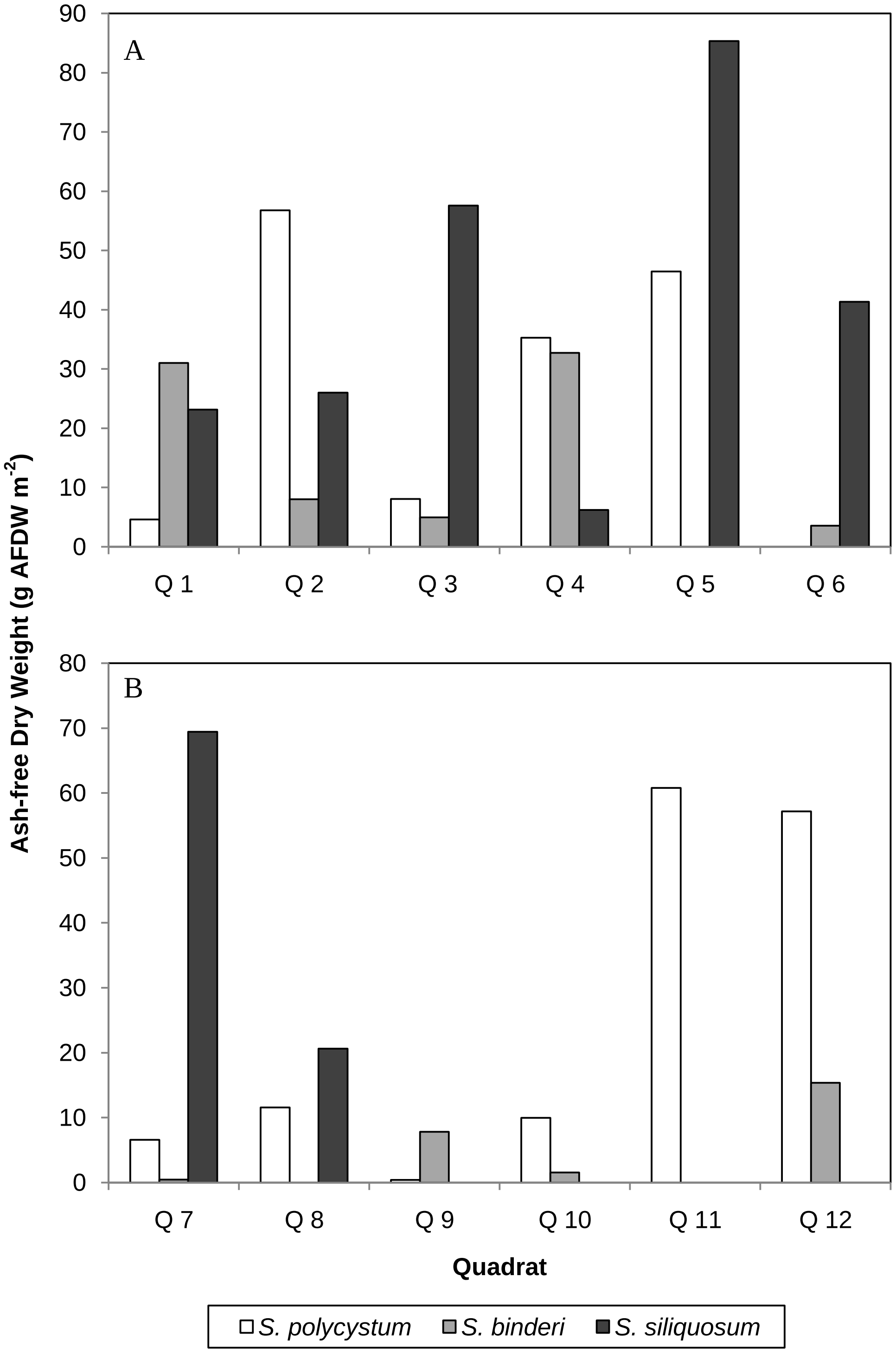


Figure 4.9: Ash-free dry weight (g AFDW m^{-2}) of *Sargassum* species collected from destructive sampling in September 2009 along line transects of (A) Left Reef and (B) Right Reef

4.4.1.2 November 2009

Total number of plants collected in November amounted to 486 plants (*S. polycystum* = 279 plants; *S. binderi* = 55 plants; *S. siliquosum* = 152 plants), 228 plants from the LR (*S. polycystum* = 57 plants; *S. binderi* = 25 plants; *S. siliquosum* = 146 plants), and 258 plants from the RR (*S. polycystum* = 222 plants; *S. binderi* = 30 plants; *S. siliquosum* = 6 plants) (Table 4.3). Despite being found in every quadrat on the LR, *S. siliquosum* samples were only found in Q7 of the RR (Figure 4.11). Inversely, *S. polycystum* was only found in a few quadrats of the LR (Q1, Q2 and Q5) but was found in every quadrat of the RR. *S. binderi* samples were evenly spread on both reefs (LR: Q2 - Q6; RR: Q8 - Q12)

One-way ANOVA on log-transformed data tested significant ($p < 0.05$) in the MTL changes of all three species (*S. polycystum*: F = 3.613; *S. binderi*: F = 2.169; *S. siliquosum*: F = 4.650) along quadrats (Appendix D). Generally, MTL of *Sargassum* on both reefs share a similar pattern (Figure 4.10). MTL of samples were relatively short in Q1 (*S. polycystum*: 43.00 mm; *S. siliquosum*: 34.26 mm) and Q7 (*S. polycystum*: 69.46 mm; *S. siliquosum*: 32.00 mm), but this increased dramatically in Q2 (*S. polycystum*: 53.07 mm; *S. binderi*: 130.00 mm; *S. siliquosum*: 125.00 mm) and Q8 (*S. polycystum*: 94.71 mm; *S. binderi*: 96.00 mm), which was followed by a gradual decrease in Q5 (*S. polycystum*: 38.00 mm; *S. binderi*: 43.36 mm; *S. siliquosum*: 36.57 mm) and Q11 (*S. polycystum*: 31.65 mm; *S. binderi*: 39.38 mm) and an increase in Q6 (*S. binderi*:

115.00 mm; *S. siliquosum*: 59.67 mm) and Q12 (*S. polycystum*: 44.06 mm; *S. binderi*: 96.00 mm).

Biomass along quadrats in this month was illustrated in terms of wet weight (Figure 4.11), dry weight (Figure 4.12) and ash-free dry weight per quadrat (Figure 4.13). Biomass of *S. siliquosum* was the highest among the three species on the LR (977.32 g WW m^{-2}; 129.65 g DW m^{-2}; 110.5 g AFDW m^{-2}) but on the RR, total biomass was the lowest (21.24 g WW m^{-2}; 2.95 g DW m^{-2}; 2.55 g AFDW m^{-2}). Inversely, biomass of *S. polycystum* on the RR was highest among the three species (615.4 g WW m^{-2}; 98.92 g DW m^{-2}; 84.56 g AFDW m^{-2}) but on the LR was the lowest (212.48 g WW m^{-2}; 33.88 g DW m^{-2}; 28.9 g AFDW m^{-2}).

MTL was not significantly correlated ($p > 0.05$) with biomass for all species. For instance, MTL of *S. binderi* from Q6 (115 mm) was higher than *S. siliquosum* MTL of the same quadrat (59.67 mm). However when biomass was considered, *S. binderi* in Q6 (18.68 g WW m^{-2}; 2.22 g DW m^{-2}; 1.86 g AFDW m^{-2}) obtained a much lower biomass than that of *S. siliquosum* (219.96 g WW m^{-2}; 24.17 g DW m^{-2}; 20.62 g AFDW m^{-2}), which was not representative of MTL pattern.

Generally, *Sargassum* was not reproductively active during November 2009. Only a small percentage of fertile plants were found; 14.29 % of *S. polycystum* in Q8 (1 fertile plant) and 7.14 % of *S. binderi* in Q9 (1 fertile plant). Both were found in the RR.

Pearson's correlation revealed that percentage fertility was significantly correlated ($p < 0.01$) with MTL (*S. polycystum*: r = 0.205; *S. binderi*: r = 0.270) but not significantly correlated ($p > 0.05$) with biomass.

Table 4.3: Total number of plants, number of fertile plants and percentage fertility (%) of *Sargassum* species collected from destructive sampling on November 2009 along line transects of (A) Left Reef and (B) Right Reef

A

Quadrat (Left Reef)	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
1	4	0	0.00	0	0	0.00	27	0	0.00
2	46	0	0.00	2	0	0.00	27	0	0.00
3	0	0	0.00	2	0	0.00	12	0	0.00
4	0	0	0.00	5	0	0.00	32	0	0.00
5	7	0	0.00	14	0	0.00	30	0	0.00
6	0	0	0.00	2	0	0.00	18	0	0.00
Total	57	0	0.00	25	0	0.00	146	0	0.00

B

Quadrat (Right Reef)	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
7	28	0	0.00	0	0	0.00	6	0	0.00
8	7	1	14.29	1	0	0.00	0	0	0.00
9	54	0	0.00	14	1	7.14	0	0	0.00
10	34	0	0.00	6	0	0.00	0	0	0.00
11	48	0	0.00	8	0	0.00	0	0	0.00
12	51	0	0.00	1	0	0.00	0	0	0.00
Total	222	1	0.45	30	0	3.33	6	0	0.00

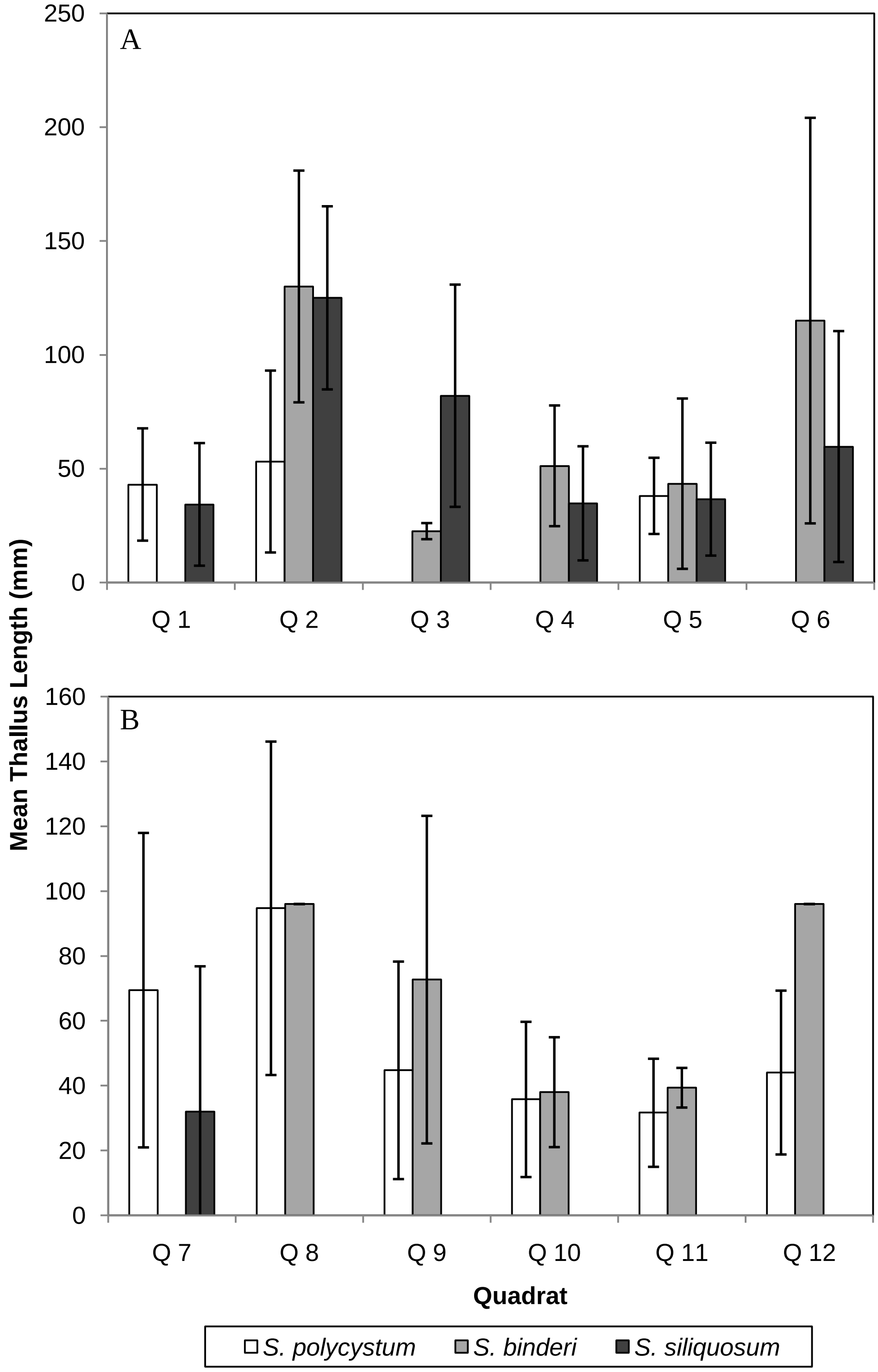


Figure 4.10: Mean thallus length (mm ± SD) of *Sargassum* species collected from destructive sampling in November 2009 along line transects of (A) Left Reef and (B) Right Reef

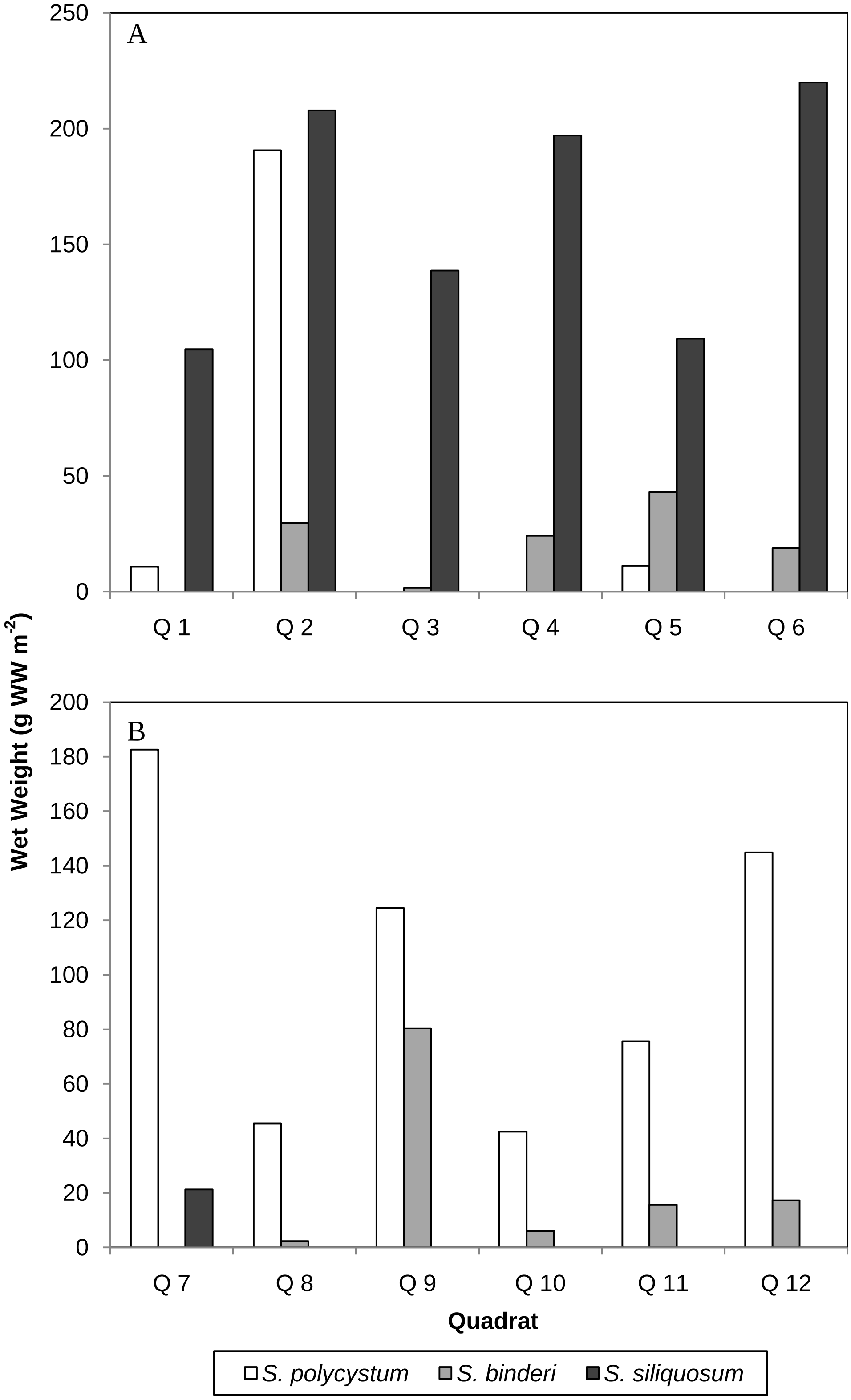


Figure 4.11: Wet weight (g WW m^{-2}) of *Sargassum* species collected from destructive sampling in November 2009 along line transects of (A) Left Reef and (B) Right Reef

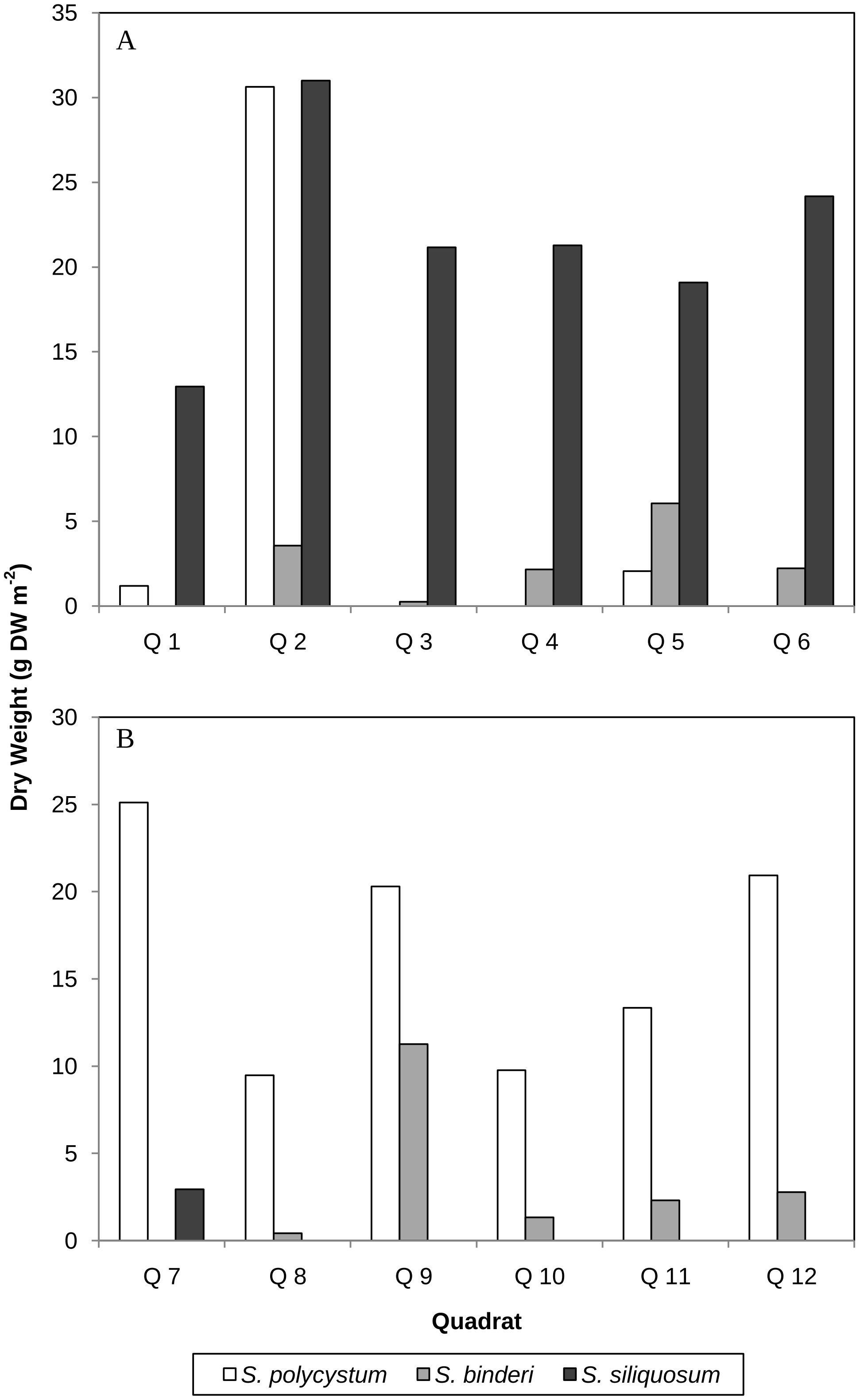


Figure 4.12: Dry weight (g DW m^{-2}) of *Sargassum* species collected from destructive sampling in November 2009 along line transects of (A) Left Reef and (B) Right Reef

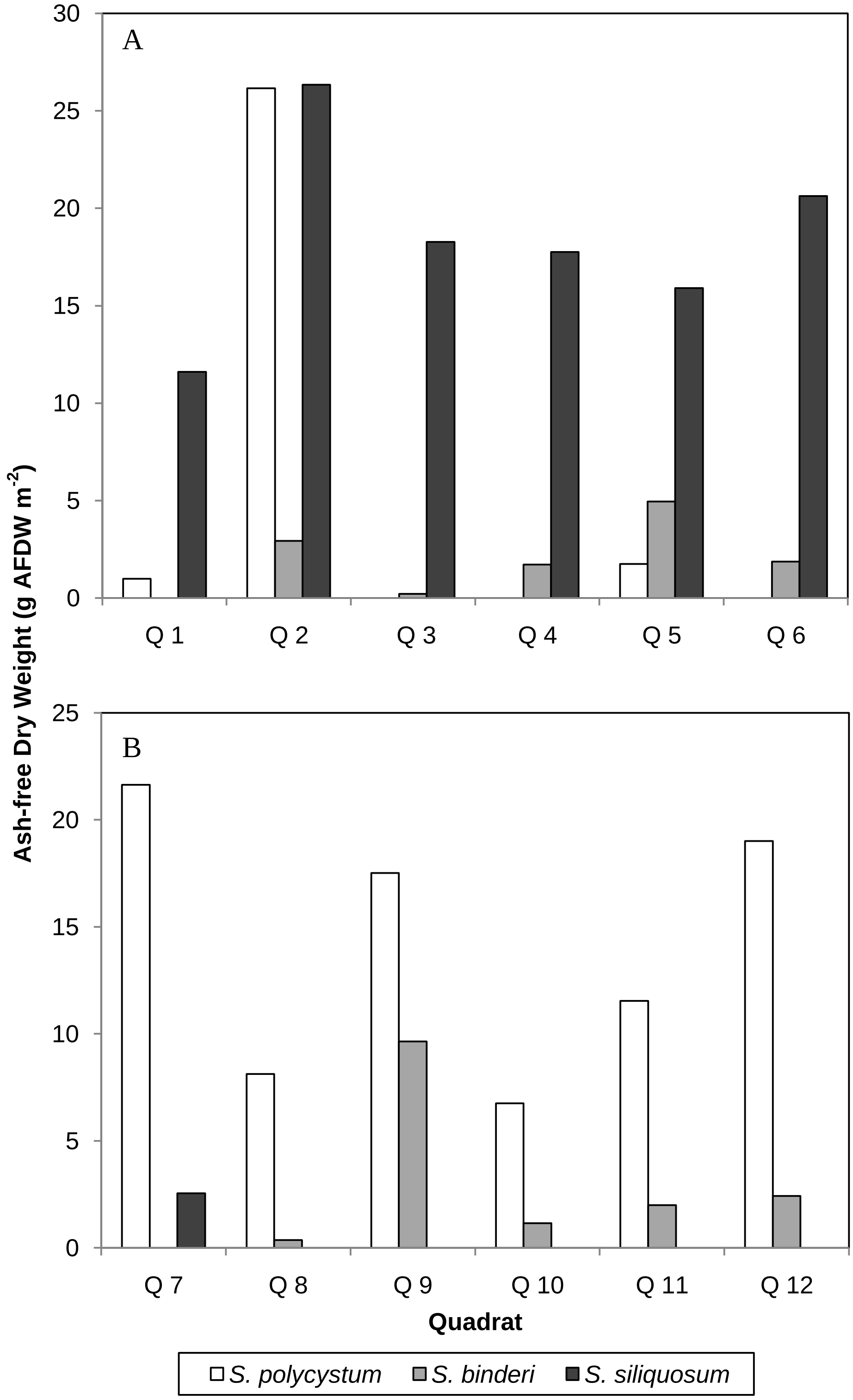


Figure 4.13: Ash-free dry weight (g AFDW m^{-2}) of *Sargassum* species collected from destructive sampling in November 2009 along line transects of (A) Left Reef and (B) Right Reef

4.4.1.3 January 2010

A decreased total of 306 plants were collected (*S. polycystum* = 140 plants; *S. binderi* = 45 plants; *S. siliquosum* = 121 plants), 216 plants from the LR (*S. polycystum* = 68 plants; *S. binderi* = 35 plants; *S. siliquosum* = 113 plants) and 90 plants from the RR (*S. polycystum* = 72 plants; *S. binderi* = 10 plants; *S. siliquosum* = 8 plants). *S. polycystum* was found in all quadrats except in Q8. Both *S. binderi* and *S. siliquosum* were found more on the LR compared to the RR, where they were only present in two quadrats each (*S. binderi*: Q8 and Q11; *S. siliquosum*: Q11 and Q12).

Figure 4.14 presents a trend in *Sargassum* MTL along quadrats of both reefs. One-way ANOVA on log-transformed data tested significant ($p < 0.05$) for MTL changes of only *S. polycystum* (F = 4.696) along quadrats (Appendix D). On the LR, MTL of *S. polycystum* and *S. binderi* were relatively low in Q1 (*S. polycystum*: 112.90 mm; *S. binderi*: 68.50 mm) but ended relatively high in Q6 (*S. polycystum*: 318.00 mm; *S. binderi*: 149.67 mm). There was no significant pattern in MTL distribution of *S. siliquosum* along the quadrats. As for the RR, MTL of *S. polycystum* gradually decreased from Q7 (114.39 mm) to Q11 (53.21 mm), followed by a dramatic increase in Q12 (159.91 mm). In Q6, a single *S. polycystum* individual was collected that month and it was measured up to 318 mm.

Figures 4.15, 4.16 and 4.17 illustrate biomass pattern along quadrats in terms of wet weight, dry weight and ash-free dry weight per quadrat individually. On the LR, biomass of *S. polycystum* gradually increased from Q1 (101.08 g WW m^{-2}; 13.52 g DW m^{-2}; 10.00 g AFDW m^{-2}) to Q3 (231.64 g WW m^{-2}; 2.76 g DW m^{-2}; 2.41 g AFDW m^{-2}) and then gradually decreased until Q6 (18.64 g WW m^{-2}; 2.76 g DW m^{-2}; 2.41 g AFDW m^{-2}). Inversely, biomass of the same species on the RR gradually decreased from Q7 (137.76 g WW m^{-2}; 21.62 g DW m^{-2}; 18.72 g AFDW m^{-2}) to Q10 (42.68 g WW m^{-2}; 7.06 g DW m^{-2}; 6.11 g AFDW m^{-2}), and was followed by an increase until Q12 (128.56 g WW m^{-2}; 30.49 g DW m^{-2}; 26.33 g AFDW m^{-2}). Largest biomass collected that month was from *S. binderi* samples of Q4 (407.92 g WW m^{-2}; 42.29 g DW m^{-2}; 36.48 g AFDW m^{-2}).

MTL of *Sargassum* this month was not significantly correlated with biomass ($p > 0.05$). For instance, MTL of *S. polycystum* from Q6 (318.00 mm) was highest among all the quadrats, but biomass obtained (18.64 g WW m^{-2}; 2.76 g DW m^{-2}; 2.41 g AFDW m^{-2}) was one of the lowest among all.

Percentage fertility of *Sargassum* was generally low in January 2010 (Table 4.4). *S. polycystum* only had fertile plants in Q3 (18.18 %) and Q12 (27.27 %), as did *S. siliquosum* in Q3 (12.50 %) and Q6 (3.33 %). More fertile plants were found for *S. binderi* in Q2 (14.29 %), Q4 (33.33 %), Q5 (50.00 %), Q6 (16.67 %) and Q8 (33.33 %) which were mostly found on the LR. Highest percentage fertility belonged to *S. binderi* samples from Q5, with 3 fertile plants (50.00 %).

Pearson's correlation revealed that percentage fertility was significantly correlated ($p < 0.01$) with MTL (*S. polycystum*: r = 0.488; *S. binderi*: r = 0.611; *S. siliquosum*: r = 0.553). Percentage fertility was also significantly correlated ($p < 0.05$) with biomass of *S. polycystum* (% Fert & WW: r = 0.753; % Fert & DW: r = 0.709; % Fert & AFDW: r = 0.682) but not correlated ($p > 0.05$) with biomass of *S. binderi* and *S. siliquosum*.

Table 4.4: Total number of plants, number of fertile plants and percentage fertility (%) of *Sargassum* species collected from destructive sampling on January 2010 along line transects of (A) Left Reef and (B) Right Reef

A

Quadrat (Left Reef)	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
1	10	0	0.00	4	0	0.00	6	0	0.00
2	29	0	0.00	7	1	14.29	0	0	0.00
3	11	2	18.18	3	0	0.00	8	1	12.5
4	12	0	0.00	9	3	33.33	49	0	0.00
5	5	0	0.00	6	3	50.00	20	0	0.00
6	1	0	0.00	6	1	16.67	30	1	3.33
Total	68	2	2.94	35	8	22.86	113	2	3.13

B

Quadrat (Right Reef)	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
7	18	0	0.00	0	0	0.00	0	0	0.00
8	0	0	0.00	3	1	33.33	0	0	0.00
9	12	0	0.00	0	0	0.00	0	0	0.00
10	7	0	0.00	0	0	0.00	0	0	0.00
11	24	0	0.00	7	0	0.00	5	0	0.00
12	11	3	27.27	0	0	0.00	3	0	0.00
Total	72	3	4.17	10	1	10.00	8	0	0.00

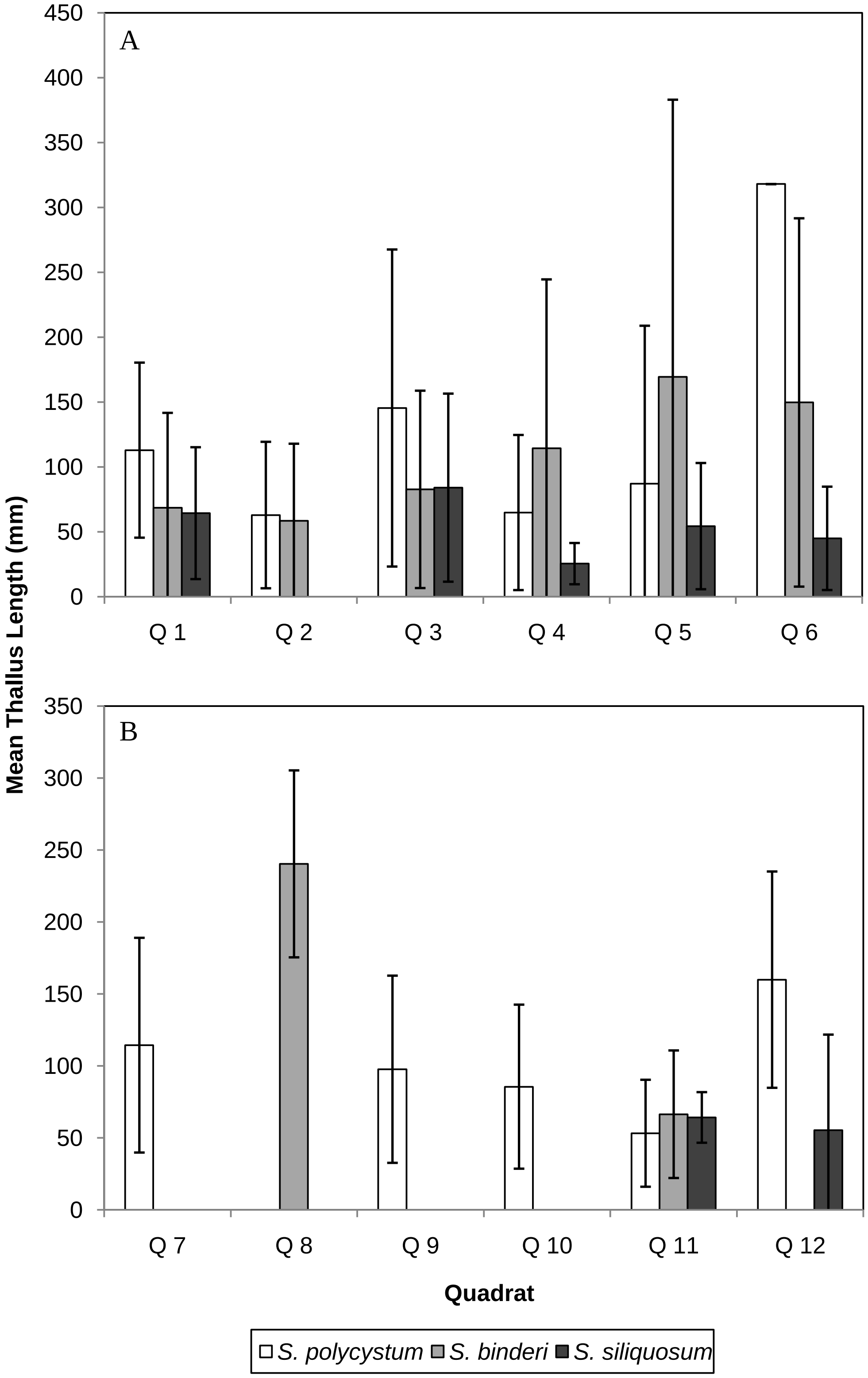


Figure 4.14: Mean thallus length (mm ± SD) of *Sargassum* species collected from destructive sampling in January 2010 along line transects of (A) Left Reef and (B) Right Reef

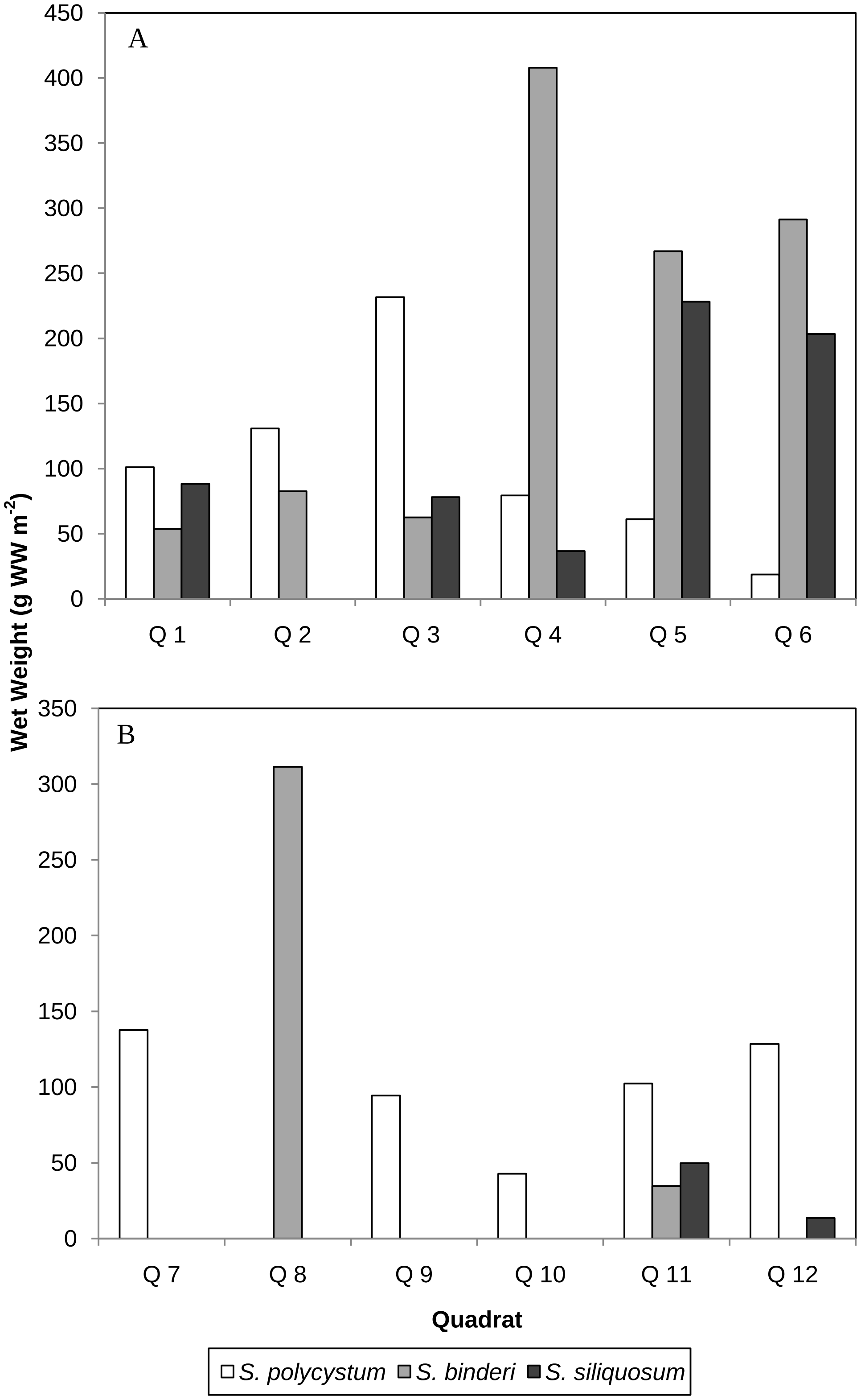


Figure 4.15: Wet weight (g WW m^{-2}) of *Sargassum* species collected from destructive sampling in January 2010 along line transects of (A) Left Reef and (B) Right Reef

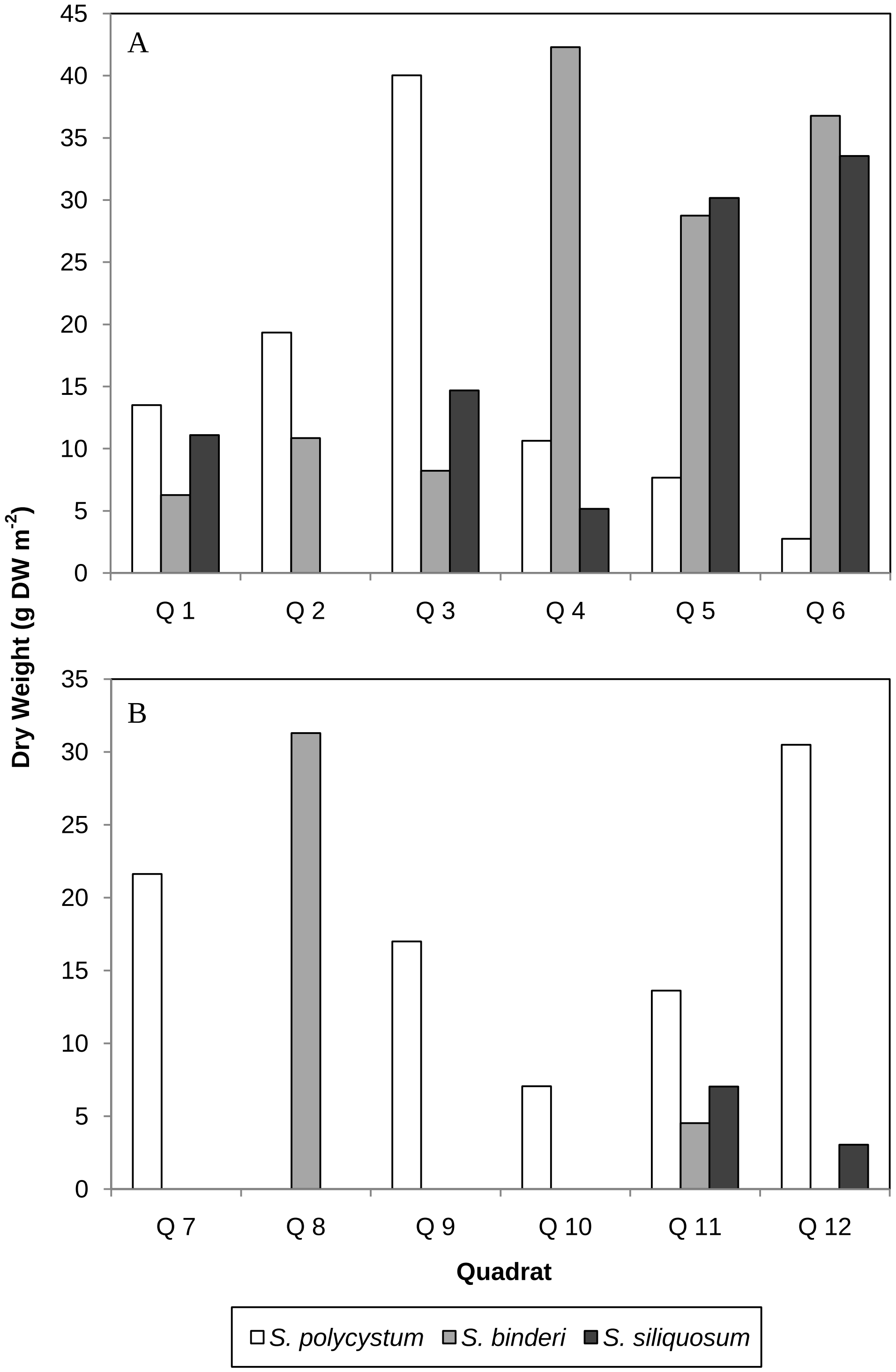


Figure 4.16: Dry weight (g DW m^{-2}) of *Sargassum* species collected from destructive sampling in January 2010 along line transects of (A) Left Reef and (B) Right Reef

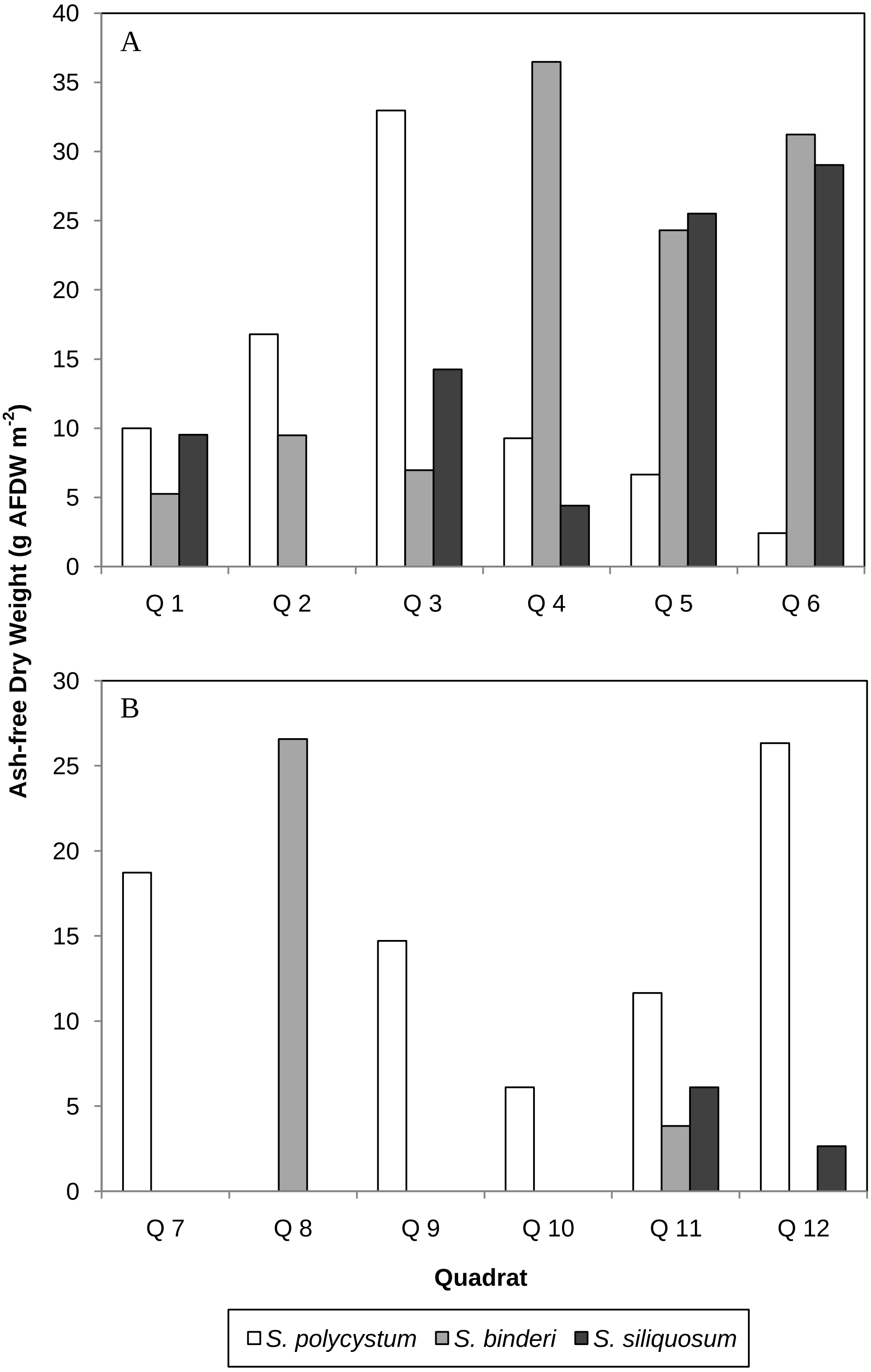


Figure 4.17: Ash-free dry weight (g AFDW m^{-2}) of *Sargassum* species collected from destructive sampling in January 2010 along line transects of (A) Left Reef and (B) Right Reef

4.4.1.4 March 2010

Sampling resulted in a total of 431 plants harvested (*S. polycystum* = 208 plants; *S. binderi* = 110 plants; *S. siliquosum* = 113 plants), 198 plants from the LR (*S. polycystum* = 22 plants; *S. binderi* = 63 plants; *S. siliquosum* = 113 plants), and 233 plants from the RR (*S. polycystum* = 186 plants; *S. binderi* = 47 plants; *S. siliquosum* = 0 plants). Both *S. polycystum* and *S. binderi* were found in almost every quadrat except in Q2 for *S. polycystum* and Q9 for *S. binderi*. *S. siliquosum* samples were found in all quadrats of the LR, but none on the RR

Figure 4.18 presents a trend in *Sargassum* MTL along quadrats of both reefs. One-way ANOVA on log-transformed data tested significant ($p < 0.05$) for MTL changes of *S. polycystum* (F = 4.810) and *S. binderi* (F = 2.679) along quadrats (Appendix D). On the LR, MTL of *S. binderi* gradually decreased from Q1 (137.65 mm) to Q4 (44.67 mm), which then increased until Q6 (245.00 mm). MTL of *S. siliquosum* also showed a gradual change along quadrats of the LR. From Q1 (84.00 mm), MTL increased in Q2 (145.21 mm), followed by a gradual decrease until Q4 (101.53 mm) and finally increased until Q6 (121.27 mm). Similar pattern was seen for *S. polycystum* on the RR whereby MTL of samples located in the middle of the reef (Q4: 220.50 mm) were relatively shorter than those on the edges (Q1: 101.50 mm; Q6: 31.83 mm). MTL of *S. binderi* in Q6 (245.00 ± 355.16 mm) possessed a very large standard deviation due to extreme differences in sample lengths; shortest measuring 32 mm while longest was 655 mm.

Figures 4.19, 4.20 and 4.21 illustrate biomass pattern along quadrats in terms of wet weight, dry weight and ash-free dry weight per quadrat individually. From the figures, it was clearly seen that biomass of *S. polycystum* was very low on the LR (lowest in Q3: 2.04 g WW m^{-2}; 0.43 g DW m^{-2}; 0.38 g AFDW m^{-2}), but was high on the RR (highest in Q7: 230.12 g WW m^{-2}; 48.11 g DW m^{-2}; 37.51 g AFDW m^{-2}), decreasing from Q7 to Q12 (68.44 g WW m^{-2}; 11.80 g DW m^{-2}; 9.58 g AFDW m^{-2}). Inversely, biomass of *S. siliquosum* was highest on the LR (highest in Q6: 586.68 g WW m^{-2}; 102.45 g DW m^{-2}; 84.43 g AFDW m^{-2}) which was increasing from Q1 (53.00 g WW m^{-2}; 11.21 g DW m^{-2}; 8.80 g AFDW m^{-2}) to Q6, but none was found on the RR.

MTL of samples this month was not significantly correlated with biomass ($p > 0.05$). For instance, there was only one sample of *S. binderi* collected from Q8, measuring up to 242 mm. This was the highest MTL measurement among all the quadrats of the right reef, but biomass obtained (15.04 g WW m^{-2}; 3.68 g DW m^{-2}; 2.75 g AFDW m^{-2}) was one of the lowest among all.

All three species of *Sargassum* were fertile, especially *S. binderi* and *S. siliquosum* (Table 4.5). There were fertile plants in almost every quadrat, except in Q9. Both Q8 and Q11 both contained *S. binderi* samples of 100.00 % fertility, although each quadrat only contained one sample each. Fertile *S. siliquosum* plants were found in every quadrat of the LR, but none on the RR. Only a few fertile *S. polycystum* plants were scattered throughout both reefs (Q4: 50.00 %; Q7: 30.00 %; Q8: 22.22 %; Q12: 6.67 %).

Pearson's correlation revealed that percentage fertility was significantly correlated ($p < 0.01$) with MTL (*S. polycystum*: r = 0.666; *S. binderi*: r = 0.683; *S. siliquosum*: r = 0.851) but not significantly correlated ($p > 0.05$) with biomass.

Table 4.5: Total number of plants, number of fertile plants and percentage fertility (%) of *Sargassum* species collected from destructive sampling on March 2010 along line transects of (A) Left Reef and (B) Right Reef

A

Quadrat (Left Reef)	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
1	2	0	0.00	20	9	45.00	5	1	20.00
2	0	0	0.00	4	2	50.00	14	5	35.71
3	3	0	0.00	19	2	10.53	9	2	22.22
4	8	4	50.00	3	0	0.00	32	5	15.63
5	3	0	0.00	14	3	21.43	19	4	21.05
6	6	0	0.00	3	1	33.33	34	6	17.65
Total	22	4	18.18	63	17	26.98	113	23	20.35

B

Quadrat (Right Reef)	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
7	30	9	30.00	9	0	0.00	0	0	0.00
8	9	2	22.22	1	1	100.00	0	0	0.00
9	46	0	0.00	0	0	0.00	0	0	0.00
10	62	0	0.00	11	1	9.09	0	0	0.00
11	24	0	0.00	1	1	100.00	0	0	0.00
12	15	1	6.67	25	3	12.00	0	0	0.00
Total	186	12	6.45	47	6	12.77	0	0	0.00

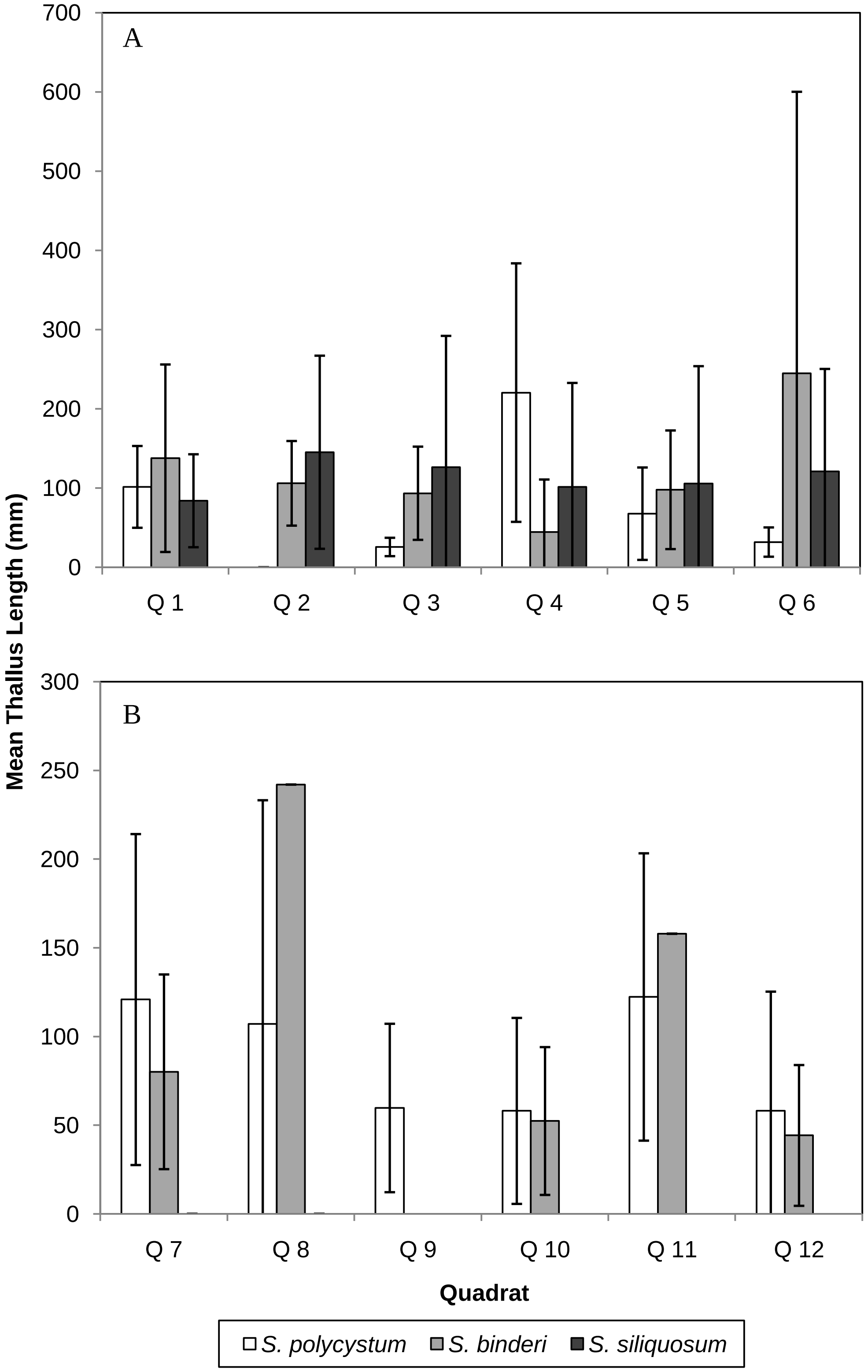


Figure 4.18: Mean thallus length (mm ± SD) of *Sargassum* species collected from destructive sampling in March 2010 along line transects of (A) Left Reef and (B) Right Reef

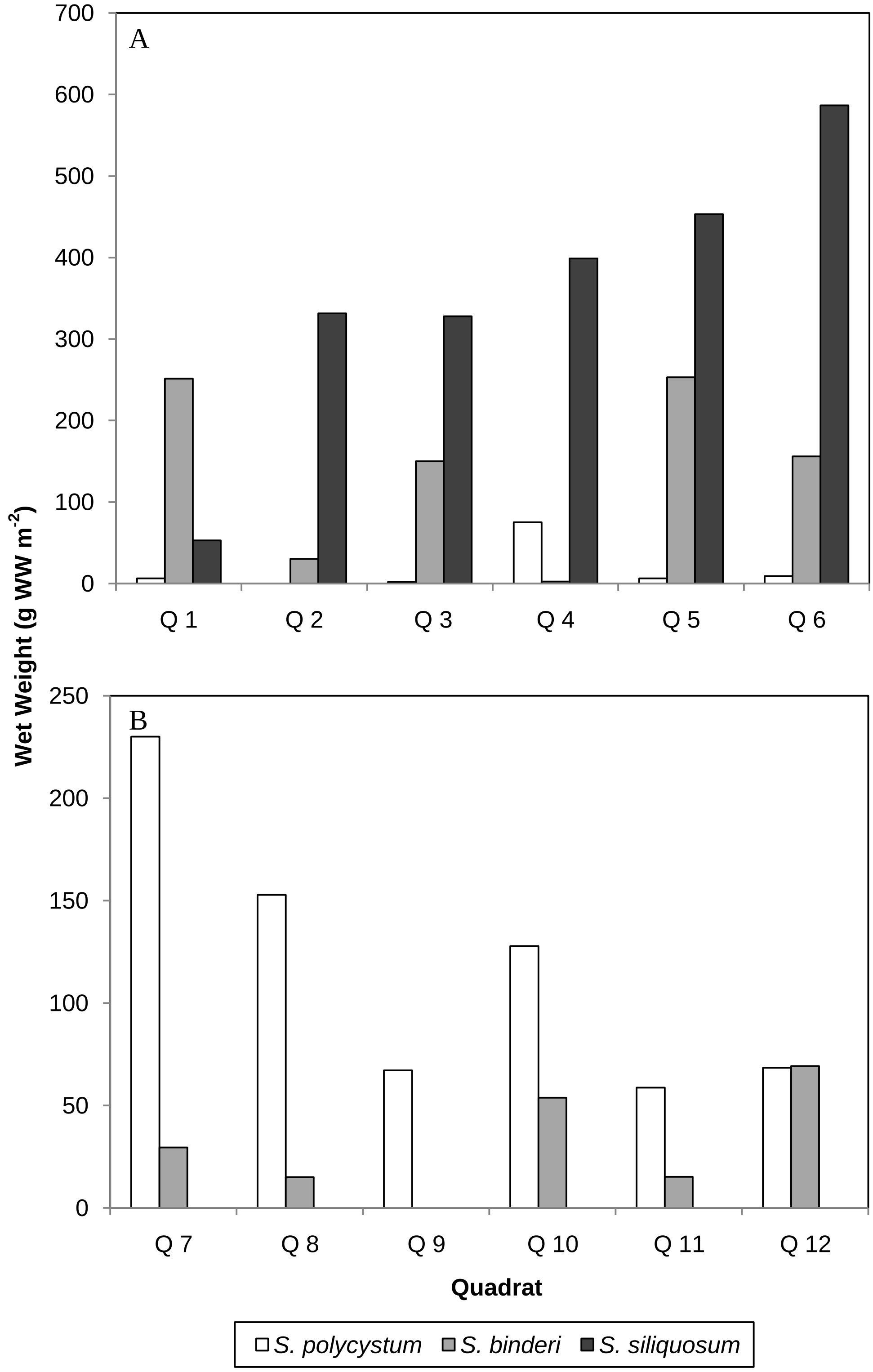


Figure 4.19: Wet weight (g WW m^{-2}) of *Sargassum* species collected from destructive sampling in March 2010 along line transects of (A) Left Reef and (B) Right Reef

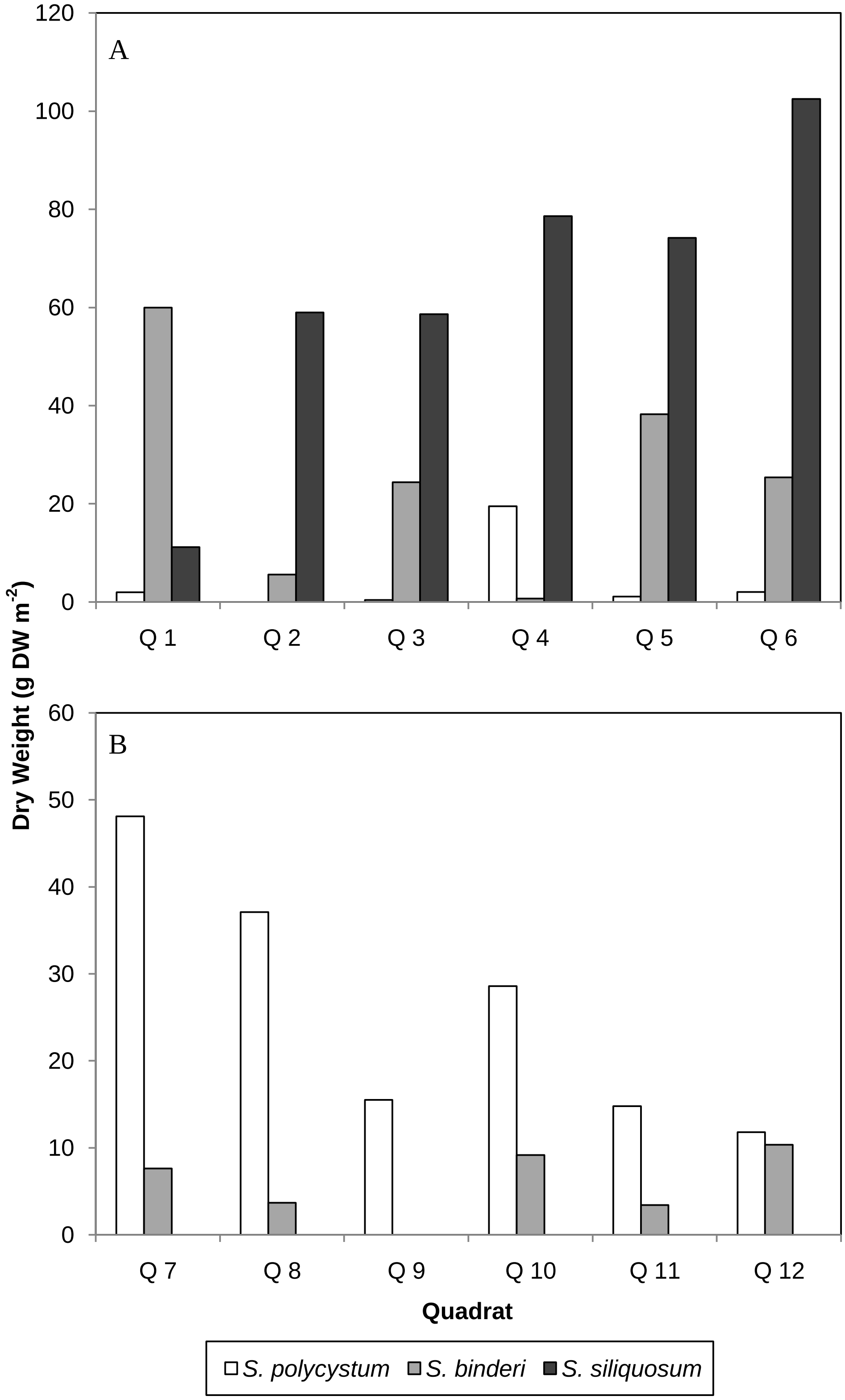


Figure 4.20 Dry weight (g DW m^{-2}) of *Sargassum* species collected from destructive sampling in March 2010 along line transects of (A) Left Reef and (B) Right Reef

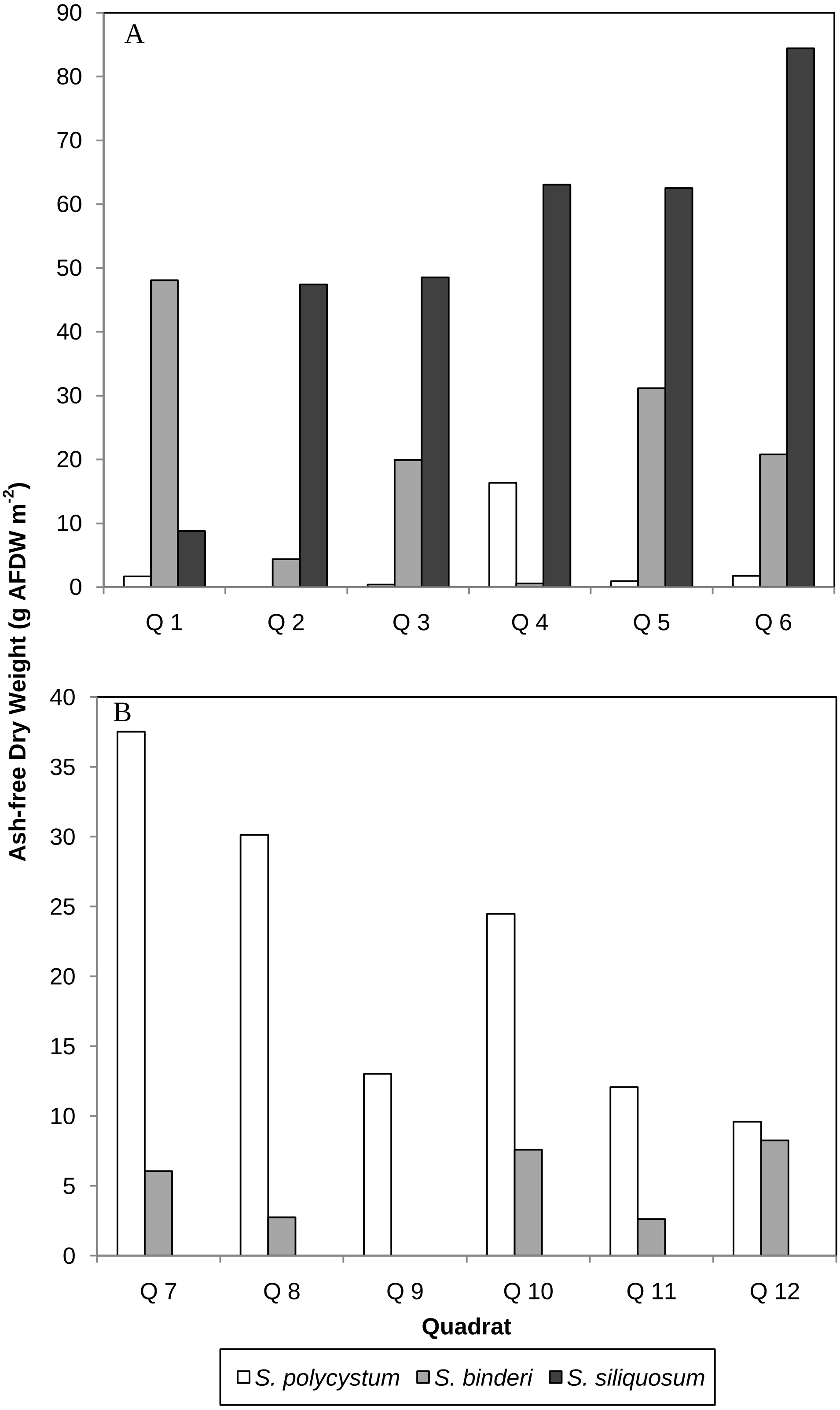


Figure 4.21: Ash-free dry weight (g AFDW m^{-2}) of *Sargassum* species collected from destructive sampling in March 2010 along line transects of (A) Left Reef and (B) Right Reef

4.4.1.5 May 2010

Sampling resulted in a total of 379 plants harvested (*S. polycystum* = 243 plants; *S. binderi* = 60 plants; *S. siliquosum* = 76 plants), 237 plants from the LR (*S. polycystum* = 121 plants; *S. binderi* = 41 plants; *S. siliquosum* = 75 plants) and 142 plants from the RR (*S. polycystum* = 122 plants; *S. binderi* = 19 plants; *S. siliquosum* = 1 plants). All three species could be found in every quadrat of the LR. On the RR, however, only *S. polycystum* was present at every quadrat, while the other two species appeared in only a few quadrats (*S. binderi*: Q7, Q10 and Q12; *S. siliquosum*: Q12).

One-way ANOVA on log-transformed data tested significant ($p < 0.05$) for MTL changes of all three species (*S. polycystum*: F = 2.378; *S. binderi*: F = 3.539; *S. siliquosum*: F = 3.247) along quadrats (Appendix D). From Figure 4.22, similar patterns on the LR were observed for the three species. MTL of samples started at their highest in Q1 (*S. polycystum*: 145 mm; *S. binderi*: 94.29 mm; *S. siliquosum*: 116.09 mm) which decreased dramatically in Q2 (*S. polycystum*: 50.88 mm; *S. binderi*: 37.50 mm; *S. siliquosum*: 58.75 mm). These increased in Q3 (*S. polycystum*: 99.89 mm; *S. binderi*: 43.43 mm; *S. siliquosum*: 72.00 mm) and gradually decreased until Q5 (*S. polycystum*: 50.71 mm; *S. binderi*: 24.50 mm; *S. siliquosum*: 25.40 mm), from which MTL increased again in Q6 (*S. polycystum*: 74.87 mm; *S. binderi*: 60.00 mm; *S. siliquosum*: 48.00 mm). On the RR, *S. polycystum* MTL fluctuated throughout the transect, with the largest MTL in Q11 (122.5 mm).

From Figures 4.23, 4.24 and 4.25, biomass pattern along quadrats in terms of wet weight, dry weight and ash-free dry weight per quadrat were clearly seen. On the LR, biomass of *S. polycystum* increased from Q1 (44.60 g WW m^{-2}; 7.62 g DW m^{-2}; 6.39 g AFDW m^{-2}) to Q12 (214.60 g WW m^{-2}; 31.41 g DW m^{-2}; 26.72 g AFDW m^{-2}), while the opposite was true for *S. siliquosum*, whereby biomass decreased from Q1 (313.40 g WW m^{-2}; 44.97 g DW m^{-2}; 37.33 g AFDW m^{-2}) to Q12 (0.60 g WW m^{-2}; 0.10 g DW m^{-2}; 0.09 g AFDW m^{-2}). On the RR, *S. polycystum* biomass gradually decreased from Q7 (4.24 g WW m^{-2}; 0.44 g DW m^{-2}; 0.34 g AFDW m^{-2}) to Q9 (8.48 g WW m^{-2}; 1.15 g DW m^{-2}; 0.98 g AFDW m^{-2}) and then increased until Q12 (48.04 g WW m^{-2}; 5.83 g DW m^{-2}; 4.99 g AFDW m^{-2}). Highest biomass belonged to samples of *S. siliquosum* in Q1 (313.4 g WW m^{-2}; 44.97 g DW m^{-2}; 37.33 g AFDW m^{-2}).

MTL of samples was not significantly correlated with biomass (p > 0.05). For instance, MTL of *S. polycystum* in Q1 (145.00 mm) were measured to be the largest in May 2010. But when compared to biomass measurements, *S. polycystum* in that quadrat (44.6 g WW m^{-2}; 7.62 g DW m^{-2}; 6.39 g AFDW m^{-2}) was very low compared to the rest.

Percentage fertility was overall very low for all species in May 2010 (Figure Table 4.6). Only Q1 and Q6 contained fertile plants. *S. binderi* only bore fertile laterals in Q1 with 28.57 % (2 fertile plants) while *S. siliquosum* bore fertile laterals in Q1 and Q6, each achieved percentage fertility of 18.18 % (2 fertile plants) and 5.26 % (1 fertile plant) respectively. *S. polycystum* was not fertile in this month.

Pearson's correlation revealed that percentage fertility was significantly correlated ($p < 0.01$) with MTL (*S. binderi*: r = 0.356; *S. siliquosum*: r = 0.384; *S. polycystum*: cannot be computed because at least one of the variables is constant) but not significantly correlated ($p > 0.05$) with biomass.

Table 4.6: Total number of plants, number of fertile plants and percentage fertility (%) of *Sargassum* species collected from destructive sampling on May 2010 along line transects of (A) Left Reef and (B) Right Reef

A

Quadrat (Left Reef)	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
1	2	0	0.00	7	2	28.57	11	2	18.18
2	24	0	0.00	10	0	0.00	12	0	0.00
3	9	0	0.00	7	0	0.00	9	0	0.00
4	21	0	0.00	12	0	0.00	14	0	0.00
5	42	0	0.00	2	0	0.00	10	0	0.00
6	23	0	0.00	3	0	0.00	19	1	5.26
Total	121	0	0.00	41	2	4.88	75	3	4.00

B

Quadrat (Right Reef)	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
7	35	0	0.00	1	0	0.00	0	0	0.00
8	11	0	0.00	0	0	0.00	0	0	0.00
9	1	0	0.00	0	0	0.00	0	0	0.00
10	52	0	0.00	9	0	0.00	0	0	0.00
11	4	0	0.00	0	0	0.00	0	0	0.00
12	19	0	0.00	9	0	0.00	1	0	0.00
Total	122	0	0.00	19	0	0.00	1	0	0.00

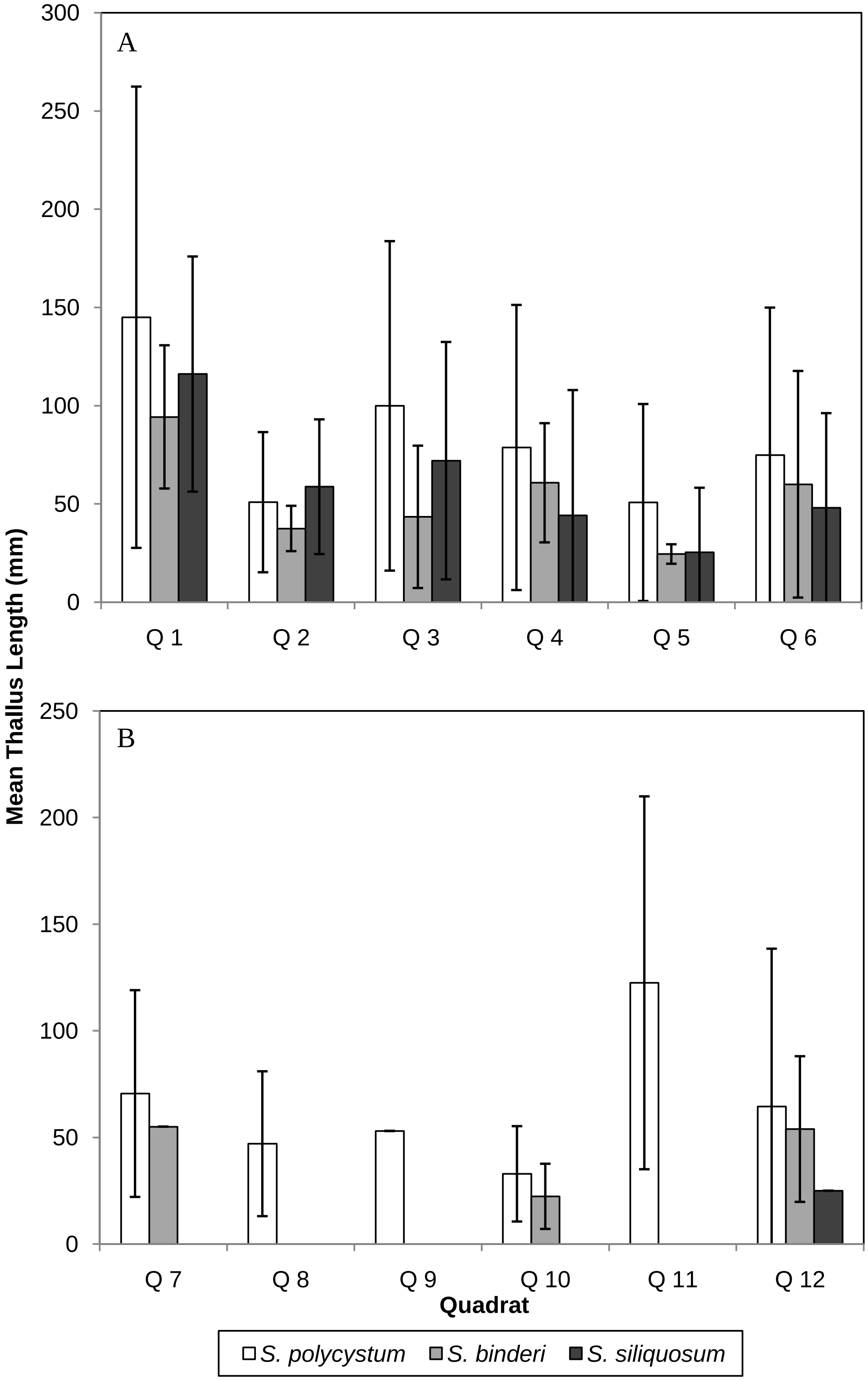


Figure 4.22: Mean thallus length (mm ± SD) of *Sargassum* species collected from destructive sampling in May 2010 along line transects of (A) Left Reef and (B) Right Reef

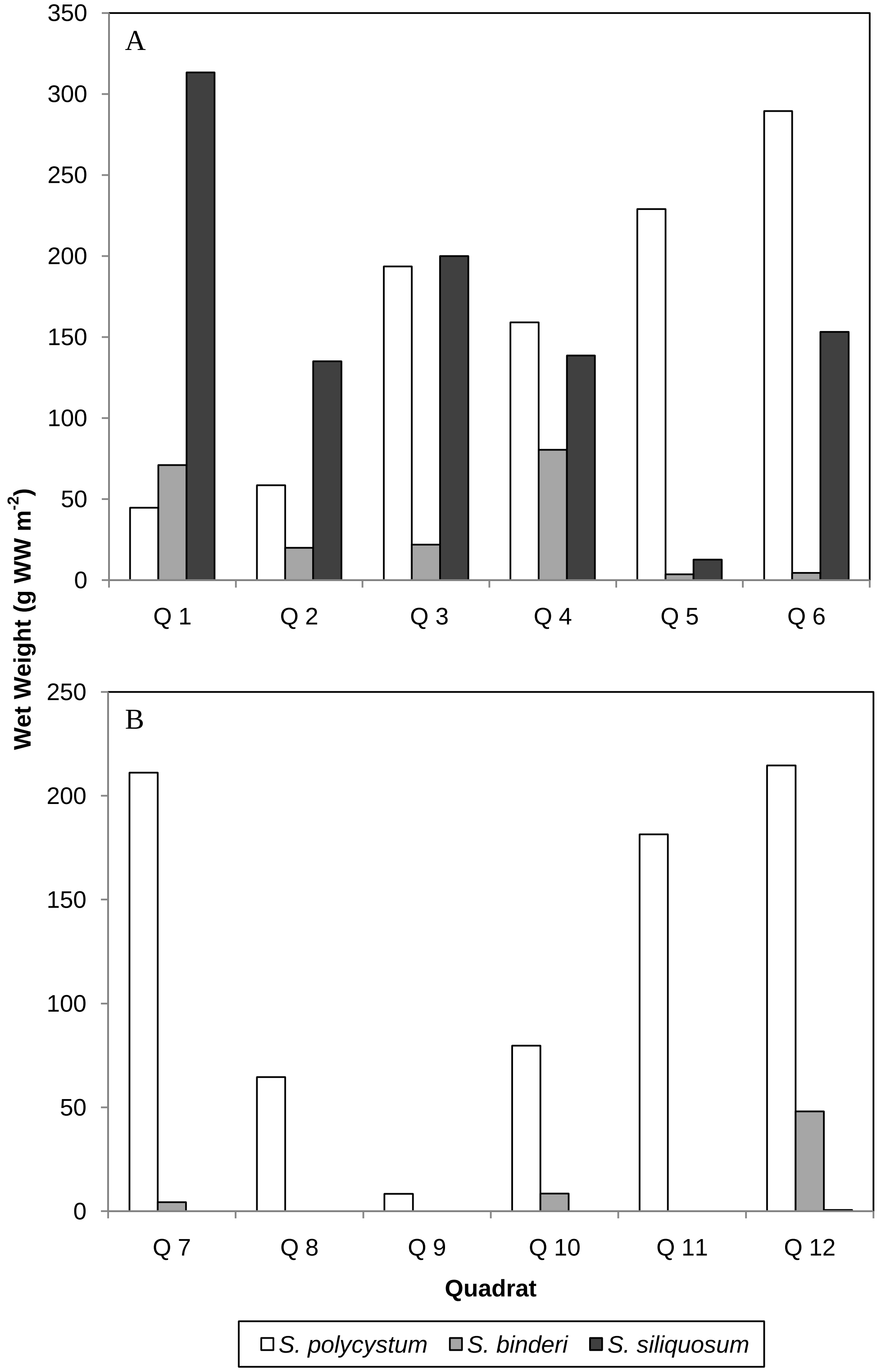


Figure 4.23: Wet weight (g WW m^{-2}) of *Sargassum* species collected from destructive sampling in May 2010 along line transects of (A) Left Reef and (B) Right Reef

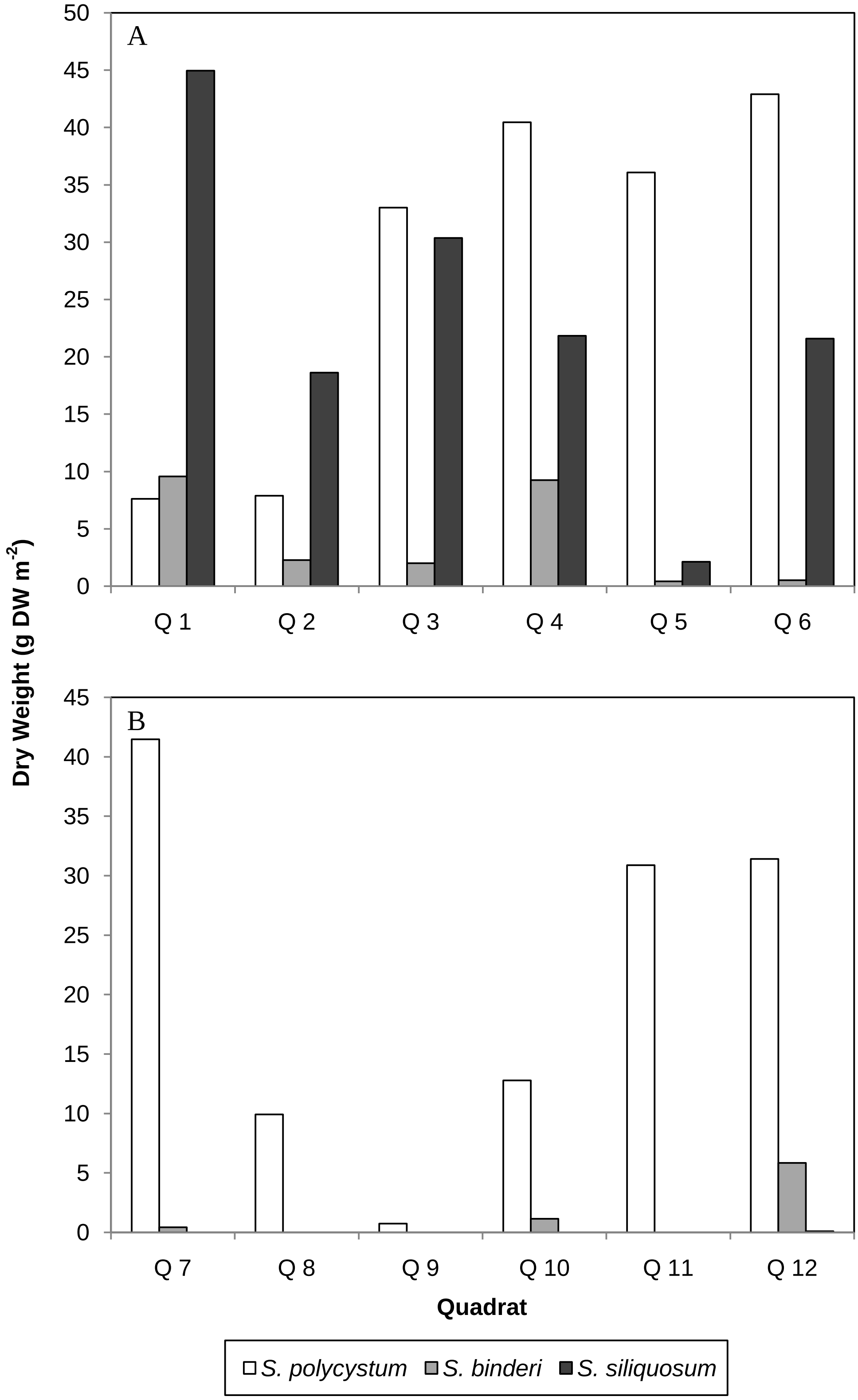


Figure 4.24: Dry weight (g DW m^{-2}) of *Sargassum* species collected from destructive sampling in May 2010 along line transects of (A) Left Reef and (B) Right Reef

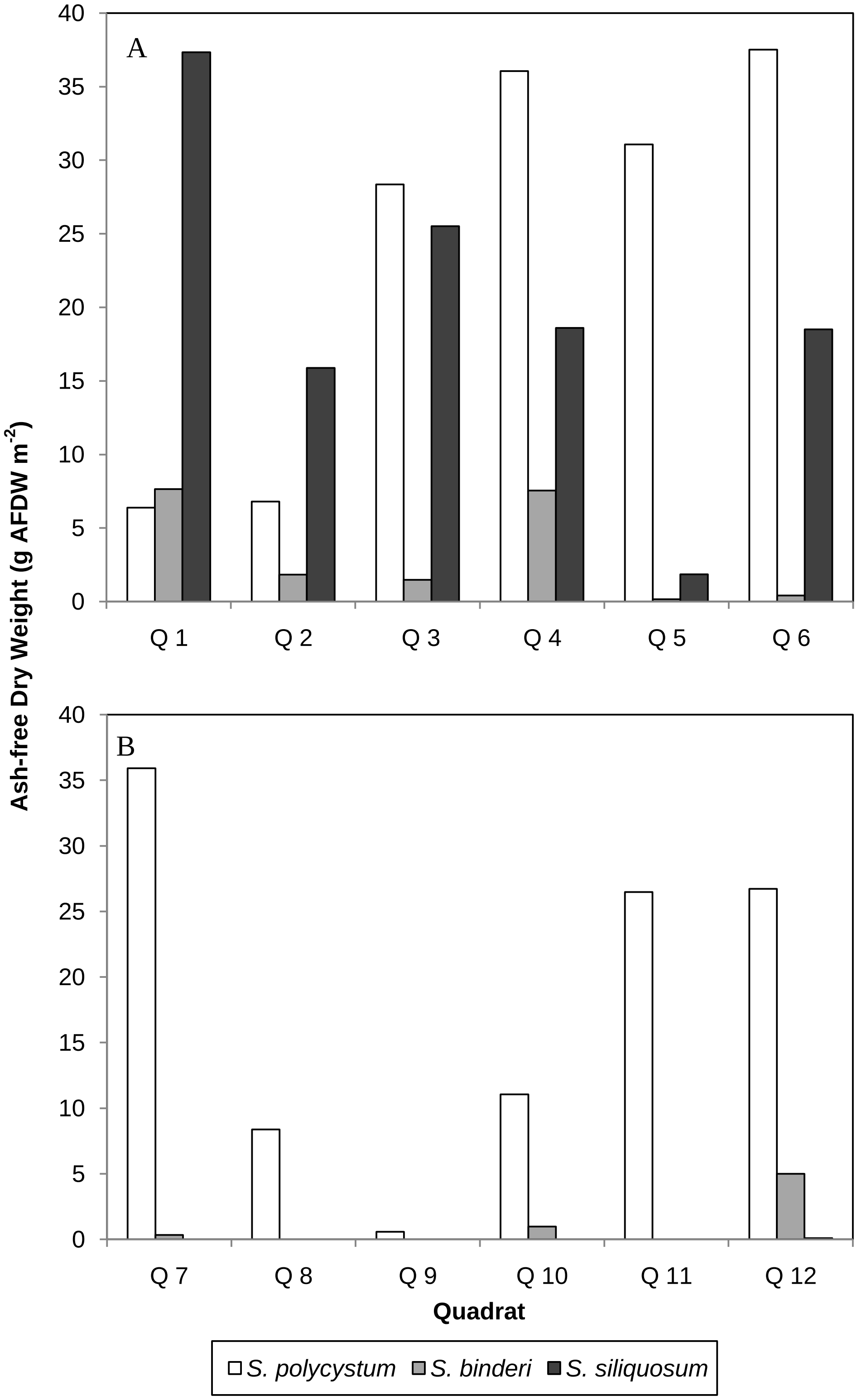


Figure 4.25: Ash-free dry weight (g AFDW m^{-2}) of *Sargassum* species collected from destructive sampling in May 2010 along line transects of (A) Left Reef and (B) Right Reef

4.4.1.6 July 2010

A total of 285 *Sargassum* samples were collected (*S. polycystum* = 191 plants; *S. binderi* = 39 plants; *S. siliquosum* = 55 plants), 131 plants from the LR (*S. polycystum* = 54 plants; *S. binderi* = 23 plants; *S. siliquosum* = 54 plants) and 154 plants from the RR (*S. polycystum* = 137 plants; *S. binderi* = 16 plants; *S. siliquosum* = 1 plants). All three species could be found in a quadrats of the LR. *S. polycystum* samples were present in all quadrats. On the LR, *S. siliquosum* samples were found in all quadrats, but on the RR were only found in Q12. *S. binderi* samples were randomly scattered throughout the transect.

One-way ANOVA on log-transformed data tested significant ($p < 0.05$) for MTL changes of *S. polycystum* (F = 3.058) and *S. binderi* (F = 4.632) along quadrats (Appendix D). From Figure 4.26, a similar trend was seen for *S. polycystum* on both reefs. MTL initially increased from Q1 (200.29 mm) and Q7 (203.80 mm) to Q2 (427.40 mm) and Q8 (251.08 mm) and were then gradually decreased to Q3 (308.08 mm) and Q10 (94.13 mm) where MTL smoothly increased again to Q6 (532.00 mm) and Q12 (349.56 mm). *S. siliquosum* also went through a similar pattern on the LR, except that towards the end, MTL decreased again in Q6.

Changes in biomass along quadrats in terms of wet weight, dry weight and ash-free dry weight per quadrat for the month of July 2010 were illustrated in Figures 4.27, 4.28 and 4.29. On the LR, biomass of *S. polycystum* increased from Q1 (646.24 g WW m^{-2}; 88.30 g DW m^{-2}; 76.15 g AFDW m^{-2}) to Q3

(1976.68 g WW m^{-2}; 292.32 g DW m^{-2}; 246.81 g AFDW m^{-2}), followed by a gradual decrease until Q6 (660.24 g WW m^{-2}; 101.68 g DW m^{-2}; 85.85 g AFDW m^{-2}). Similar pattern was seen for *S. siliquosum* on the LR except that from Q4 (149.04 g WW m^{-2}; 44.53 g DW m^{-2}; 38.32 g AFDW m^{-2}), biomass gradually increased to Q12 (739.36 g WW m^{-2}; 106.55 g DW m^{-2}; 91.61 g AFDW m^{-2}). This trend was also seen for *S. polycystum* on the RR, with largest biomass found in Q3 (1976.68 g WW m^{-2}; 292.32 g DW m^{-2}; 112.06 g AFDW m^{-2}).

MTL of samples this month was not significantly correlated with biomass ($p > 0.05$). For instance, MTL of *S. binderi* samples in Q6 (261 mm) were measured to be higher than that of *S. siliquosum* samples (201.33 mm) within the same quadrat. However, when biomass was considered, measurements of *S. siliquosum* (739.36 g WW m^{-2}; 106.55 g DW m^{-2}; 91.6 g AFDW m^{-2}) were higher than those of *S. binderi* (243.48 g WW m^{-2}; 34.87 g DW m^{-2}; 28.59 g AFDW m^{-2}).

Fertile laterals were seen for all three species in July 2010 (Table 4.7). On the LR, fertility was observed in all quadrats for *S. polycystum* (Q1: 28.57 %; Q2: 40.00 %; Q3: 25.00 %; Q4: 38.89 %; Q5: 42.86 %; Q6: 60.00 %) and *S. siliquosum* Q1: 33.33 %; Q2: 54.55 %; Q3: 60.00 %; Q4: 11.11 %; Q5: 12.50 %; Q6: 33.33 %). As for the RR, only few quadrats contained fertile plants including *S. polycystum* (Q7: 20.00 %) and *S. binderi* (Q8: 22.22 %; Q11: 50.00 %; Q12: 40.00 %). Highest percentage fertility belonged to *S. binderi* samples in Q6 with 66.67 % (4 fertile plants).

Pearson's correlation revealed that percentage fertility of all three species were significantly correlated ($p < 0.01$) with MTL (*S. polycystum*: r = 0.714; *S. binderi*: r = 0.729; *S. siliquosum*: r = 0.806) but not significantly correlated ($p > 0.05$) with biomass.

Table 4.7: Total number of plants, number of fertile plants and percentage fertility (%) of *Sargassum* species collected from destructive sampling on July 2010 along line transects of (A) Left Reef and (B) Right Reef

A

Quadrat	*S. polycystum*			*S. binderi*			*S. siliquosum*		
(Left Reef)	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
1	7	2	28.57	9	3	33.33	3	1	33.33
2	5	2	40.00	0	0	0.00	11	6	54.55
3	12	3	25.00	4	0	0.00	5	3	60.00
4	18	7	38.89	0	0	0.00	18	2	11.11
5	7	3	42.86	4	0	0.00	8	1	12.50
6	5	3	60.00	6	4	66.67	9	3	33.33
Total	54	20	37.04	23	7	30.43	54	16	29.63

B

Quadrat	*S. polycystum*			*S. binderi*			*S. siliquosum*		
(Right Reef)	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
7	5	1	20.00	0	0	0.00	0	0	0.00
8	13	0	0.00	9	2	22.22	0	0	0.00
9	25	0	0.00	0	0	0.00	0	0	0.00
10	52	0	0.00	0	0	0.00	0	0	0.00
11	33	0	0.00	2	1	50.00	0	0	0.00
12	9	0	0.00	5	2	40.00	1	0	0.00
Total	137	1	0.73	16	5	31.25	1	0	0.00

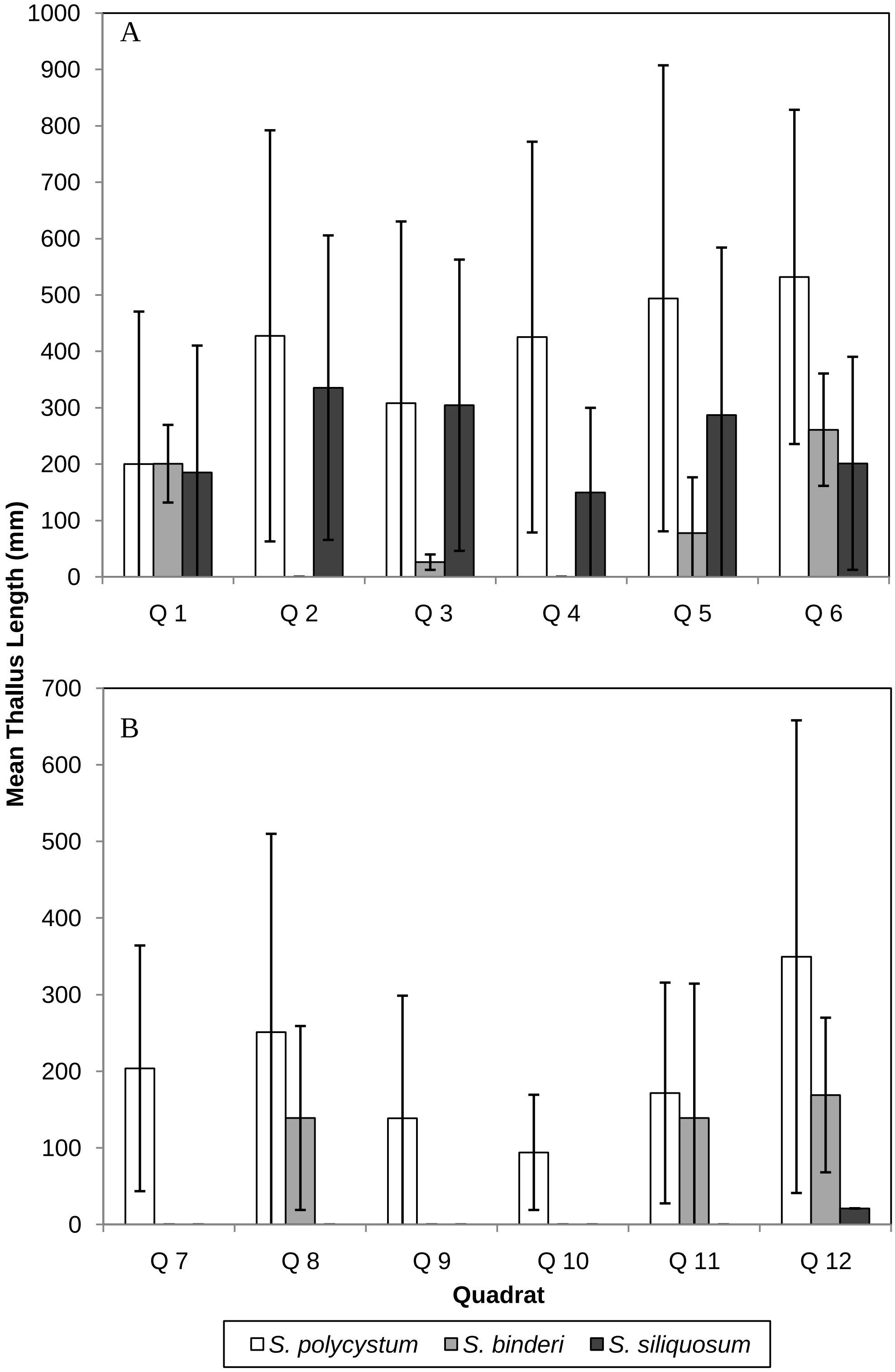


Figure 4.26: Mean thallus length (mm ± SD) of *Sargassum* species collected from destructive sampling in July 2010 along line transects of (A) Left Reef and (B) Right Reef

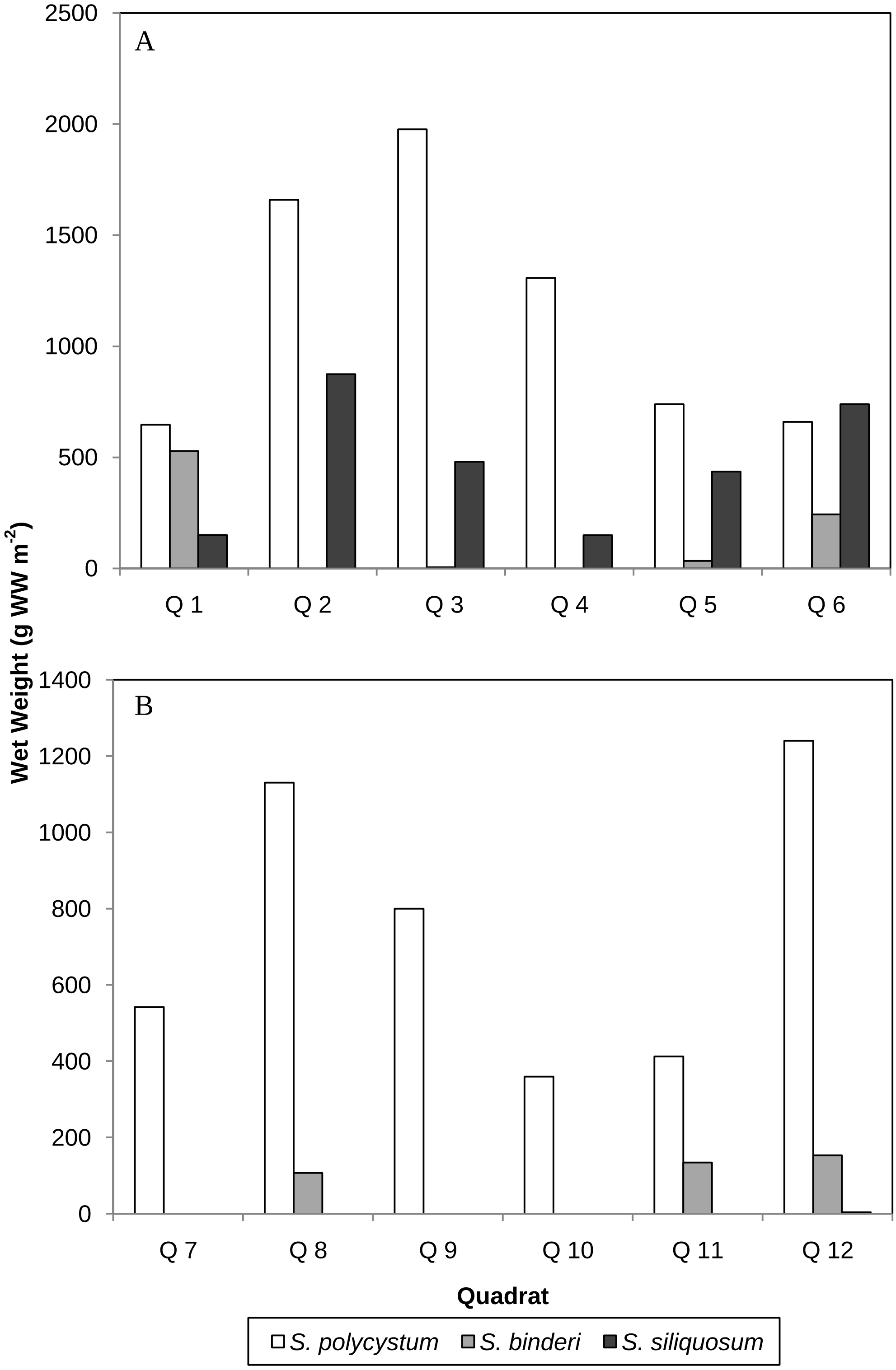


Figure 4.27: Wet weight (g WW m^{-2}) of *Sargassum* species collected from destructive sampling in July 2010 along line transects of (A) Left Reef and (B) Right Reef

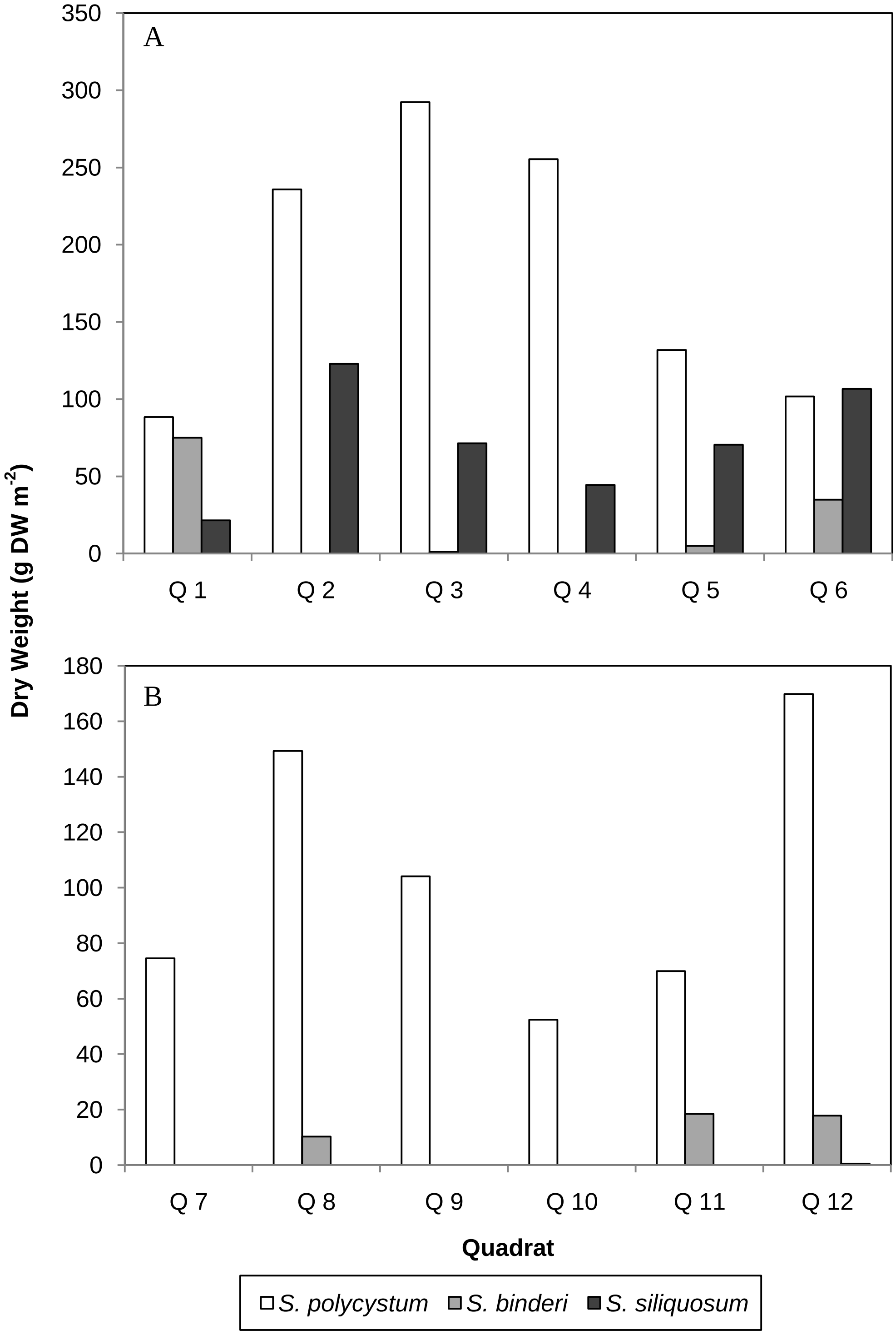


Figure 4.28: Dry weight (g DW m^{-2}) of *Sargassum* species collected from destructive sampling in July 2010 along line transects of (A) Left Reef and (B) Right Reef

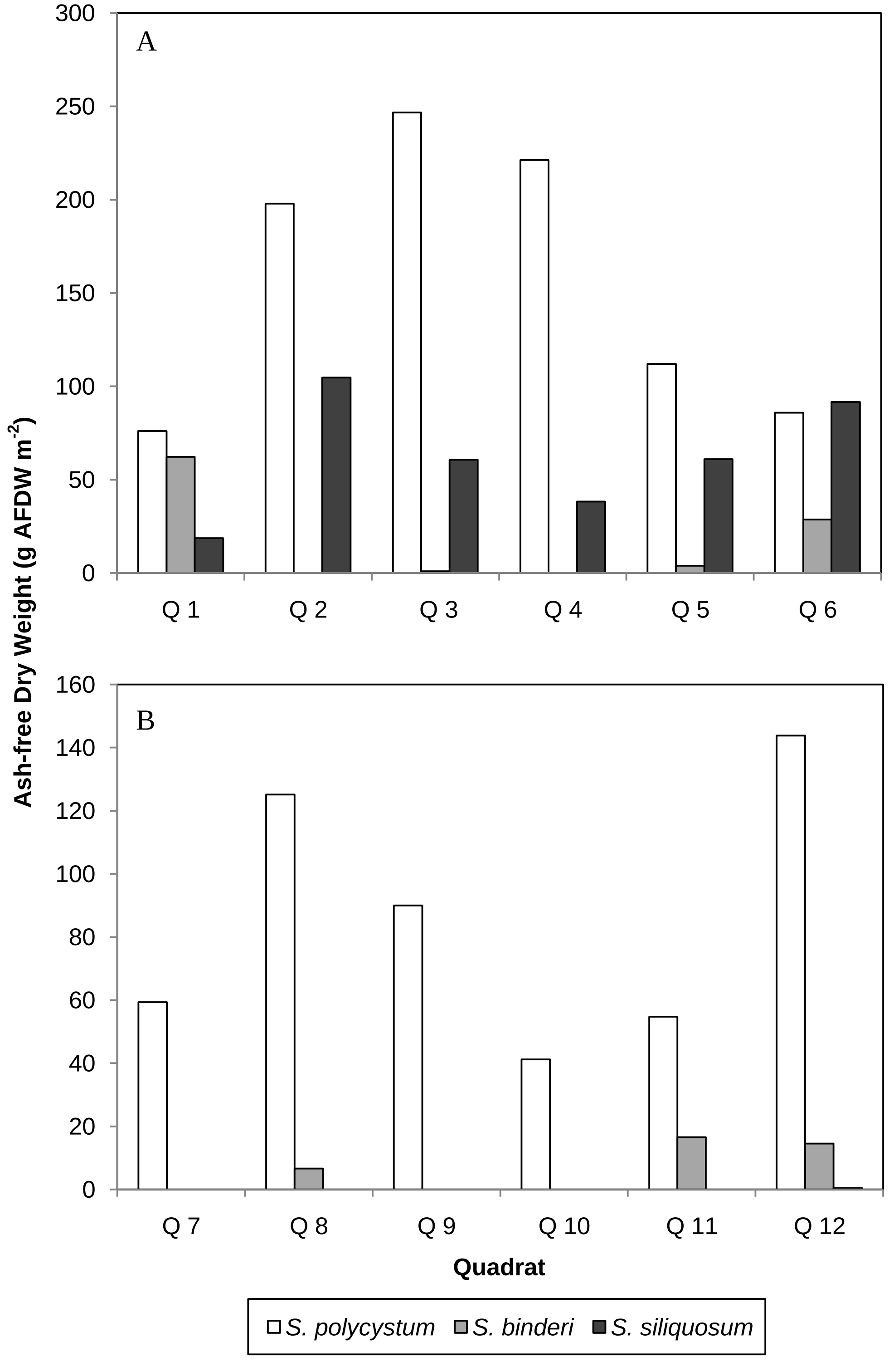


Figure 4.29: Ash-free dry weight (g AFDW m^{-2}) of *Sargassum* species collected from destructive sampling in July 2010 along line transects of (A) Left Reef and (B) Right Reef

4.4.1.7 September 2010

In the last destructive sampling, number of harvested samples increased with a total of 361 samples (*S. polycystum* = 166 plants; *S. binderi* = 62 plants; *S. siliquosum* = 133 plants), 223 plants from the LR (*S. polycystum* = 53 plants; *S. binderi* = 37 plants; *S. siliquosum* = 133 plants) and 138 plants from the RR (*S. polycystum* = 113 plants; *S. binderi* = 25 plants; *S. siliquosum* = 0 plants). *S. polycystum* and *S. binderi* were present in all quadrats on both reefs except in Q8 where *S. polycystum* was absent. *S. siliquosum* was present in all the quadrats of the LR, but none on the RR.

One-way ANOVA on log-transformed data tested significant ($p < 0.05$) for MTL changes of only *S. binderi* (F = 2.235) along quadrats (Appendix D). From Figure 4.30, both *S. binderi* and *S. siliquosum* showed a similar trend on the LR, whereby MTL decreased gradually from Q1 (*S. binderi*: 85.75 mm; *S. siliquosum*: 64.17 mm) to Q3 (*S. binderi*: 26.86 mm; *S. siliquosum*: 50.18 mm), and then increased in Q4 (*S. binderi*: 92.50 mm) and Q5 (*S. siliquosum*: 99.67 mm), before decreasing in Q6 (*S. binderi*: 31.90 mm; *S. siliquosum*: 45.74 mm). MTL of *S. polycystum* on the RR increased from Q7 (53.22 mm) towards the right, peaking in Q12 (92.11 mm). Overall, largest MTL belonged to *S. binderi* of Q11 (190.67 mm).

Changes in biomass along quadrats in terms of wet weight, dry weight and ash-free dry weight per quadrat for the month of September 2010 were illustrated in Figures 4.31, 4.32 and 4.33. On the LR, *S. polycystum* obtained highest biomass in Q4 (123.64 g WW m^{-2}; 19.78 g DW m^{-2}; 17.15 g AFDW m^{-2}), while *S. binderi* in Q1 (120.88 g WW m^{-2}; 16.56 g DW m^{-2}; 13.84 g AFDW m^{-2}) and *S. siliquosum* in Q2 (225.36 g WW m^{-2}; 46.74 g DW m^{-2}; 40.87 g AFDW m^{-2}). On the RR, *S. polycystum* obtained highest biomass in Q8 (143.60 g WW m^{-2}; 26.16 g DW m^{-2}; 21.46 g AFDW m^{-2}) and *S. binderi* in Q11 (115.52 g WW m^{-2}; 15.49 g DW m^{-2}; 13.50 g AFDW m^{-2}) while *S. siliquosum* was absent in all quadrats of the RR.

MTL of samples was not significantly correlated with biomass ($p >$ 0.05). For instance, MTL of *S. siliquosum* in Q5 (99.67 mm) was higher than those found in Q6 (45.74 mm). However, when biomass was considered, measurements in Q6 (171.68 g WW m^{-2}; 29.49 g DW m^{-2}; 25.44 g AFDW m^{-2}) were higher than those in Q5 (116.4 g WW m^{-2}; 19.66 g DW m^{-2}; 16.82 g AFDW m^{-2}).

Percentage fertility of all three species were relatively low in September 2010 (Table 4.8). Fertile *S. siliquosum* plants were only found on the LR (Q1: 12.50 %; Q2: 11.11 %; Q3: 5.88 %; Q4: 8.33 %; Q5: 16.67 %) and none on the RR. In contrast, fertile plants of *S. polycystum* were only found on the RR (Q7: 11.11 %; Q8: 4.55 %; Q10: 11.76 %; Q11: 3.85 %; Q12: 33.33 %). Highest percentage fertility belonged to *S. binderi* samples in Q4 with 50.00 % (1 fertile plant).

Pearson’s correlation revealed that percentage fertility of all three species were significantly correlated ($p < 0.01$) with MTL (*S. polycystum*: r =

0.621; *S. binderi*: r = 0.554; *S. siliquosum*: r = 0.702) but not significantly correlated ($p > 0.05$) with biomass.

Table 4.8: Total number of plants, number of fertile plants and percentage fertility (%) of *Sargassum* species collected from destructive sampling on September 2010 along line transects of (A) Left Reef and (B) Right Reef

A

Quadrat (Left Reef)	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
1	8	0	0.00	8	1	12.50	24	3	12.50
2	7	0	0.00	1	0	0.00	18	2	11.11
3	8	0	0.00	7	0	0.00	34	2	5.88
4	25	0	0.00	2	1	50.00	24	2	8.33
5	5	0	0.00	9	1	11.11	6	1	16.67
6	0	0	0.00	10	0	0.00	27	0	0.00
Total	53	0	0.00	37	3	8.11	133	10	7.52

B

Quadrat (Right Reef)	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
7	18	2	11.11	6	2	33.33	0	0	0.00
8	22	1	4.55	3	0	0.00	0	0	0.00
9	21	0	0.00	2	0	0.00	0	0	0.00
10	17	2	11.76	5	0	0.00	0	0	0.00
11	26	1	3.85	3	0	0.00	0	0	0.00
12	9	3	33.33	6	1	16.67	0	0	0.00
Total	113	9	7.96	25	3	12.00	0	0	0.00

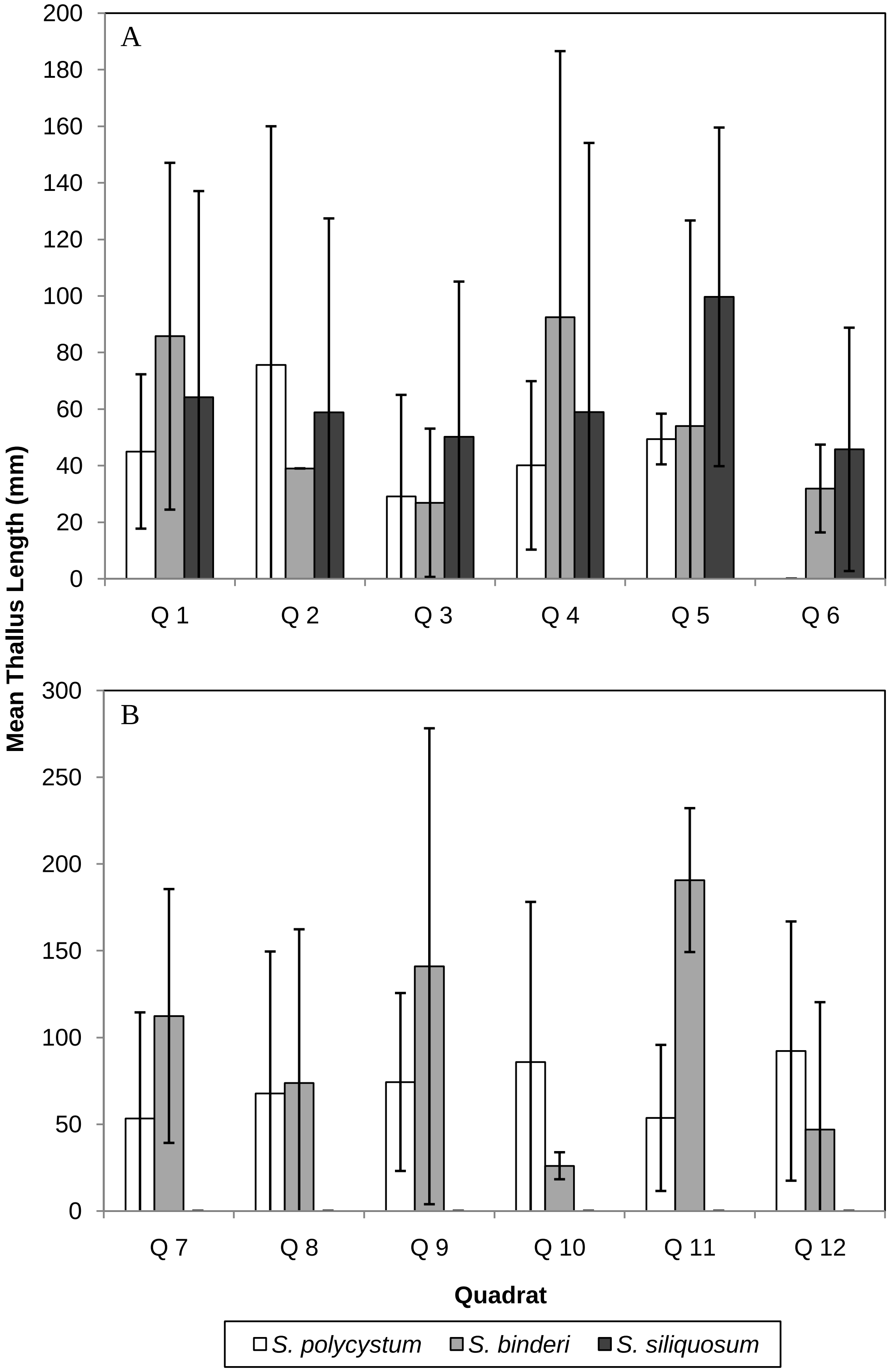


Figure 4.30: Mean thallus length (mm ± SD) of *Sargassum* species collected from destructive sampling in September 2010 along line transects of (A) Left Reef and (B) Right Reef

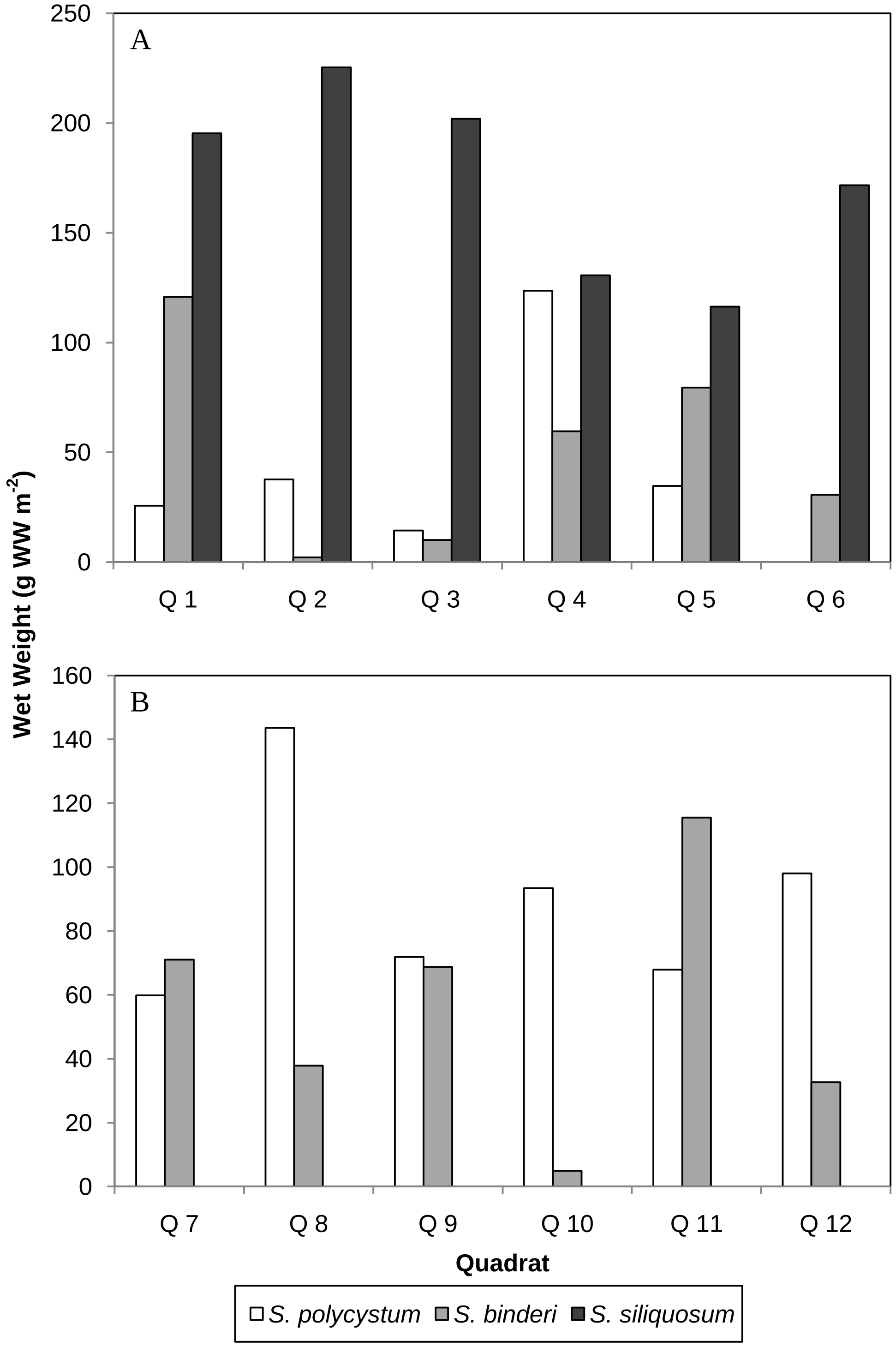


Figure 4.31: Wet weight (g WW m^{-2}) of *Sargassum* species collected from destructive sampling in September 2010 along line transects of (A) Left Reef and (B) Right Reef

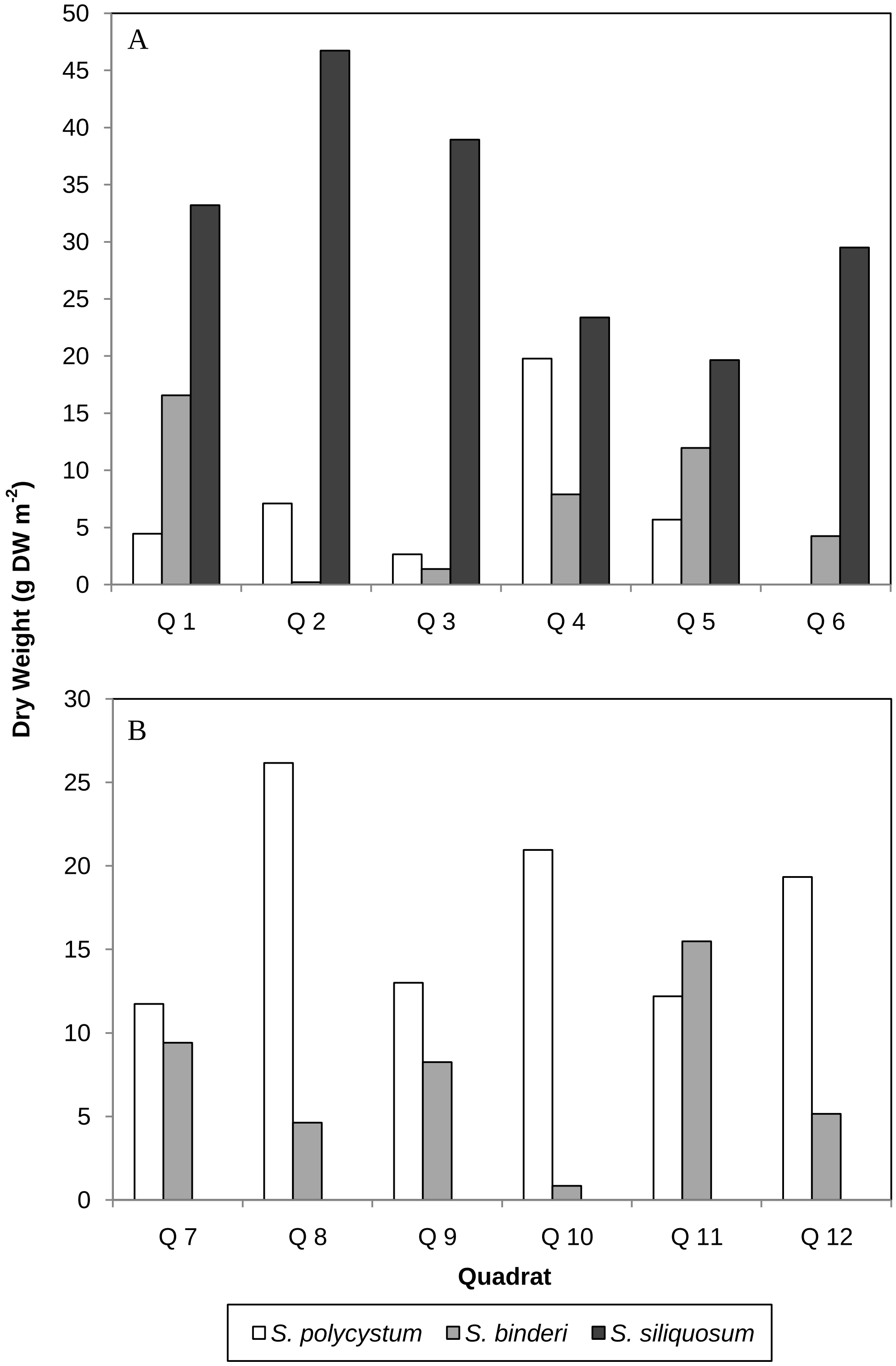


Figure 4.32: Dry weight (g DW m^{-2}) of *Sargassum* species collected from destructive sampling in September 2010 along line transects of (A) Left Reef and (B) Right Reef

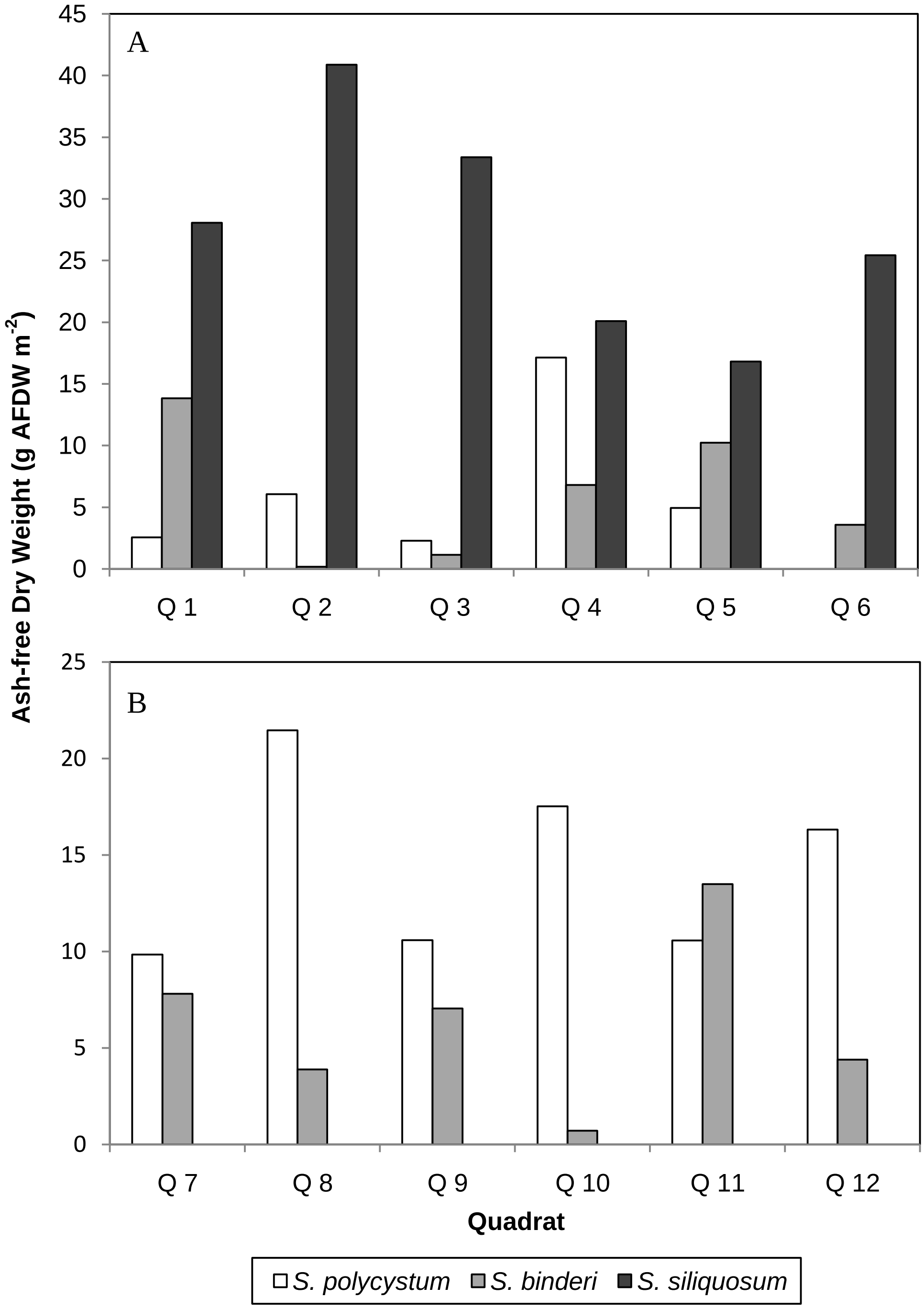


Figure 4.33: Ash-free dry weight (g AFDW m^{-2}) of *Sargassum* species collected from destructive sampling in September 2010 along line transects of (A) Left Reef and (B) Right Reef

4.4.2 Measurements by Months

Throughout sampling period, a total of 2555 plants were harvested (*S. polycystum* = 1361 plants; *S. binderi* = 418 plants; *S. siliquosum* = 776 plants) (Table 4.9). Measurements of MTL and biomass by month were illustrated in Figures 4.34 to 4.37 while percentage fertility in Table 4.9. Raw data of overall monthly measurements were listed in Appendix E.

One-way ANOVA and Post Hoc test (Tukey) denoted significant differences ($p < 0.05$) in bimonthly MTL change for *S. polycystum* (F = 71.360) (between: Sept 09 & Nov 09; Nov 09 & Jan 10; Mar 10 & May 10; May 10 & July 10; July 10 & Sept 10) *S. binderi* (F = 11.280) (between: Sept 09 & Nov 09; May 10 & July 10; July 10 & Sept 10) and *S. siliquosum* (F = 34.580) (between: Sept 09 & Nov 09; Jan 10 & Mar 10; Mar 10 & May 10; May 10 & July 10; July 10 & Sept 10) (Appendix D).

Figure 4.34 illustrated similar MTL patterns in all species whereby MTL was at one of its highest in September 2009 (*S. polycystum*: 210.32 mm; *S. binderi*: 163.34 mm; *S. siliquosum*: 152.27 mm), which then decreased dramatically to November 2009 (*S. polycystum*: 46.19 mm; *S. binderi*: 57.29 mm; *S. siliquosum*: 46.18 mm), followed by an increase in January 2010, (*S. polycystum*: 92.49 mm; *S. binderi*: 112.67 mm; *S. siliquosum*: 51.96 mm). From January 2010 to March 2010, *S. siliquosum* continued to increase significantly (*S. siliquosum*: 114.81 mm) while both *S. polycystum* and *S. binderi* gradually decreased (*S. polycystum*: 82.60 mm; *S. binderi*: 90.86 mm), after which all three species decreased to one of its lowest in May 2010 (*S. polycystum*: 59.17 mm; *S. binderi*: 50.63 mm; *S. siliquosum*: 58.42 mm). This was followed by a drastic increase in July 2010 (*S polycystum*: 222.32 mm; *S. binderi*: 157.95 mm; *S. siliquosum*: 228.89 mm) and finally a drastic decrease in September 2010 (*S polycystum*: 60.58 mm; *S. binderi*: 65.53 mm; *S. siliquosum*: 56.79 mm).

One-way ANOVA and Post Hoc test (Tukey) denoted significant differences ($p < 0.05$) in bimonthly biomass for *S. polycystum* (WW: F = 10.146; DW: F = 7.954; AFDW: F = 20.766) (for WW, DW & AFDW between: May 10 & July 10; July 10 & Sept 10), *S. binderi* (WW: F = 3.458; DW: F = 4.177; AFDW: F = 8.641) (for WW, DW & AFDW between: Nov 10 & Jan 10; for AFDW between May 10 & July 10) and *S. siliquosum* (WW: F = 1.735; DW: F = 2.006; AFDW: F = 6.934) (for AFDW between: May 10 & July 10) (Appendix D).

Figures 4.35 to 4.37 illustrated that in September 2009, average biomass were relatively high for *S. polycystum* (323.39 g WW m^{-2}; 33.03 g DW m^{-2}; 24.81 g AFDW m^{-2}), *S. binderi* (101.08 g WW m^{-2}; 13.84 g DW m^{-2}; 8.79 g AFDW m^{-2}) and *S. siliquosum* (339.38 g WW m^{-2}; 48.71 g DW m^{-2}; 27.48 g AFDW m^{-2}) but biomass decreased to one of its lowest in November 2009 (*S. polycystum*: 91.99 g WW m^{-2}; 14.76 g DW m^{-2}; 9.46 g AFDW m^{-2}; *S. binderi*: 23.87 g WW m^{-2}; 3.24 g DW m^{-2}; 2.27 g AFDW m^{-2}; *S. siliquosum*: 142.65 g WW m^{-2}; 18.94 g DW m^{-2}; 9.42 g AFDW m^{-2}). Biomass of *S. siliquosum* continued to decrease to its lowest in January 2010 (99.72 g WW m^{-2}; 14.96 g DW m^{-2}; 7.62 g AFDW m^{-2}) while *S. polycystum* and *S. binderi* increased (*S. polycystum*: 102.58 g WW m^{-2}; 16.70 g DW m^{-2}; 12.97 g AFDW m^{-2}; *S. binderi*: 188.87 g WW m^{-2}; 121.13 g DW m^{-2}; 12.01 g AFDW m^{-2}). Biomass continued to fluctuate for the next few months but increased dramatically to one of its highest in July 2010 (*S. polycystum*: 956.02 g WW m^{-2}; 143.80 g DW m^{-2}; 121.19 g AFDW m^{-2}; *S. binderi*: 172.26 g WW m^{-2}; 23.19 g DW m^{-2}; 11.11 g AFDW m^{-2}; *S. siliquosum*: 404.75 g WW m^{-2}; 62.55 g DW m^{-2}; 31.29 g AFDW m^{-2}). This was followed by a drastic decrease in September 2010 (*S. polycystum*: 70.06 g WW m^{-2}; 13.01 g DW m^{-2} *S. binderi*: 52.80 g WW m^{-2}; 7.17 g DW m^{-2}; 6.10 g AFDW m^{-2}; *S. siliquosum*: 173.57 g WW m^{-2}; 31.90 g DW m^{-2}; 27.44 g AFDW m^{-2}).

One-way ANOVA and Post Hoc test (Tukey) denoted significant differences ($p < 0.05$) in bimonthly number of fertile plants for *S. polycystum* (F = 85.387) (between: Sept 09 & Nov 09; Mar 10 & May 10; May 10 & July 10), *S. binderi* (F = 10.705) (between: Sept 09 & Nov 09; Mar 10 & May 10; May 10 & July 10) and *S. siliquosum* (F = 23.827) (between: Sept 09 & Nov 09; Jan 10 & Mar 10; Mar 10 & May 10; May 10 & July 10; July 10 & Sept 10) (Appendix D).

Table 4.9 showed that *S. binderi* was fertile throughout the sampling period, while no fertile plants were seen for *S. polycystum* and *S. siliquosum* in certain months (*S. polycystum*: November 2009 and May 2010; *S. siliquosum*: November 2009). Percentage fertility of all three species were at its highest in September 2009 (*S. polycystum*: 52.99 %; *S. binderi*: 48.94 % and *S.*

siliquosum: 38.10 %), followed by a drastic decrease in fertility in November 2009 (*S. polycystum*: 0 %; *S. binderi*: 1.82 %; *S. siliquosum*: 0 %). Percentage fertility went on to peak in March 2010 (*S. polycystum*: 7.69 %; *S. binderi*: 20.91 % and *S. siliquosum*: 20.35 %) and peak again in July 2010 (*S. polycystum*: 11.00 %; *S. binderi*: 30.77 % and *S. siliquosum*: 29.09 %).

Table 4.9: Total number of plants, number of fertile plants and percentage fertility (%) of *Sargassum* species collected bimonthly from September 2009 to September 2010

Month	*S. polycystum*			*S. binderi*			*S. siliquosum*		
	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility	Total No. Plts	No. Fertile Plts	% Fertility
Sept 09	134	71	52.99	47	23	48.94	126	48	38.10
Nov 09	279	1	0.36	55	1	1.82	152	0	0.00
Jan 10	140	5	3.57	45	9	20.00	121	2	1.65
Mar 10	208	16	7.69	110	23	20.91	113	23	20.35
May 10	243	0	0.00	60	2	3.33	76	3	3.95
Jul10	191	21	11.00	39	12	30.77	55	16	29.09
Sept 10	166	9	5.42	62	6	9.68	133	10	7.52
Total	1361	123	9.04	418	76	18.18	776	102	13.14

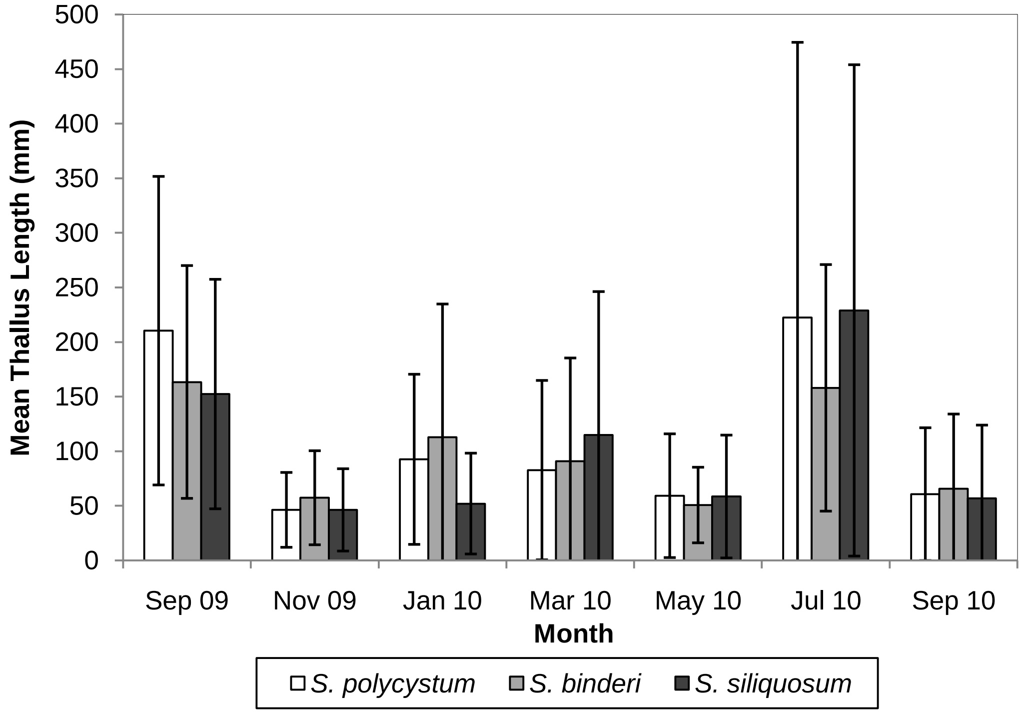


Figure 4.34: Bimonthly mean thallus length (mm ± SD) of *Sargassum* species from September 2009 to September 2010

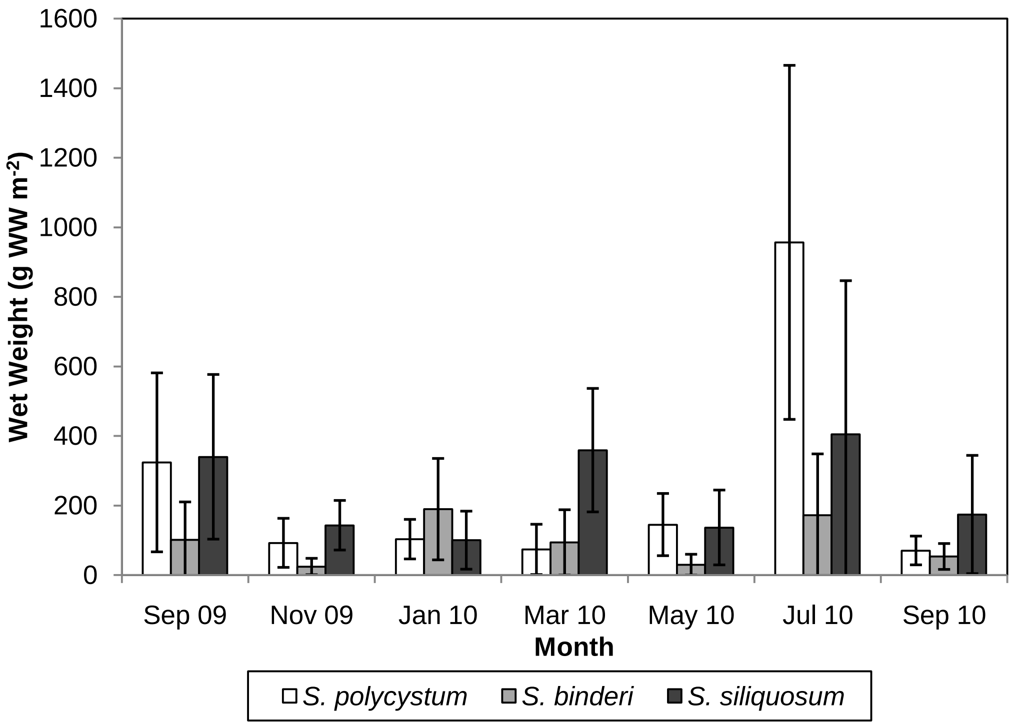


Figure 4.35: Bimonthly mean wet weight (g WW m^{-2} ± SD) of *Sargassum* species from September 2009 to September 2010

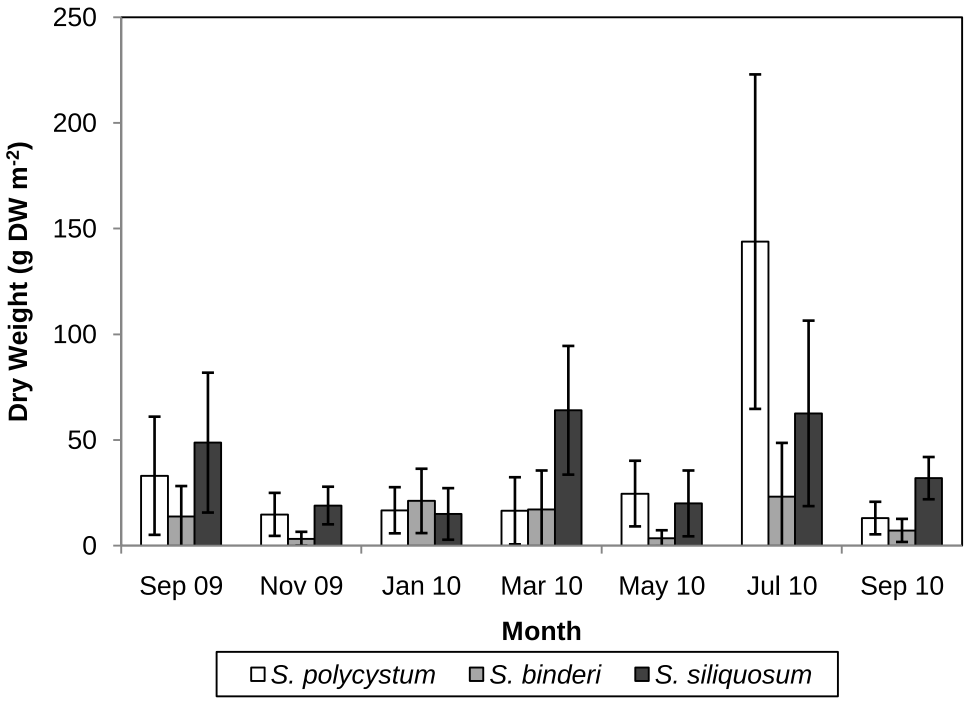


Figure 4.36: Bimonthly mean dry weight (g DW m^{-2} ± SD) of *Sargassum* species from September 2009 to September 2010

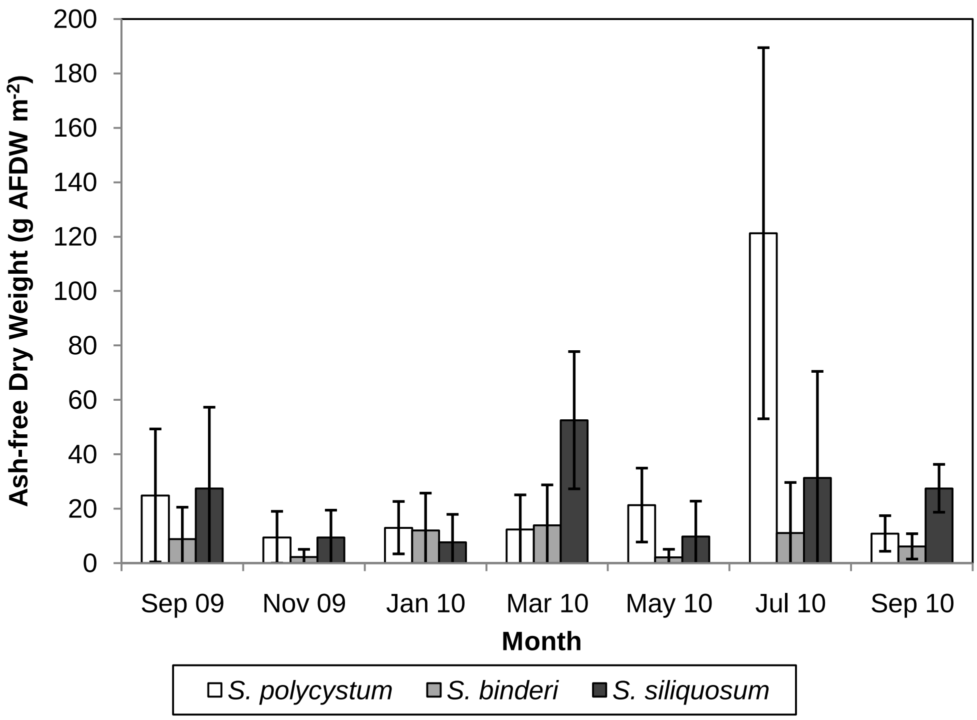


Figure 4.37: Bimonthly mean ash-free dry weight (g AFDW m^{-2} ± SD) of *Sargassum* species from September 2009 to September 2010

4.4.3 Comparison between Measurements

From Figure 4.38, peak MTL was indicated to coincide with peak biomass. However, Pearson's correlation failed to correlate MTL and biomass for all three species ($p > 0.05$).

When MTL increased (Figure 4.39), so did percentage fertility of samples, and vice versa. This pattern was confirmed when Pearson's correlation tested significant ($p < 0.01$) between bimonthly MTL and number of fertile plants for all species (*S. polycystum*: r = 0.619; *S. binderi*; r = 0.697; *S. siliquosum*: r = 0.749).

Results of Pearson's correlation denoted no significance ($p > 0.05$) in correlation between bimonthly biomass and number of fertile plants for all three species. This was seen in Figure 4.40 whereby peak biomass did not necessarily coincide with peak fertility. For instance, average biomass of *S. binderi* was highest in January 2010 (188.87 g WW m^{-2}; 21.13 g DW m^{-2}; 12.01 g AFDW m^{-2}), but percentage fertility was only 20.00 %, which was lower compared to the highest percentage fertility in September 2009 (48.94 %).

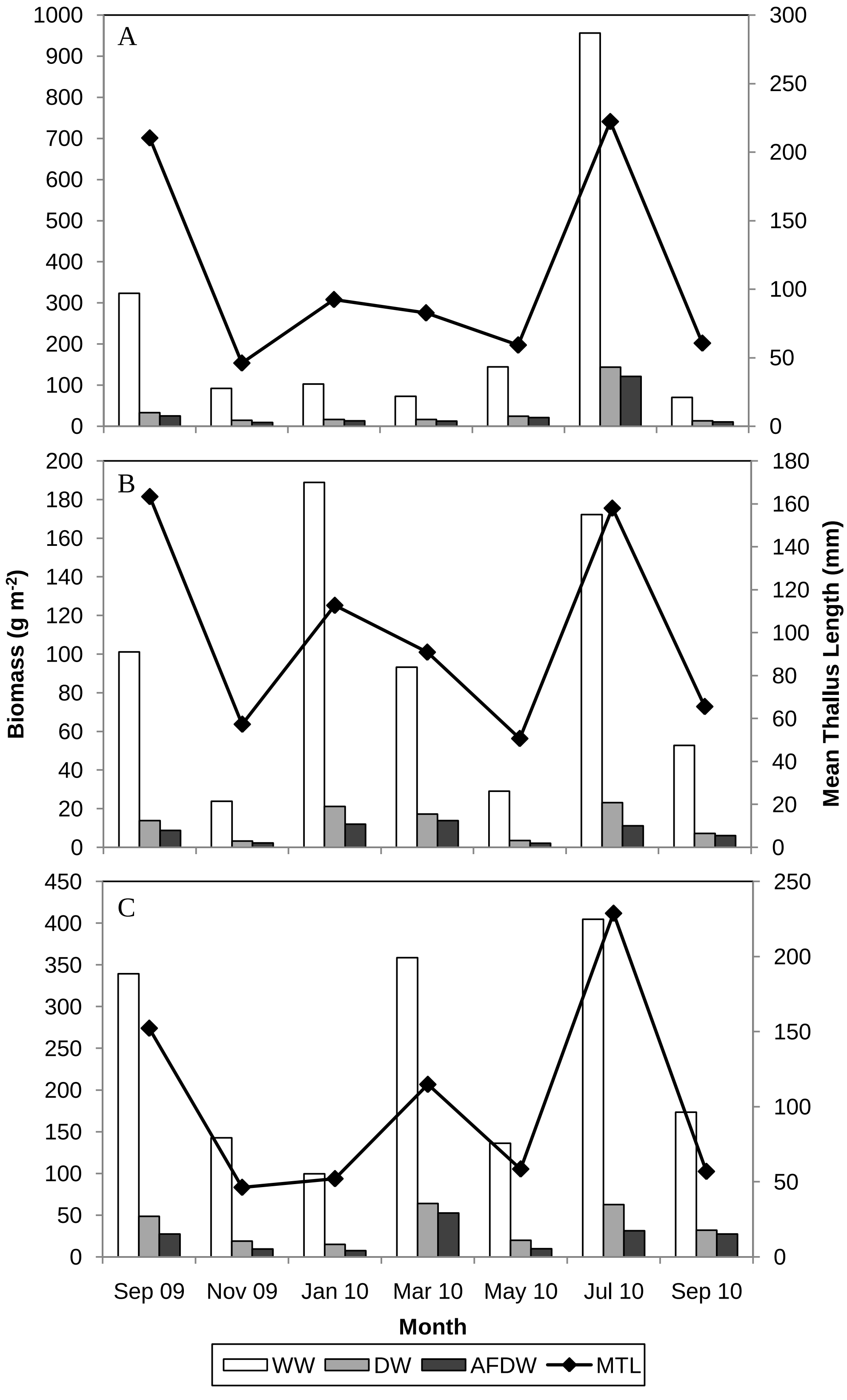


Figure 4.38: Comparison between bimonthly biomass (g m^{-2}) and mean thallus length (mm) of (A) *S. polycystum*, (B) *S. binderi* and (C) *S. siliquosum*

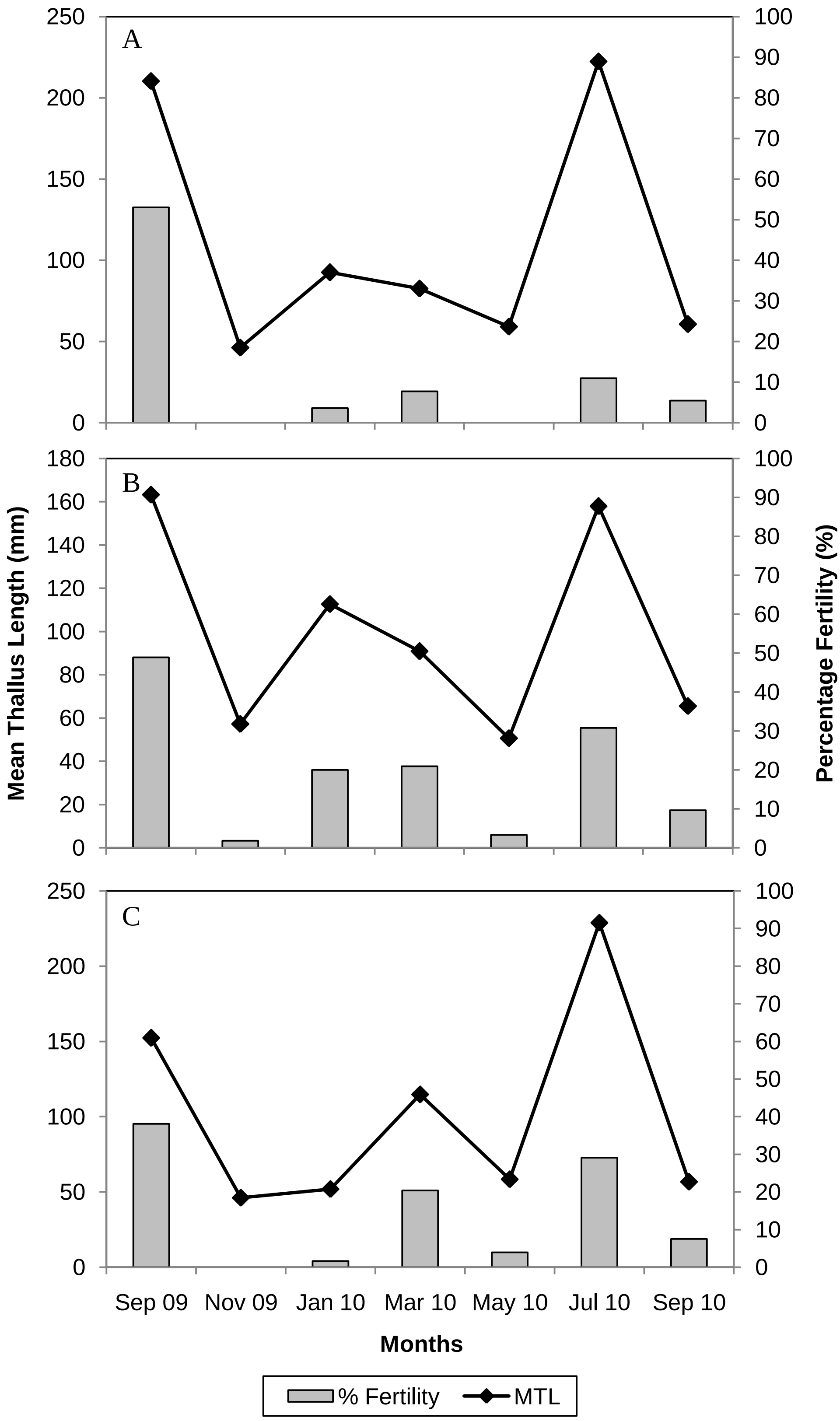


Figure 4.39: Comparison between bimonthly mean thallus length (mm) and percentage fertility (%) of (A) *S. polycystum*, (B) *S. binderi* and (C) *S. siliquosum*

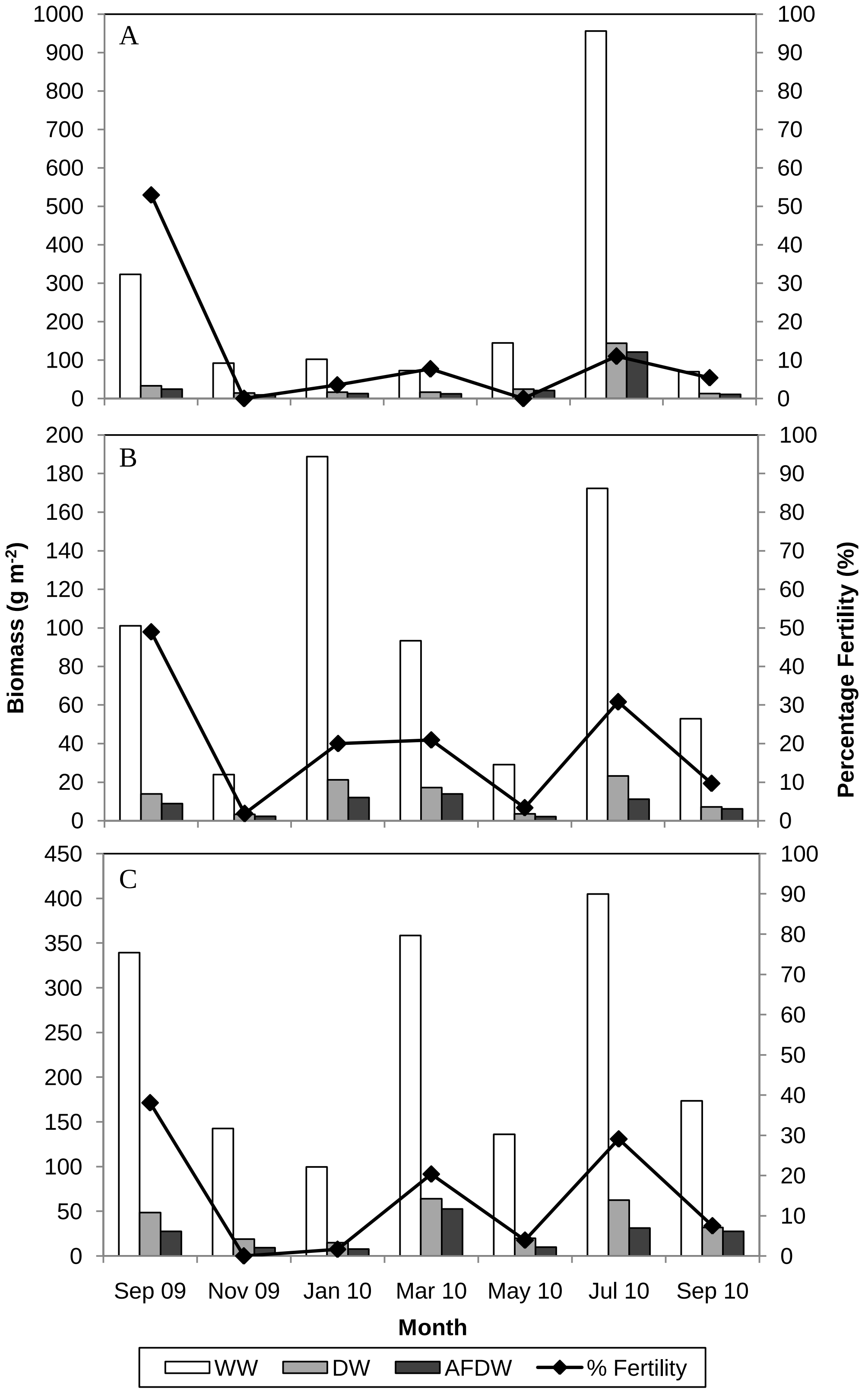


Figure 4.40: Comparison between bimonthly biomass (g m^{-2}) and percentage fertility (%) of (A) *S. polycystum*, (B) *S. binderi* and (C) *S. siliquosum*

4.4.4 Percentage Sexuality

Cross section of bimonthly receptacles confirmed that *S. binderi* plants were androgynous, possessing both male and female reproductive parts within the same receptacle (Figure 4.41B); while *S. polycystum* (Figure 4.41A) and *S. siliquosum* (Figure 4.41C) were dioecious, possessing male and female reproductive parts in separate plants. Throughout sampling period, there was a higher female to male plant ratio for *S. polycystum* (88 female : 35 male) with 71.54 % female and 28.46 % male plants. Similarly, *S. siliquosum* also had higher female to male plant ratio (29 female : 22 male) with 56.86 % female and male: 43.14 % male plants (Table 4.10). Proportions of female percentage were more in *S. polycystum* than in *S. siliquosum* plants. In the case of *S. siliquosum*, there were certain months whereby percentage of male plants exceeded that of female plants, such as in May 2010 (1 female : 2 male) and July 2010 (5 female : 11 male).

Table 4.10: Bimonthly sex ratio and overall percentage sexuality for *Sargassum* species

Month	*S. polycystum*		*S. binderi*	*S. siliquosum*	
	Female	Male	Androgynous	Female	Male
Sept 09	52	19	23	29	19
Nov 09	1	0	1	0	0
Jan 10	5	0	9	1	1
Mar 10	10	6	23	14	9
May 10	0	0	2	1	2
July 10	13	8	12	5	11
Sept 10	7	2	6	8	2
Total	88	35	76	58	44
% Sexuality	71.54	28.46	-	56.86	43.14

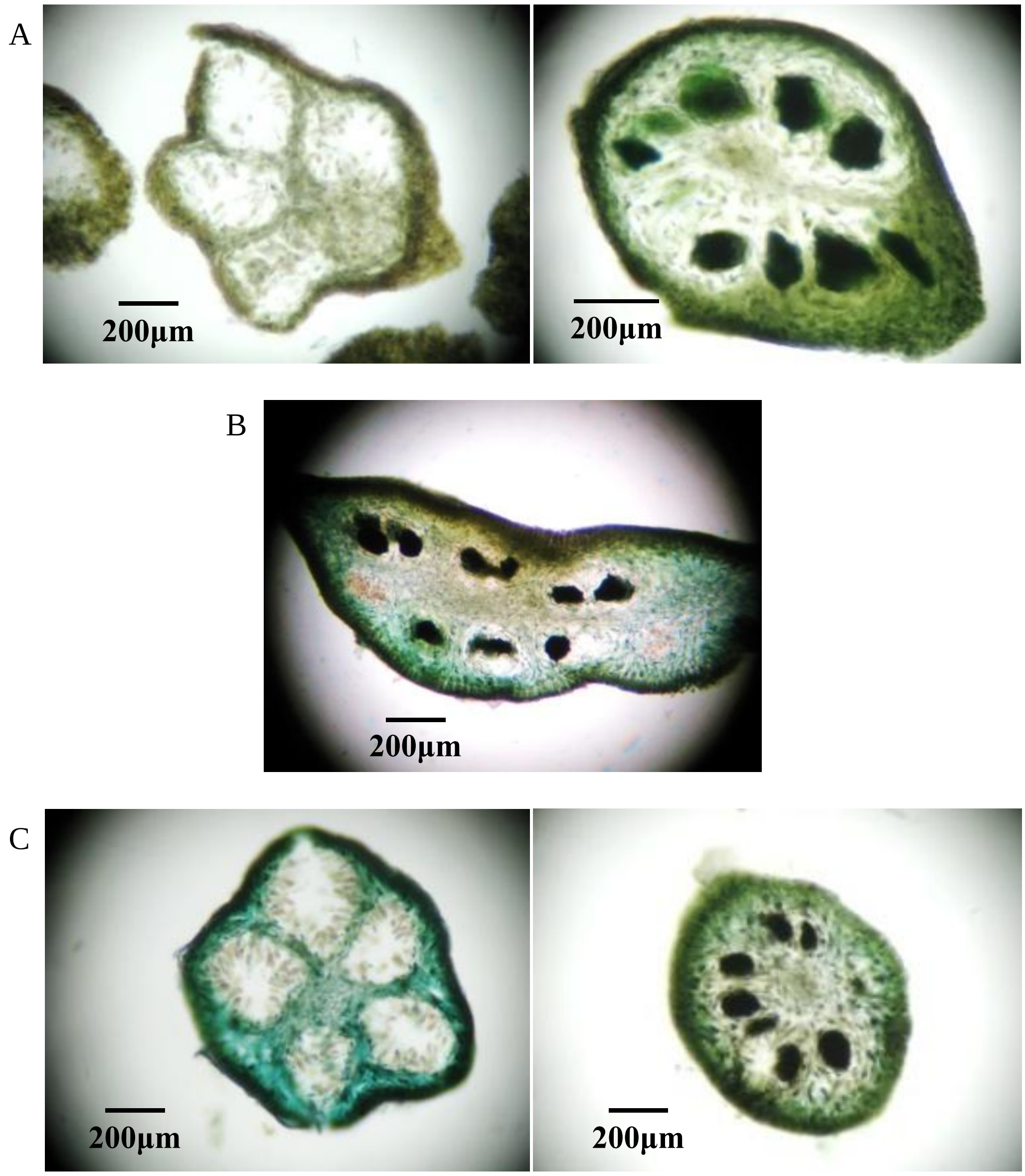


Figure 4.41: Cross Section of (A) *S. polycystum* male (left) and female (right) receptacle, (B) *S. binderi* androgynous receptacle and (C) *S. siliquosum* male (left) and female (right) receptacle

4.4.5 Length Classes

Thallus lengths of bimonthly samples were arranged into length classes of 0 - 99 mm for *S. polycystum* (Figure 4.42), *S. binderi* (Figure 4.43) and *S. siliquosum* (Figure 4.44).

S. polycystum samples of length classes 0 – 99 mm amounted to the largest percentage frequency in all months (September 2009: 30.6 %; November 2009: 92.11 %; January 2010: 64.29 %; March 2010: 70.67 %; May 2010: 95.88 %; July 2010: 50.26 %; September 2010: 83.13 %). The months of September 2009 and July 2010 saw a more diverse range in thallus lengths, with the largest samples in September 2009 belonging to length classes of 800 – 899 mm (0.75 %) while largest in July belonging to 1000 – 1099 mm (0.52 %). However, in November 2009 and May 2010, all samples harvested consisted only of smaller sized plants (< 300 mm).

Similar to *S. polycystum*, majority of *S. binderi* samples were measured to be in the smallest length class of 0 – 99 mm in all months (September 2009: 38.30 %; November 2009: 85.45 %; January 2010: 64.44 %; March 2010: 66.36 %; May 2010: 100.00 %; July 2010: 38.46 %; September 2010: 75.81 %). Largest samples were found in March 2010 with length classes of 600 – 699 mm (0.91 %). In the months of November 2009, May 2010 and September 2010, all samples harvested consisted of smaller sized plants (< 300 mm), with May 2010 consisting only of samples smaller than 100 mm.

Majority of *S. siliquosum* samples were also measured to be in the smallest length classes of 0 – 99 mm in all months (September 2009: 42.86 %; November 2009: 90.79 %; January 2010: 86.42 %; March 2010: 66.37 %; May 2010: 97.37 %; July 2010: 43.64 %; September 2010: 81.20 %). Largest samples were found in July 2010 with length classes of 700 – 799 mm (3.64 %). In the months of November 2009, January 2010 and May 2010, only small samples (< 300 mm) were harvested.

Overall length classes of *Sargassum* samples throughout the study period were illustrated in Figure 4.45. Results showed that majority of harvested samples were in the length classes of 0 – 99 mm (*S. polycystum*: 71 25 %; *S. binderi*: 67.22 %; *S. siliquosum*: 71.74 %). Of all three species, *S. polycystum* possessed the largest sized sample, reaching up to length classes of 1000 – 1099 mm, followed by *S. siliquosum* with 700 – 799 mm and *S. binderi* with 600 – 699 mm. Overall, *Sargassum* species in Teluk Kemang consisted mostly of smaller sized plants (< 200 mm) with only small percentage frequencies of larger sized plants.

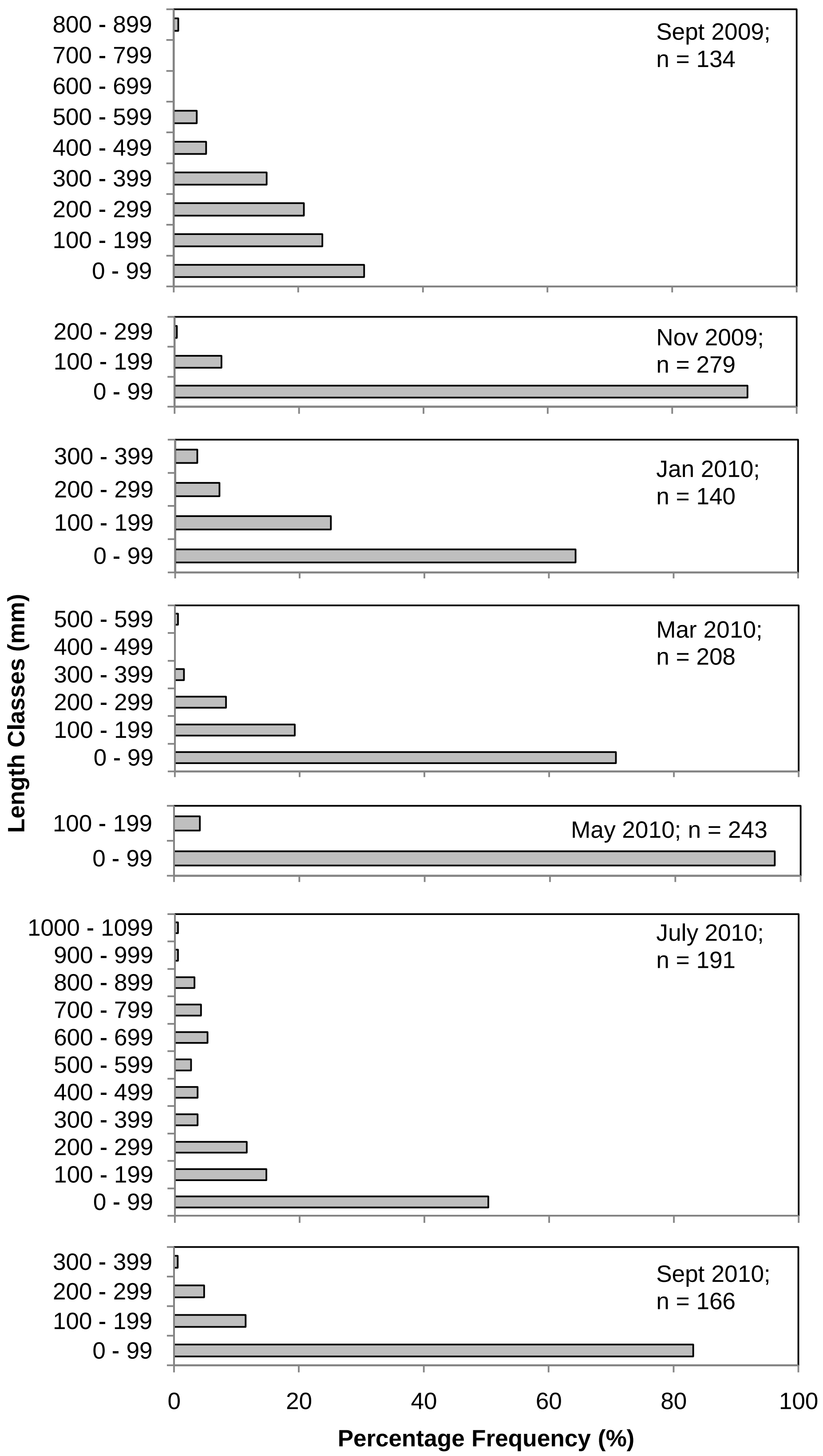


Figure 4.42: Seasonal variation in *S. polycystum* length classes (mm) from September 2009 to September 2010 measured using destructive sampling method

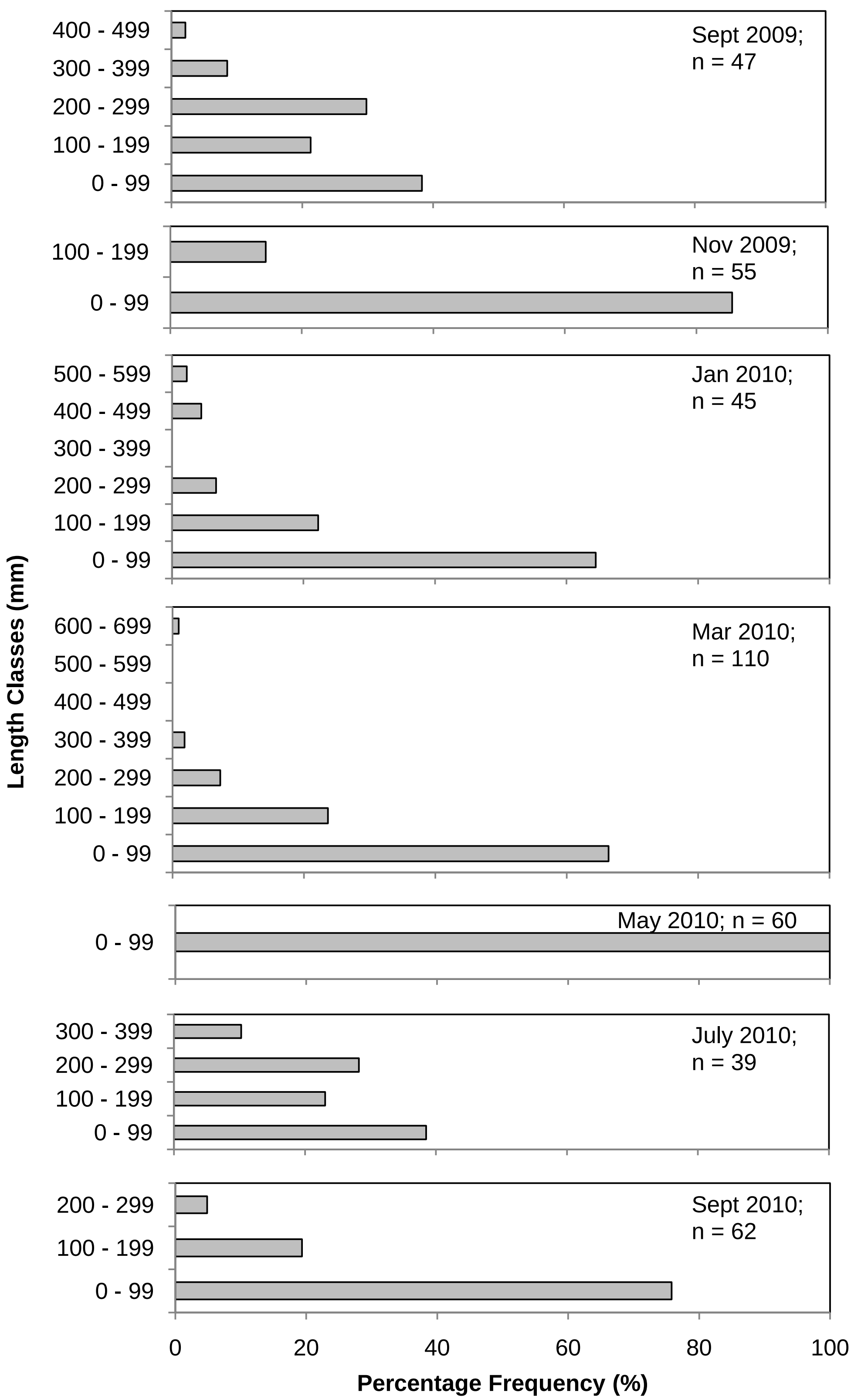


Figure 4.43: Seasonal variation in *S. binderi* length classes (mm) from September 2009 to September 2010 measured using destructive sampling method

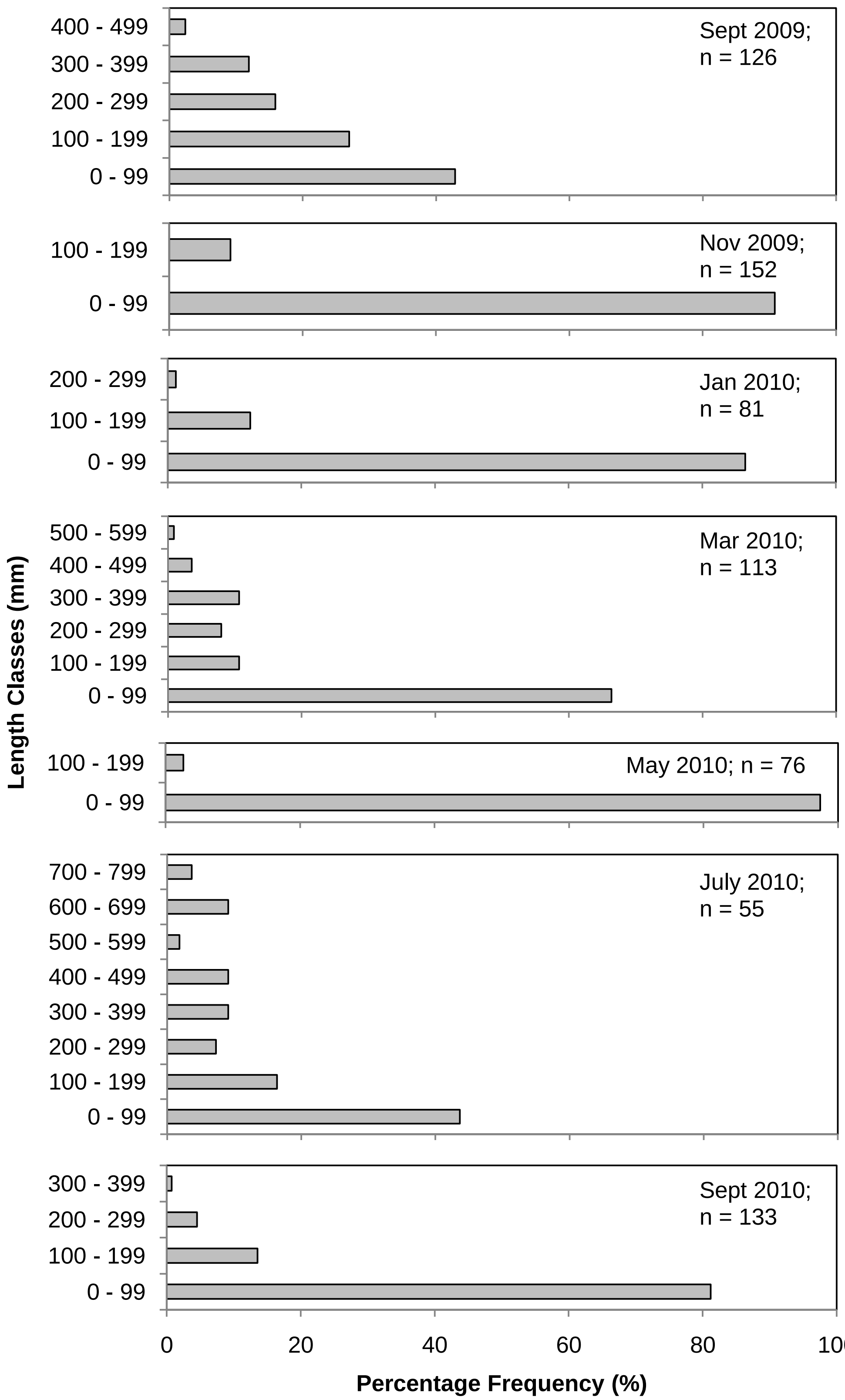


Figure 4.44: Seasonal variation in *S. siliquosum* length classes (mm) from September 2009 to September 2010 measured using destructive sampling method

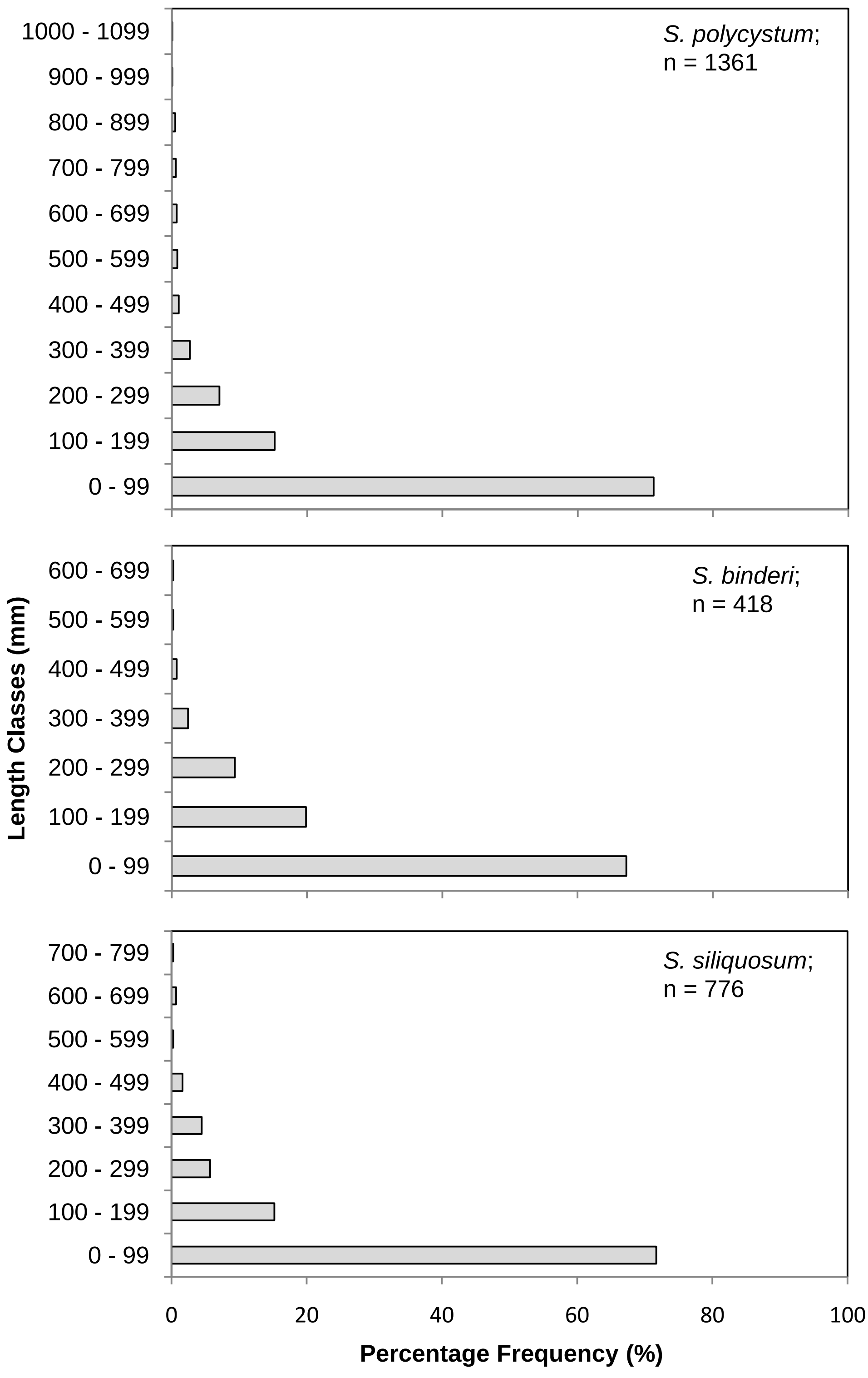


Figure 4.45: Overall length classes (mm) of *S. polycystum*, *S. binderi* and *S. siliquosum* measured using destructive sampling method

4.5 Non-Destructive Sampling

4.5.1 Measurements by Quadrats

Measurements of tagged samples were conducted every month from September 2009 to September 2010. Throughout the study period, total number of *S. polycystum* plants that were tagged amounted to 346 plants (LR: 92 tags; RR: 254 tags), while *S. binderi* amounted to 125 plants (LR: 92 tags; RR: 33 tags) and *S. siliquosum* amounted to 193 plants (LR: 182 tags; RR: 11 tags). Table 4.11 revealed that *S. polycystum* samples were present in all quadrats, with the most number of tagged plants in Q9 (67 tags). *S. binderi* samples were present in all except Q9, with most number of plants in Q6 (34 tags). As for *S. siliquosum*, samples were present in almost every quadrat except in Q8 and Q11, with highest number in Q4 (48 plants).

Figure 4.46 illustrates the overall MTL of *Sargassum* species along quadrats. Highest MTL of *S. polycystum* was in Q6 (234.17 mm), while for *S. binderi*, highest MTL was in Q10 (125.00 mm) and lastly *S. siliquosum* MTL was highest in Q1 (177.60 mm). No standard deviation was seen for *S. siliquosum* in Q9 due to presence of only one plant. One-way ANOVA denoted significant differences in MTL along quadrats only for *S. polycystum* (F = 4.691; $p < 0.01$) (Appendix F).

Overall percentage fertility of *Sargassum* species along quadrats was seen in Table 4.11. *S. polycystum* samples obtained highest percentage fertility in Q6 (33.33 %) but no fertile samples were found in Q8. Highest percentage fertility of *S. binderi* was in Q7 (28.57 %) while no fertile samples were seen in Q8 and Q9. Lastly, percentage fertility of *S. siliquosum* was highest in Q2 (33.33 %) but no fertile plants were found on the RR throughout the sampling period. Changes in percentage fertility between quadrats were significant ($p < 0.05$) only for *S. polycystum* (F = 3.622) and *S. siliquosum* (F = 2.482) (Appendix F).

Table 4.11: Total number of tags and overall percentage fertility (%) of *Sargassum* species from non-destructive sampling from September 2009 to September 2010 along line transects of (A) Left Reef and (B) Right Reef

A

Quadrat (Left Reef)	*S. polycystum*		*S. binderi*		*S. siliquosum*	
	Total Tags	Overall % Fert	Total Tags	Overall % Fert	Total Tags	Overall % Fert
1	5	18.18	13	21.88	16	12.00
2	15	17.39	6	25.00	23	33.33
3	17	4.17	15	6.45	37	11.45
4	10	10.00	14	19.05	48	15.87
5	41	6.98	10	7.69	29	19.09
6	4	33.33	34	8.54	29	8.91
Total	92	10.14	92	12.67	182	15.38

B

Quadrat (Right Reef)	*S. polycystum*		*S. binderi*		*S. siliquosum*	
	Total Tags	Overall % Fert	Total Tags	Overall % Fert	Total Tags	Overall % Fert
7	27	15.25	5	28.57	2	0.00
8	31	0.00	1	0.00	0	0.00
9	67	5.88	0	0.00	1	0.00
10	51	2.11	3	25.00	4	0.00
11	49	8.73	8	4.76	0	0.00
12	29	16.18	16	12.50	4	0.00
Total	254	7.60	33	12.12	11	0.00

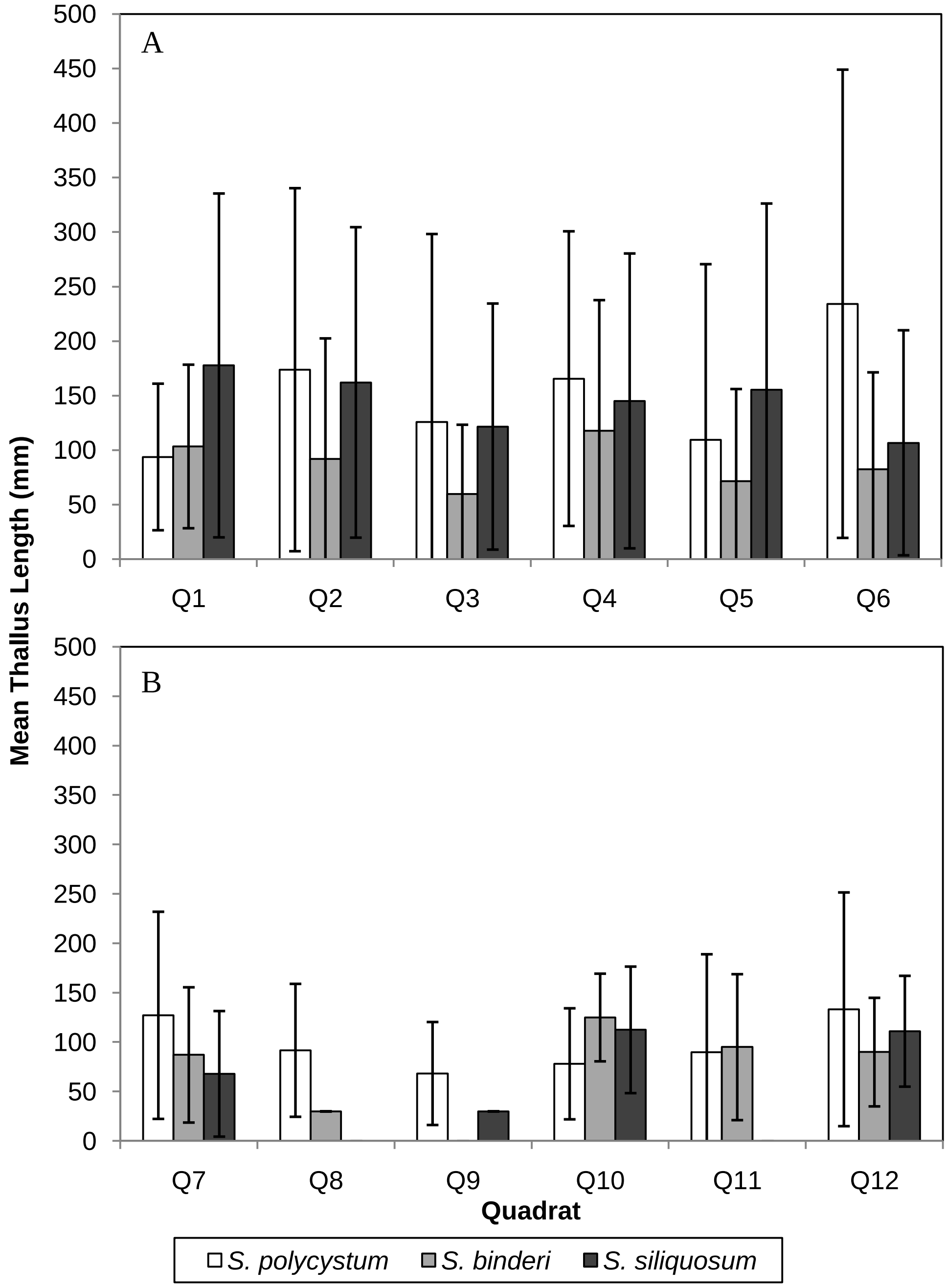


Figure 4.46: Overall mean thallus length (mm ± SD) of tagged samples along quadrats from (A) Left Reef and (B) Right Reef

4.5.2 Measurements by Months

A clear pattern in monthly MTL variation was observed for all three species in Figure 4.47. One-way ANOVA test denoted significant differences in monthly MTL variation ($p < 0.01$) for *S. polycystum* (F = 19.218), *S. binderi* (F = 6.601) and *S. siliquosum* (F = 13.721) as listed in Appendix F.

Tagged samples were measured to be moderately large in September 2009 (*S. polycystum*: 76.43 mm; *S. binderi*: 135.94 mm; *S. siliquosum*: 119.64 mm) which gradually decreased and increased in MTL for the next few months until February 2010 where MTL peaked (*S. polycystum*: 127.21 mm; *S. binderi*: 121.96 mm; *S. siliquosum*: 223.30 mm). This was followed by another cycle of gradual decrease in MTL toward the middle of the year and thereafter another increase until July 2010, where MTL were highest for all three species (*S. polycystum*: 228.62 mm; *S. binderi*: 166.88 mm; *S. siliquosum*: 281.14 mm). MTL then decreased again until September 2010.

One-way ANOVA denoted significant differences ($p < 0.01$) in variation of monthly percentage fertilitiy for *S. polycystum* (F = 3.801), *S. binderi* (F = 5.062) and *S. siliquosum* (F = 11.971) (Appendix F), of which a clear pattern, similar to that of MTL variation, was seen (Figure 4.48).

Percentage fertility of all three species were relatively high in September 2009 (*S. polycystum*: 7.14 %; *S. binderi*: 60 %; *S. siliquosum*: 27.87 %), in which tagged samples of *S. binderi* were most fertile found.

Fertility decreased in the following month (except for *S. polycystum* which increased) until no fertile tagged plants were found in November 2009. For the next few months, percentage fertility gradually increased and peaked in February 2010 (*S. polycystum*: 13.95 %) and March 2010 (*S. binderi*: 18.18 %; *S. siliquosum*: 35.19 %). This was followed by a period of 0 % fertile plants in May 2010 for *S. polycystum* and *S. binderi* samples; and in June 2010 for *S. polycystum* and *S. siliquosum.* Percentage fertility then soared up to its highest in August 2010 for *S. polycystum* (17.19 %) and *S. siliquosum* (50 %), after which, fertility of all three species decreased again in September 2010.

Every month, the numbers of existing tags that went missing and new tags that were added were noted (Table 4.12). For *S. siliquosum*, June 2010 saw the highest number of lost tags and percentage loss (24 lost tags; 46.15 % loss). As for both *S. polycystum* and *S. binderi*, the most number of lost tags were in April 2010 (*S. polycystum*: 38 lost tags; 43.18 % loss; *S. binderi*: 15 lost tags; 45.45 % loss), but highest percentage of tags lost were in November 2009 (*S. polycystum*: 35 lost tags; 77.78 % loss; *S. binderi*: 11 lost tags; 57.89 % loss). November 2009 was also the month where least new tags were added for all three species (*S. polycystum*: 2 new tags; *S. binderi*: 6 new tags; *S. siliquosum*: 3 new tags). In the next month of December 2009, *S. polycystum* gained the most number of new tags (55 new tags), while the most number of new tags for *S. binderi* was in January 2010 and September 2010 (18 new tags each), and for *S. siliquosum* also in September 2010 (21 new tags). Overall percentage of tags lost was 77.17 % (267 lost tags) for *S. polycystum*, 76.00 % (95 lost tags) for *S. binderi* and 73.06 % (141 lost tags) for *S. siliquosum*.

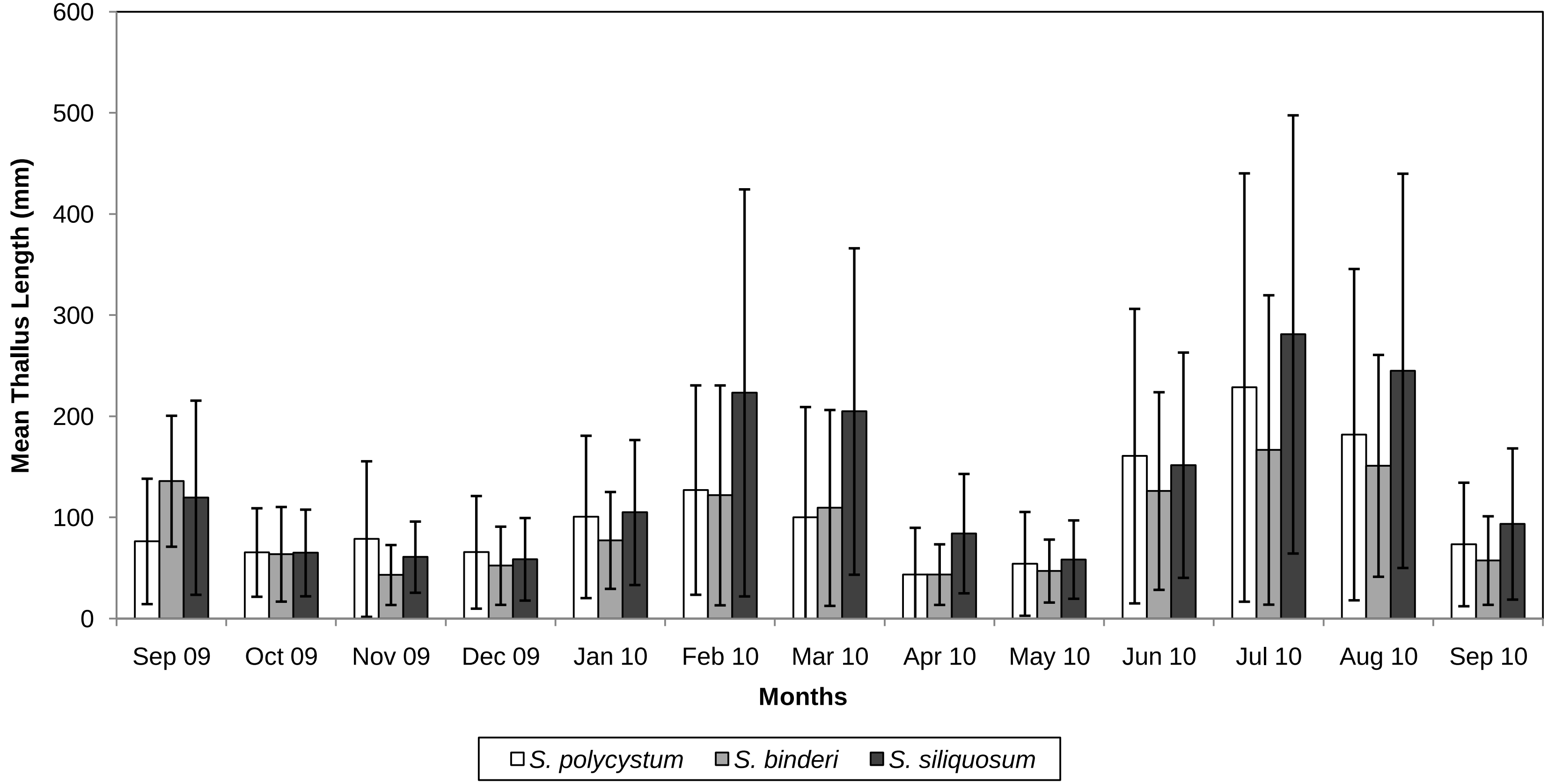


Figure 4.47: Monthly mean thallus length (mm ± SD) of tagged *Sargassum* species from September 2009 to September 2010

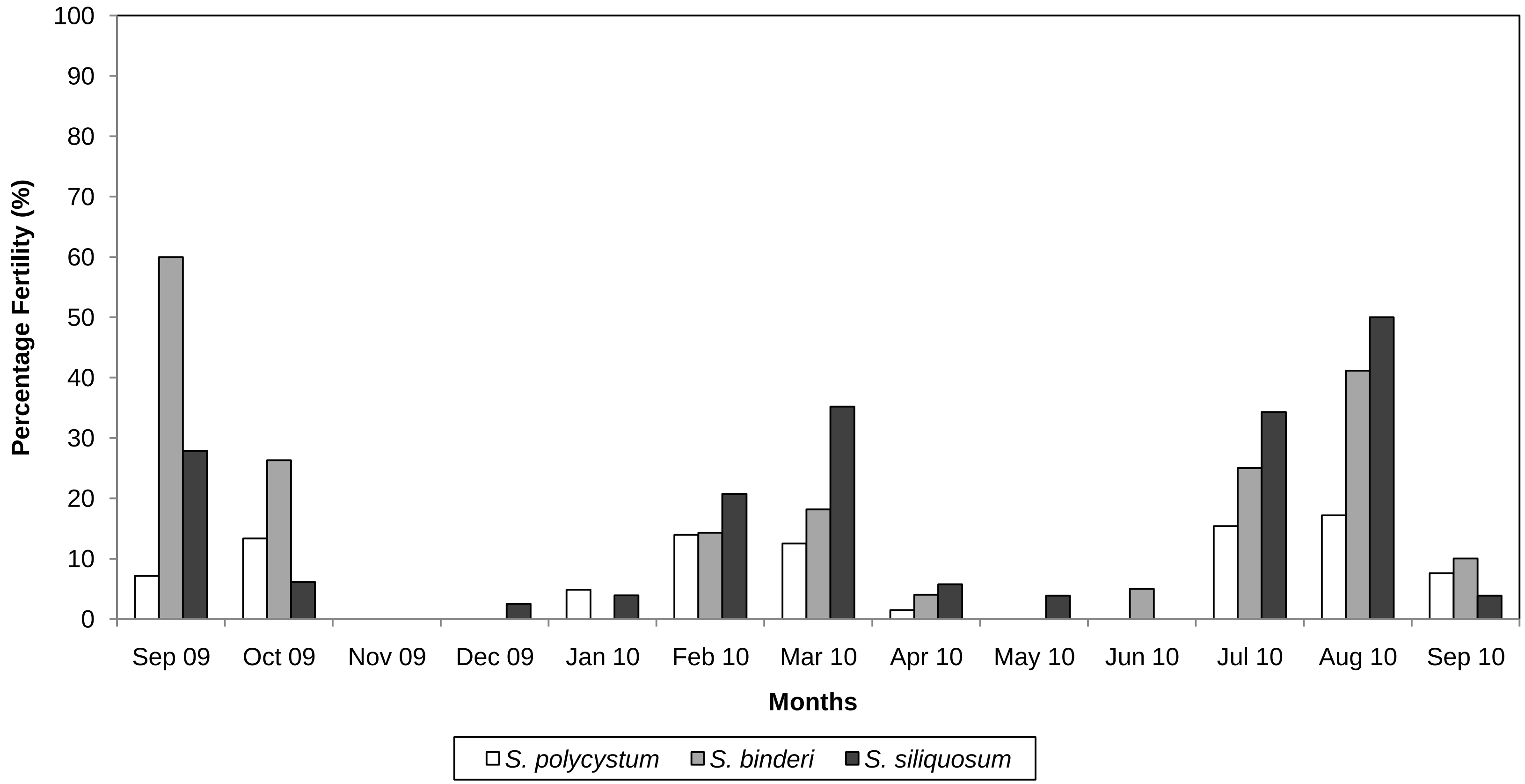


Figure 4.48: Monthly percentage fertility (%) of tagged *Sargassum* species from September 2009 to September 2010

Table 4.12: Number of monthly lost tags, new tags and percentage loss of tags of *Sargassum* samples from non-destructive sampling from September 2009 to September 2010

Month	*S. polycystum*				*S. binderi*				*S. siliquosum*			
	Lost Tags	New Tags	Total tags	% Loss	Lost Tags	New Tags	Total tags	% Loss	Lost Tags	New Tags	Total tags	% Loss
Sep 09	-	14	14	-	-	10	10	-	-	61	61	-
Oct 09	3	34	45	21.43	5	14	19	50.00	16	4	49	26.23
Nov 09	35	2	12	77.78	11	6	14	57.89	12	3	40	24.49
Dec 09	4	55	63	33.33	7	10	17	50.00	5	5	40	12.50
Jan 10	21	20	62	33.33	4	18	31	23.53	6	17	51	15.00
Feb 10	12	36	86	19.35	10	7	28	32.26	7	9	53	13.73
Mar 10	24	26	88	27.91	2	7	33	7.14	9	10	54	16.98
Apr 10	38	18	68	43.18	15	7	25	45.45	11	9	52	20.37
May 10	21	18	65	30.88	7	8	26	28.00	9	9	52	17.31
Jun 10	30	30	65	46.15	13	7	20	50.00	24	19	47	46.15
Jul 10	37	37	65	56.92	11	7	16	55.00	18	6	35	38.30
Aug 10	22	21	64	33.85	5	6	17	31.25	15	20	40	42.86
Sep 10	20	35	79	31.25	5	18	30	29.41	9	21	52	22.50
Total	267	346	-	77.17	95	125	-	76.00	141	193	-	73.06

4.5.3 Growth Rate

All three species experienced similar pattern in growth rate (Figure 4.49). From September 2009 to October 2009, tagged samples experienced a degenerative rate. Samples eventually experienced peak growth rate in January 2010 (*S. polycystum*: 1.17 mm day^{-1}) and February 2010 (*S. binderi*: 1.54 mm day^{-1}; *S. siliquosum*: 4.08 mm day^{-1}), in which *S. siliquosum* grew at its highest rate. This was followed by one of the lowest degenerative rate in April 2010 (*S. polycystum*: -1.96 mm day^{-1}; *S. binderi*: -2.27 mm day^{-1}; *S. siliquosum*: -4.17 mm day^{-1}). Another peak growth rate was achieved in June 2010 (*S. polycystum*: 2.54 mm day^{-1}; *S. binderi*: 1.89 mm day^{-1}) and July 2010 (*S. siliquosum*: 3.01 mm day^{-1}), whereby in June 2010, *S. polycystum* and *S. binderi* were growing at its highest rate. After which all species ended in September 2010 with highest degenerative rate (*S. polycystum*: -3.75 mm day^{-1}; *S. binderi*: -3.23 mm day^{-1}; *S. siliquosum*: -5.22 mm day^{-1}).

4.5.4 Length Classes

Distribution of *Sargassum* length classes varied every month, and was similar in pattern for all three species (Figure 4.50 to 4.52). In September 2009, samples were found in small sizes for *S. polycystum* and *S. binderi* (largest thallus within 200 - 299 mm), but in moderate sizes for *S. siliquosum* (largest thallus within 500 - 599 mm). Thallus lengths then decreased to its shortest in October 2009 for *S. polycystum* (largest thallus within 100 - 199 mm) while in November 2009 for *S. binderi* (largest thallus within 0 - 99 mm) and *S.*

siliquosum (largest thallus within 100 - 199 mm). Size distribution grew wider in the next few months leading up to February 2010 (*S. binderi*: largest thallus within 500 - 599 mm; *S. siliquosum*: largest thallus within 900 - 999 mm) and March 2010 (*S. polycystum*: largest thallus within 600 - 699 mm). This was followed by a drastic thallus length decrease in April 2010 for *S. polycystum* (largest thallus within 200 - 299 mm) but a gradual decrease until May 2010 for *S. binderi* and *S. siliquosum* (largest thallus within 100 - 199 mm). Thallus of samples then gradually grew larger, before climaxing in July 2010 for all three species (*S. polycystum*: largest thallus within 800 - 899 mm; *S. binderi*: largest thallus within 500 - 599 mm; *S. siliquosum*: largest thallus within 700 - 799 mm). Following this, tagged samples gradually decreased in length again until September 2010 (*S. polycystum*: largest thallus within 200 - 299 mm; *S. binderi*: largest thallus within 100 - 199 mm; *S. siliquosum*: largest thallus within 300 - 399 mm).

Overall, *Sargassum* species in Teluk Kemang consisted mostly of smaller sized plants (< 200 mm) with small percentage frequencies of larger sized plants. Figure 4.53 showed that majority of samples were in the length classes of 0 – 99 mm (*S. polycystum*: 64.20 %; *S. binderi*: 68.29 %; *S. siliquosum*: 56.80 %). Of all species, thallus lengths of *S. siliquosum* were the most diverse in range, (largest thallus within 900 – 999 mm), followed by *S. polycystum* (largest thallus within 800 – 899 mm) and *S. binderi (*largest thallus within 500 – 599 mm).

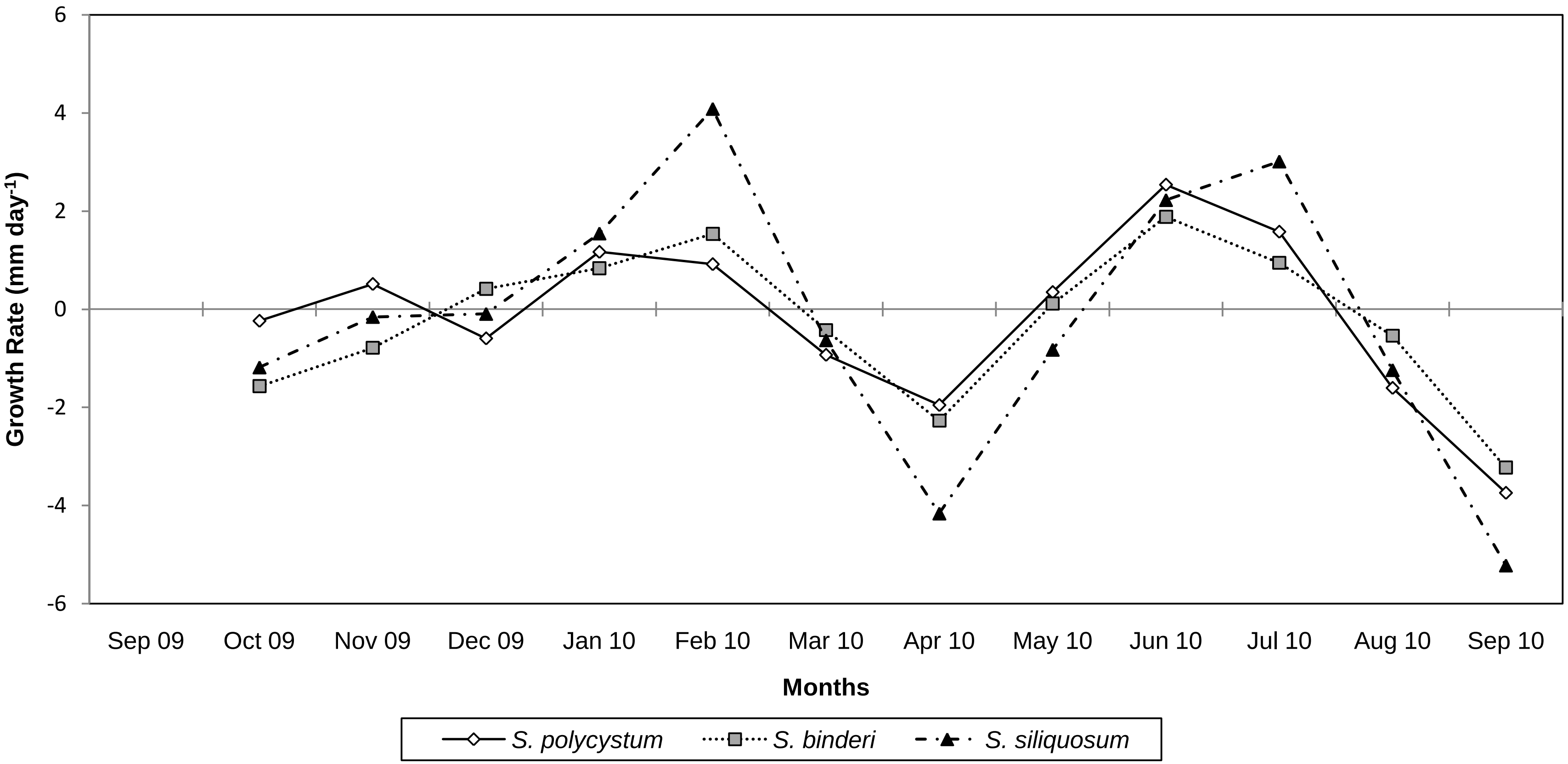


Figure 4.49: Monthly growth rate of *Sargassum* species from September 2009 to September 2010

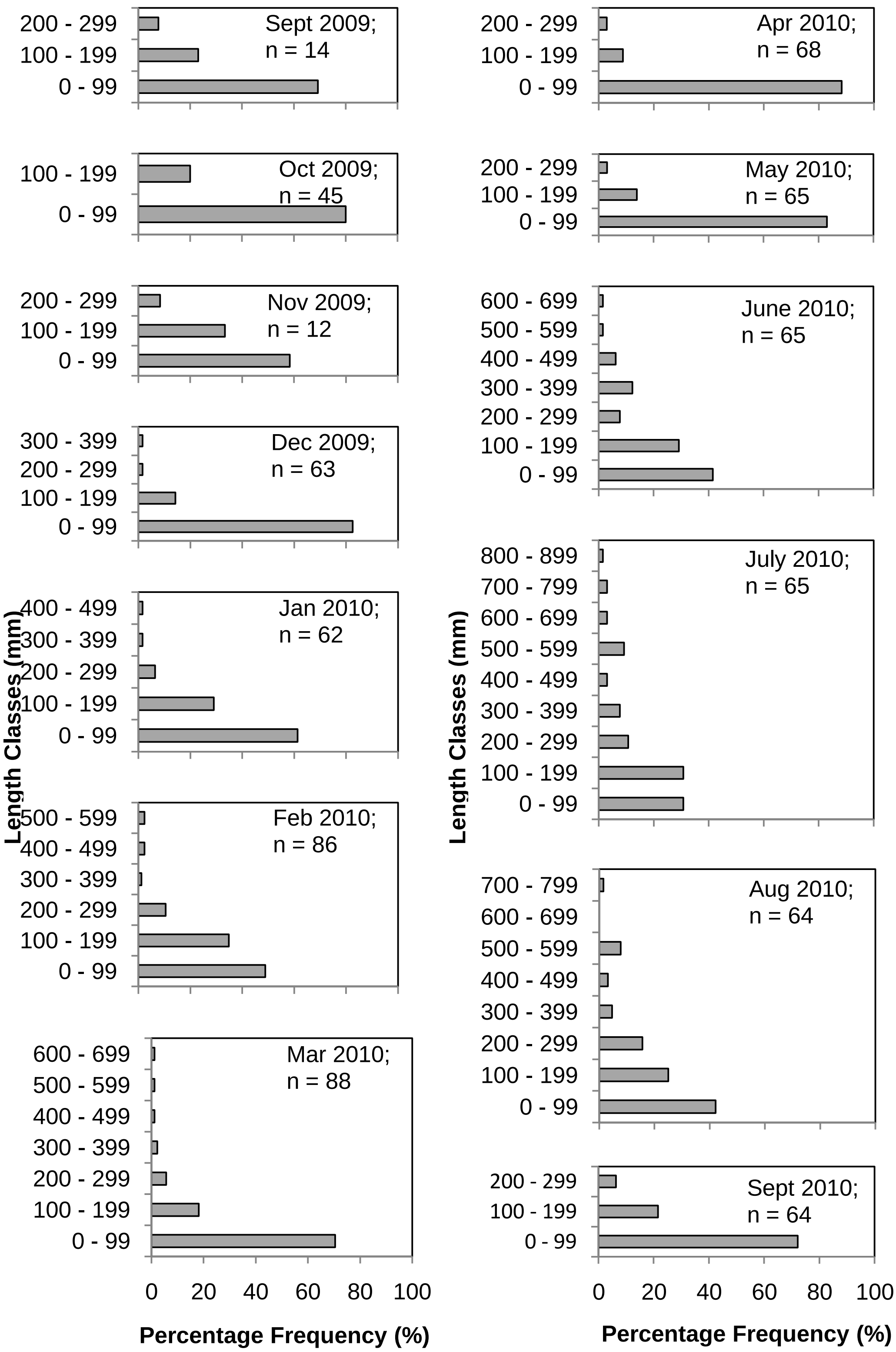


Figure 4.50: Seasonal variation in *S. polycystum* length classes (mm) from September 2009 to September 2010 measured using non-destructive sampling method

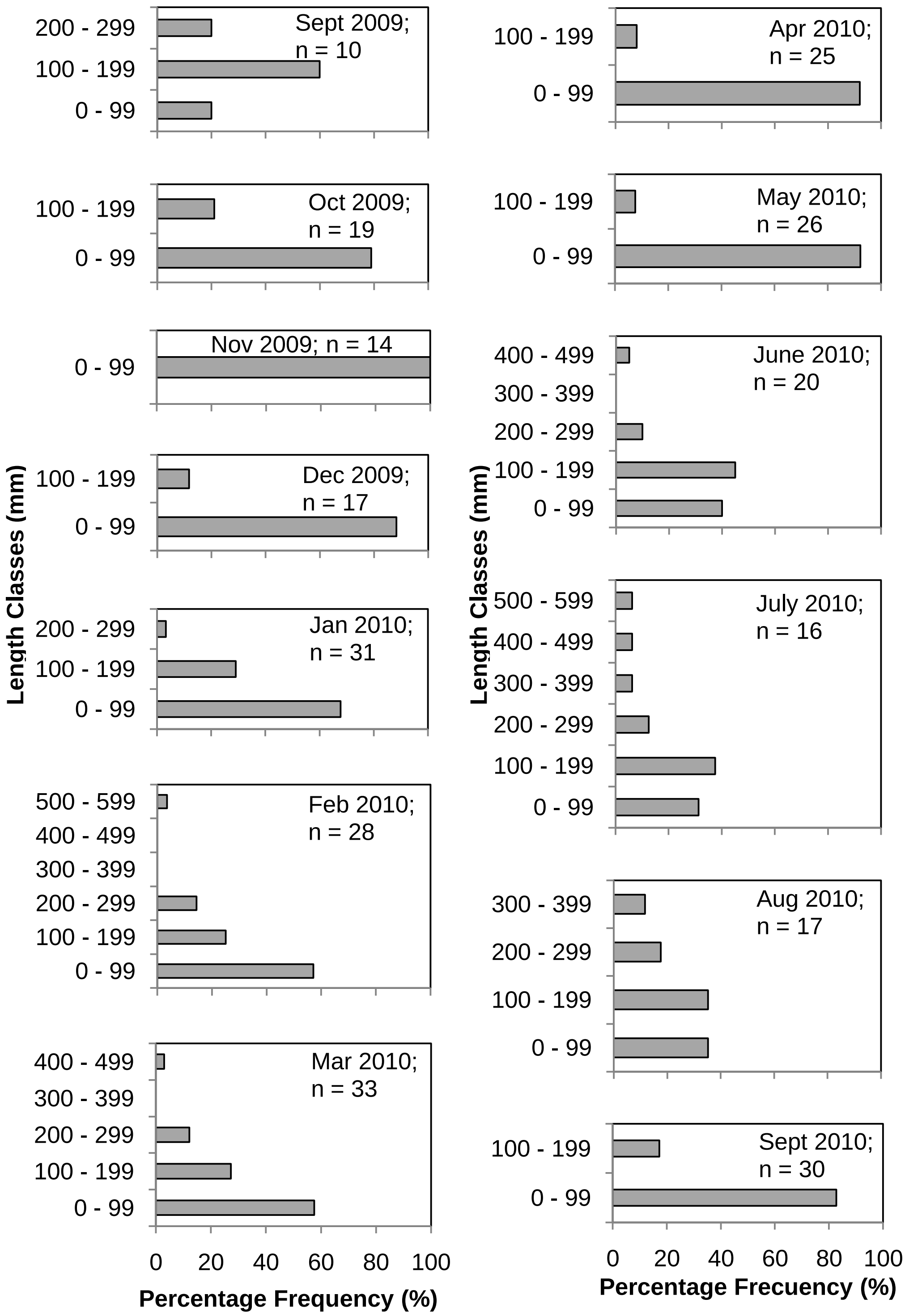


Figure 4.51: Seasonal variation in *S. binderi* length classes (mm) from September 2009 to September 2010 measured using non-destructive sampling method

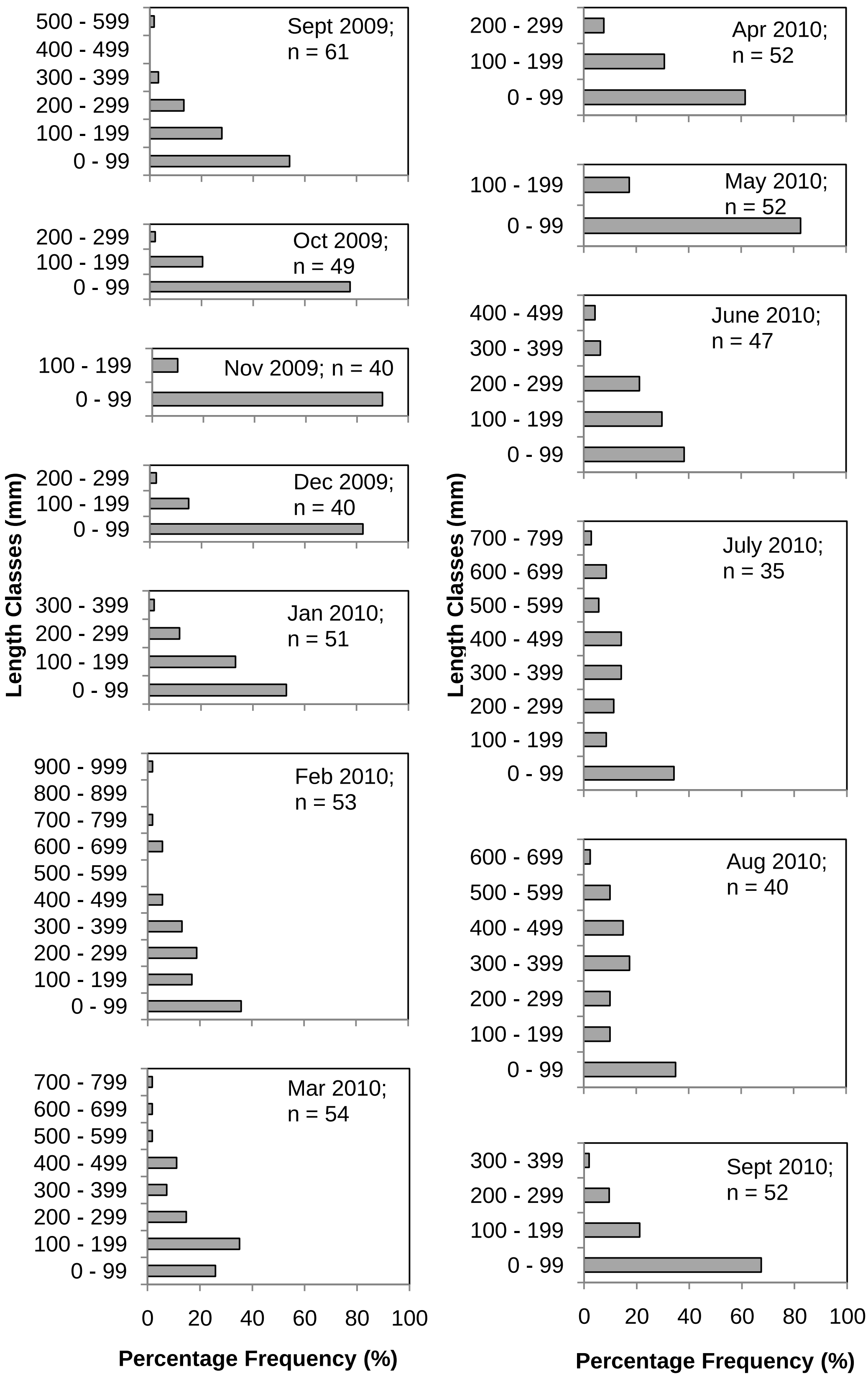


Figure 4.52: Seasonal variation in *S. siliquosum* length classes (mm) from September 2009 to September 2010 measured using non-destructive sampling method

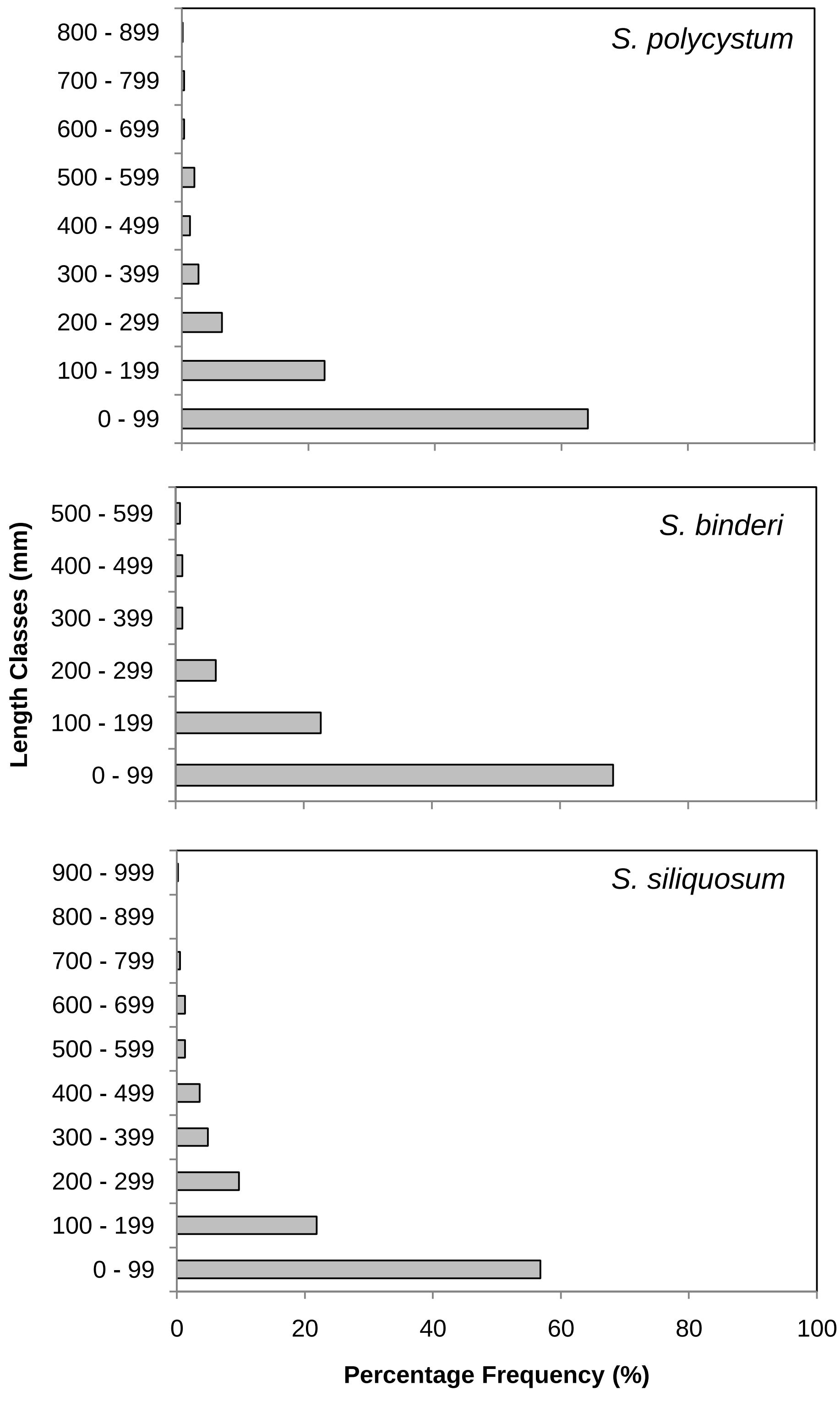


Figure 4.53: Overall length classes of *S. polycystum*, *S. binderi* and *S. siliquosum* measured using non-destructive sampling method

4.6 Comparison between Left and Right Reef

4.6.1 Destructive Sampling

Results from destructive sampling revealed relatively more plants collected on the LR for *S. binderi* (LR: 255 plants; RR: 163 plants) and *S. siliquosum* (LR: 733 plants; RR: 43 plants); but more on the RR for *S. polycystum* (LR: 421 plants; RR: 940 plants) (Table 4.13). On the LR, *S. siliquosum* was the most abundant species (733 plants) and the least abundant was *S. binderi* (255 plants). On the RR, the most abundant species was *S. polycystum* (940 plants), and the least was *S. siliquosum* (43 plants). Overall, the most abundant species in Teluk Kemang was *S. polycystum* (1361 plants), followed by *S. siliquosum* (776 plants) and lastly *S. binderi* (418 plants).

Measurements of MTL, biomass and percentage fertility were compared between LR and RR, based on data from destructive sampling (Figure 4.54). When compared, almost all measurements on the LR (*S. polycystum*: 129.77 mm; 287.56 g WW m^{-2}; 45.64 g DW m^{-2}; 38.85 g AFDW m^{-2}; 14.25 %; *S. binderi*: 103.00 mm; 109.42 g WW m^{-2}; 15.24 g DW m^{-2}; 12.66 g AFDW m^{-2}; 20.78 %; *S. siliquosum*: 90.13 mm; 256.28 g WW m^{-2}; 40.56 g DW m^{-2}; 34.27 g AFDW m^{-2}; 12.14 %) were higher compared to the RR (*S. polycystum*: 88.79 mm; 239.05 g WW m^{-2}; 33.70 g DW m^{-2}; 30.94 g AFDW m^{-2}; 6.60 %; *S. binderi*: 79.01 mm; 58.17 g WW m^{-2}; 7.68 g DW m^{-2}; 6.18 g AFDW m^{-2}; 14.11 %; *S. siliquosum*: 128.14 mm; 126.22 g WW m^{-2};

17.59 g DW m^{-2}; 25.22 g AFDW m^{-2}; 30.23 %). Only exception was MTL and percentage fertility of *S. siliquosum* samples, which were higher on the RR.

Results of One-way ANOVA (Appendix G) showed that for *S. polycystum*, only difference in number of fertile plants was significant between the two reefs (F = 16.593; p < 0.01). As for *S. binderi*, only MTL was significantly different (F = 4.261; p < 0.05), while all measurements of *S. siliquosum* were significantly different (p < 0.01) between LR and RR (MTL: F = 8.142; WW: F = 16.852; DW: F = 18.481; AFDW: F = 17.982; Fertility: F = 10.999).

Table 4.13: Overall number of plants collected from destructive sampling along line transects of (A) Left Reef and (B) Right Reef

A

Quadrat (Left Reef)	Number of Individuals		
	S. polycystum	*S. binderi*	*S. siliquosum*
Q 1	37	59	94
Q 2	121	29	90
Q 3	47	44	90
Q 4	101	42	173
Q 5	80	49	123
Q 6	35	32	163
Total	421	255	733

B

Quadrat (Right Reef)	Number of Individuals		
	S. polycystum	*S. binderi*	*S. siliquosum*
Q 7	141	17	26
Q 8	71	17	7
Q 9	161	18	-
Q 10	235	33	-
Q 11	195	21	5
Q 12	137	57	5
Total	940	163	43

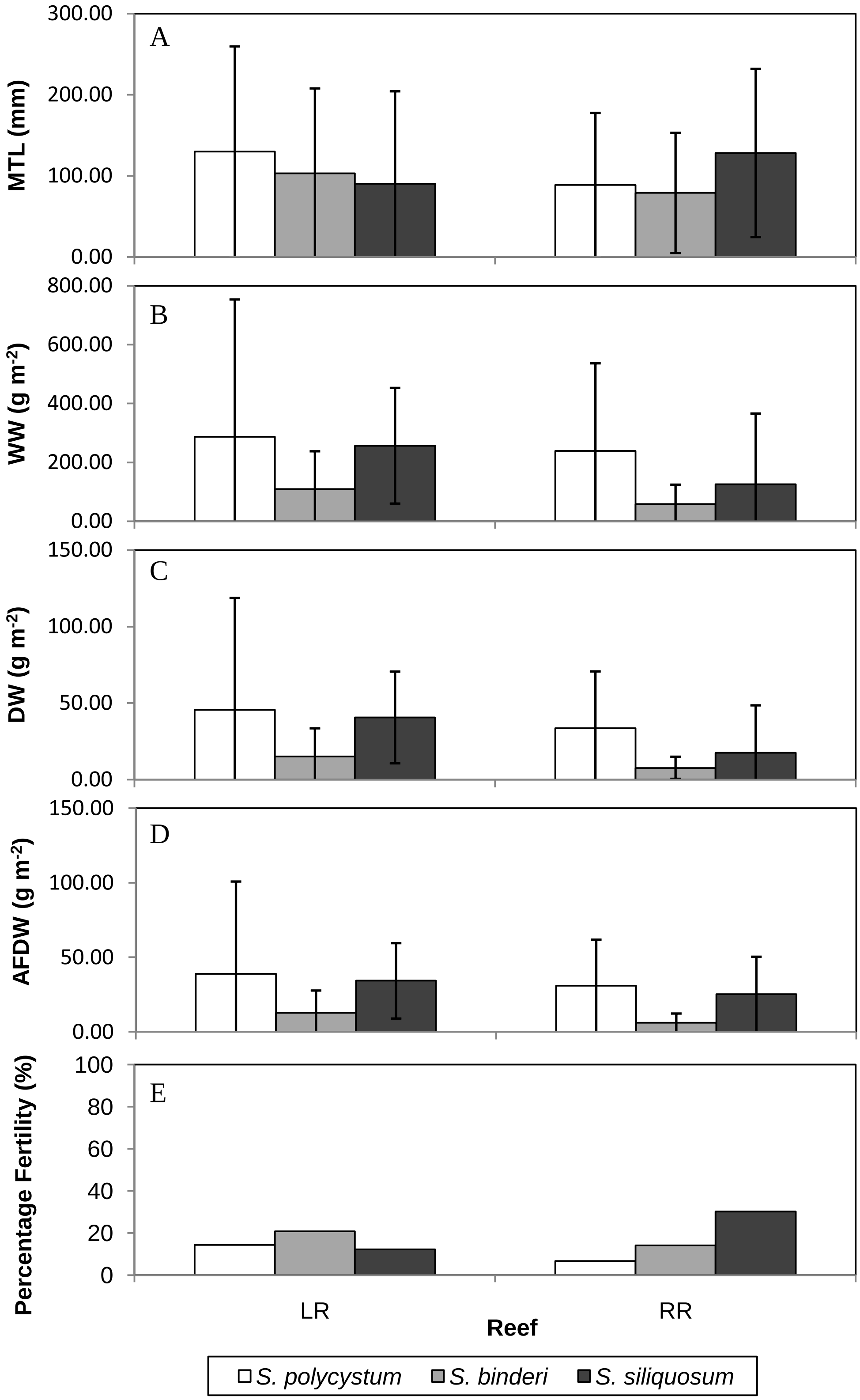


Figure 4.54: Overall comparison between Left Reef and Right Reef for (A) mean thallus length (mm ± SD), (B) wet weight (g m^{-2}), (C) dry weight (g m^{-2}), (D) ash-free dry weight (g m^{-2}) and (E) percentage fertility (%) measured using destructive sampling

4.6.2 Non-destructive Sampling

Results from non-destructive sampling revealed relatively more plants tagged on the LR for *S. binderi* (LR: 95 plants; RR: 33 plants) and *S. siliquosum* (LR: 182 plants; RR: 11 plants); but more on the RR for *S. polycystum* (LR: 92 plants; RR: 254 plants) (Table 4.14). On the LR, tagged *S. siliquosum* was the most abundant species (182 plants) and the least abundant was *S. polycystum* (92 plants). On the RR, the most abundant species was *S. polycystum* (254 plants), and the least was *S. siliquosum* (11 plants). Overall, the most abundant species in Teluk Kemang was *S. siliquosum* (386 plants), followed by *S. polycystum* (346 plants) and lastly *S. binderi* (250 plants).

Measurements of MTL, and percentage fertility were compared between LR and RR, based on data from non-destructive sampling (Figure 4.55). When compared, all measurements on the LR (*S. polycystum*: 122.69 mm; 8.58 %; *S. binderi*: 94.06 mm; 14.01 %; *S. siliquosum*: 137.45 mm; 15.41 %) were higher compared to the RR (*S. polycystum*: 99.69 mm; 7.40 %; *S. binderi*: 75.19 mm; 10.13 %; *S. siliquosum*: 91.73 mm; 0 %).

Results of One-way ANOVA (Appendix G) showed that for *S. polycystum*, only difference in MTL was significant between the two reefs (F = 6.596; $p < 0.01$), while for *S. siliquosum*, only number of fertile plants were significantly different (F = 4.721; $p < 0.05$). As for *S. binderi*, neither MTL nor number of fertile plants were significantly different ($p > 0.05$) between LR and RR.

Table 4.14: Overall number of plants tagged from non-destructive sampling along line transects of (A) Left Reef and (B) Right Reef

A

Quadrat (Left Reef)	Number of Individuals		
	S. polycystum	*S. binderi*	*S. siliquosum*
Q 1	5	14	16
Q 2	15	7	23
Q 3	17	16	37
Q 4	10	14	48
Q 5	41	10	29
Q 6	4	34	29
Total	92	95	182

B

Quadrat (Right Reef)	Number of Individuals		
	S. polycystum	*S. binderi*	*S. siliquosum*
Q 7	27	5	2
Q 8	31	1	-
Q 9	67	-	1
Q 10	51	3	4
Q 11	49	8	-
Q 12	29	16	4
Total	254	33	11

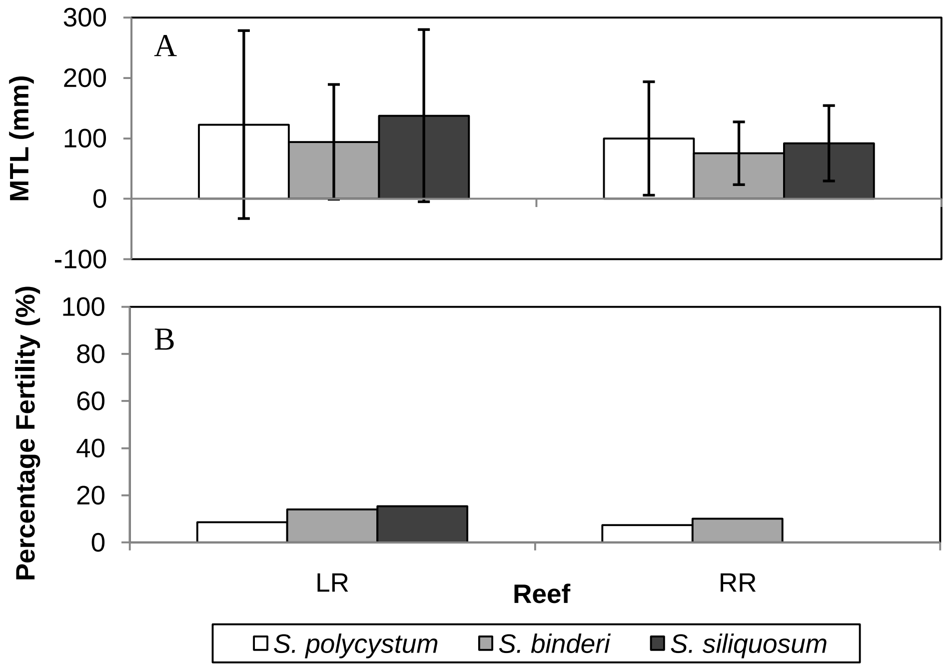


Figure 4.55: Overall comparison between Left Reef and Right Reef for (A) mean thallus length (mm ± SD) and (B) percentage fertility (%) measured using non-destructive sampling

4.7 Correlation with Environmental Parameters

4.7.1 Redundancy Analysis (RDA)

4.7.1.1 Destructive Sampling

Relationships between bimonthly variations of sample measurements (MTL, WW, DW and AFDW) and environmental variables were illustrated in RDA ordination triplots. Interpretation of an ordination diagram can provide illustrative information such as the approximation in relationship between species and environmental variables (Lepš & Šmilauer, 2003). These are judged based on relative distances, relative directions or relative ordering of projection points.

Based on log transform data of bimonthly MTL, the first two axes in Figure 4.56 explained 99.1 % of total variance (Table 4.15). Similarly, based on log transform data of bimonthly WW, DW and AFDW, the first two axes in Figures 4.57, 4.58 and 4.59 each explained 91.8 % of total variance (Table 4.16), 91.7 % of total variance (Table 4.17) and 92 % of total variance (Table 4.18), respectively. In addition, results of correlation matrix from the CANOCO Log View were summarised in Table 4.19 for samples of *S. polycystum*, *S. binderi* and *S. siliquosum*.

RDA triplots (Figures 4.56 to 4.59) indicated that bimonthly changes of *S. polycystum* were negatively correlated with pH. Upon further inspection of the correlation matrix (Table 4.19), relationship was tested significant for MTL (r = -0.6281) and WW (r = -0.6040).

Figure 4.56 indicated a negative correlation between bimonthly changes of *S. binderi* MTL and parameters of pH and salinity, but only correlation with pH was tested significant (r = -0.4691) from the correlation matrix (Table 4.19). MTL was also significantly correlated with water temperature (r = -0.9038) and phosphate (r = 0.8370). Based on the first two axes in Figures 4.57 to 4.59, biomass was indicated to be negatively correlated with ammonia, and positively correlated with radiation. But correlation matrix (Table 4.19) denoted significance in correlation between biomass and water temperature (WW: r = -0.5549), salinity (WW: r = 0.4513), phosphate (WW: r = 0.6345; DW: r = -0.4655; AFDW: r = -0.4596) and radiation (WW: r = 0.5365; DW: r = -0.6620; AFDW: r = -0.6566).

RDA triplot of Figure 4.56 indicated that bimonthly changes in *S. siliquosum* MTL was negatively correlated with phosphate and pH, but correlation matrix (Table 4.19) denoted significance only with radiation (r = -0.6078). There were indications of negative correlation between *S. siliquosum* biomass and parameters of pH and ammonia (only with DW and AFDW) (Figures 4.57 to 4.59) but none were proven significant. Correlations were only significant between biomass and water temperature (WW: r = -0.7253; DW: r = -0.8734; AFDW: r = -0.8796), nitrate (WW: r = 0.5428; DW: r = 0.4941; AFDW: r = 0.4889), phosphate (WW: r = 0.5535; DW: r = 0.7624; AFDW: r = 0.7692) and rainfall (WW: r = -0.5750; DW: -0.6469; AFDW: r = 0.6401).

Table 4.15: Summary of RDA results based on log transformed data of *Sargassum* bimonthly MTL and environmental parameters

Axes	1	2	3	4	Total Variance
Eigenvalues:	0.923	0.068	0.009	0.000	1.000
Species -environment correlations:	1.000	1.000	1.000	0.000	
Cumulative percentage variance					
of species data:	92.3	99.1	100.0	0.0	
of species-environment relation:	92.3	99.1	100.0	0.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					1.000

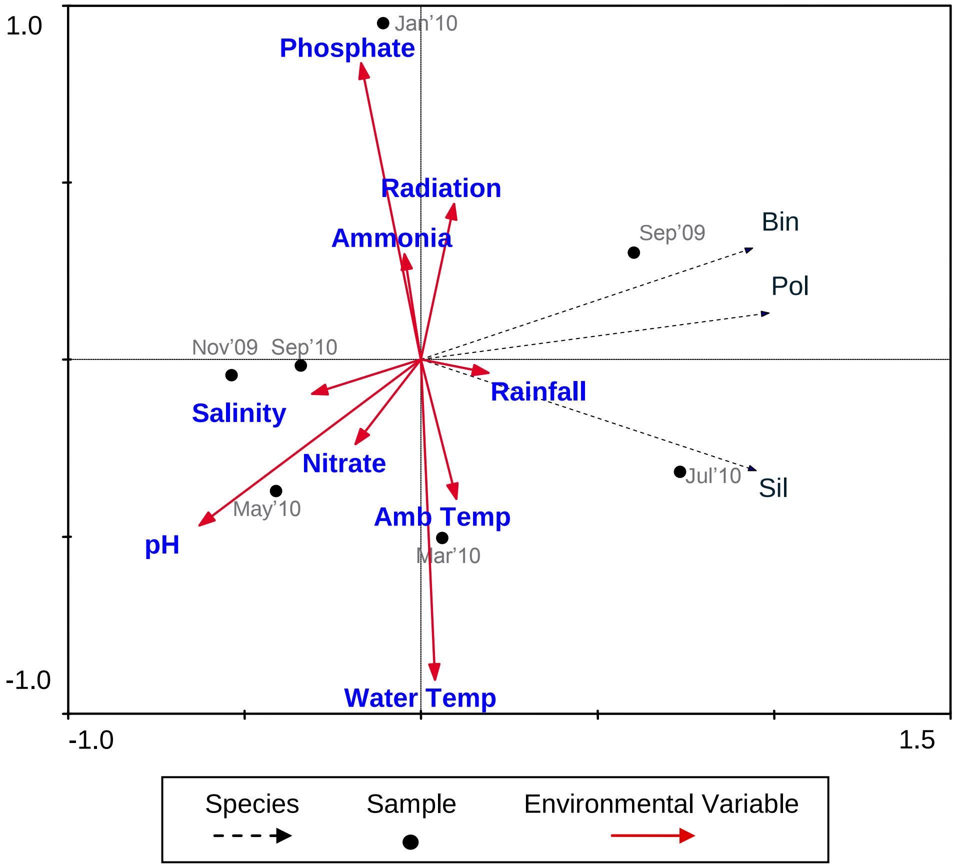


Figure 4.56: RDA triplot comparing between bimonthly mean thallus length (MTL) of three *Sargassum* species from destructive sampling and variation in environmental parameters, with eigenvalues 0.923 and 0.068 for the first two axes. Abbreviations: *S. polycystum* (Pol); *S. binderi* (Bin) and *S. siliquosum* (Sil)

Table 4.16: Summary of RDA results based on log transformed data of *Sargassum* bimonthly WW and environmental parameters

Axes	1	2	3	4	Total Variance
Eigenvalues:	0.690	0.229	0.082	0.000	1.000
Species -environment correlations:	1.000	1.000	1.000	0.000	
Cumulative percentage variance					
of species data:	69.0	91.8	100.0	0.0	
of species-environment relation:	69.0	91.8	100.0	0.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					1.000

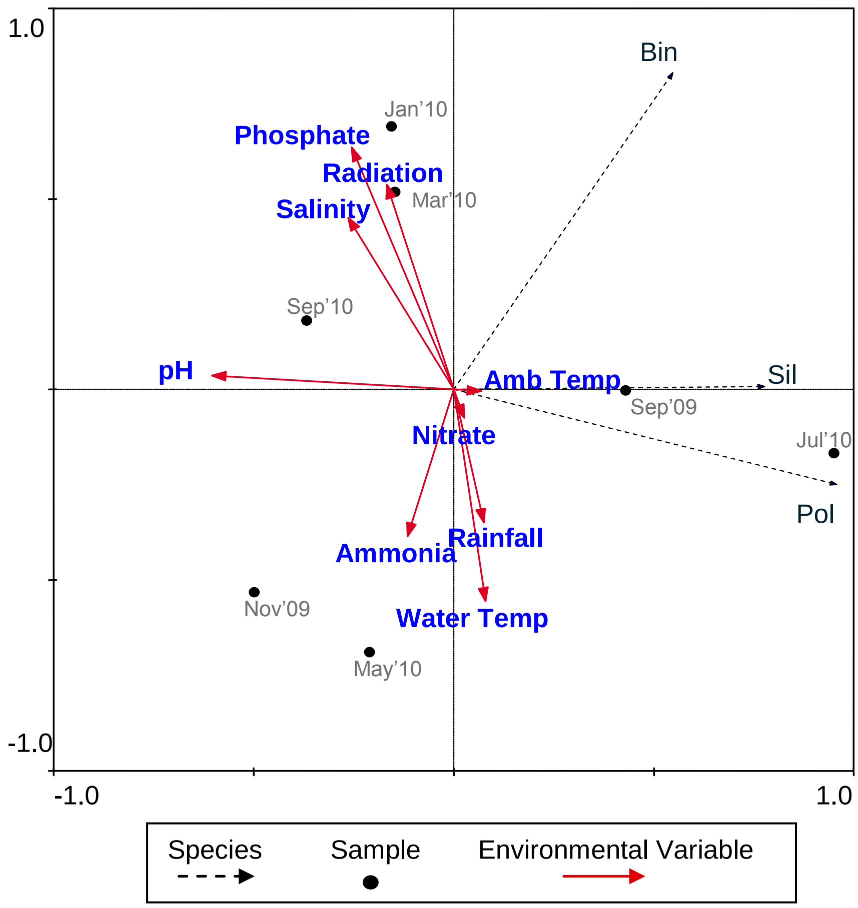


Figure 4.57: RDA triplot comparing between bimonthly wet weight (WW) of three *Sargassum* species from destructive sampling and variation in environmental parameters, with eigenvalues 0.690 and 0.229 for the first two axes. Abbreviations: *S. polycystum* (Pol); *S. binderi* (Bin) and *S. siliquosum* (Sil)

Table 4.17: Summary of RDA results based on log transformed data of *Sargassum* bimonthly DW and environmental parameters

Axes	1	2	3	4	Total Variance
Eigenvalues:	0.677	0.241	0.083	0.000	1.000
Species -environment correlations:	1.000	1.000	1.000	0.000	
Cumulative percentage variance					
of species data:	67.7	91.7	100.0	0.0	
of species-environment relation:	67.7	91.7	100.0	0.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					1.000

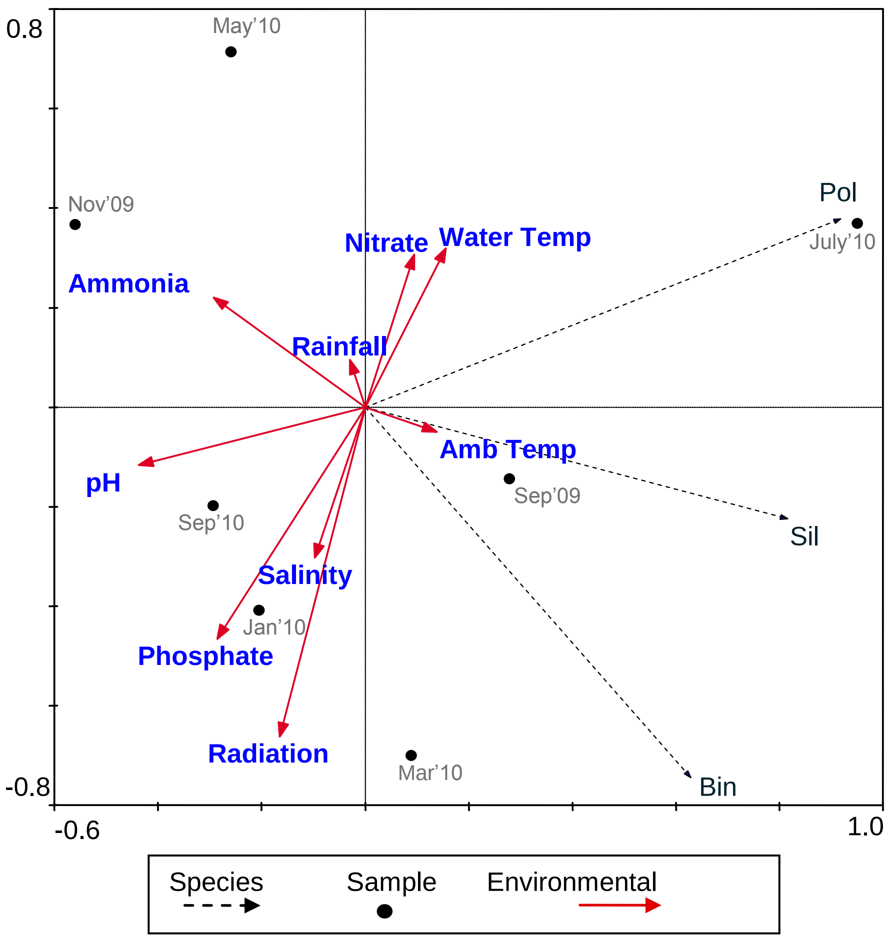


Figure 4.58: RDA triplot comparing between bimonthly dry weight (DW) of three *Sargassum* species from destructive sampling and variation in environmental parameters, with eigenvalues 0.677 and 0.241 for the first two axes. Abbreviations: *S. polycystum* (Pol); *S. binderi* (Bin) and *S. siliquosum* (Sil)

Table 4.18: Summary of RDA results based on log transformed data of *Sargassum* bimonthly AFDW and environmental parameters

Axes	1	2	3	4	Total Variance
Eigenvalues:	0.673	0.247	0.080	0.000	1.000
Species -environment correlations:	1.000	1.000	1.000	0.000	
Cumulative percentage variance					
of species data:	67.3	92.0	100.0	0.0	
of species-environment relation:	67.3	92.0	100.0	0.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					1.000

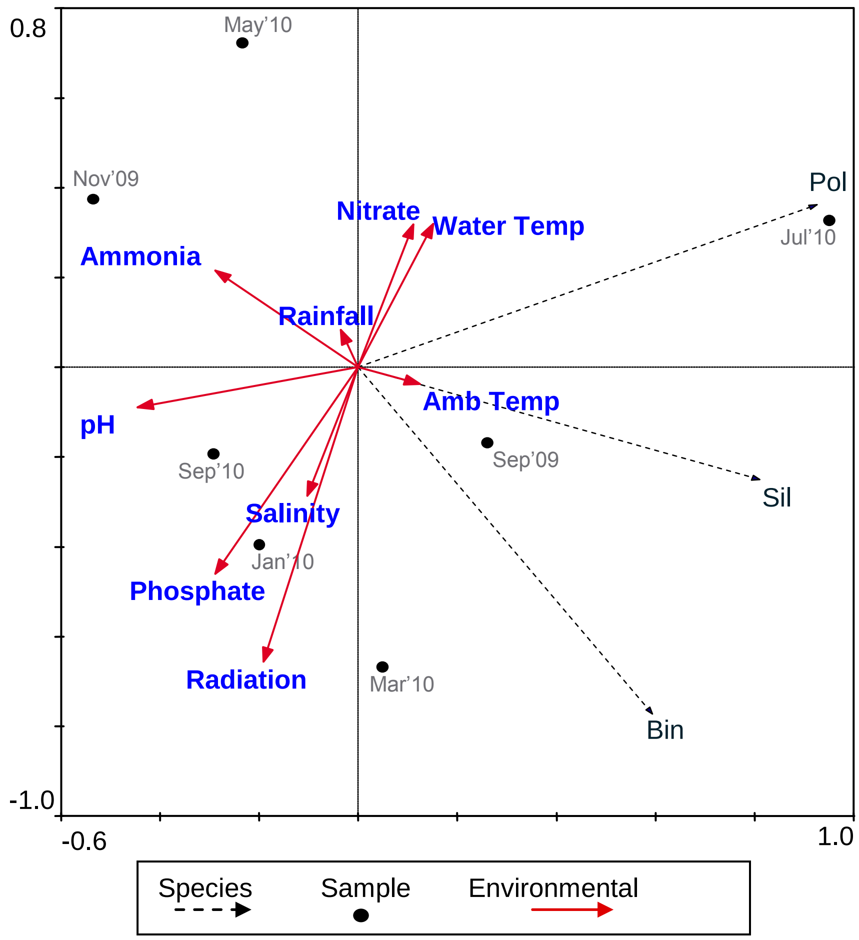


Figure 4.59: RDA triplot comparing between bimonthly ash-free dry weight (AFDW) of three *Sargassum* species from destructive sampling and variation in environmental parameters, with eigenvalues 0.673 and 0.247 for the first two axes. Abbreviations: *S. polycystum* (Pol); *S. binderi* (Bin) and *S. siliquosum* (Sil)

Table 4.19: Summary of correlation matrix between *Sargassum* measurements from destructive sampling and environmental variables

Species	Measurements	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
S. polycystum	MTL	0.0397	-0.6281*	-0.3089	-0.1861	-0.0469	-0.1699	0.1903	0.0942	0.0992
	WW	0.0791	-0.6040*	-0.2642	0.0260	-0.1156	-0.2550	0.0747	-0.1672	0.0690
	DW	0.1554	-0.4372	-0.0976	0.0943	-0.2926	-0.2858	-0.0289	-0.1647	0.1387
	AFDW	0.1514	-0.4445	-0.1023	0.1107	-0.2876	-0.2883	-0.0347	-0.1915	0.1247
S. binderi	MTL	-0.9038*	-0.4691*	-0.0974	-0.2391	0.2975	0.8370*	-0.0379	0.4398	-0.3938
	WW	-0.5549*	0.0370	0.4513*	-0.0741	-0.3845	0.6345*	-0.3481	0.5365*	-0.0033
	DW	0.3189	-0.1166	-0.3027	0.3059	0.2206	-0.4655*	0.0945	-0.6620*	-0.0494
	AFDW	0.3197	-0.0887	-0.2863	0.3187	0.2162	-0.4596*	0.0827	-0.6566*	-0.0369
S. siliquosum	MTL	0.1217	-0.2007	-0.2340	0.3088	0.1370	-0.4140	-0.0211	-0.6078*	0.2986
	WW	-0.7253*	-0.1832	0.2831	0.5428*	-0.1739	0.5535*	-0.5750*	-0.3010	-0.2365
	DW	-0.8734*	-0.2178	0.3909	0.4941*	-0.2941	0.7624*	-0.6469*	-0.0347	-0.2354
	AFDW	-0.8796*	-0.2215	0.3822	0.4889*	-0.2802	0.7692*	-0.6401*	-0.0221	-0.2299

*Significantly different ($p < 0.05$)

Table 4.20: Summary of correlation matrix between *Sargassum* MTL from non-destructive sampling and environmental variables

Species	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
S. polycystum	-0.0636	0.0917	-0.2230	-0.1416	0.2048	0.2416	-0.0055	0.0702	-0.1567
S. binderi	0.1151	0.2050	-0.0244	-0.2155	-0.0825	-0.2125	-0.0320	0.0124	0.5395*
S. siliquosum	-0.0112	0.4124	0.5419*	0.3457	-0.4603*	-0.1900	-0.2124	-0.3186	-0.1490

*Significantly different ($p < 0.05$)

4.7.1.2 Non-destructive Sampling

Relationship between monthly variations in MTL of tagged samples and environmental variations were illustrated in RDA ordination triplot (Figure 4.60). The diagram showed that 91.6 % of the total variance can be explained based on the first two axes (Table 4.21). In addition, results of correlation matrix from the CANOCO Log View were summarised in Table 4.20 for samples of *S. polycystum*, *S. binderi* and *S. siliquosum*.

RDA triplot in Figure 4.60 indicated that MTL of *S. polycystum* was positively correlated with nitrate but negatively correlated with pH. However, no parameters were tested significant from the correlation matrix (Table 4.20)

MTL of *S. binderi* was indicated to positively correlate with salinity and ambient temperature, while negatively correlate with radiation (Figure 4.60). However, correlation matrix in Table 4.20 showed that MTL was significantly correlated only with ambient temperature ($r = 0.5395$).

Lastly, MTL of *S. siliquosum* was indicated to positively correlate with salinity and ambient temperature while negatively correlate with ammonia and phosphate (Figure 4.60). However, correlation matrix showed significance only with salinity ($r = 0.5419$) and ammonia ($r = -0.4603$).

Table 4.21: Summary of RDA results based on log transformed data of *Sargassum* monthly MTL and environmental parameters

Axes	1	2	3	4	Total Variance
Eigenvalues:	0.210	0.038	0.023	0.712	1.000
Species -environment correlations:	0.491	0.734	0.632	0.000	
Cumulative percentage variance					
of species data:	21.0	24.8	27.1	98.3	
of species-environment relation:	77.7	91.6	100.0	0.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.271

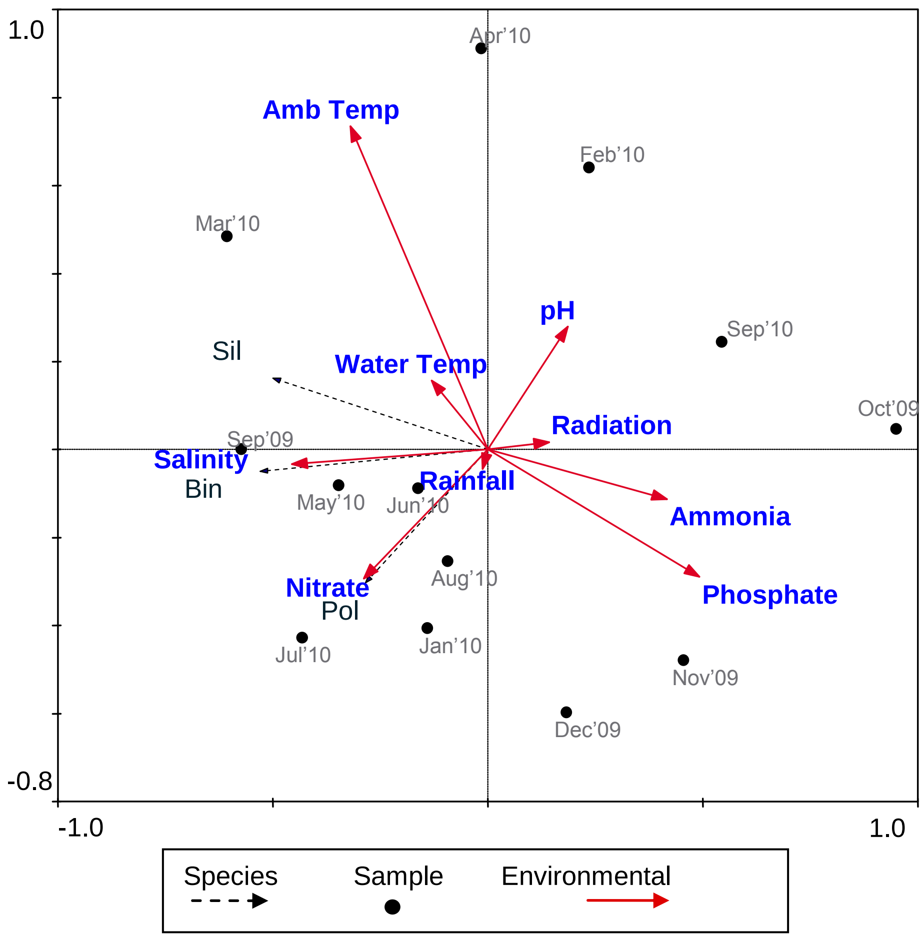


Figure 4.60: RDA triplot comparing between monthly mean thallus length (MTL) of three *Sargassum* species from non-destructive sampling with variation in environmental parameters, with eigenvalues 0.210 and 0.038 for the first two axes. Abbreviations: *S. polycystum* (Pol); *S. binderi* (Bin) and *S. siliquosum* (Sil)

4.7.2 Cross Correlation

4.7.2.1 Destructive Sampling

Cross correlation with time lag of two months were conducted between bimonthly measurements of *Sargassum* species and environmental parameters on both reefs separately. Table 4.22 showed that increase in *S. polycystum* MTL on the LR was significantly correlated ($p < 0.05$) with decrease in pH (Time lag 0; r = -0.510) and decrease in ammonia (Time lag 0; r = -0.514) (Time lag +1; r = -0.471). Increase in biomass of *S. polycystum* was significantly correlated ($p < 0.05$) with decrease in pH (Time lag 0; WW: r = -0.477) and water temperature (Time lag 0; WW: r = -0.509; DW: r = -0.453; AFDW: r = -0.454). In contrast to LR, increase in *S. polycystum* MTL collected from the RR (Table 4.23) were significantly correlated ($p < 0.05$) with increase in ammonia (Time lag -1; r = 0.482) (Time lag 0; r = 0.560). Number of fertile plants were also significantly correlated ($p < 0.05$) with increase in ammonia (Time lag 0; r = 0.500) but with decrease in water temperature (Time lag 0; r = -0.490).

Table 4.24 showed that on the LR, increase in *S. binderi* biomass was significantly correlated ($p < 0.05$) with increase in radiation (Time lag 0; DW: r = 0.514; AFDW: r = 0.514) (Time lag +1; WW: r = 0.453; DW: r = 0.537; AFDW: r = 0.535). Similarly, increased in number of fertile plants was significantly correlated ($p < 0.05$) with radiation (Time lag 0; r = 0.471) and ambient temperature (Time lag 0; r = 0.483) (Time lag +1; r = 0.456). However, biomass of *S. binderi* collected from the RR (Table 4.25) was significantly correlated ($p < 0.05$) with increase in ammonia (Time lag 0; DW: r = 0.454; AFDW: r = 0.469) (Time lag +1; AFDW: r = 0.458) (Time lag +2; AFDW: r = 0.472).

Table 4.26 showed that on the LR, increase in *S. siliquosum* biomass were significantly correlated ($p < 0.05$) only with ammonia (Time lag 0; WW: r = 0.530; DW: r = 0.507) (Time lag +1; WW: r = 0.630; DW: r = 0.611; AFDW: r = 0.550). However, bimonthly variations of samples from the RR were significantly correlated ($p < 0.05$) with all parameters tested (Table 4.27). These included negative correlations between *S. siliquosum* measurements and water temperature (Time lag 0; MTL: r = -0.506; WW: r = -0.953; DW: r = -0.958; AFDW: r = -0.958; Fert: r = -0.613), pH (Time lag -2; Fert: r = -0.510) (Time lag -1; MTL: r = -0.457; Fert: r = -0.501) (Time lag 0; MTL: r = -0.595; WW: r = -0.833; DW: r = -0.830; AFDW: r = -0.827; Fert: r = -0.792) (Time lag +1; Fert: r = -0.501), salinity (Time lag 0; WW: r = -0.863; DW: r = -0.835; AFDW: r = -0.835; Fert: r = -0.589), nitrate (Time lag 0; WW: r = -0.800; DW: r = -0.777; AFDW: r = -0.779) and phosphate (Time lag 0; Fert: r = -0.456). In addition, positive correlations were obtained between measurements of *S. siliquosum* and ammonia (Time lag 0; WW: r = 0.885; DW: r = -0.884; AFDW: r = -0.885), rainfall (Time lag 0; WW: r = 0.724; DW: r = 0.682; AFDW: r = 0.682; Fert: r = 0.531), radiation (Time lag -1; MTL: r = 0.671) (Time lag 0; MTL: r = 0.649; DW: r = 0.487; AFDW: r = 0.488) and ambient temperature (Time lag -1; MTL: r = 0.542) (Time lag 0; MTL: r = 0.476).

Table 4.22: Cross correlation between *S. polycystum* measurements and environmental parameters of the Left Reef with lag time of two months based on bimonthly destructive sampling

Measurements	Time Lag	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
MTL	-2	-0.233	-0.305	-0.161	-0.273	-0.095	0.141	0.077	0.129	-0.070
	-1	-0.152	-0.336	-0.031	-0.177	-0.412	0.209	-0.082	0.388	-0.024
	0	-0.214	-0.510*	-0.123	-0.177	-0.514*	0.158	-0.105	0.409	0.021
	1	-0.097	-0.363	-0.044	-0.177	-0.471*	0.050	-0.159	0.373	0.088
	2	0.020	-0.204	0.039	0.096	-0.419	0.017	-0.182	0.280	0.091
WW	-2	-0135	-0.135	0.031	0.047	-0.270	-0.144	-0.164	0.036	-0.031
	-1	-0.427	-0.382	-0.176	-0.193	-0.069	-0.221	-0.040	-0.083	-0.146
	0	-0.509*	-0.477*	-0.151	-0.191	-0.264	-0.260	-0.136	-0.027	-0.170
	1	-0.347	-0.364	-0.110	-0.140	-0.229	-0.141	-0.093	-0.094	-0.177
	2	-0.336	-0.267	-0.134	-0.244	0.129	-0.099	0.067	-0.204	-0.252
DW	-2	-0.097	-0.096	0.065	0.101	-0.285	-0.161	-0.196	0.059	-0.003
	-1	-0.399	-0.354	-0.162	-0.167	-0.053	-0.233	-0.043	-0.074	-0.128
	0	-0.453*	-0.432	-0.125	-0.146	-0.242	-0.270	-0.144	0.041	-0.116
	1	-0.295	-0.335	-0.088	-0.115	-0.220	-0.124	-0.093	-0.016	-0.135
	2	-0.300	-0.249	-0.113	-0.226	0.106	-0.087	0.060	-0.126	-0.215
AFDW	-2	-0.100	-0.099	0.062	0.099	-0.285	-0.164	-0.196	0.072	0.004
	-1	-0.399	-0.353	-0.165	-0.168	-0.048	-0.234	-0.040	-0.073	-0.124
	0	-0.454*	-0.440	-0.140	-0.152	-0.223	-0.274	-0.132	0.042	-0.106
	1	-0.295	-0.341	-0.101	-0.119	-0.203	-0.127	-0.082	-0.017	-0.126
	2	-0.298	-0.255	-0.124	-0.227	0.119	-0.089	0.069	-0.131	-0.208
No. fertile plants	-2	-0.307	-0.317	-0.380	-0.343	0.316	-0.080	0.351	0.090	0.065
	-1	-0.345	-0.361	-0.358	-0.355	0.316	-0.147	0.307	0.090	0.016
	0	-0.383	-0.404	-0.335	-0.366	0.316	-0.215	0.262	0.090	-0.032
	1	-0.229	-0.245	-0.145	-0.195	0.158	-0.175	0.086	0.045	-0065
	2	-0.075	-0.086	0.046	-0.023	0.000	-0.135	-0.089	0.000	-0.097

*Significantly different ($p < 0.05$)

Table 4.23: Cross correlation between *S. polycystum* measurements and environmental parameters of the Right Reef with lag time of two months based on bimonthly destructive sampling

Measurements	Time Lag	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
MTL	-2	-0.254	-0.170	-0.249	-0.108	0.427	0.040	0.228	-0.164	-0.092
	-1	-0.312	-0.318	-0.357	-0.109	0.482*	0.025	0.296	-0.150	-0.066
	0	-0.331	-0.296	-0.320	-0.122	0.560*	-0.090	0.298	0.035	-0.036
	1	-0.201	-0.122	-0.202	-0.132	0.322	-0.044	0.213	-0.047	-0.009
	2	-0.007	-0.126	-0.071	-0.014	0.133	-0.130	0.070	0.199	0.056
WW	-2	0.058	0.065	0.161	0.171	0.059	0.052	-0.172	0.002	-0.184
	-1	0.043	0.037	0.178	0.225	0.073	-0.044	-0.175	0.083	-0.177
	0	0.125	0.025	0.216	0.284	-0.011	-0.077	-0.219	0.062	-0.171
	1	0.103	0.038	0.170	0.221	0.024	-0.043	-0.164	-0.043	-0.190
	2	0.067	-0.046	0.071	0.135	-0.070	-0.084	-0.083	0.114	0.001
DW	-2	0.059	0.113	0.171	0.106	0.118	0.048	-0.157	0.000	-0.206
	-1	0.048	0.101	0.183	0.120	0.149	-0.062	-0.141	0.071	-0.197
	0	0.148	0.107	0.237	0.167	0.051	-0.113	-0.191	0.084	-0.166
	1	0.119	0.091	0.189	0.138	0.067	-0.066	-0.154	0.010	-0.177
	2	0.089	-0.017	0.081	0.100	-0.067	-0.095	-0.079	0.123	0.018
AFDW	-2	0.059	0.110	0.173	0.105	0.116	0.044	-0.160	0.019	-0.198
	-1	0.069	0.115	0.206	0.133	0.129	-0.057	-0.165	0.082	-0.196
	0	0.167	0.123	0.260	0.184	0.028	-0.103	-0.217	0.089	-0.166
	1	0.134	0.105	0.205	0.151	0.055	-0.050	-0.172	-0.009	-0.190
	2	0.109	0.002	0.102	0.113	-0.088	-0.085	-0.100	0.110	0.012
No. fertile plants	-2	-0.304	-0.165	-0.187	-0.036	0.250	-0.126	0.186	0.064	-0.025
	-1	-0.443	-0.291	-0.327	-0.108	0.375	-0.161	0.322	0.097	0.000
	0	-0.490*	-0.219	-0.327	-0.287	0.500*	-0.284	0.393	0.261	0.075
	1	-0.331	-0.035	-0.187	-0.323	0.375	-0.213	0.292	0.229	0.087
	2	-0.186	-0.055	-0.140	-0.251	0.250	-0.159	0.207	0.196	0.100

*Significantly different ($p < 0.05$)

Table 4.24: Cross correlation between *S. binderi* measurements and environmental parameters of the Left Reef with lag time of two months based on bimonthly destructive sampling

Measurements	Time Lag	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
MTL	-2	-0.116	-0.013	-0.194	-0.104	0.402	-0.289	0.238	0.159	0.218
	-1	-0.133	-0.044	-0.265	-0.152	0.487	-0.306	0.318	0.172	0.248
	0	-0.037	-0.041	-0.232	-0.097	0.424	-0.265	0.278	0.219	0.288
	1	0.162	-0.027	-0.098	-0.018	0.170	-0.008	0.154	0.204	0.202
	2	0.079	-0.028	-0.037	0.008	0.022	0.024	0.040	0.061	0.070
WW	-2	-0.162	-0.227	-0.076	-0.116	-0.169	0.050	-0.035	0.054	-0.039
	-1	-0.168	-0.375	-0.132	-0.145	-0.337	0.133	-0.070	0.289	0.099
	0	-0.166	-0.398	-0.136	-0.158	-0.289	0.107	-0.054	0.411	0.152
	1	0.061	-0.205	-0.059	-0.036	-0.176	0.133	-0.016	0.453*	0.235
	2	-0.005	-0.170	-0.059	-0.042	-0.120	0.056	-0.018	0.357	0.191
DW	-2	-0.117	-0.213	-0.060	-0.110	-0.159	0.076	-0.025	0.114	-0.020
	-1	-0.109	-0.366	-0.114	-0.136	-0.328	0.167	-0.055	0.361	0.116
	0	-0.074	-0.368	-0.104	-0.130	-0.276	0.146	-0.040	0.514*	0.188
	1	0.118	-0.194	-0.033	-0.016	-0.187	0.163	-0.018	0.537*	0.257
	2	0.042	-0.155	-0.043	-0.021	-0.117	0.070	-0.016	0.400	0.207
AFDW	-2	-0.117	-0.215	-0.057	-0.113	-0.165	0.084	-0.027	0.118	-0.024
	-1	-0.112	-0.369	-0.109	-0.141	-0.336	0.176	-0.058	0.362	0.108
	0	-0.079	-0.373	-0.099	-0.137	-0.285	0.156	-0.044	0.514*	0.177
	1	0.114	-0.197	-0.029	-0.022	-0.195	0.171	-0.020	0.535*	0.247
	2	0.038	-0.158	-0.043	-0.025	-0.120	0.073	-0.017	0.396	0.201
No. fertile plants	-2	-0.071	-0.172	-0.246	-0.190	0.272	-0.006	0.270	0.188	0.143
	-1	-0.017	-0.216	-0.338	-0.241	0.408	0.019	0.398	0.345	0.261
	0	0.163	-0.088	-0.301	-0.032	0.408	-0.023	0.330	0.471*	0.483*
	1	0.289	0.040	-0.148	0.106	0.272	0.010	0.188	0.441	0.456*
	2	0.234	0.084	-0.055	0.157	0.136	-0.016	0.060	0.283	0.339

*Significantly different ($p < 0.05$)

Table 4.25: Cross correlation between *S. binderi* measurements and environmental parameters of the Right Reef with lag time of two months based on bimonthly destructive sampling

Measurements	Time Lag	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
MTL	-2	-0.066	0.142	0.169	0.152	0.141	0.112	-0.167	0.044	-0.195
	-1	-0.172	0.026	0.085	0.127	0.331	0.133	-0.117	0.086	-0.243
	0	-0.155	0.095	0.134	0.080	0.377	0.219	-0.171	0.124	-0.267
	1	-0.169	0.002	0.105	0.152	0.322	0.309	-0.213	0.139	-0.256
	2	-0.089	-0.047	-0.035	-0.071	0.237	0.106	-0.004	0.080	-0.072
WW	-2	-0.093	-0.265	-0.248	0.106	0.029	0.094	0.165	-0.075	0.003
	-1	0.037	-0.025	-0.015	0.017	-0.073	0.058	-0.008	-0.005	-0.045
	0	-0.220	-0.130	0.023	0.169	0.293	0.234	-0.160	0.237	-0.152
	1	-0.127	0.144	0.144	0.013	0.328	0.203	-0.170	0.171	-0.189
	2	-0.300	-0.020	-0.152	-0.147	0.386	0.040	0.205	-0.117	-0.211
DW	-2	-0.139	-0.299	-0.270	0.095	0.068	0.088	0.177	0.054	0.016
	-1	-0.012	-0.093	-0.081	-0.094	0.043	-0.013	0.071	0.112	-0.006
	0	-0.249	-0.165	-0.044	-0.026	0.454*	0.137	-0.050	0.362	-0.135
	1	-0.141	0.121	0.102	-0.125	0.445	0.136	-0.099	0.259	-0.185
	2	-0.243	0.003	-0.156	-0.247	0.464*	-0.002	0.240	-0.119	-0.212
AFDW	-2	-0.155	-0.305	-0.281	0.101	0.070	0.103	0.185	0.037	0.001
	-1	-0.034	-0.105	-0.098	-0.086	0.051	0.005	0.083	0.086	-0.020
	0	-0.281	-0.179	-0.066	-0.020	0.469*	0.162	-0.034	0.332	-0.157
	1	-0.166	0.108	0.086	-0.120	0.458*	0.157	-0.089	0.240	-0.203
	2	-0.276	-0.004	-0.167	-0.243	0.472*	0.024	0.245	-0.141	-0.238
No. fertile plants	-2	-0.207	0.025	-0.060	-0.093	0.158	0.070	0.109	0.038	-0.016
	-1	-0.405	-0.138	-0.242	-0.185	0.316	-0.116	0.285	0.077	0.016
	0	-0.405	-0.163	-0.181	-0.093	0.316	0.116	0.171	0.149	-0.032
	1	-0.396	-0.351	-0.302	-0.093	0.316	0.141	0.237	0.149	0.016
	2	-0.198	-0.188	-0.121	0.000	0.158	0.187	0.061	0.110	-0.016

*Significantly different ($p < 0.05$)

Table 4.26: Cross correlation between *S. siliquosum* measurements and environmental parameters of the Left Reef with lag time of two months based on bimonthly destructive sampling

Measurements	Time Lag	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
MTL	-2	-0.026	-0.132	-0.155	-0.020	0.047	-0.058	0.059	0.138	0.169
	-1	-0.144	-0.209	-0.213	-0.080	0.010	-0.095	0.046	0.201	0.207
	0	-0.150	-0.238	-0.099	-0.132	-0.056	-0.007	0.011	0.260	0.046
	1	-0.145	-0.180	-0.036	-0.167	-0.052	0.083	0.026	-0.009	-0.161
	2	-0.124	-0.106	0.056	-0.112	-0.103	0.052	-0.049	0.122	-0.122
WW	-2	0.147	0.097	-0.018	0.037	0.258	-0.073	0.116	0.088	0.107
	-1	0.179	0.142	-0.007	0.036	0.438	-0.149	0.182	0.085	0.085
	0	0.020	0.128	-0.077	0.019	0.530*	-0.320	0.188	0.040	0.128
	1	-0.158	0.065	-0.165	-0.067	0.630*	-0.419	0.235	-0.004	0.116
	2	-0.128	0.031	-0.059	-0.018	0.272	-0.247	0.071	-0.049	0.021
DW	-2	0.199	0.140	0.038	0.083	0.269	-0.101	0.084	0.157	0.138
	-1	0.258	0.202	0.085	0.094	0.409	-0.141	0.125	0.177	0.109
	0	0.163	0.231	0.050	0.111	0.507*	-0.303	0.121	0.177	0.183
	1	-0.038	0.156	-0.071	-0.004	0.611*	-0.371	0.192	0.072	0.141
	2	-0.036	0.091	0.011	0.028	0.238	-0.203	0.037	0.021	0.044
AFDW	-2	0.236	0.183	0.098	0.140	0.194	-0.093	0.029	0.130	0117
	-1	0.284	0.235	0.149	0.150	0.301	-0.124	0.057	0.150	0.082
	0	0.185	0.258	0.110	0.159	0.395	-0.282	0.057	0.138	0.142
	1	-0.055	0.138	-0.066	-0.013	0.550*	-0.350	0.177	0.053	0.115
	2	-0.051	0.075	0.012	0.019	0.201	-0.188	0.027	0.008	0.025
No. fertile plants	-2	0.000	0.049	-0.028	0.136	0.000	-0.113	-0.061	0.000	0.147
	-1	-0.133	0.029	-0.083	0.005	0.213	-0.186	0.039	0.062	0.133
	0	-0.159	0.114	0.056	0.021	0.213	-0.284	-0.063	0.062	0.044
	1	-0.158	0.065	0.083	-0.115	0.213	-0.171	-0.002	0.062	-0.103
	2	-0.158	0.065	0.083	-0.115	0.213	-0.171	-0.002	0.062	-0.103

*Significantly different ($p < 0.05$)

Table 4.27: Cross correlation between *S. siliquosum* measurements and environmental parameters of the Right Reef with lag time of two months based on bimonthly destructive sampling

Measurements	Time Lag	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
MTL	-2	-0.271	-0.410	-0.068	0.047	-0.003	-0.173	-0.019	0.459	0.402
	-1	-0.289	-0.457*	0.061	0.208	-0.062	-0.131	-0.177	0.671*	0.542*
	0	-0.506*	-0.595*	-0.153	-0.030	0.128	-0.117	0.005	0.649*	0.476*
	1	-0.286	-0.393	-0.042	0.066	0.013	-0.127	-0.050	0.474	0.386
	2	-0.127	-0.154	-0.015	0.024	0.017	-0.037	-0.023	0.190	0.146
WW	-2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	-1	0.148	-0.185	-0.165	-0.141	0.079	-0.071	0.145	0.053	0.055
	0	-0.953*	-0.833*	-0.863*	-0.800*	0.885*	0.091	0.724*	0.378	-0.214
	1	-0.272	-0.335	-0.299	-0.255	0.166	-0.129	0.263	0.181	0.100
	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DW	-2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	-1	-0.164	-0.199	-0.177	-0.151	0.090	-0.077	0.156	0.065	0.059
	0	-0.958*	-0.830*	-0.835*	-0.777*	0.884*	0.139	0.682*	0.487*	-0.213
	1	-0.263	-0.319	-0.284	-0.242	0.160	-0.123	0.250	0.175	0.095
	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AFDW	-2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	-1	-0.165	-0.199	-0.178	-0.151	0.090	-0.077	0.156	0.066	0.060
	0	-0.958*	-0.827*	-0.835*	-0.779*	0.885*	0.142	0.682*	0.488*	-0.213
	1	-0.263	-0.318	-0.284	-0.242	0.159	-0.123	0.249	0.174	0.095
	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
No. fertile plants	-2	-0.309	-0.510*	-0.358	-0.251	0.056	-0.340	0.323	0.228	0.321
	-1	-0.259	-0.501*	-0.341	-0.226	0.000	-0.358	0.308	0.228	0.341
	0	-0.613*	-0.792*	-0.589*	-0.449	0.250	-0.456*	0.531*	0.342	0.422
	1	-0.259	-0.501*	-0.341	-0.226	0.000	-0.358	0.308	0.228	0.341
	2	-0.104	-0.246	-0.162	-0.101	-0.028	-0.188	0.146	0.114	0.180

*Significantly different ($p < 0.05$)

4.7.2.2 Non-destructive Sampling

Increase in *S. polycystum* MTL on the LR was significantly correlated ($p < 0.05$) with increase in ammonia (Time lag 0; r = 0.562) (Time lag +1; r = 0.498) (Table 4.28), while its growth rate was significantly correlated ($p < 0.05$) with water temperature (Time lag 0; r = 0.526), nitrate (Time lag 0; r = 0.461) and rainfall (Time lag 0; r = 0.456). However, environmental parameters did not denote any significant effects onto *S. polycystum* of the RR (Table 4.29).

MTL of tagged *S. binderi* samples from the LR were shown to significantly correlate ($p < 0.05$) with radiation (Time lag 0; r = 0.529), while growth rate was correlated with ammonia (Time lag -1; r = 0.439) (Time lag 0; r = 0.500) (Table 4.30). Monthly changes in number of fertile plants were not correlated (p > 0.0d45) with any environmental parameters (Table 4.31).

For *S. siliquosum* of the LR, significance was tested in the negative relationship between MTL and phosphate (Time lag 0; r = -0.505). In addition, increase in growth rate of tagged samples were significantly correlated ($p < 0.05$) with decrease in water temperature (Time lag 0; r = 0.572) and ammonia (Time lag 0; r = 0.495) (Table 4.32). Monthly changes in *S. siliquosum* measurements from the RR were also tested not significant ($p > 0.05$) with environmental parameters (Table 4.35). In fact, correlation between number of fertile plants and the parameters could not be computed as there were no tagged fertile plants found on the RR throughout the sampling period.

Table 4.28: Cross correlation between *S. polycystum* measurements and environmental parameters of the Left Reef with lag time of two months based on monthly non-destructive sampling

Measurements	Time Lag	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
MTL	-2	0.016	-0.127	0.034	-0.103	0.206	-0.014	-0.063	0.053	-0.038
	-1	0.048	-0.164	0.006	-0.132	0.389	-0.057	-0.020	0.165	0.049
	0	0.135	-0.105	0.061	-0.049	0.562*	-0.115	-0.101	0.273	0.139
	1	0.185	-0.026	0.061	0.040	0.498*	-0.131	-0.102	0.297	0.174
	2	0.118	0.022	0.027	0.054	0.356	-0.102	-0.039	0.220	0.178
Growth Rate	-2	0.130	0.057	0.049	0.070	0.365	-0.180	0.098	0.112	0.057
	-1	0.067	0.087	0.084	0.099	0.235	-0.195	0.094	0.107	0.091
	0	0.526*	0.442	0.446	0.461*	0.215	-0.354	0.456*	0.296	0.444
	1	0.247	0.242	0.245	0.247	-0.007	-0.104	0.225	0.187	0.241
	2	0.114	0.196	0.201	0.193	-0.119	0.006	0.160	0.276	0.196
No. fertile plants	-2	0.024	0.001	0.068	-0.005	0.000	-0.040	0.028	0.000	-0.034
	-1	0.084	-0.087	0.019	-0.021	0.302	-0.084	0.000	0.220	0.111
	0	0.246	0.027	0.159	0.053	0.302	-0.090	-0.135	0.279	0.101
	1	0.246	0.027	0.159	0.053	0.302	-0.090	-0.135	0.279	0.101
	2	0.222	0.026	0.092	0.059	0.302	-0.050	-0.162	0.279	0.135

*Significantly different ($p < 0.05$)

Table 4.29: Cross correlation between *S. polycystum* measurements and environmental parameters of the Right Reef with lag time of two months based on monthly non-destructive sampling

Measurements	Time Lag	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
MTL	-2	-0.109	0.065	0.096	0.150	-0.267	-0.101	0.027	0.086	-0.041
	-1	0.218	0.089	-0.001	0.151	-0.130	-0.002	0.028	0.289	0.086
	0	0.218	-0.021	-0.015	0.213	-0.076	0.011	0.075	0.253	0.100
	1	0.218	-0.005	-0.010	0.152	-0.013	-0.026	0.075	0.213	0.101
	2	0.327	-0.086	-0.111	0.063	0.191	0.021	0.048	0.168	0.141
Growth Rate	-2	0.137	0.148	0.150	0.149	-0.120	-0.083	0.153	0.148	0.149
	-1	0.337	0.222	0.220	0.225	-0.133	-0.060	0.239	0.150	0.220
	0	0.102	0.051	0.036	0.044	0.049	0.007	0.155	0.041	0.049
	1	0.219	0.136	0.125	0.127	-0.029	-0.151	0.201	0.140	0.137
	2	0.021	0.060	0.053	0.060	-0.007	0.087	0.087	0.107	0.059
No. fertile plants	-2	0.092	0.110	0.054	-0.056	-0.109	-0.046	-0.056	0.191	-0.017
	-1	0.048	0.079	-0.134	-0.164	0.218	0.087	-0.045	0.176	-0.013
	0	0.113	0.014	-0.080	-0.250	0.218	0.100	-0.190	0.356	0.076
	1	0.113	0.014	-0.080	-0.250	0.218	0.100	-0.190	0.356	0.076
	2	0.021	-0.096	-0.134	-0.194	0.327	0.145	-0.133	0.166	0.094

Table 4.30: Cross correlation between *S. binderi* measurements and environmental parameters of the Left Reef with lag time of two months based on monthly non-destructive sampling

Measurements	Time Lag	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
MTL	-2	0.033	-0.188	-0.122	-0.031	0.166	0.045	-0.060	0.337	0.161
	-1	0.009	-0.313	-0.007	-0.025	0.259	-0.078	-0.168	0.429	0.166
	0	0.039	-0.331	-0.003	-0.085	0.441	-0.080	-0.201	0.529*	0.160
	1	0.013	-0.235	0.046	-0.058	0.387	-0.011	-0.187	0.448	0.121
	2	0.007	-0.143	0.119	-0.054	0.276	-0.126	-0.140	0.129	-0.002
Growth Rate	-2	0.044	-0.021	-0.028	-0.015	0.299	-0.165	0.010	-0.065	-0.021
	-1	0.103	0.032	0.026	0.033	0.439*	-0.273	0.070	-0.003	0.031
	0	0.008	0.023	0.023	0.005	0.500*	-0.291	0.080	-0.014	0.024
	1	0.211	0.255	0.256	0.242	0.433	-0.367	0.265	0.208	0.257
	2	0.087	0.139	0.141	0.134	0.208	-0.140	0.130	0.232	0.140
No. fertile plants	-2	0.065	-0.103	-0.207	-0.149	0.172	0.160	0.018	0.235	0.154
	-1	-0.025	-0.239	-0.209	-0.215	0.344	0.049	0.008	0.350	0.169
	0	-0.118	-0.321	-0.308	-0.345	0.344	0.111	0.071	0.364	0.162
	1	-0.159	-0.286	-0.244	-0.262	0.344	0.022	0.033	0.307	0.126
	2	-0.182	-0.218	-0.101	-0.196	0.172	-0.048	0.053	0.129	0.008

*Significantly different ($p < 0.05$)

Table 4.31: Cross correlation between *S. binderi* measurements and environmental parameters of the Right Reef with lag time of two months based on monthly non-destructive sampling

Measurements	Time Lag	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
MTL	-2	-0.071	0.073	0.253	0.166	-0.196	0.039	-0.072	0.063	-0.142
	-1	-0.147	0.162	0.206	0.158	-0.114	0.136	0.023	0.136	-0.189
	0	0.021	0.213	0.292	0.232	-0.307	0.126	-0.029	0.118	-0.264
	1	0.038	0.172	0.093	0.097	-0.086	0.145	0.068	0.087	-0.183
	2	0.092	0.160	0.051	0.080	-0.111	0.084	0.068	-0.030	-0.178
Growth Rate	-2	0.057	0.111	0.113	0.118	-0.090	-0.081	0.131	0.097	0.112
	-1	-0.054	-0.001	-0.005	0.001	0.099	0.030	-0.002	0.000	0.001
	0	0.115	0.186	0.179	0.179	-0.123	-0.027	0.217	0.269	0.196
	1	0.126	0.186	0.185	0.172	-0.236	-0.032	0.179	0.219	0.188
	2	-0.046	0.010	0.012	0.018	-0.147	-0.034	0.031	-0.029	0.010
No. fertile plants	-2	-0.200	0.079	0.064	0.111	0.000	-0.117	0.004	0.396	0.031
	-1	-0.010	0.145	0.067	0.096	-0.149	-0.096	0.057	0.379	-0.046
	0	-0.010	0.145	0.067	0.096	-0.149	-0.096	0.057	0.379	-0.046
	1	0.086	0.301	0.062	0.037	-0.149	-0.012	0.154	0.000	-0.081
	2	0.178	0.056	-0.007	-0.025	-0.149	0.008	0.061	0.004	-0.043

Table 4.32: Cross correlation between *S. siliquosum* measurements and environmental parameters of the Left Reef with lag time of two months based on monthly non-destructive sampling

Measurements	Time Lag	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
MTL	-2	0.023	-0.018	0.264	0.121	0.280	-0.365	0.057	0.106	0.007
	-1	-0.030	-0.049	0.282	0.071	0.326	-0.411	-0.008	0.203	0.005
	0	-0.007	0.038	0.318	0.109	0.415	-0.505*	0.059	0.232	0.037
	1	0.031	0.053	0.246	0.102	0.257	-0.339	0.025	0.162	0.037
	2	-0.030	0.055	0.055	-0.012	0.135	-0.140	0.003	0.126	0.030
Growth Rate	-2	0.124	0.115	0.113	0.117	0.110	-0.089	0.115	0.171	0.116
	-1	0.100	0.021	0.016	0.007	0.338	-0.126	-0.014	0.077	0.025
	0	0.572*	0.108	0.103	0.091	0.495*	-0.293	0.073	0.028	0.113
	1	0.244	0.092	0.088	0.082	0.265	-0.155	0.071	0.103	0.095
	2	0.156	0.134	0.132	0.132	0.136	-0.125	0.123	0.173	0.135
No. fertile plants	-2	-0.045	-0.192	0.061	-0.099	0.183	-0.145	-0.008	0.163	0.017
	-1	-0.144	-0.245	0.012	-0.215	0.367	-0.256	0.050	0.287	0.094
	0	-0.237	-0.327	-0.087	-0.345	0.367	-0.194	0.112	0.303	0.086
	1	-0.147	-0.224	-0.114	-0.266	0.367	-0.132	0.086	0.309	0.128
	2	-0.192	-0.134	-0.148	-0.247	0.183	-0.048	0.121	0.139	0.069

*Significantly different ($p < 0.05$)

Table 4.33: Cross correlation between *S. siliquosum* measurements and environmental parameters of the Right Reef with lag time of two months based on monthly non-destructive sampling

Measurements	Time Lag	Water Temp	pH	Salinity	Nitrate	Ammonia	Phosphate	Rainfall	Radiation	Amb Temp
MTL	-2	0.127	0.037	0.012	0.052	-0.107	0.094	0.079	-0.131	-0.119
	-1	-0.034	-0.013	-0.042	0.110	0.000	0.105	0.069	-0.020	-0.052
	0	-0.017	0.342	0.276	0.173	-0.337	-0.027	0.037	0.179	0.026
	1	-0.079	0.419	0.367	0.142	-0.409	-0.096	-0.039	0.172	0.066
	2	-0.163	0.149	0.095	-0.068	0.039	-0.077	-0.176	0.127	0.059
Growth Rate	-2	-0.254	-0.126	-0.125	-0.076	0.031	0.165	-0.110	-0.066	-0.123
	-1	-0.034	0.034	0.030	0.090	0.009	0.218	0.076	0.029	0.035
	0	-0.056	0.056	-0.067	0.145	-0.067	0.220	0.094	0.020	0.053
	1	0.041	0.040	0.055	0.090	-0.274	-0.002	0.072	-0.096	0.037
	2	-0.087	0.003	0.007	0.026	0.029	0.101	-0.028	0.110	0.005

Cross correlation of monthly number of fertile plants could not be computed as there were no fertile plants tagged on the RR throughout sampling period

CHAPTER 5.0

DISCUSSION

5.1 Comparison between Measurements

Comparison between MTL and biomass of harvested samples from destructive sampling were illustrated in Figure 4.38. Similar growth patterns between these two measurements indicate that increase in thallus length contribute to increase in biomass. However, when number of samples was taken into consideration, MTL did not necessarily correlate with biomass of that month. For instance, if there was a large population of smaller sized samples involved, MTL would be small, but biomass would still be large due to biomass accumulation from all the samples. This was verified when correlations between biomass and MTL for all samples were tested not significant.

A clearer contrast between the three species was seen in Figure 4.30 to 4.33. In September 2010, MTL of *S. binderi* (65.53 mm) was slightly larger than that of *S. siliquosum* (56.79 mm) of the same month. However, biomass was much lower for *S. binderi* (52.80 g WW m^{-2}; 7.17 g DW m^{-2}, 6.10 g AFDW m^{-2}) compared to *S. siliquosum* (173.57 g WW m^{-2}; 31.90 g DW m^{-2}, 27.44 g AFDW m^{-2}) of that month. The fact is that in September 2010, there were fewer samples of *S. binderi* (62 plants) harvested compared to *S.*

siliquosum (133 plants) (Table 4.9). Thus, despite measuring slightly larger than *S. siliquosum* in length, the fewer quantity of *S. binderi* contributed to lower biomass obtained.

Plants have to grow to a certain size before they are able to reproduce. In this study, variation in bimonthly MTL and percentage fertility were compared (Figure 4.39) and all three species tested significant in correlation. This implies that as MTL increased, so did percentage fertility of samples. Similarly, percentage fertility also decreased when MTL decreased.

A study done by Zhang et al. (2009) showed a strong correlation between thallus length and number of lateral branches at peak reproduction. Prior to the onset of reproduction, laterals branch out at multiple points along the primary branch axis. This creates larger canopies which would also lead to increase in biomass. Hence, when biomass and percentage fertility of samples are compared, there should be a significant correlation between the two. However, this was not the case in this study, as Pearson's correlation failed to correlate variation in bimonthly biomass with fertility for all three species. The increased thallus length and additional laterals before peak reproduction may have contributed to the biomass increase, but only to a certain extent.

Zhang et al. (2009) also stated that after peak period of reproduction, fertile laterals will begin to necrose and die back. Field observations revealed that even in the midst of peak reproduction, some fertile laterals could be seen necroting. These were samples that attained fertility slightly earlier and were now moving on to the next phase of senescence or die-back. This loss of fertile laterals and even of whole thalli, as in the case of tagged sample, affected the overall increase in biomass at peak reproduction.

5.2 Life Cycle

It has been reported that a typical life cycle of *Sargassum* species includes growth, reproduction and degeneration (Ang, 2006). This cycle was clearly seen in *Sargassum* species of this study, as summarized in Table 5.1. Timing of these phases were similar among all three species being studied, with only minor differences.

Growth phase is defined as the period of time whereby increment of thallus length occurs. Results analyzed from destructive sampling (Figure 4.34) and non-destructive sampling (Figure 4.47) revealed two periods of peak growth within a year, as summarized in Table 5.1. For all three species, timing of the two growth phases were similar, which was from December 2009 to February 2010 (*S. binderi*: November 2009 to February 2010) and from April 2010 to July 2010. Results were more accurate for non-destructive method because sampling was conducted every month, as opposed to bimonthly for destructive sampling. However, comparison between these two methods only differed by one month at most.

Table 5.1: Summary of *Sargassum* life cycle in Teluk Kemang from September 2009 to September 2010 based on (A) destructive sampling and (B) non-destructive sampling

A

Life Cycle	Destructive Sampling		
Stages	*S. polycystum*	*S. binderi*	*S. siliquosum*
Reproduction 1	Sept 09	Sept 09 - Nov 09	Sept 09
Degeneration 1	Sept 09 - Nov 09	Sept 09 - Nov 09	Sept 09 - Nov 09
Growth 1	Nov 09 - Jan 10	Nov 09 - Jan 10	Nov 09 - Mar 10
Reproduction 2	Jan 10 - Mar 10	Nov 09 - May 10	Jan 10 - May 10
Degeneration 2	Jan 10 - May 10	Jan 10 - May 10	Mar 10 - May 10
Growth 2	May 10 - Jul 10	May 10 - Jul 10	May 10 - Jul 10
Reproduction 3	Jul 10 - Sept 10	May 10 - Sept 10	May 10 - Sept 10
Degeneration 3	Jul 10 - Sept 10	Jul 10 - Sept 10	Jul 10 - Sept 10

B

Life Cycle	Non-Destructive Sampling		
Stages	*S. polycystum*	*S. binderi*	*S. siliquosum*
Reproduction 1	Sept 09 - Oct 09	Sept 09 - Oct 09	Sept 09 - Oct 09
Degeneration 1	Sept 09 - Dec 09	Sept 09 - Nov 09	Sept 09 - Dec 09
Growth 1	Dec 09 - Feb 10	Nov 09 - Feb 10	Dec 09 - Feb 10
Reproduction 2	Jan 10 - Apr 10	Feb 10 - Apr 10	Dec 09 - May 10
Degeneration 2	Feb 10 - Apr 10	Feb 10 - Apr 10	Feb 09 - May 10
Growth 2	Apr 10 - Jul 10	Apr 10 - Jul 10	Apr 10 - Jul 10
Reproduction 3	Jul 10 - Sept 10	Jul 10 - Sept 10	Jul 10 - Sept 10
Degeneration 3	Jul 10 - Sept 10	Jul 10 - Sept 10	Jul 10 - Sept 10

Reproductive phase is regarded as the most sensitive stage in a macroalgal life history (Steen, 2004). It refers to the occasion after peak growth, and is characterized by appearances of receptacles. Overlapping in the period of peak growth and reproduction is a strategic way to maximize allocation of resources to reproductive structures (DeWreede & Klinger, 1988).

Analysis of destructive (Table 4.9) and non-destructive data (Figure 4.48) reveal that within a span of 13 months, there were three occasions of receptacles appearing (Table 5.1). Unlike growth phase, period of reproductive phases varied for all three species. Generally, *Sargassum* in Teluk Kemang was shown to be reproductively active during the first and third quarter of the year, implying that they undergo biannual reproduction. Non-destructive data showed that these samples peaked in September 2009 (October 2009 for *S. polycystum*), March 2010 (February 2010 for *S. polycystum*) and August 2010. In other studies, *Sargassum* was more commonly reported to undergo an annual reproductive cycle (Zhang et al., 2009), rather than a biannual cycle as seen in this study. Wong (1997) reported that within a period of 15 months, *S. baccularia* in Cape Rachado, Port Dickson produced receptacles twice, while *S. binderi* at three occasions. Some species of *Sargassum* may resort to biannual reproduction as an adaptive strategy to survive in harsh environments (Akira & Masafumi, 1999).

For *S. polycystum*, appearances of receptacles were strictly within the reproductive phase, as no fertile samples were observed outside these phases from November 2009 to December 2009, and from May 2010 to June 2010 (Figure 4.48). This is important as synchronization of gamete release at a specific time frame was one of the strategies employed to increase successful fertilization (Brawley & Johnson, 1992). Field observations noted that during periods of 0 % fertility, most *S. polycystum* samples lacked secondary branches, and only primary axes attached to perennial holdfasts remained. In addition, exceptionally numerous and extensive rhizoidal holdfasts were observed within these months, indicating vegetative reproduction.

Based on destructive sampling, *S. binderi* was reproductively active throughout the study period, with lowest percentage fertility in November 2009 (1.82 %). This is a phenomenon common in certain *Sargassum* species, such as in *S. binderi* from Cape Rachado (located 2.5 km away from present site). Wong and Phang (2004) reported this species to be constantly bearing fertile laterals throughout the whole year and were continuously recruiting new plants every month. However, monitoring of non-destructive samples in the current study revealed periods whereby fertile laterals were absent from tagged *S. binderi* samples (November 2009 to January 2010; May 2010) which was not shown in destructive method. Similarly, *S. siliquosum* was reproductively active almost all year round, with 0 % fertility only in November 2009 and June 2010 for non-destructive sampling (only in November 2009 for destructive sampling). Continuous reproduction, as opposed to strict seasonal reproduction can be beneficial to ensure its survival.

Degenerative phase which includes both senescence and die-back, typically occurs after reproductive phase. *Sargassum* species are perennial plants that are able to live through several rounds of growth cycles in its lifetime. It has been reported that during periods of harsh environments, *Sargassum* species would die-back and leave a short, primary axis attached to its perennial holdfast (Zhang et al., 2009). When conditions are ideal, primary branches arise again from the surviving thallus until the onset of reproduction again. It could take several years before *Sargassum* species senescent and die off.

In this study, three occurrences of degeneration were noted within the span of 13 months (Table 5.1). Overall, timing of these degenerative phases were similar among species and sampling methods. Degeneration, characterized by decrease in MTL was observed in non-destructive sampling of tagged samples from September 2009 to December 2009 (*S. binderi*: September 2009 to November 2009), with a high degenerative rate in October 2009 (*S. polycystum*: -0.24 mm day^{-1}; *S. binderi*: -1.66 mm day^{-1}; *S. siliquosum*: -1.19 mm day^{-1}). The next degenerative phase occurred from February 2010 to May 2010 (*S. siliquosum*: March 2010 to May 2010), with highest degenerative rate in April 2010 (*S. polycystum*: -1.96 mm day^{-1}; *S. binderi*: -2.27 mm day^{-1}; *S. siliquosum*: -4.17 mm day^{-1}), following which another degenerative phase from and July 2010 to September 2010, whereby samples reached highest degenerative rate in September 2010 (*S. polycystum*: -3.75 mm day^{-1}; *S. binderi*: -3.23 mm day^{-1}; *S. siliquosum*: -5.22 mm day^{-1}).

In non-destructive sampling, loss of lateral branches and even of whole plants during degenerative phase was indicated in the loss of tags from the respective quadrats. According to Table 4.12, the number of lost tags was high during these phases. For instance, number of lost *S. polycystum* tags peaked in November 2009 (35 lost tags; 77.78 % loss), April 2010 (38 lost tags; 43.18 % loss) and July 2010 (37 lost tags; 56.92 %). It was observed that in late July 2010, abundant *Sargassum* seaweeds were found washed off to shore. Most of these were whole plants, still attached to the holdfasts. Overall, the amount of lost tags is relatively very high when compared to other studies employing permanent quadrat. For instance, Ateweberhan et al. (2005) recorded 30 *S. ilicifolium* samples that were tagged in September 1999, and out of these, the number of lost tags was only one in March 2000, one in March 2001, two in April 2000 and three in May 2000.

From destructive sampling, MTL and biomass of harvested *S. polycystum* samples were relatively high in September 2009 (210.32 ± 141.31 mm; 323.39 ± 257.26 g WW m^{-2}; 33.03 ± 27.96 g DW m^{-2}; 24.81 ± 24.44 g AFDW m^{-2}), which also coincided with highest percentage fertility (52.99 %) of the year. However, the number of samples harvested (134 plants) was the lowest throughout sampling period. Analysis of length classes distribution (Figure 4.42) showed that in September 2009, *S. polycystum* samples harvested were more widely distributed in length sizes, with largest samples reaching up to 800 - 899 mm. Thus, it can be deduced that although the numbers of *S. polycystum* were few, high MTL and biomass in September 2009 were contributed by larger sized samples, bearing more laterals. When population density is low, there is less competition between individuals. Hence, plants would have enough room and resources to grow more lateral branches with longer lengths. Presence of receptacles also contributed to the overall biomass.

Subsequently, MTL and biomass of *S. polycystum* reduced to one of its lowest in November 2009 (46.19 mm; 91.99 g WW m^{-2}; 14.76 g DW m^{-2}; 9.46

g AFDW m^{-2}), but the number of harvested samples (279 plants) was highest ever collected. Analysis of length classes distribution revealed that samples harvested in November 2009 were mainly made up of smaller sized samples, with the largest percentage frequency (92.11 %) falling under length classes of 0 - 99 mm. Samples in this month were a mixture of short perennial thalli that remained after degenerative phase, as well as new recruits that grew after reproductive phase.

Recruitment of new plants can be illustrated by the sudden shift in percentage frequency from larger length classes to smaller ones. For instance, non-destructive sampling on *S. polycystum* (Figure 4.48) revealed a drastic shift from larger length classes distribution in March 2010 (largest thallus within 600 - 699 mm) to a smaller one in April 2010 (largest thallus within 200 - 299 mm). Wong and Phang (2004) stated that after reproductive phase, it would take roughly three to six months before new recruits appear. This pattern can be illustrated when comparing periods of peak fertility and of shift in length classes distribution patterns. For instance, peak fertility of *S. polycystum* was seen in October 2009, February 2010 and August 2010 (Figure 4.48), while a shift to smaller length classes was observed in October 2009, April 2010 and September 2010 (Figure 4.48). Similarly, peak fertility for *S. binderi* and *S. siliquosum* was in September 2009, March 2010 and August 2010, but a shift to smaller length classes occurred in November 2009, May 2010 and September 2010. In the current study, the comparison revealed that recruitment occurred 1 to 2 months after peak reproduction.

Figure 4.49 revealed two occasions whereby tagged samples experienced peak growth rate, which was in February 2010 (January 2010 for *S. polycystum*) and June 2010 (July 2010 for *S. siliquosum*). This is in agreement with a study in Cape Rachado, Port Dickson whereby growth rate of *Sargassum* species (*S. baccularia* and *S. binderi*) also attained two peaks, in June 1995 and February 1996 (Wong, 1997). Similarly, degenerative rate of the current study was highest at two occasions, in April 2010 and September 2010. Wong found that high degenerative rate of *S. baccularia* occurred between February to March 1995, in April 1995, early June 1995 and between June to July 1995. For *S. binderi*, Wong found that high degenerative rate occurred between March to April 1995, between June to July 1995 and between September to October 1995. This proves that seasonal growths of *Sargassum* samples in Teluk Kemang are similar to those from Cape Rachado in terms of growth rate.

Peak growth rate in June 2010 (July 2010 for *S. siliquosum*) was evidenced in the distribution pattern of length classes from destructive data. There was a sudden shift from smaller length classes in May 2010 (*S. polycystum*: < 200 m; *S. binderi*: < 100 mm; *S. siliquosum*: < 200 mm) to larger length classes in July 2010 (*S. polycystum*: < 1100 m; *S. binderi*: < 400 mm; *S. siliquosum*: < 800 mm). At this point, percentage frequency of samples measuring under the smallest length classes of 0 - 99 mm decreased dramatically to half from May 2010 (*S. polycystum*: 95.88 %; *S. binderi*: 100 %; *S. siliquosum*: 97.37 %) to July 2010 (*S. polycystum*: 50.26 %; *S. binderi*: 38.46 %; *S. siliquosum*: 43.64 %). The presence of large standard deviations for *Sargassum* MTL in July 2010 (Figure 4.34) further points to large size inequality among seaweeds within a quadrat. As the size of *Sargassum* plants increases, asymmetric competitions occur whereby the larger sized plants tend to suppress the growth of smaller sized plants (Ateweberhan et al., 2006), as evidenced in the reduction of plants harvested from May 2010 (*S. polycystum*: 243 plants; *S. binderi*: 60; *S. siliquosum*: 76) to July 2010 (*S. polycystum*: 191 plants; *S. binderi*: 39; *S. siliquosum*: 55) (Tables 4.9). Thus size inequality was evident especially during peak growth. In fact, standard deviations for monthly MTL were relatively large for all three species throughout the study period. This was due to large size inequality during the overlap of different growth phases, as was also seen in the wide distribution of length class frequencies.

Following peak growth, lowest degenerative rate which was in September 2010 could also be demonstrated by length classes distribution of destructive sampling. From larger length classes in July 2010, samples obtained in the following month of September 2010 decreased again in length sizes (*S. polycystum*: < 400 m; *S. binderi*: < 300 mm; *S. siliquosum*: < 400 mm). Percentage frequency of samples measuring 0 - 99 mm also increased from July 2010 to September 2010 (*S. polycystum*: 83.13 %; *S. binderi*: 75.81 %; *S. siliquosum*: 81.20 %). As the size of *Sargassum* plants decreased, so did competition for space. Following peak reproduction, new recruits had more space to grow, as seen in the increment of plants harvested from July 2010 (*S. polycystum*: 191 plants; *S. binderi*: 39; *S. siliquosum*: 55) and

September 2010 (*S. polycystum*: 166 plants; *S. binderi*: 62; *S. siliquosum*: 133) (Tables 4.9).

In this study, *S. binderi* and *S. siliquosum* experienced the first peak growth rate in February 2010, which was located towards the end of the growth phase. This resulted in immediate peak MTL in February 2010. In the second peak growth rate (June 2010), *S. polycystum* and *S. binderi* experienced rapid growth in the middle of the growth phase. Pedersen et al. (2005) stated that large biomass of *S. muticum* obtained at its peak was contributed by rapid growth early in the growth phase. This was also noted by Ateweberhan et al. (2008) whereby initiation of *S. subrepandum* growth was restricted to the early part of the cooler months. This was to allow growth and reproduction to peak before the arrival of harsh summer conditions.

5.3 Correlation with Environmental Parameters

In Teluk Kemang, seasonal variation in environmental factors are governed by the annual Northeast Monsoon (November to March) and the Southwest Monsoon (June to September), which in turn controls seasonal growth of seaweeds. This was also agreed by Wong and Phang (2004) along the tropical coast of Cape Rachado, Malaysia. Different species of seaweeds respond differently to strong seasonal changes.

Effects of environmental parameters onto growth of *Sargassum* were taken into consideration based on results of RDA and its correlation matrix.

Strong wave action brought about by heavy rainfall was reported to directly inflict physical stress onto seaweeds, causing a drag and lift effect that ultimately result in tearing of laterals and even detachment of whole thalli from substrates (Wichachucherd et al., 2009; Nishihara & Terada, 2010b). This was the case indicated in the current study whereby heavy rainfall significantly reduced biomass of *S. siliquosum* obtained from destructive sampling (WW: r = -0.5750; DW: -0.6469; AFDW: r = 0.6401). This indicated a direct physical detachment of many *Sargassum* samples brought about by strong water motions.

Results from RDA and its correlation matrix indicated a strong relationship ($p < 0.05$) between radiation and biomass of *S. binderi* (WW: r = 0.5365; DW: r = -0.6620; AFDW: r = -0.6566). It is important to note that data for mean daily radiation was only provided until March 2010 due to faulty weather station in Malacca. Thus, data for this parameter is not representative of the whole study period. *S. binderi* was more sensitive to the effects of radiation, probably due to its flattened or compressed branches, compared to the terete branches of *S. polycystum* and *S. siliquosum*. This creates a higher surface area on *S. binderi* branches that causes it to absorb or lose water more easily through evaporation.

Changes in monthly seawater composition, consisting of water temperature, pH and salinity are dependent on seasonal water circulation and retention on the reefs. During rainy seasons, slightly acidic water droplets from the rain may affect pH of seawater, while strong currents that bring in cool water from the sea decrease water temperature and dilute its salinity. However, during daily low tides, water trapped on the reef evaporates under scorching sun, causing water temperature to increase and salinity to concentrate during reef emersion, as mentioned by Lobban and Harrison (1994). In the current study, destructive sampling revealed that high water temperature was strongly detrimental ($p < 0.05$) to growth of *S. binderi* (MTL: r = -0.9038; WW: r = -0.5549) and *S. siliquosum* (WW: r = -0.7253; DW: r = -0.8734; AFDW: r = -0.8796). As expected, water temperature in the present study played a major role in affecting macroalgal growth, just as how biomass of *Sargasuum* from the Red Sea were negatively correlated with water temperature (Ateweberhan et al., 2006).

On the other hand, salinity significantly ($p < 0.05$) increased *S. binderi* measurements from both destructive (WW: r = 0.4513) and non-destructive samplings (MTL: r = 0.5419). In the present study, salinity of seawater measured on both reefs of Teluk Kemang ranged from 20 - 30 ‰. According to Raikar *et al*. (2001), it was within this salinity range (20 - 30‰) that *Gracilaria* species from Japan grew optimally.

Similar to effects of water temperature, high pH was also detrimental to growth of *S. polycystum* (MTL: r = -0.6182; WW: r = -0.6040) and *S. binderi* (MTL: r = -0.4691). In February 2010, constructions of concrete-stilted balconies were carried out toward the RR. Alkaline cement ashes from the construction may have affected pH levels on both reefs, as seen in the marked increase in pH levels from February 2010 onwards (Figure 4.5).

Although the increase in pH was not tested significantly different after commencement of construction (Post-Hoc test: $p > 0.05$) (Appendix B), slight increase in monthly pH nonetheless brought damaging effects especially to *S. polycystum* samples that were more abundantly found on the shallow RR.

Monthly changes in nutrient levels affected *S. binderi* and *S. siliquosum* populations, as revealed by both destructive and non-destructive samplings. From destructive sampling, nitrate was strongly related with ($p < 0.05$) *S. siliquosum* (WW: r = 0.5428; DW: r = 0.4941; AFDW: r = 0.4889), while phosphate levels strongly with *S. binderi* (MTL: r = 0.8370; WW: r = 0.6345; DW: r = -0.4655; AFDW: r = -0.4596) and *S. siliquosum* (WW: r = 0.5535; DW: r = 0.7624; AFDW: r = 0.7692). For non-destructive sampling, ammonia was strongly related to *S. siliquosum* (MTL: r = -0.4603). Dawes (1998) explained that the rate of nutrient uptake is affected by environmental factors of abiotic and biotic factors. Ang (1986) noted that strong water motion during typhoon months encouraged aeration and nutrient regeneration within *Sargassum* community in the Philippines. Similarly, strong water motion during monsoon periods as experienced by the west coast of Peninsular Malaysia, constantly disturbs seabed and encourages nutrient circulation.

Nutrient levels, when in short supply, can become a limiting factor for seaweed growth (Lobban & Harrison, 1994), but when in high concentrations, can be detrimental to growth (Brown, 1995). Throughout the course of the study, effluent waste was constantly released into the sea by the resort fronting

LR. Pollutants such as sewage effluents and fertilizer factory effluents were reported to have exhibited detrimental effects on the reproductive features and growth properties of several studied green and blue-green algae (Agrawal, 2009). However, in some cases such as on the Lagoons of Venice, sewage polluted waters did not show any deteriorating effects on *S. muticum*, but were advantageous for another brown seaweed *Undaria pinnatifida* (Curiel et al., 1998). Similarly addition of nutrients to the reefs of North Carolina, USA, brought no effects on brown seaweeds, but instead increased cover of red seaweeds significantly (Miller & Hay, 1996). This was the case in the current study whereby high ammonia levels from effluent wastes actually encouraged growth of *Sargassum* on the reefs.

5.4 Comparison between Left and Right Reef

Despite the short distance between the reefs (80 m apart), spatial variation could be seen in the abundance between all three species. *S. polycystum* was more abundant on the RR, while both *S. binderi* and *S. siliquosum* were more abundant on the LR (Table 4.13 and 4.14). This was due to geographical differences between the two reefs and ability of *Sargassum* species to adapt.

Substrates onto which *Sargassum* holdfast attach may vary from small stones (< 10 cm), to medium stones (< 20 cm) and to big boulders (> 20 cm), with preference to solid boulders than to stones (Thomsen et al., 2006). As such, distribution of *Sargassum* species is very much dependent on textures and types of substrates. *Sargassum* is also commonly found attached to dead or dying corals (Ismail & Go, 1994; Guillermo & McCook, 2004; Noiraksa et al., 2006). New recruits that land on smaller sized substrates would only survive for a short period of time before strong currents wash both recruit and substrate to shore. Field observations showed that RR was predominated by smaller sized substrates such as sand, pebbles and stones, while LR was predominated by larger substrates of boulders and corals. Comparison between the two reefs revealed that both *S. binderi* and *S. siliquosum* were more abundant on the LR than on the RR (Table 4.13). This spatial distribution was determined by availability of larger substrates on the LR that provided more solid base for holdfast attachment. On the contrary, *S. polycystum* was more abundant on the RR despite presence of looser and smaller sized substrates.

Based on biomechanical and morphological studies, species from Phaeophyceae was equipped to adapt to a wide variety of wave exposed environments (Koehl, Silk, Liang & Mahadevan, 2008). Holdfast structure of *Sargassum* in particular, varied among the three species studied. *S. binderi* samples in this study were noted to possess small holdfasts of discoid shape (Noiraksa et al., 2006), while holdfast of *S. siliquosum* was described as being shield-shaped in younger plants but massive and amorphous in old thalli (Trono, 1997). Characteristics of both *S. binderi* and *S. siliquosum* holdfasts limited their attachments to only hard and stable substrates of the LR. On the other hand, *S. polycystum* plants were reported to possess small holdfasts with secondary rhizoidal holdfasts, called stolons protruding out from it (Trono, 1997; Noiraksa et al., 2006; Wong, Ng & Phang, 2007). These stolons assist in holdfast attachment that contributes to a stronger grip between plant and substrate, hence, its adaptability to thrive on the RR.

Overall, measurements of samples from destructive sampling (Figure 4.54) and non-destructive sampling (Figure 4.55) were similar for *S. polycystum* and *S. binderi*, whereby all measurements were higher on the LR. As for *S. siliquosum,* MTL and percentage fertility obtained from non-destructive sampling was also higher on the LR, but from destructive sampling were larger on the RR.

In addition to tide levels, wave action also varied between the two reefs. Field observations showed that the LR was more exposed to strong wave action while large rock formations on the outer reef's edge of the RR sheltered the inshore reef from harsh wave action. Studies have shown that effects of strong waves and wave-induced water motion vary with seaweed phyla (Nishihara & Terada, 2010b), often affecting growth and reproduction negatively (Akira & Masafumi, 1999; Wichachucherd et al., 2009; Zhang et al., 2009). These directly inflict physical stress on seaweeds, causing laterals to tear off and even whole thalli to break from its substrates. Reproductive gametes as well as fertilized zygotes that are released into the water risk being swept away by strong water motions, thus affecting both reproduction and recruitment. This was proven in a study on Pulau Tioman by Ismail and Go (1994) who reported low seaweed density and diversity on more turbulent waters of Kampung Juara and Kampung Mukut, as opposed to moderately wave-exposed Kampung Tekek, Kampung Air Batang and Kampung Paya that yielded high density and diversity of seaweeds. However, the opposite trend was also observed in other studies, such as noted by Baer and Stengel (2010) along different study sites of the Irish west coast with different degrees of wave exposure. Growth and receptacle development of *S. muticum* populations were found lower at a more sheltered site, while development was normal at a more exposed site where populations grew to maximum lengths. Similarly, results in the current study revealed that as an overall, MTL and percentage fertility obtained from both destructive and non-destructive samplings were higher on the more wave-exposed LR (except for *S. siliquosum* of destructive sampling) which indicated that desiccation stress as experienced by seaweeds on the RR was more detrimental to growth than was stronger wave action on the LR.

Figure 4.54 showed that biomass of all three species were relatively higher on the LR (significantly higher for *S. siliquosum*). Despite its abundance on the RR (RR: 940 plants; LR: 421 plants), *S. polycystum* yielded higher biomass on the LR. This can be explained in the different biogeography of the two reefs. During daytime low tides of each month (0.3 m above sea level), most part of the RR was seen exposed to the air, unlike most part of the LR which was still submerged under water. Constant submergence, such as in the case of the LR, shield seaweeds from damaging effects of the sun's radiation (Wong & Phang, 2004), thus providing a more conducive environment for *Sargassum* growth and survival. On the other hand, seaweeds on the RR were exposed to desiccation stress that limited growth. This was also observed in *S. hemiphyllum* in the shallow subtidal reefs of Tung Ping

Chau, Hong Kong whereby plants of this species were exposed at extreme low tides but other subtidal *Sargassum* species were not. Ang (2006) related the difference in die-back timing between *S. hemiphyllum* and the other species to variation in their geographical distribution. In the current study, *S. siliquosum* was more abundantly found on the deeper waters of the LR, but this was in contrast to a zonation study from the Philippines that found *S. siliquosum* plants only within the shoreward quadrats, whereby a large portion of the reef flat was exposed for considerable periods at extreme low tide (Ang, 1986).

In the current study, time series analysis of cross correlation with time lag of two months was conducted separately on both reefs between sample growth and environmental parameters. It was noted that certain parameters that were not tested significant in correlation using 0 month time lag were found significantly correlated when time lag of one or two months was conducted. This was also implemented in other studies (Ang, 1986; Glenn, Smith & Doty, 1990; Wong, 1997) that agreed to changes in sample measurements being influenced by parameters of the past, rather than those of concurrent. For instance, Ang (1986) reported that the time taken for environmental variables to significantly affect algal cover in the Philippines was two to three weeks. Although intervals longer than 3 weeks were possible, justification for such correlation was more difficult in a biological sense.

From Table 4.28, rainfall was shown to encourage growth rate of *S. polycystum* from non-destructive sampling of the LR. Nishihara and Terada (2010b) explained that wave and wave-induced water motion can directly or indirectly affect seaweed biology. In their study, results revealed that although species richness of most seaweed phyla were negatively correlated to wave exposure, seaweeds from Phaeophyceae, which includes *Sargassum* was proven to increase in species richness as exposure increases. In another instance, a study in Cape Rachado, Port Dickson (Wong & Phang, 2004) revealed a positive correlation between fertility and biomass of *Sargassum* species with rainfall. Similarly, after the monsoon period in November 1995, biomass and fertility were shown to be lowest in January 1996.

Based on destructive and non-destructive samplings, strong radiation strongly encouraged ($p < 0.05$) the increment of *S. binderi* MTL (Time lag 0; r = 0.529) (Table 4.30), biomass (Time lag 0; DW: r = 0.514; AFDW: r = 0.514) (Time lag +1; WW: r = 0.453; DW: r = 0.537; AFDW: r = 0.535) (Table 4.24) and of the number of fertile plants (Time lag 0; r = 0.471) (Table 4.24) on the LR, but not on the RR. Due to its spatial distribution, *S. binderi* is mainly found in the lower intertidal zone that allows it to be submerged in the water most of the time (Wong & Phang, 2004). Even during low tides, *S. binderi* that was more abundant on the LR were seen constantly submerged in the water. This sheltered *S. binderi* from harsh desiccation stress inflicted by scorching tropical sun, as experienced by seaweeds on the RR. In fact, being constantly submerged in the water puts *S. binderi* in an environment whereby they have to compete for light, especially during raining seasons with low radiation and high water turbidity. However, Ang (1986) found that high water levels minimize shading effects among erect thalli, thus allowing light to penetrate onto *Sargassum* and encourage growth. This was evident in the current study when high radiation was not detrimental to *S. binderi* growth, but instead caused increment in biomass and encouraged reproduction. For instance, there were only 45 plants of *S. binderi* harvested in January 2010, whereas *S. polycystum* and *S. siliquosum* had 140 and 121 each. Despite obtaining roughly three times lower the amount of plants, *S. binderi* managed to reach a biomass roughly double the weight of *S. polycystum* and *S. siliquosum.*

Damaging effects of desiccation stress on the more exposed RR was obvious when MTL, biomass and percentage fertility of both *S. polycystum* and *S. binderi* from destructive sampling were found lower on that reef. Similarly, *S. siliquosum* biomass was also lower on the RR, but this did not tally with higher MTL and percentage fertility of that species there. This seemingly contradicting result was made clear when other factors were taken into consideration. Table 4.13 revealed that throughout the sampling period, *S. siliquosum* was present in every quadrat of the LR but was only present in four quadrats of the RR (Q7, Q8, Q11 and Q12). In total, harvested plants on the RR were very few in comparison to the LR, with highest number amounting to only 26 plants in Q7 of RR, followed by seven plants in Q8. Despite low abundance of *S. siliquosum* on the RR, overall MTL of destructive samples in both Q7 and Q8 were found to be larger than those of the LR. These were contributed by a few large samples in September 2009 (largest sample in Q7: 326 mm; largest sample in Q8: 300 mm) and in November 2009 (largest sample in Q7 was 118 mm) in the midst of the remaining smaller *S. siliquosum* plants. These larger plants were an exception to the norm as they grew on small patches of submerged reef (field observation), safe from both desiccation stress experienced by the rest of *Sargassum* on the shallow RR. Coincidently, September 2009 and November 2009 were also months with low radiation and relatively high rainfall (Figure 4.5) that further encouraged growth of these few large samples. In fact, cross correlation of *S. siliquosum* from the destructive sampling revealed that radiation strongly encouraged ($p < 0.05$) the increment of MTL (Time lag -1; r = 0.671) (Time lag 0; r = 0.649) and biomass (Time lag 0; DW: r = 0.487; AFDW: r = 0.488) of samples from the RR, but not from the LR (Table 4.27). This was comparable to results from non-destructive sampling, whereby census of *S. siliquosum* samples were also more on the LR (182 tagged plants) than on the RR (11 tagged plants) (Table 4.14). However, unlike results from destructive sampling, overall MTL of *S. siliquosum* from non-destructive sampling were relatively smaller on the RR (Figure 4.55) due to the absence of the larger plants.

Based on destructive sampling, ammonia levels were tested to inflict contrasting effects onto MTL of *S. polycystum* from LR and RR. On the LR, high ammonia levels were strongly detrimental ($p < 0.05$) to MTL of *S. polycystum* (Time lag 0; r = -0.514) (Time lag +1; r = -0.471), but these instead encouraged growth of samples on the RR (Time lag -1; r = 0.482) (Time lag 0; r = 0.560). This contrast could be contributed by the effluent waste that was constantly released into the sea by the resort fronting LR, indicating that *S. polycystum* requires low levels of ammonia in order to thrive.

S. polycystum which was more abundant on the RR, attained a higher female to male ratio (88 female : 35 male) (Table 4.10). Sheltered from harsh wave action, dilution of sperm after being released into moderately circulated waters of the RR was not as big a concern as was the survival of new recruits on flimsy substrates with the eventual threat of desiccation stress. In other words, priority could possibly be placed on successful recruitment rather than on successful fertilization, which drove *S. polycystum* to allocate more resources in developing more female plants. As for *S. siliquosum* which was more abundant on the wave exposed LR, overall percentage sexuality also attained a higher female to male ratio (29 female : 22 male) but this ratio was more balanced compared to *S. polycystum.* There were two instances of male percentage exceeding that of female, such as in May 2010 (1 female : 2 male) and July 2010 (5 female : 11 male) that coincided with peak rainfall of the previous month (Figure 4.5). Harsh water motion, brought about by heavy rainfall, easily dilutes the number of sperms released into the water. Thus, a higher male to female ratio for *S. siliquosum* in those months would be necessary for survival. All these indicate that determination of percentage sexuality could be affected by tidal pattern and water motion. This is an interesting hypothesis that should be further analysed.

From this study, spatial variations in *Sargassum* were seen even among nearby reefs. Araújo et al. (2005) mentioned that spatial variations can be seen across large distances or even small ones if habitat complexity is high. Combining results of LR and RR, *Sargassum* has been found to be in smaller length classes throughout the year with only a few large plants. Majority of *Sargassum* species were in the lower length classes (< 200 mm) (*S. polycystum* = 86.47%; *S. binderi* = 87.08%; *S. siliquosum* = 86.96%). This is comparable to another study conducted in Cape Rachado, Port Dickson whereby 89 % of *S. binderi* plants were found to be shorter than 200 mm (Wong & Phang, 2004). Similar observance of smaller-sized plants was also reported in other brown seaweeds such as *Padina boryana* (Wichachucherd et al., 2009) and *Turbinaria triquetra* (Ateweberhan et al., 2005). However, MTL of local *Sargassum* species were relatively short compared to those found in neighbouring countries such as in the Philippines (Trono, 1997; 1999) and Thailand (Noiraksa et al., 2006). Wong and Phang explained that this is because most of the local *Sargassum* plants have adapted to live within the intertidal zone where waves are strong and desiccation stress is high. Thus, survivors that can resist such physical stress tend to be in smaller length sizes. This decreases the risk of whole organisms facing fatal damage. In foreign, colonized waters like in the Lagoons of Venice, *S. muticum* can grow up to over three metres in length, while records of *S. muticum* measuring up to 10 m were found in French Atlantic coasts (Curiel et al., 1998). These were very much larger than *Sargassum* in native waters of Teluk Kemang which were measured not larger than 1.1 m. Curiel et al. explained that in native countries, *S. muticum* tend to achieve shorter reproductive cycles and smaller thallus lengths due to strong competition.

5.5 Future Studies

The importance of *Sargassum* seaweeds has been thoroughly noted in many literatures (Abbott, 1996; Trono, 1999; McHugh, 2003; Smit, 2004; Phang, 2006; Li et al., 2008; Fenoradosoa et al., 2010). Aside from playing an important ecological role, *Sargassum* species in recent years have been sought after for their bioactive compounds, especially for alginate extracts (Zubia et al., 2008) and for biomedical applications (Li et al., 2008).

Generally, seaweeds are easily cultivated as they possess a rapid growth rate. In addition, there is potential to control production of bioactive compounds by manipulating cultivation conditions (Tierney et al., 2010). Despite its natural abundance along Malaysian coasts, seaweed cultivation is solely carried out in Sabah, mainly off the coast of Semporna, Kunak, Kudat and Lahad Datu (Ahemad et al., 2006). In order to promote *Sargassum* mariculture in Port Dickson and its subsequent commercial applications, extended studies on *Sargassum* standing crop have to be done, exploring its feasibility also on other reefs in Port Dickson. This is important to determine if harvest of naturally-growing seaweeds from the wild is sustainable, or if cultivation is needed to obtain sufficient biomass. Knowledge on seasonality of *Sargassum* species has already been established and is well understood in many studies, including this. Specifically, knowledge on the ideal environment to spur *Sargassum* growth and the best period for harvest is important to yield high biomass for optimum profit. Although still lacking behind in knowledge and progress compared to other countries, local studies have already provided sufficient baseline data for farmers to proceed with *Sargassum* mariculture.

Currently, only 11 local companies of producers and suppliers of seaweed products were listed in the official directory of Department of Fisheries Malaysia; mostly focusing on red seaweeds for food and carrageenan production, with none on *Sargassum* species (Department of Fisheries Malaysia, 2011). Hence, public awareness on *Sargassum* utilisation would have to be spread if more investments and business ventures were to be realised. Nonetheless, seaweed production as a whole, is slowly gaining importance in Malaysia, as seen in the records of the Department of Fisheries Malaysia of an increase in 24.8 % on seaweed production from 2008 (111 300 tonnes) to 2009 (138 856 tonnes), contributed by the increase in productivity and culture area from 6 936 hectares in 2008 to 7 538 hectares in 2009. In fact, the Malaysian government, under the 10th Malaysia plan has acknowledged the importance of agriculture which includes seaweed cultivation, and has come up with several strategies to increase gross domestic production from 1 % in 2009 to 2 % by 2015 (The Economic Planning Unit, 2010). All these point to a promising future of seaweed production in Malaysia.

CHAPTER 6.0

CONCLUSIONS

Three *Sargassum* species were studied on two nearby reefs of Teluk Kemang, Port Dickson. Harvest from destructive sampling amounted to a total of 2555 plants, while tagging from non-destructive sampling amounted to 664 plants tagged. From both samplings, *S. polycystum* was most abundant, followed by *S. siliquosum* and *S. binderi.* These consisted mostly of smaller sized plants within length class of 0 - 99 mm (destructive sampling: *S. polycystum*: 71 25 %; *S. binderi*: 67.22 %; *S. siliquosum*: 71.74 %) (non-destructive sampling: *S. polycystum*: 64.20 %; *S. binderi*: 68.29 %; *S. siliquosum*: 56.80 %).

All three species experienced similar seasonal growth patterns with only minor variations. Both sampling methods revealed a bimodal pattern in MTL and biomass variation, having three peaks within 13 months. Similar trend was seen for all species with peaks in from September 2009 to October 2009, from January to March 2010 and from July to August 2010. *Sargassum* also showed biannual reproduction with percentage fertility peaking in September 2009 to October 2009, February 2010 to March 2010 and July 2010 to August 2010. Destructive sampling revealed that *S. binderi* was reproductively active in every sampling occasion. Variation in non-destructive MTL revealed two occasions of high growth rate (*S. polycystum*: January 2010

& June 2010; *S. binderi*: February 2010 & June 2010; *S. siliquosum*: February 2010 & July 2010) and two of high degenerative rate (April 2010 & September 2010).

While *S. binderi* was androgynous, an overall higher female to male ratio was obtained for dioecious *S. polycystum* plants (88 female : 35 male) and *S. siliquosum* plants (29 female : 22 male). Rare instances of higher *S. siliquosum* male to female ratio occurred in May 2010 (1 female : 2 male) and July 2010 (5 female : 11 male). Higher male percentages in those months were necessary for survival as both occasions coincided with peak rainfall of the previous month that risked dilution in number of sperms released into sea.

Spatial variation was evident among the two nearby reefs, despite only being 80m apart. Field observations showed that the many geographical differences between the reefs determined the distribution of the respective *Sargassum* species. *S. binderi* and *S. siliquosum* were more abundant on the LR, while *S. polycystum* was more on the RR. Measurements of parameters on both reefs varied, as results from cross correlations showed that the same parameters had different affects on *Sargassum* species from different reefs.

This study reviews the seasonality of MTL, biomass and fertility of *Sargassum* species on two reefs of Teluk Kemang. These act as a baseline data for possible establishment of seaweed mariculture in Teluk Kemang. Further studies involving seaweed cultivation could be conducted to encourage mariculture in Peninsular Malaysia.

LIST OF REFERENCES

Abbott, I. A. (1996). Ethnobotany of seaweeds: clues to uses of seaweeds. *Hydrobiologia*, 15-20.

Abu Hena, M. K., Misri, K., Japar Sidik, B., Hishamuddin, O., & Hidir, H. (2001). Photosynthetis and respiration responses of Dugong Grass *Thalassia hemprichii* (Ehrenb) Aschers. at Teluk Kemang seagrass bed, Malaysia. *Pakistan Journal of Biological Sciences, 12*,1487-1489

Agrawal, S. C. (2009). Factors affecting spore germination in algae - review. *Folia Microbiology, 54*, 273-302.

Ahemad, S., Ismail, A., & Mohammad R. M. A. (2006). The seaweed industry in Sabah, East Malaysia. *Jati*, *11,* 97-107.

Akira, K., & Masafumi, I. (1999). On growth and maturation of *Sargassum thunbergii* from southern part of Nagasaki Prefecture, Japan. *Japanese Journal of Phycology, 3,* 179-186.

Ang, P. O. Jr. (1986). Analysis of the vegetation structure of a *Sargassum* community in the Philippines. *Marine Ecology, 28,* 9-19.

Ang, P. O. Jr. (2006). Phenology of *Sagassum* spp. in Tung Ping Chau Marine Park, Hong Kong SAR, China. *Journal of Applied Phycology, 18,* 629-636.

Araújo, R., Bárbara, I., Sousa-Pinto, I., & Quintino, V. (2005). Spatial variability of intertidal rocky shore assemblages in the northwest coast of Portugal. *Estuarine, Coastal and Shelf Science, 64*, 658-670.

Ateweberhan, M., Bruggemann, J. H., & Breeman, A. M., (2005). Seasonal dynamics of *Sargassum ilicifolium* (Phaeophyta) on a shallow reef flat in the southern Red Sea (Eritrea). *Marine Ecology Progress Series, 292*, 159-171.

Ateweberhan, M., Bruggemann, J. H., & Breeman, A. M., (2006). Effects of extreme seasonality on community structure and functional group dynamics of coral reef algae in the southern Red Sea (Eritrea). *Coral Reefs*, *25,* 391-406.

Ateweberhan, M., Bruggemann, J. H., & Breeman, A. M., (2008). Seasonal module dynamics in *Sargassum subrepandum* (Fucales, Phaeophyta). *Journal of Phycology, 44,* 269-283.

Baer, J., & Stengel, D. B. (2010). Variability in growth, development and reproduction of the non-native seaweed *Sargassum muticum* (Phaeophyceae) on the Irish west coast. *Estuarine, Coastal and Shelf Science, 90*, 185-194.

Brawley, S. H., & Johnson, L. E. (1992). Gametogenesis, gametes and zygotes: an ecological perspective on sexual reproduction in the algae. *British Phycological Journal*, *27*, 233-252.

Brown, M. T. (1995). Interactions between environmental variables on growth rate and carrageenan content of *Solieria chordalis* (Solieriaceae, Rhodophyceae) in culture. *Journal of Applied Phycology, 7,* 427-432.

Choi, T. S., & Kim, K. Y. (2004). Spatial pattern of intertidal macroalgal assemblages associated with tidal levels. *Hydrobiologia, 512*, 49-56.

Chung, I. C., Hwang, R. L., Lin, S. H., Wu, T. M., Wu, J. Y., Su, S. W., ... Lee, T. M. (2007). Nutrients, temperature, and salinity as primary factors influencing the temporal dynamics of macroalgal abundance and assemblage structure on a reef of Du-Lang Bay I Taitung in southeastern Taiwan. *Botanical Studies, 48,* 419-433.

Curiel, D., Bellemo, G., Marzocchi, M., Scattolin, M., & Parisi, G. (1998). Distribution of introduced Japanese macroalgae *Undaria pinnatifida, Sargassum muticum* (Phaeophyta) and *Antithamnion Pectinatum* (Rhodophyta) in the Lagoon of Venice. *Hydrobiologia, 385,* 17-22.

Dar, A., Baig, H. S., Saifullah, S. M., Ahmad, V. U., Yasmeen, S., & Nizamuddin, M. (2007). Effect of seasonal variation on the anti-inflammatory activity of *Sargassum wightii* growing on the N. Arabian Sea coast of Pakistan. *Journal of Experimental Marine Biology and Ecology, 351*, 1-9.

Dawes, C. J. (1987). Physiological ecology of two species of *Sargassum* (Fucales, Phaeophyta) on the west coast of Florida, *Bulletin of Marine Science, 40*, 198-209.

Dawes, C. J. (1998). *Marine Botany* (2nd ed.). New York: John Wiley & Sons.

De Wreede, R. E. (1976). The phenology of three species of *Sargassum* (Sargassaceae, Phaeophyta) in Hawaii. *Phycologia, 15,* 175-183.

De Wreede, R. E. and Klinger, T. (1988). Reproductive strategies in algae. In D. J. Lovett & D. L. Lovett (Eds.), *Plant Reproductive Ecology: Patterns and Strategies.* (pp. 267-284). New York: Oxford University Press.

Department of Fisheries Malaysia (2011). *Scenario of Malaysia fisheries industry*. Retrieved from http://www.dof.gov.my

Engelen, A. H., Breeman, A. M., Olsen, J. L., Stam, W. T., & Aberg, P. (2005). Life history flexibility allows *Sargassum polyceratium* to persist in different environments subjected to stochastic disturbance events. *Coral Reefs, 24*, 670-680.

Fernández de Lara, V. C., Bonilla, H. R., & Zaragoza, E. S. (2010). A tropical assemblage of benthic macroalgae on rocky reefs in a temperate zone on the western Baja California peninsula, Mexico. *Botanica Marina*, *53*, 195-203.

Fenoradosoa, T. A., Ali, G., Delattre, C., Laroche, C., Petit, E., Wadouachi, A., & Michaud, P. (2010). Extraction and characterization of an alginate from the brown seaweed *Sargssum turbinarioides* Grunow. *Journal of Applied Phycology*, 131-137.

Gillespie, R. D., & Critchley, A. T. (1999). Phenology of *Sargassum* sp. (Sargassaceae, Phaeophyta) from Reunion Rocks, KwaZulu-Natal, South Africa. *Hydrobiologia*, *398*, 201-210.

Glenn, E. P., Smith, C. M., & Doty, M. S. (1990). Influence of antecedent water temperatures on standing crop of a *Sargassum* spp. dominated reef flat in Hawaii. *Marine Biology*, *105,* 323-328.

Graham, L. E., & Wilcox, L. W. (2000). Ochrophytes IV - Chrysomeridaleans, Phaeothamniophycians, Tribophyceans, and Phaeophyceans. In *Algae* (pp. 301-342). Upper Saddle River, New Jersey: Prentice-Hall, Inc..

Guillermo, D. P., & McCook, L. J. (2004). Effects of live coral, epilithic algal communities and substrate type on algal recruitment. *Coral Reefs*, *23*, 225-233.

Guiry, M. D., & Guiry, G. M. (2011). *AlgaeBase*. Retrieved January 28, 2011, from http://www.algaebase.org

Hach Company (2007). *DR 28000 Spectrophotometer Procedures Manual*. Retrieved September 3, 2009 from http://www.hach.com

Hameed, S., & Ahmed, M. (1999). Seasonal variation in seaweed biomass from the rocky shore of Pacha, near Karachi, Pakistan (Arabian Sea). *Pakistan Journal of Biological Sciences, 2*, 1044-1052.

Hall, J. (2008). *The most important organism?* Retrieved June 10, 2010 from http://ecology.com/features/mostimportantorganism/index.html

Hewitt, C. L., Campbell, M. L., Thresher, R. E., Martin, R. B., Boyd, S., Cohen, B. F., … Wilson, R. S. (2004). Introduced and cryptogenic species in Port Phillip Bay, Victoria, Australia. *Marine Biology*, *144*, 183–202.

Hodge, F. J., Buchanan, J., & Zuccarello, G. C. (2010). Hybridization between the endemic brown algae *Carpophyllum maschalocarpum* and *Carpophyllum angustifolium* (Fucales): Genetic and morphological evidence. *Phycological Research*, *58*, 239-247.

Hurd, C. L., & Dring, M. J. (1990). Phosphate uptake by intertidal algae in relation to zonation and season. *Marine Biology*, *107,* 281-289.

Hurtado, A. Q., & Ragaza, A. R. (1999). *Sargassum* studies on Currimao, Ilocis Norte, Northern Philippines. I. Seasonal variations in the biomass of *Sargassum carpophyllun* Agardh J., *Sargassum ilicifolium* (Turner) Agardh C., and *Sargassum siliquosum* Agardh J. (Phaeophyta, Saegassaceae). *Botanica Marina*, *42*, 321-325.

Hwang, R. L., Tsai, C. C., & Lee. T. M. (2004). Assessment of temperature and nutrient limitation on seasonal dynamics among species of *Sargassum* from a coral reef in southern Taiwan. *Journal of Phycology*, *40*, 463-473.

Hwang, E. K., Park, C. S., & Baek, J. M. (2006). Artificial seed production and cultivation of the edible brown alga, *Sargassum fulvellum* (Turner) C. Agardh: Developing a new species for seaweed cultivation in Korea. *Journal of Applied Phycology*, *18*, 251-257.

Ismail, A., & Go, R. (1994). Distribution and diversity of seaweeds in Pulau Tioman. *Alga Biotechnology in the Asia-Pacific Region.*

Iwao, T., Yamaguchi, T., Kurashima, A., & Maegawa, M. (2010). Effect of laminaran accumulation on maturation in sporophyte fragments from *Ecklonia cava* (Phaeophyceae, Laminariales) under various laboratory light and temperature conditions. *Phycological Research*, *58*, 132-137.

Kaur, C. R., & Ang, M. G. H (2009). Report for seminar on developing the seaweed aquaculture sector in Malaysia. *MIMA Bulletin, 16*, 32-36.

Khorramabadi, G. S., & Soltani, R. D. C. (2008). Evaluation of the marine algae *Gracilaria salicornia* and *Sargassum* sp. for the biosorption of Cr (VI) from aqueous solutions. *Journal of Applied Sciences, 8,* 2163-2167.

Kitadai, Y., & Kadowaki, S. (2007). Growth, nitrogen and phosphorus uptake rates and O_2 production rate of seaweeds cultured on coastal fish farms. *Bulletin of Fisheries Research Agency*, *19*, 149-154.

Koehl, M. A. R., Silk, W. K., Liang, H., & Mahadevan, L. (2008). How kelp produce blade shapes suited to different flow regimes: a new wrinkle. *Integrative and Comparative Biology*, *48*, 834-851.

Komatsu, T., Tatsukawa, K., Filippi, J. B., Sagawa, T., Matsunaga, D., Mikami, A., … Sugimoto, T. (2007). Distribution of drifting seaweeds in eastern East China Sea. *Journal of Marine Systems*, *67*, 245-252.

Kong, C. S. L., & Ang, P. O. Jr. (2004). Seasonal occurrence and reproduction of *Hypnea charoides* (Rhodophyta) in Tung Ping Chau, N. T., Hong Kong SAR, China. In P. O. Ang Jr. (Ed.), *Asian Pacific phycology in the 21st century: prospects and challenges* (pp. 63-78). Netherlands: Kluwer Academic Publishers.

Kraan, S. (2008). *Sargassum muticum* (Yendo) Fensholt in Ireland: an invasive species on the move. *Journal of Applied Phycology*, *20*, 825-832.

Kraufvelin, P., Lindholm, A., Pedersen, M. F., Kirkerud, L. A., & Bonsdorff, E. (2009). Biomass, diversity nd production of rocky shore macroalgae at two nutrient enrichment and wave action levels. *Marine Biology*, *157*, 29-47.

Krishnaiah, D., Sarbatly, R., Prasad, D. M. R., & Bono, A. (2008). Mineral content of some seaweeds from Sabah’s South China Sea. *Asian Journal of Scientific Research, 1*, 166-170.

Lapointe, B. E., Littler, M. M., & Littler, D. S. (1992). Modification of benthic community structure by natural eutrophication: the Belize barrier reef. In R. H. Richmond (Ed.), *Proceedings of the Seventh International Coral Reef Symposium* - 1 (pp. 323-334). Mangilao, Guam: University of Guam Press.

Lapointe, L., & Bourget, E. (1999). Influence of substratum heterogeneity scales and complexity on a temperate epibenthic marine community. *Marine Ecology Progress Series, 189*, 159-170.

Largo, D. B., & Ohno, M. (1992). Phenology of two species of brown seaweeds, *Sargassum myriocystum* J. Agardh and *Sargassum siliquosum* J. Agardh (Sargassaceae, Fucales) in Liloan, Cebu, in Central Philippines. *Bulletin of Marine Science and Fisheries*, *1*, 17-27.

Leite, F. P. P., & Turra, A. (2003). Temporal variation in *Sargassum* biomass, *Hypnea* epiphytism and associated fauna. *Brazilian Archives of Biology and Technology*, *46*, 665-671.

Lepš, J. and Šmilauer, P. (2003). Multivariate analysis of ecological data using CANOCO™. New York: Cambridge University Press.

Li, B., Lu, F., Wei, X., & Zhao, R. (2008). Fucoidan: Structure and bioactivity. *Molecules*, *13*, 1671-1695.

Littler, M. M., & Littler, D. S. (1984). Models of tropical reef biogenesis: the contribution of algae. *Progress in Phycological Research, 3*, 323-364

Littler, M. M., Littler, D. S., & Titlyanov, E. A. (1991). Comparisons of N- and P-limited productivity between high granitic islands versus low carbonate atolls in the Seychelles Archipelago: a test of the relative-dominance paradigm. *Coral Reefs, 10*, 199-209.

Lobban, C. S., & Harrison, P. J. (1994). Morphology, life histories and morphogenesis. In *Seaweed Ecology and Physiology* (pp. 1-67). Cambridge: Cambridge University Press.

Lüning, K. (1990). Seaweeds: Their Environment, Biogeography, and Ecophysiology. In C. Yarish & H. Kirkman (Eds.). New York: Wiley-Interscience.

Lüning, K. (1993). Environmental and internal control of seasonal growth in seaweeds. *Hydrobiologia*, *260*, 1-14.

Malaysian Meteorological Department (2011). *El Niño / La Niña*. Retrieved May 29, 2011 from http://www.met.gov.my

Mattio, L., Dirberg, G., Payri, C. E., & Andrefouet, S. (2008). Diversity, biomass and distribution pattern of *Sargassum* beds in the South West lagoon of New Caledonia (South Pacific). *Journal of Applied Phycology, 20*, 811-823.

Mattio, L., & Payri, C. E. (2010). 190 Years of *Sargassum* Taxonomy, Facing the Advent of DNA Phylogenies. *Botanical Review*, *77*, 31-70.

Mayakun, J., & Prathep, A. (2005). Seasonal variations in diversity and abundance of macroalgae at Samui Island, Surat Thani Province, Thailand. *Songklanakarin Journal of Science and Technology, 27*, 653-663.

McCourt R. M. (1984). Seasonal patterns of abundance, distribution and phenology in relation to growth strategies of three *Sargassum* species. *Journal of Experimental Marine Biology and Ecology, 74*, 141-156.

McHugh, D. J. (2003). A guide to the seaweed industry. In *FAO Fisheries Technical Paper* (pp. 43-98). Rome: FAO.

Miller, M. W., & Hay, M. E. (1996). Coral-Seaweed-Grazer-Nutrient Interactions on Temperate Reefs. *Ecological Monographs*, *66*, 323-344.

Molles, M. C. Jr. (1999). *Ecology: Concepts and Application* (International ed.). USA: McGraw-Hill.

Msuya, F. E., & Salum, D. (2006). The effect of cultivation, duration, seasonality and nutrient concentration of the growth rate and biomass yield of the seaweeds *Kappapycus alvarezi* and *Euchema denticulutum* in Zanzibar, Tanzania. *WIOMSA/MARG-1/2006-7*

Murray, S. N., Ambrose, R. F., & Dethier, M. N. (2002). Methods for performing monitoring, impact and ecological studies on rocky shores. OCS Study MMS 01-070, U.S. Minerals Management Service, Pacific OCS Region.

Nishihara, G. N., & Terada, R. (2010a). Spatial variations in nutrient supply to the red algae *Euchema serra* (J. Agardh) J. Agardh. *Phycological Research*, *58*, 29-34.

Nishihara, G. N., & Terada, R. (2010b). Species richness of marine macrophytes is correlated to a wave exposure gradient. *Phycological Research*, *58*, 280-292.

Noiraksa, T., Ajisaka, T., & Kaewsuralikhit, C. (2006). Species of *Sargassum* in the East Coast of the Gulf of Thaliland. *ScienceAsia*, *32*, 99-106.

Nybakken, J. W. and Bertness, M. D. (2004). *Marine biology: an ecological approach* (6th ed.). San Francisco: Pearson Education Inc.

Pang, S. J., Liu, F., Shan, T. F., Gao, S. Q., & Zhang, Z. H. (2009). Cultivation of the brown alga *Sargassum horneri*: sexual reproduction and seedling production in tank culture under reduced solar irradiance in ambient temperature. *Journal of Applied Phycology*, *21*, 413-422.

Pedersen, M. F., Stæhr, P. A., Wernberg, T., & Thomsen, M. S. (2005). Biomass dynamics of exotic *Sargassum muticum* and native *Halidrys siliquosa* in Limfjorden, Denmark- Implications of species replacement on turnover rates. *Aquatic Botany*, *83*, 31-47.

Peters, A. F., Wijik, S. J., Cho, G. Y., Scornet, D., Hanyuda, T., Kawai, H., … Boo, S. M. (2010). Reinstatement of *Ectocarpus crouaniorum* Thuret in Le Jolis as a third common species of *Ectocarpus* (Ectocarpales, Phaeophyceae) in Western Europe, and its phenology at Roscoff, Brittany. *Phycological Research*, *58*, 157-170.

Phang, S. M. (1988). The effect of siltation on algal biomass production at a fringing coral reef flat, Port Dickson, Peninsular Malaysia. *Wallaceana*, *51*, 3-5.

Phang, S. M. (1995). Distribution and abundance of marine algae on the coral reef flats at Cape Rachado, Port Dickson, Peninsular Malaysia. *Malaysian Journal of Science*, *16A*, 23-32.

Phang, S. M. (2006). Seaweed resources in Malaysia: Current status and future prospects. *Aquatic Ecosystem Health and Management*, *9*, 185-202.

Raikar, S. V., Iima, M., & Fujita, Y. (2001). Effect of temperature, salinity and light intensity on the growth of *Gracilaria* spp. (Gracilariales, Rhodophyta) from Japan, Malaysia and India. *Indian Journal of Marine Sciences*, *30*, 98-104.

Schaffelke, B., Smith, J. E., & Hewitt, C. L. (2006). Introduced macroalgae – A growing concern. *Journal of Applied Phycology*, *18*, 529-541.

Shimabukuro, H., Terada, R., Sotobayashi, J., Nishihara, G. N., & Noro, T. (2007). Phenology of *Sargassum duplicatum* (Fucales, Phaeophyceae) from the southern coast of Satsuma Peninsula, Kagoshima, Japan. *Nippon Suisan Gakkaishi*, *73*, 454-460.

Shirkey, B., McMaster, N. J., Smith, S. C., Wright, D. J., Rodriguez, H., Jaruga, P., ... Potts, M. (2003). Genomic DNA of *Nostoc commune* (*Cyanobacteria*) becomes covalently modified during long term (decades) dessication but is protected from oxidative damage and degradation. *Nucleic Acids Research*, *31*, 2995-3005.

Singh, V., Pande, P. C., & Jain, D. K. (2010). *A text book of Botany* (4^{th} ed.). New Delhi, India: Rastogi Publications.

Smit, A. J. (2004). Medicinal and pharmaceutical uses of seaweed natural products: A review. *Journal of Applied Phycology*, *16*, 245-262.

Steen, H. (2004). Effects of reduced salinity on reproduction and germling development in *Sargassum muticum* (Phaeophyceae, Fucales). *European Journal of Phycology*, *39*, 293-299.

Sumich, J. L. and Morrissey, J. F (2004). *Introduction to the Biology of Marine Life* (8^{th} ed.). Sadbury: Jones and Bartlett Publishers.

Suplee, C. (1999). El Niño/La Niña: Nature’s Vicious Cycle. *National Geographic*, 72-95.

The Economic Planning Unit (2010). *Tenth Malaysia Plan 2011-2015*. (pp. 134). Putrajaya: Prime Minister’s Departmet.

Thomsen, M. S., Wernberg, T., Stæhr, P. A., & Pedersen, M. F (2006). Spatio-temporal distribution patterns of the invasive macroalga *Sargassum muticum* within a Danish *Sargassum*-bed. *Helgoland Marine Research*, *60*, 50-58.

Tide Tables Malaysia (2009). Hydrographic Directorate and Royal Malaysian Navy. *1*, 70-71.

Tide Tables Malaysia (2010). Hydrographic Directorate and Royal Malaysian Navy. *1*, 105-107.

Tierney, M. S., Craft, A. K., & Hayes, M. (2010). A review of antihypertensive and antioxidant activities in macroalgae. *Botnica Marina*, *53*, 387-408.

Trobajo, R., Mann, D. G., Clavero, E. Evans, K. M., Vanormelingen, P., & McGregor, R. C. (2011). The use of partial *cox*1, *rbc*L and LSU rDNA sequence for phylogenetics and species identification within the *Nitzschia palea* species complex (Bacillariophyceae). *European Journal of Phycology*, *45*, 413-425.

Trono, G. C. Jr. (1997). *Field guide and atlas of the seaweed resources of the Philippines*. Philippines: Bookmark, Inc.

Trono, G. C. Jr. (1999). Diversity of the seaweed flora of the Philippines and its utilization. *Hydrobiologia*, *398*, 1-6.

Umezaki, I. (1974). Ecological studies of *Sargassum thunbergii* (Mertens) O. Kuntze in Maizuru Bay, Japan Sea. *Botanic Magazine*, *87*, 285-292.

Umezaki, I. (1984). Ecological studies of *Sargassum horneri* (Turner) C. Agardh in Obama Bay, Japan Sea. *Bulletin of the Japanese Society of Scientific Fisheries*, *50*, 1193-1200.

Vadas, R. L., Johnson, S., & Norton, T. A. (1992). Recruitment and mortality of early post-settlement stages of benthic algae. *British Phycological Journal*, *27*, 331-351.

Vairappan, C. S., Anangdan, S. A., Tan, K. L., & Matsunaga, S. (2010). Role of secondary metabolites as defense chemicals against ice-ice disease bacteria in biofouler at carrageenophyte farms. *Journal of Applied Phycology*, 305-311.

Valdez, M. C., & Ramírez, R. N. A. (2008). Spatial variation of biomass of seaweed assemblages in the temperate-tropical transition zone of Baja California Peninsula, Mexico. *Hydrobiológica*, *18*, 137-146.

Villaça, R., Fonseca, A. C., Jensen, V. K., & Knoppers, B. (2010). Species composition and distribution of macroalgae on Atol das Rocas, Brazil, SW Atlantic. *Botanica Marina*, *53*, 113-122.

Wernberg, T., Thomson, M. S., Stæhr, P. A., & Pedersen, M. F. (2001). Comparative Phenology of *Sargassum muticum* and *Halidrys siliquosa* (Phaeophyceae: Fucales) in Limfjorden, Denmak. *Botanica Marina*, *44*, 31-39.

Wichachucherd, B., Liddle, L. B., & Prathep, A. (2009). Population structure, recruitment, and succession of the brown alga, *Padina boryana* Thivy (Dictyotales, Heterokontophyta), at an exposed shore of Sirinart National Park and a sheltered area of Tang Khen Bay, Phuket Province, Thailand. *Aquatic Botany*, *92*, 93 – 98.

Wong, C. L. (1997). *Phenological studies of two species of Sargassum (Sargassaceae, Phaeophyta) on the coral reef flats at Cape Rachado, Peninsular Malaysia*. Unpublished master's thesis. University of Malaya, Malaysia

Wong, C. L., & Phang, S. M. (2004). Biomass production of two *Sargassum* species at Cape Rachado, Malaysia. *Hydrobiologia*, *512*, 79-88.

Wong, C. L., Ng, S. M., & Phang, S. M. (2007). Use of RAPD in differentiation of selected species of *Sargassum* (Sargassaceae, Phaeophyta). *Journal of Applied Phycology*, *19*, 771 - 781.

Yoshida, G., Yoshikawa, K., & Terawaki, T. (2003). Biannual maturation observed in forced seedlings of *Sargassum horneri* (Phaeophyta, Fucales). *Japanese Journal of Phycology, 51*, 173-175.

Yotsukara, N., Nagai, K., Kimura, H., & Morimoto, K. (2010). Seasonal changes in proteomic profiles of Japanese kelp: *Saccharina japonica* (Laminariales, Phaeophyceae). *Journal of Applied Phycology*, *22*, 443-451.

Zhang, Q. S., Li, W., & Pan, J. H. (2009). Size-dependence of reproductive allocation of *Sargassum thunbergii* (Sargassaceae, Phaeophyta) in Bohai Bay, China. *Aquatic Botany, 91*, 194-198.

Zubia, M., Payri, C., & Deslandes, E. (2008). Alginate, mannitol, phenolic compounds and biological activities of two range-extending brown algae, *Sargassum mangarevense* and *Turbinaria ornata* (Phaeophyta: Fucales), from Tahiti (French Polynesia). *Journal of Applied Phycology*, *20*, 1033-1043

Appendix A

Procedures for Water Analysis

A. Nitrate (DR 2800, USA) (Hach Company, 2007)

Nitrate

Method 8171 | **Cadmium Reduction Method**

Powder Pillows or AccuVac® Ampuls | **MR (0.1 to 10.0 mg/L NO_3^-–N)**

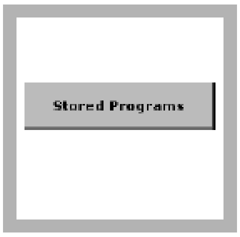
Scope and Application: For water, wastewater, and seawater

Test Preparation

Collect the following items:	Quantity
Powder Pillow Test:	
NitraVer® 5 Nitrate Reagent Powder Pillow	1
Sample Cells, 1-inch square, 10-mL	2
Stopper, Neoprene #2, solid	2
AccuVac Test:	
Collect at least 40 mL of sample in a 50-mL beaker	40 mL
NitraVer® 5 Nitrate Reagent AccuVac® Ampul	1
Beaker, 50-mL (AccuVac test)	1
Sample Cell, 10-mL	1

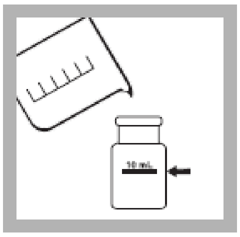
Note: Reorder information for consumables and replacement items is on page 6.

Powder Pillows — Method 8171

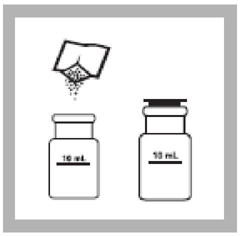


1. Press **STORED PROGRAMS**.

2. Select the test.



3. Fill a square sample cell with 10 mL of sample.



4. **Prepared Sample:** Add the contents of one NitraVer 5 Nitrate Reagent Powder Pillow. Insert a stopper into the cell.

5. Press **TIMER>OK**.

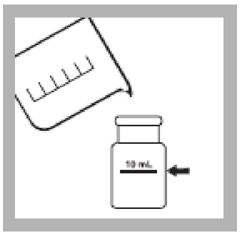
A one-minute reaction period will begin.

Shake the cell vigorously until the timer expires.

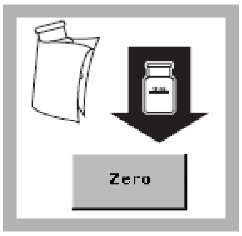
6. When the timer expires, press **TIMER>OK**.

A five-minute reaction period will begin.

An amber color will develop if nitrate is present.



7. **Blank Preparation:** When the timer expires, fill a second square sample cell with 10 mL of sample.



8. Insert the blank into the cell holder with the fill line facing right. Press **ZERO**.

The display will show:

0.0 mg/L NO_3^-–N

B. Ammonia (DR 2800, USA) (Hach Company, 2007)

Nitrogen, Ammonia

Method 8155 | **Salicylate Method[1]**

Powder Pillows | **(0.01 to 0.50 mg/L NH_3–N)**

Scope and Application: For water, wastewater, and seawater

[1] Adapted from *Clin. Chim. Acta.*, *14*, 403 (1966)

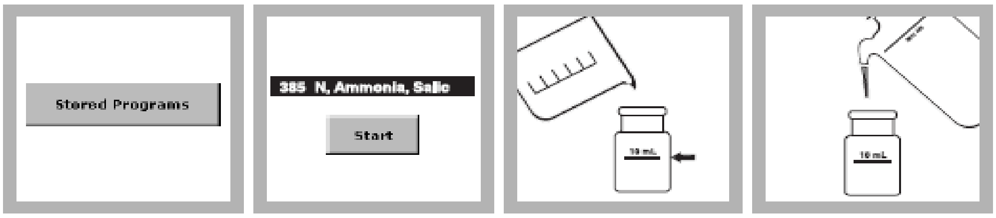
Test Preparation

Collect the following items:	Quantity
Ammonia Cyanurate Reagent pillows	2
Ammonia Salicylate Reagent pillows	2
Sample Cells, 1-inch square, 10-mL	2

Note: Reorder information for consumables and replacement items is on page 5.

Note: A green color will develop if ammonia nitrogen is present.

Powder Pillows — Method 8155

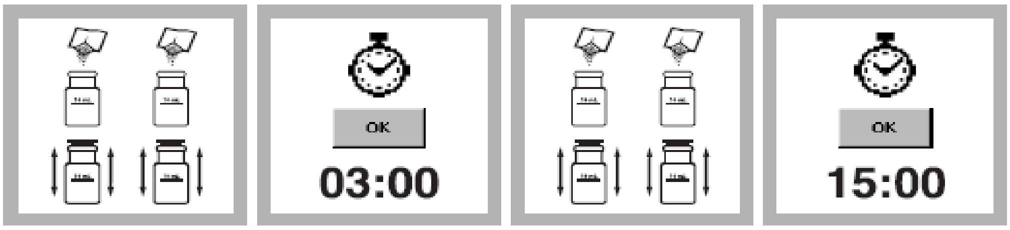


1. Press **STORED PROGRAMS**.

1. Select the test.

2. **Prepared Sample:** Fill a square sample cell to the 10-mL mark with sample.

3. **Blank Preparation:** Fill a second square sample cell to the 10-mL mark with deionized water.



4. Add the contents of one Ammonia Salicylate Powder Pillow to each cell.

   Stopper and shake to dissolve.

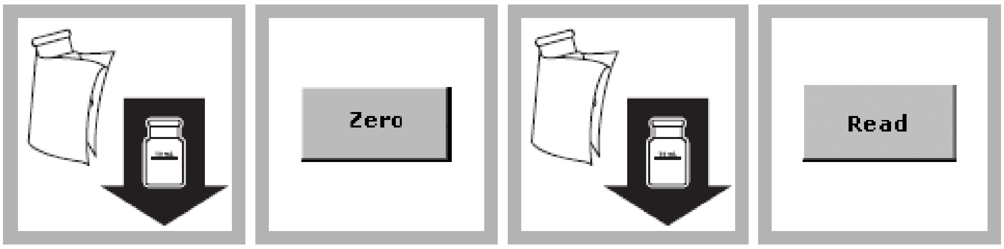
5. Press **TIMER>OK**. A three-minute reaction period will begin.

6. When the timer expires, add the contents of one Ammonia Cyanurate Reagent Powder Pillow to each cell.

   Stopper and shake to dissolve.

7. Press **TIMER>OK**. A 15-minute reaction period will begin.

   A green color will develop if ammonia-nitrogen is present.



8. When the timer expires, insert the blank into the cell holder with the fill line facing right.

9. Press **ZERO**. The display will show: 0.00 mg/L NH_3–N

10. Wipe the sample and insert it into the cell holder with the fill line facing right.

11. Press **READ**.

    Results are in mg/L NH_3–N.

C. Phosphate (DR 2800, USA) (Hach Company, 2007)

Phosphorus, Reactive (Orthophosphate)

★Method 8048 — **PhosVer 3 (Ascorbic Acid) Method**[1]

Powder Pillows or AccuVac® Ampuls — **(0.02 to 2.50 mg/L PO_4^{3-})**

Scope and Application: For water, wastewater, and seawater; USEPA Accepted for reporting for wastewater analyses[2]

[1] Adapted from *Standard Methods for the Examination of Water and Wastewater*

[2] Procedure is equivalent to USEPA method 365.2 and Standard Method 4500-P-E for wastewater.

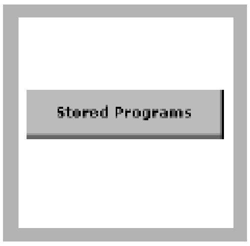
Test Preparation

Collect the following items:	Quantity
Powder Pillow Test:	
PhosVer® 3 Phosphate Reagent powder pillow	1
Sample Cells, 1-in. square, 10-mL	2
Stopper for 18 mm Tube	1
AccuVac Test:	
Collect at least 40 mL of sample in a 50-mL beaker	40 mL
PhosVer® 3 Phosphate Reagent AccuVac® Ampul	1
Beaker, 50-mL	1
Sample Cell, 10-mL round	1
Stopper for 18-mm Tube (supplied with PhosVer AccuVacs)	1

Note: Reorder information for consumables and replacement items is on page 6.

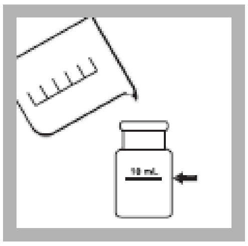
Note: A blue color will develop if phosphorus is present.

Powder Pillows — Method 8048

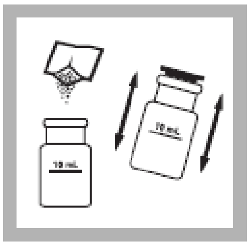


1. Press **STORED PROGRAMS**.

2. Select the test.



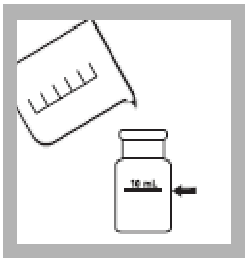
3. Fill a square sample cell with 10-mL of sample.



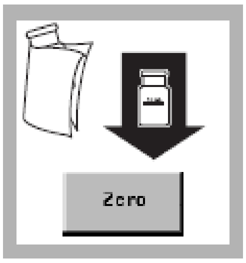
4. **Prepared Sample:** Add the contents of one PhosVer 3 phosphate Powder Pillow to the cell. Immediately stopper and shake vigorously for 30 seconds.

5. Press **TIMER>OK**.

A two-minute reaction period will begin. If the sample was digested using the Acid Persulfate digestion, a ten-minute reaction period is required.

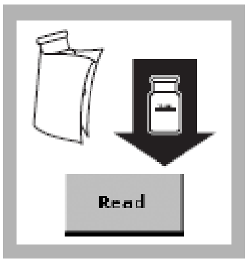


6. **Blank Preparation:** Fill a second square sample cell with 10 mL of sample.



7. When the timer expires, wipe the blank and insert it into the cell holder with the fill line facing right.

Press **ZERO**. The display will show:



8. Wipe the prepared sample and insert it into the cell holder with the fill line facing right.

Press **READ**. Results are in mg/L PO_4^{3-}.

Appendix B

Environmental Parameters: One-way ANOVA

Parameter	ANOVA		Post Hoc Test (Tukey HSD)	
	F	*p*	Between Months	*p*
Water Temperature	4.699	0.012*	-	-
Salinity	7.947	0.000*	Sept 09 & Sept 10	0.033*
			Oct 09 & Nov 09	0.018*
			Oct 09 & Dec 09	0.001*
			Oct 09 & Jan 10	0.000*
			Oct 09 & Feb 10	0.009*
			Oct 09 & Mar 10	0.000*
			Oct 09 & Apr 10	0.003*
			Oct 09 & May 10	0.001*
			Oct 09 & June 10	0.003*
			Oct 09 & July 10	0.001*
			Oct 09 & Aug 10	0.000*
			Oct 09 & Sept 10	0.000*
pH	6.040	0.001*	Sept 09 & Mar 10	0.013*
			Sept 09 & Apr 10	0.049*
			Sept 09 & June 10	0.007*
			Sept 09 & Aug 10	0.030*
			Sept 09 & Sept 10	0.001*
			Dec 09 & Sept 10	0.021*
			Jan 10 & Sept 10	0.021*
			Feb 10 & Sept 10	0.017*
			July 10 & Sept 10	0.025*
Nitrate	3.461	0.017*	-	-
Ammonia	2.114	0.098	-	-
Phosphate	8.846	0.000*	Sept 09 & Oct 09	0.002*
			Sept 09 & Jan 10	0.010*
			Oct 09 & Nov 09	0.010*
			Oct 09 & Dec 09	0.010*
			Oct 09 & Feb 10	0.001*
			Oct 09 & Mar 10	0.003*
			Oct 09 & Apr 10	0.001*
			Oct 09 & May 10	0.000*
			Oct 09 & June 10	0.005*
			Oct 09 & July 10	0.001*
			Oct 09 & Aug 10	0.005*
			Oct 09 & Sept 10	0.002*
			Jan 10 & Feb 10	0.003*
			Jan 10 & Mar 10	0.021*
			Jan 10 & Apr 10	0.007*
			Jan 10 & May 10	0.002*
			Jan 10 & June 10	0.030*
			Jan 10 & July 10	0.007*
			Jan 10 & Aug 10	0.030*
			Jan 10 & Sept 10	0.014*

* Significantly different ($p < 0.05$)

Appendix C

Destructive Sampling: Number of Plants, Mean Thallus Length, Biomass and Percentage Fertility by Month

A. <u>September 2009</u>

S. polycystum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	11	200.82 ± 87.23	297.40	36.86	31.01	63.64
2	5	162.40 ± 79.02	80.16	9.66	8.02	40.00
3	2	205.50 ± 225.57	43.24	6.11	4.95	50.00
4	11	191.64 ± 225.57	268.08	38.15	32.73	45.45
5	-	-		-	-	-
6	2	137.50 ± 142.13	28.60	4.58	3.56	50.00
7	1	65.00 ± 0.00	3.84	0.58	0.46	-
8	-	-		-	-	-
9	2	128.50 ± 160.51	86.16	9.26	7.82	100.00
10	2	81.50 ± 33.23	5.92	1.70	1.56	-
11	-	-		-	-	-
12	11	125.18 ± 68.72	96.32	17.63	15.36	45.45

S. binderi

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	4	140.75 ± 94.31	30.24	5.32	4.59	50.00
2	10	296.40 ± 109.93	431.80	68.14	56.78	70.00
3	4	191.75 ± 82.10	50.32	8.95	8.07	50.00
4	17	272.53 ± 137.89	312.28	38.73	35.30	76.47
5	11	273.64 ± 87.06	393.32	55.79	46.47	90.91
6	-	-	-	-	-	-
7	7	157.00 ± 72.36	47.28	8.01	6.58	57.14
8	9	165.44 ± 63.16	119.60	20.80	11.59	44.44
9	2	26.50 ± 2.12	3.52	0.49	0.42	-
10	11	279.09 ± 238.16	300.80	11.68	9.95	54.55
11	36	174.14 ± 138.00	699.80	76.61	60.79	25.00
12	23	185.48 ± 134.72	575.24	68.78	57.18	60.87

S. siliquosum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	18	92.67 ± 80.48	200.80	27.14	23.13	16.67
2	8	198.00 ± 120.96	207.60	31.00	26.00	50.00
3	13	227.69 ± 120.91	468.08	68.75	57.56	61.54
4	4	219.25 ± 113.66	89.32	13.93	6.23	50.00
5	30	157.43 ± 105.04	695.48	102.29	85.35	40.00
6	26	99.58 ± 69.14	258.80	43.36	41.34	23.08
7	20	188.10 ± 99.94	658.92	84.96	69.45	60.00
8	7	146.14 ± 93.87	136.04	24.47	20.65	14.29
9	-	-	-	-	-	-
10	-	-	-	-	-	-
11	-	-	-	-	-	-
12	-	-	-	-	-	-

B. November 2009

S. polycystum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	4	43.00 ± 24.67	10.68	1.19	0.99	-
2	46	53.07 ± 39.96	190.64	30.63	26.16	-
3	-	-	-	-	-	-
4	-	-	-	-	-	-
5	7	38.00 ± 16.73	11.16	2.054	1.75	-
6	-	-	-	-	-	-
7	28	69.46 ± 48.49	182.60	25.11	21.64	-
8	7	94.71 ± 51.42	45.36	9.47	8.12	14.29
9	54	44.74 ± 33.54	124.48	20.30	17.51	-
10	34	35.76 ± 23.94	42.48	9.77	6.76	-
11	48	31.65 ± 16.67	75.64	13.34	11.54	-
12	51	44.06 ± 25.26	144.84	20.94	19.00	-

S. binderi

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	-	-	-	-	-	-
2	2	130.00 ± 50.91	29.60	3.57	2.93	-
3	2	22.50 ± 3.54	1.64	0.25	0.21	-
4	5	51.20 ± 26.52	24.12	2.16	1.72	-
5	14	43.36 ± 37.42	43.16	6.06	4.96	-
6	2	115.00 ± 89.10	18.68	2.22	1.86	-
7	-	-	-	-	-	-
8	1	96.00 ± 0.00	2.28	0.43	0.36	-
9	14	72.71 ± 50.51	80.36	11.27	9.65	7.14
10	6	38.00 ± 16.95	6.04	1.33	1.15	-
11	8	39.38 ± 6.12	15.60	2.31	1.99	-
12	1	96.00 ± 0.00	17.24	2.78	2.43	-

S. siliquosum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	27	34.26 ± 26.93	104.64	12.95	11.60	-
2	27	125.00 ± 40.22	207.84	31.01	26.34	-
3	12	82.00 ± 48.82	138.68	21.17	18.27	-
4	32	34.72 ± 25.07	197.00	21.28	17.76	-
5	30	36.57 ± 24.80	109.20	19.09	15.90	-
6	18	59.67 ± 50.73	219.96	24.17	20.62	-
7	6	32.00 ± 44.82	21.24	2.95	2.55	-
8	-	-	-	-	-	-
9	-	-	-	-	-	-
10	-	-	-	-	-	-
11	-	-	-	-	-	-
12	-	-	-	-	-	-

C. <u>January 2010</u>

S. polycystum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	10	112.90 ± 67.41	101.08	13.52	10.00	-
2	29	62.90 ± 56.44	130.80	19.34	16.79	-
3	11	145.36 ± 122.18	231.64	40.03	32.97	18.18
4	12	64.83 ± 59.78	79.36	10.64	9.27	-
5	5	87.00 ± 121.79	61.12	7.67	6.64	-
6	1	318.00 ± 0.00	18.64	2.76	2.41	-
7	18	114.39 ± 74.59	137.76	21.62	18.72	-
8	-	-	-	-	-	-
9	12	98.00 ± 65.01	94.32	16.99	14.71	-
10	7	85.57 ± 56.97	42.68	7.06	6.11	-
11	24	53.21 ± 37.15	102.36	13.62	11.66	-
12	11	159.91 ± 75.12	128.56	30.49	26.33	27.27

S. binderi

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	4	68.50 ± 73.15	53.68	6.28	5.24	-
2	7	58.43 ± 59.44	82.68	10.86	9.49	14.29
3	3	82.67 ± 76.05	62.44	8.23	6.96	-
4	9	114.33 ± 130.17	407.92	42.29	36.48	33.33
5	6	169.50 ± 213.49	266.92	28.74	24.31	50.00
6	6	149.67 ± 141.93	291.28	36.78	31.24	16.67
7	-	-	-	-	-	-
8	3	240.33 ± 64.93	311.32	31.30	26.58	33.33
9	-	-	-	-	-	-
10	-	-	-	-	-	-
11	7	66.43 ± 44.30	34.72	4.54	3.84	-
12	-	-	-	-	-	-

S. siliquosum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	6	64.33 ± 50.82	88.40	11.08	9.53	-
2	-	-	-	-	-	-
3	8	84.00 ± 72.47	78.08	14.69	14.26	12.50
4	49	25.44 ± 15.9	36.68	5.15	4.41	-
5	20	54.35 ± 48.64	228.20	30.16	25.52	-
6	30	44.93 ± 39.83	203.48	33.55	29.02	3.33
7	-	-	-	-	-	-
8	-	-	-	-	-	-
9	-	-	-	-	-	-
10	-	-	-	-	-	-
11	5	64.20 ± 17.57	49.68	7.05	6.12	-
12	3	55.33 ± 66.40	13.52	3.05	2.65	-

D. March 2010

S. polycystum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	2	101.50 ± 51.62	6.44	2.00	1.67	-
2	-	-	-	-	-	-
3	3	25.67 ± 11.59	2.04	0.43	0.38	-
4	8	220.50 ± 163.15	75.36	19.49	16.35	50.00
5	3	67.67 ± 58.32	6.44	1.10	0.94	-
6	6	31.83 ± 18.49	9.28	2.04	1.75	-
7	30	120.83 ± 93.28	230.12	48.11	37.51	30.00
8	9	107.00 ± 126.19	152.84	37.11	30.14	22.22
9	46	59.72 ± 47.47	67.08	15.52	13.02	-
10	62	58.07 ± 52.42	127.80	28.60	24.47	-
11	24	122.29 ± 80.98	58.68	14.77	12.07	-
12	15	58.20 ± 67.10	68.44	11.80	9.58	6.67

S. binderi

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	20	137.65 ± 118.32	251.16	59.97	48.10	45.00
2	4	106.00 ± 53.37	30.28	5.57	4.39	50.00
3	19	93.47 ± 58.83	150.08	24.42	19.92	10.53
4	3	44.67 ± 66.11	2.60	0.72	0.59	-
5	14	97.86 ± 74.87	253.00	38.26	31.18	21.43
6	3	245.00 ± 355.16	155.92	25.39	20.82	33.33
7	9	80.11 ± 54.88	29.52	7.63	6.05	-
8	1	242.00 ± 0.00	15.04	3.68	2.75	100.00
9	-	-	-	-	-	-
10	11	52.36 ± 41.66	53.84	9.15	7.60	9.09
11	1	158.00 ± 0.00	15.16	3.40	2.62	100.00
12	25	44.24 ± 39.68	69.20	10.34	8.25	12.00

S. siliquosum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	5	84.00 ± 58.67	53.00	11.21	8.80	20.00
2	14	145.21 ± 121.87	331.48	59.01	47.45	35.71
3	9	126.44 ± 165.63	328.08	58.65	48.53	22.22
4	32	101.53 ± 131.16	398.76	78.58	63.05	15.63
5	19	105.84 ± 148.01	453.08	74.19	62.54	21.05
6	34	121.27 ± 129.10	586.68	102.45	84.43	17.65
7	-	-	-	-	-	-
8	-	-	-	-	-	-
9	-	-	-	-	-	-
10	-	-	-	-	-	-
11	-	-	-	-	-	-
12	-	-	-	-	-	-

E. May 2010

S. polycystum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	2	145.00 ± 117.38	44.60	7.62	6.39	-
2	24	50.88 ± 35.67	58.60	7.89	6.80	-
3	9	99.89 ± 83.84	193.68	33.02	28.36	-
4	21	78.71 ± 72.56	159.12	40.46	36.06	-
5	42	50.71 ± 50.14	229.08	36.08	31.08	-
6	23	74.87 ± 75.05	289.48	42.91	37.52	-
7	35	70.54 ± 48.49	211.16	41.48	35.91	-
8	11	47.00 ± 33.98	64.52	9.92	8.38	-
9	1	53.00 ± 0.00	8.32	0.73	0.57	-
10	52	32.89 ± 22.37	79.72	12.78	11.06	-
11	4	122.50 ± 87.46	181.40	30.88	26.48	-
12	19	64.42 ± 74.08	214.60	31.41	26.72	-

S. binderi

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	7	94.29 ± 36.45	71.08	9.58	7.64	28.57
2	10	37.50 ± 11.54	19.92	2.28	1.83	-
3	7	43.43 ± 36.23	21.88	2.00	1.47	-
4	12	60.75 ± 30.33	80.44	9.24	7.55	-
5	2	24.50 ± 4.95	3.48	0.43	0.15	-
6	3	60.00 ± 57.67	4.44	0.53	0.42	-
7	1	55.00 ± 0.00	4.24	0.44	0.34	-
8	-	-	-	-	-	-
9	-	-	-	-	-	-
10	9	22.33 ± 15.29	8.48	1.15	0.98	-
11	-	-	-	-	-	-
12	9	53.89 ± 34.17	48.04	5.83	4.99	-

S. siliquosum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	11	116.09 ± 59.83	313.40	44.97	37.33	18.18
2	12	58.75 ± 34.28	135.04	18.63	15.87	-
3	9	72.00 ± 60.42	200.04	30.37	25.51	-
4	14	44.21 ± 63.72	138.68	21.85	18.61	-
5	10	25.40 ± 32.83	12.72	2.13	1.85	-
6	19	48.00 ± 48.19	153.16	21.60	18.50	5.26
7	-	-	-	-	-	-
8	-	-	-	-	-	-
9	-	-	-	-	-	-
10	-	-	-	-	-	-
11	-	-	-	-	-	-
12	1	25.00 ± 0.00	0.60	0.10	0.09	-

F. July 2010

S. polycystum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	7	200.29 ± 270.20	646.24	88.30	76.15	28.57
2	5	427.40 ± 364.61	1658.92	235.92	197.97	40.00
3	12	308.08 ± 322.20	1976.68	292.32	246.81	25.00
4	18	425.22 ± 346.58	1308.08	255.37	221.20	38.89
5	7	494.00 ± 413.26	738.88	131.90	112.06	42.86
6	5	532.00 ± 296.43	660.24	101.68	85.85	60.00
7	5	203.80 ± 160.32	541.60	74.52	59.34	20.00
8	13	251.08 ± 258.82	1130.36	149.33	125.11	-
9	25	138.68 ± 159.97	799.64	104.10	90.00	-
10	52	94.13 ± 75.19	359.08	52.37	41.24	-
11	33	171.64 ± 144.08	412.12	69.93	54.74	-
12	9	349.56 ± 308.43	1240.40	169.87	143.79	-

S. binderi

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	9	200.67 ± 68.88	528.20	75.04	62.23	33.33
2	-	-	-	-	-	-
3	4	26.00 ± 13.64	5.40	1.13	0.94	-
4	-	-	-	-	-	-
5	4	77.50 ± 99.00	34.08	4.83	3.85	-
6	6	261.00 ± 99.66	243.48	34.87	28.59	66.67
7	-	-	-	-	-	-
8	9	139.00 ± 120.03	106.80	10.22	6.60	22.22
9	-	-	-	-	-	-
10	-	-	-	-	-	-
11	2	139.00 ± 175.36	134.48	18.42	16.55	50.00
12	5	169.00 ± 100.91	153.40	17.79	14.53	40.00

S. siliquosum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	3	185.00 ± 225.19	150.92	21.56	18.68	33.33
2	11	335.55 ± 270.04	874.16	122.80	104.77	54.55
3	5	304.40 ± 258.30	480.04	71.44	60.73	60.00
4	18	149.56 ± 150.19	149.04	44.53	38.32	11.11
5	8	287.00 ± 297.09	436.20	70.42	60.92	12.50
6	9	201.33 ± 188.97	739.36	106.55	91.61	33.33
7	-	-	-	-	-	-
8	-	-	-	-	-	-
9	-	-	-	-	-	-
10	-	-	-	-	-	-
11	-	-	-	-	-	-
12	1	21.00 ± 0.00	3.56	0.54	0.46	-

G. <u>September 2010</u>

S. polycystum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	8	45.00 ± 27.29	25.64	4.45	2.56	-
2	7	75.57 ± 84.41	37.64	7.11	6.07	-
3	8	29.13 ± 35.89	14.36	2.67	2.28	-
4	25	40.08 ± 29.78	123.64	19.78	17.15	-
5	5	49.40 ± 8.96	34.72	5.69	4.94	-
6	-	-	-	-	-	-
7	18	53.22 ± 61.19	59.80	11.74	9.85	11.11
8	22	67.64 ± 81.87	143.60	26.16	21.46	4.55
9	21	74.29 ± 51.28	71.88	13.00	10.58	-
10	17	85.76 ± 92.34	93.40	20.95	17.53	11.76
11	26	53.58 ± 42.10	67.92	12.19	10.57	3.85
12	9	92.11 ± 74.71	98.08	19.35	16.31	33.33

S. binderi

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	8	85.75 ± 61.31	120.88	16.56	13.84	12.50
2	1	39.00 ± 0.00	2.16	0.21	0.18	-
3	7	26.86 ± 26.22	10.08	1.35	1.15	-
4	2	92.50 ± 94.05	59.64	7.88	6.80	50.00
5	9	54.00 ± 72.67	79.48	11.95	10.23	11.11
6	10	31.90 ± 15.52	30.72	4.25	3.58	-
7	6	112.33 ± 73.16	71.04	9.41	7.81	33.33
8	3	73.67 ± 88.64	37.84	4.63	3.89	-
9	2	141.00 ± 137.18	68.72	8.26	7.05	-
10	5	26.00 ± 7.78	4.92	0.84	0.72	-
11	3	190.67 ± 41.48	115.52	15.49	13.50	-
12	6	46.83 ± 73.46	32.64	5.16	4.40	16.67

S. siliquosum

Quadrat	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$)	DW ($gDWm^{-2}$)	AFDW ($gAFDWm^{-2}$)	% Fertility
1	24	64.17 ± 72.90	195.32	33.20	28.07	12.50
2	18	58.89 ± 68.52	225.36	46.74	40.87	11.11
3	34	50.18 ± 54.89	201.96	38.95	33.37	5.88
4	24	58.92 ± 95.17	130.68	23.38	20.09	8.33
5	6	99.67 ± 59.87	116.40	19.66	16.82	16.67
6	27	45.74 ± 43.02	171.68	29.49	25.44	-
7	-	-	-	-	-	-
8	-	-	-	-	-	-
9	-	-	-	-	-	-
10	-	-	-	-	-	-
11	-	-	-	-	-	-
12	-	-	-	-	-	-

Appendix D

Destructive Sampling: One-way ANOVA

A. Between Quadrats of each Month

Species	Months	F	*p*
S. polycystum	September 09	3.501	0.000*
	November 09	3.613	0.001*
	January 10	4.696	0.000*
	March 10	4.810	0.000*
	May 10	2.378	0.008*
	July 10	3.058	0.001*
	September 10	1.808	0.063
S. binderi	September 09	0.749	0.649
	November 09	2.169	0.043*
	January 10	1.084	0.393
	March 10	2.679	0.006*
	May 10	3.539	0.002*
	July 10	4.632	0.002*
	September 10	2.235	0.027*
S. siliquosum	September 09	3.903	0.001*
	November 09	4.650	0.000*
	January 10	1.283	0.276
	March 10	0.835	0.527
	May 10	3.247	0.007*
	July 10	1.007	0.432
	September 10	1.227	0.300

* Significantly different ($p < 0.05$)

(Post hoc test could not be performed because at least one group has fewer than two cases)

B. Between Months

Species	Measurements	ANOVA		Post Hoc Test (Tukey HSD)	
		F	*p*	Between Months	*p*
S. polycystum	MTL	71.360	0.000*	Sept 09 & Nov 09	0.000*
				Nov 09 & Jan 10	0.000*
				Mar 10 & May 10	0.004*
				May 10 & July 10	0.000*
				July 10 & Sept 10	0.000*
	WW	10.146	0.000*	May10 & July 10	0.000*
				July 10 & Sept 10	0.000*
	DW	7.954	0.000*	May10 & July 10	0.001*
				July 10 & Sept 10	0.000*
	AFDW	20.766	0.000*	May10 & July 10	0.000*
				July 10 & Sept 10	0.000*
	No. Fertile plts	85.387	0.000*	Sept 09 & Nov 09	0.000*
				Mar 10 & May 10	0.016*
				May 10 & July 10	0.000*
S. binderi	MTL	11.280	0.000*	Sept 09 & Nov 09	0.000*
				May 10 & July 10	0.000*
				July 10 & Sept 10	0.000*
	WW	3.458	0.005*	Nov 09 & Jan 10	0.011*
	DW	4.177	0.001*	Nov 09 & Jan 10	0.016*
	AFDW	8.641	0.000*	Nov 09 & Jan 10	0.017*
				May 10 & July 10	0.000*
	No. Fertile plts	10.705	0.000*	Sept 09 & Nov 09	0.000*
				Mar 10 & May 10	0.042*
				May 10 & July 10	0.005*
S. siliquosum	MTL	34.108	0.000*	Sept 09 & Nov 09	0.000*
				Jan 10 & Mar 10	0.029*
				Mar 10 & May 10	0.003*
				May 10 & July 10	0.000*
				July 10 & Sept 10	0.000
	WW	1.735	0.137	-	-
	DW	2.006	0.087	-	-
	AFDW	6.934	0.000*	May 10 & July 10	0.001*
	No. Fertile plts	23.827	0.000*	Sept 09 & Nov 09	0.000*
				Jan 10 & Mar 10	0.002*
				Mar 10 & May 10	0.009*
				May 10 & July 10	0.000*
				July 10 & Sept 10	0.001*

* Significantly different ($p < 0.05$)

Appendix E

Destructive Sampling: Overall Number of Plants, Mean Thallus Length, Biomass and Percentage Fertility

S. polycystum

Months	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$ ± SD)	DW ($gDWm^{-2}$ ± SD)	AFDW ($gAFDWm^{-2}$ ± SD)	% Fertility
Sept 09	134	210.32 ± 141.31	323.39 ± 257.26	33.03 ± 27.96	24.81 ± 24.44	52.99
Nov 09	279	46.19 ± 34.28	91.99 ± 70.56	14.76 ± 10.18	9.46 ± 9.52	0.36
Jan 10	140	92.49 ± 77.90	102.58 ± 56.86	16.70 ± 10.92	12.97 ± 9.63	3.57
Mar 10	208	82.60 ± 82.13	73.14 ± 72.31	16.45 ± 15.87	12.32 ± 12.0	7.69
May 10	243	59.17 ± 56.66	144.52 ± 89.45	24.60 ± 15.53	21.28 ± 13.59	-
Jul10	191	222.32 ± 252.11	956.02 ± 509.01	143.780 ± 79.14	121.19 ± 68.20	11.00
Sept 10	166	60.58 ± 60.83	70.06 ± 41.35	13.01 ± 7.70	10.85 ± 6.54	5.42

S. binderi

Months	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$ ± SD)	DW ($gDWm^{-2}$ ± SD)	AFDW ($gAFDWm^{-2}$ ± SD)	% Fertility
Sept 09	47	163.34 ± 106.62	101.08 ± 108.53	13.84 ± 14.33	8.79 ± 11.71	48.94
Nov 09	55	57.29 ± 43.06	23.87 ± 23.60	3.24 ± 3.27	2.27 ± 2.72	1.82
Jan 10	45	112.67 ± 122.08	188.87 ± 145.83	21.13 ± 15.22	12.01 ± 13.66	20.00
Mar 10	110	90.86 ± 94.44	93.26 ± 93.92	17.14 ± 18.37	13.84 ± 14.85	20.91
May 10	60	50.63 ± 34.60	29.11 ± 30.00	3.50 ± 3.75	2.11 ± 2.91	3.33
Jul10	39	157.95± 112.92	172.26 ± 175.48	23.19 ± 25.39	11.11 ± 18.47	30.77
Sept 10	62	65.53± 68.44	52.80 ± 37.21	7.17 ± 5.46	6.10 ± 4.66	9.68

S. siliquosum

Months	No. of Plants	MTL (mm ± SD)	WW ($gWWm^{-2}$ ± SD)	DW ($gDWm^{-2}$ ± SD)	AFDW ($gAFDWm^{-2}$ ± SD)	% Fertility
Sept 09	126	152.27 ± 105.08	339.38 ± 236.77	48.71 ± 33.09	27.48 ± 29.77	38.10
Nov 09	152	46.18 ± 37.69	142.65 ± 71.30	18.94 ± 8.90	9.42 ± 9.99	-
Jan 10	121	51.96 ± 46.17	99.72 ± 83.45	14.96 ± 12.20	7.62 ±10.24	1.65
Mar 10	113	114.81 ± 131.32	358.51 ± 177.55	64.01 ± 30.45	52.47 ± 25.23	20.35
May 10	76	58.42 ± 56.26	136.23 ± 107.55	19.95 ± 15.57	9.81 ± 12.91	3.95
Jul10	55	228.89 ± 225.02	404.75 ± 441.02	62.55 ± 43.89	31.29 ± 39.12	29.09
Sept 10	133	56.79 ± 67.03	173.57 ± 169.94	31.90 ± 10.00	27.44 ± 8.80	7.52

Appendix F

Non-Destructive Sampling: One-way ANOVA

A. Between Quadrats

Species	Measurements	ANOVA		Post Hoc Test (Tukey HSD)	
		F	*p*	Between Quadrats	*p*
S. polycystum	MTL	4.691	0.000*	Q2 & Q5	0.000*
				Q2 & Q9	0.001*
				Q2 & Q10	0.019*
				Q2 & Q11	0.008*
				Q4 & Q5	0.008*
				Q4 & Q9	0.007*
				Q4 & Q11	0.049*
				Q5 & Q7	0.046*
				Q7 & Q9	0.046*
	No. Fertile plts	3.622	0.000*	Q2 & Q10	0.048*
S. binderi	MTL	1.251	0.258	-	-
	No. Fertile plts	1.295	0.233	-	-
S. siliquosum	MTL	1.618	0.107	-	-
	No. Fertile plts	2.482	0.009*	-	-

* Significantly different ($p < 0.05$)

(Post hoc test could not be performed for *S. siliquosum* because at least one group has fewer than two cases)

B. Between Months

S. polycystum

Measurements	ANOVA		Post Hoc Test (Tukey HSD)	
	F	*p*	Between Months	*p*
MTL	19.218	0.000*	Sept 09 & Jul 10	0.024*
			Oct 09 & Feb 10	0.007*
			Oct 09 & Apr 10	0.048*
			Oct 09 & Jun 10	0.005*
			Oct 09 & Jul 10	0.000*
			Oct 09 & Aug 10	0.000*
			Nov 09 & Jul 10	0.002*
			Nov 09 & Aug 10	0.022*
			Dec 09 & Feb 10	0.000*
			Dec 09 & Jun 10	0.000*
			Dec 09 & Jul 10	0.000*
			Dec 09 & Aug 10	0.000*
			Jan 10 & Apr 10	0.000*
			Jan 10 & May 10	0.001*
			Jan 10 & Jul 10	0.001*
			Feb 10 & Apr 10	0.000*
			Feb 10 & May 10	0.000*
			Feb 10 & Sept 10	0.000*
			Mar 10 & Apr 10	0.000*
			Mar 10 & May 10	0.001*
			Mar 10 & Jul 10	0.000*
			Mar 10 & Aug 10	0.003*
			Apr 10 & Jun 10	0.000*
			Apr 10 & Jul 10	0.000*
			Apr 10 & Aug 10	0.000*
			Apr 10 & Sept 10	0.007*
			May 10 & Jun 10	0.000*
			May 10 & Jul 10	0.000*
			May 10 & Aug 10	0.000*
			Jun 10 & Sept 10	0.000*
			Jul 10 & Sept 10	0.000*
			Aug 10 & Sept 10	0.000*
No. Fertile plts	3.801	0.000*	Apr 10 & Aug 10	0.037*

* Significantly different ($p < 0.05$)

S. binderi

Measurements	ANOVA		Post Hoc Test (Tukey HSD)	
	F	*p*	Between Months	*p*
MTL	6.601	0.000*	Sept 09 & Nov 09	0.002*
			Sept 09 & Dec 09	0.017*
			Sept 09 & Apr 10	0.000*
			Sept 09 & May 10	0.002*
			Sept 09 & Sept 10	0.020*
			Nov 09 & Feb 10	0.013*
			Nov 09 & Mar 10	0.032*
			Nov 09 & Jun 10	0.013*
			Nov 09 & Jul 10	0.003*
			Nov 09 & Aug 10	0.004*
			Dec 09 & Jul 10	0.027*
			Dec 09 & Aug 10	0.039*
			Feb 10 & Jun 10	0.003*
			Feb 10 & Jul 10	0.014*
			Mar 10 & Apr 10	0.009*
			Mar 10 & May 10	0.037*
			Apr 10 & Jun 10	0.004*
			Apr 10 & Jul 10	0.001*
			Apr 10 & Aug 10	0.001*
			May 10 & Jun 10	0.017*
			May 10 & Jul 10	0.003*
			May 10 & Aug 10	0.005*
			Jul 10 & Sept 10	0.033*
			Aug 10 & Sept 10	0.049*
No. Fertile plts	5.062	0.000*	Sept 09 & Feb 10	0.021*
			Sept 09 & Apr 10	0.001*
			Sept 09 & Jun 10	0.002*
			Sept 09 & Sept 10	0.004*
			Apr 10 & Aug 10	0.013*
			Jun 10 & Aug 10	0.033*

* Significantly different ($p < 0.05$)

S. siliquosum

MTL				No. Fertile plts			
ANOVA		Post Hoc Test (Tukey HSD)		ANOVA		Post Hoc Test (Tukey HSD)	
F	*p*	Between Months	*p*	F	*p*	Between Months	*p*
13.721	0.000*	Sept 09 & Dec 09	0.026*	11.971	0.000*	Sept 09 & Oct 09	0.045*
		Sept 09 & May 09	0.010*			Sept 09 & Dec 09	0.013*
		Sept 09 & Jul 10	0.029*			Sept 09 & Jan 10	0.012*
		Oct 09 & Feb 10	0.000*			Sept 09 & Apr 10	0.031*
		Oct 09 & Mar 10	0.000*			Sept 09 & May 10	0.011*
		Oct 09 & Jun 10	0.001*			Sept 09 & Aug 10	0.038*
		Oct 09 & Jul 10	0.000*			Sept 09 & Sept 10	0.011*
		Oct 09 & Aug 10	0.000*			Oct 09 & Mar 10	0.000*
		Nov 09 & Feb 10	0.000*			Oct 09 & Jul 10	0.005*
		Nov 09 & Mar 10	0.000*			Oct 09 & Aug 10	0.000*
		Nov 09 & Jun 10	0.004*			Dec 09 & Mar 10	0.000*
		Nov 09 & Jul 10	0.000*			Dec 09 & Jul 10	0.001*
		Nov 09 & Aug 10	0.000*			Dec 09 & Aug 10	0.000*
		Dec 09 & Feb 10	0.000*			Jan 10 & Mar 10	0.000*
		Dec 09 & Mar 10	0.000*			Jan 10 & Jul 10	0.001*
		Dec 09 & Jun 10	0.001*			Jan 10 & Aug 10	0.000*
		Dec 09 & Jul 10	0.000*			Feb 10 & Aug 10	0.001*
		Jan 10 & Feb 10	0.030*			Mar 10 & Apr 10	0.000*
		Jan 10 & Mar 10	0.014*			Mar 10 & May 10	0.000*
		Jan 10 & Jul 10	0.004*			Mar 10 & Sept 10	0.000*
		Feb 10 & Apr 10	0.000*			Apr 10 & Jul 10	0.004*
		Feb 10 & May 10	0.000*			Apr 10 & Aug 10	0.000*
		Feb 10 & Sept 10	0.002*			May 10 & Jul 10	0.001*
		Mar 10 & Apr 10	0.000*			May 10 & Aug 10	0.000*
		Mar 10 & May 10	0.000*			Jul 10 & Sept 10	0.001*
		Mar 10 & Sept 10	0.001*			Aug 10 & Sept 10	0.000*
		Apr 10 & Jul 10	0.000*				
		Apr 10 & Aug 10	0.001*				
		May 10 & Jun 10	0.000*				
		May 10 & Jul 10	0.000*				
		May 10 & Aug 10	0.000*				
		Aug 10 & Sept 10	0.000*				

* Significantly different ($p < 0.05$)

Appendix G

Comparison between Left and Right Reef: One-way ANOVA

Destructive Sampling

Species	Measurements	F	*p*
S. polycystum	MTL	2.674	0.102
	WW	0.386	0.537
	DW	0.381	0.539
	AFDW	0.274	0.602
	Fertility	16.593	0.000*
S. binderi	MTL	4.261	0.040*
	WW	1.798	0.184
	DW	0.955	0.332
	AFDW	0.742	0.392
	Fertility	2.984	0.085
S. siliquosum	MTL	8.142	0.004*
	WW	16.852	0.000*
	DW	18.481	0.000*
	AFDW	17.982	0.000*
	Fertility	10.999	0.001*

* Significantly different ($p < 0.05$)

Non-destructive Sampling

Species	Measurements	F	*p*
S. polycystum	MTL	6.596	0.001*
	Fertility	0.355	0.551
S. binderi	MTL	2.794	0.096
	Fertility	0.762	0.383
S. siliquosum	MTL	2.653	0.104
	Fertility	4.721	0.030*

* Significantly different ($p < 0.05$)