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Spatial and Temporal Variations in Diversity and Percentage Cover of Macroalgae at Sirinart Marine National Park, Phuket Province, Thailand

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ABSTRACT: Diversity, distribution and percentage cover of macroalgae on the coastline of Sirinart National Park, Thailand were studied both in the wet and dry seasons. The study was carried out on sheltered, moderately exposed and very exposed sites. Three hundred and sixty 50 cm X 50 cm quadrats were investigated. Of the more than thirty species of macroalgae found, *Laurencia* spp. and *Padina* spp. were the most common at all sites. The richest algal community, with more than eighteen species, was at the lower level of semi-exposed shore during the dry season (April 2003). Analysis of Variance (ANOVA) revealed significant differences in percentage cover of seventeen macroalgal species with respect to degree of wave exposure, shore elevation, season and their interactions ($P<0.05$). High wave motion during the wet season was likely to play an important role in determining species diversity and the composition of macroalgae at the site. The highest diversity was found on the semi-exposed shore during the dry season, when the sea was rather calm. Surprisingly, there was greater percentage cover in the wet season, when less photosynthesis and growth were expected due to less light intensity than in the dry season, this study provides baseline data for future ecological studies and long term monitoring of macroalgal communities on tropical shores. This is the very first study of macroalgal ecology in Thailand and Southeast Asia.

KEYWORDS: diversity, distribution, percentage cover, macroalgae, marine ecology.

INTRODUCTION

Seaweeds, or macroalgae are an ecologically and economically important component of marine ecosystems worldwide. They are primary producers, shelter, nursery grounds and food sources for marine organisms. In addition, they are used around the world as foods and fertilizers, and for the extraction of valuable commercial products, such as industrial gums and chemicals (agars, carageenans and alginates). Recent research has pointed to new opportunities, particularly in the field of medicine, associated with bioactive properties of molecules extracted from seaweeds[1]. Moreover, due to their habitats and biology, seaweeds are relatively easy to observe, manipulate and measure. Therefore, they have been widely used as *model* organisms for testing various ecological theories, both in intertidal and subtidal habitats. Competition for space, light and nutrients, herbivore defensive mechanisms, and prey-predation have all been studied in using macroalgal systems [2,3,4,5] .

The role of the physical environment in determining and maintaining community structure in marine habitats has been strongly emphasized by ecologists. Seasonal patterns of distribution and abundance of macroalgae on rocky shores are influenced by various abiotic variables such as light intensity[6], tidal regimes[7,8] , wave motion [9], nutrient levels [10,11], substrate stability [12], desiccation [13,14] and sedimentation [15,16,17,18]. These factors can also affect algal distribution indirectly, by influencing the outcome of competitive [19] and grazing interactions [20,21]. Most of these studies, however, have been carried out on the temperate shores of Europe, USA and Australia. Very few studies have been made in the tropical regions of Thailand or South East Asia.

In recent years, only a few investigations have been carried out on macroalgae in Thailand [22]. Recently, the culture of *Gracilaria* has been studied [23]. Also, there have been a series of taxonomical studies on red algae such as *Gracilaria* in Thailand[24,25,26]. However, more studies on various aspects of macroalgae are still needed, especially, on population and community ecology. Such information could provide a baseline for future more complex ecological studies and coastal management, as well as applied aspects of the uses of seaweed.

I, therefore, studied not only diversity but also percentage cover of intertidal macroalgae in two distinct seasons with varying degrees of wave exposure and at different levels on the same shore. I hypothesized that (1) diversity and distribution of macroalgae will vary between sites and seasons, and (2) the macroalgal community will be determined chiefly by the degree of wave exposure and shore elevation.

Materials and Methods

Study Site and Sampling

Sirinart Marine National Park, Phuket, was chosen for this study due to its rich diversity of marine organisms. This was also to build a '*marine base*' for long term monitoring and various other studies on marine biology [27]. The study site was at the coast line of Sirinart Marine National Park near Koh Pling, north of Phuket province, Thailand (8°05'N, 98°17'E) (Figure 1). Sampling sites were selected along the shoreline at different degrees of wave exposure: sheltered (S), moderately exposed (M-E) and very exposed (E). In the exposed areas, organisms were directly affected by wave action, which was less in moderately-exposed and sheltered areas due to protection by fringing reefs. In addition, the water current was measured at each site during March 2003 using the mini current meter model 5D-4 (4A) (Sensordata a.s., Bergen, Norway). The average water current was 2 m/s at the sheltered, 4.8 m/s at the moderately exposed and 6.8 m/s at the exposed areas, respectively. The study was carried out

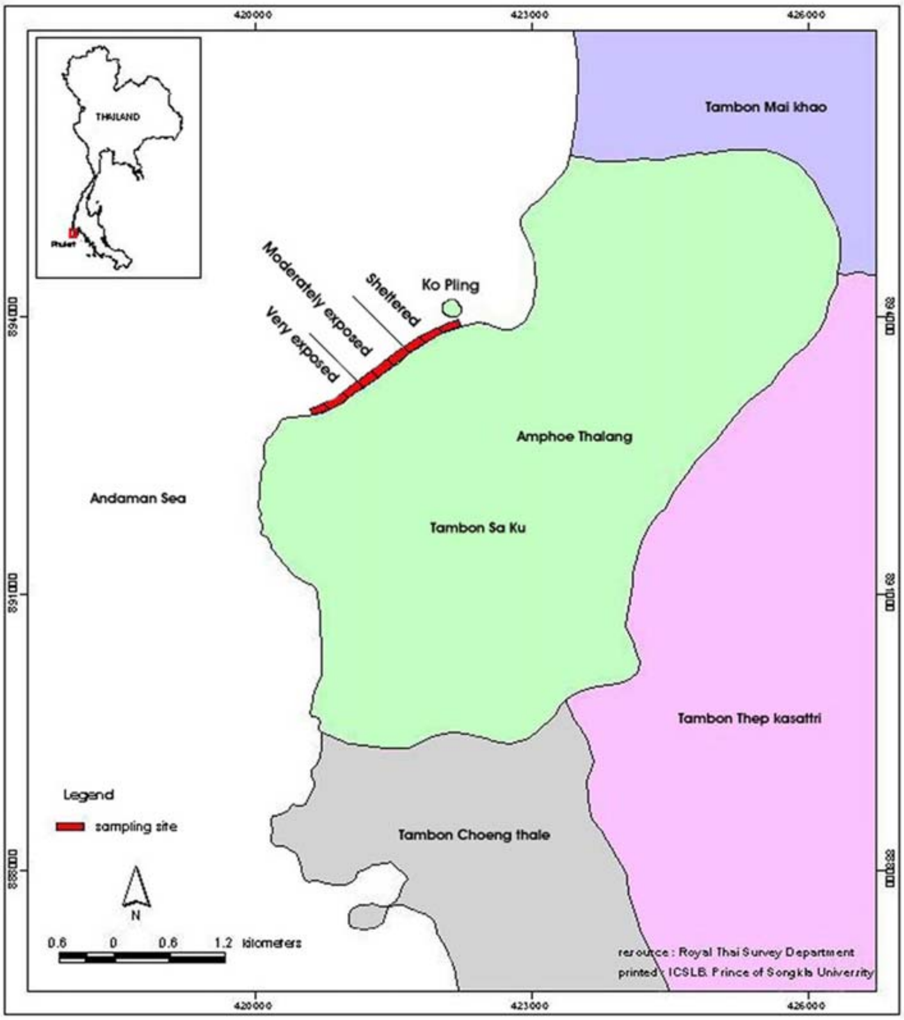

Fig 1. The study site, along the coast at Sirinart National Park, near Koh Pling island, northern Phuket, Thailand.

during low tide when seaweeds were exposed. The shore slope was very shallow and tidal cycle in Phuket, Andaman coast is rather large. The upper shore would be exposed more than 8 hrs during the low tide, while only 3 hrs for the lower shore during the spring tide. Ten line transects were conducted within the different degrees of wave exposure along the shores: four lines on the sheltered shore, and three lines on the moderately exposed and very exposed shores each. Each line was marked using A+B EpoPutty epoxy (ALTECO) and fixed on the rocks individually. Six quadrats of 50 cm x 50 cm were sampled randomly at 40 m intervals at three shore elevation levels: 0-40 m was the upper level, 41-80 m was the mid shore level and 81-120 m was the lower shore level. The tidal range at Phuket was 0.8-3.8 m above mean sea level in 2002-2003; average sea level was about 2.3 m above mean sea level (calculated from the Tide Table of the Hydrographic Department, Royal Thai Navy). Samples were monitored and recorded on the same transect lines in two seasons: a wet season predominated by the SW Monsoon and a dry season predominated by the NE Monsoon. The wet season study was conducted 4-7 October 2002, and the dry season study was conducted during 10-14 April 2003. Three hundred and sixty quadrats were analyzed. Percentage cover and substrates of macroalgae were estimated visually and recorded at the site. Macroalgae were collected

Table 1. Summary macroalgae list and distribution. Sheltered (S), moderately exposed (M-E) and exposed(E) shore at low(L), mid(M) and high (H) shore levels in wet and dry seasons; X observed, - not observed.

Phylum	Species	Wet Season									Dry Season								
		S			M-E			E			S			M-E			E		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Cyanophyta	*Lyngbya* sp.	X		X			X				X	X	X	X	X	X	X	X	X
	Brachytrichia sp.					X			X	X									
Chlorophyta	*Acetabularia* spp.	X			X						X		X	X					
	Boergesenia forbesii (Harvey) Feldmann	X	X	X	X	X				X	X	X	X	X	X				
	Boodlea composita (Harvey) Brand	X		X	X	X	X	X	X	X	X	X	X	X					
	Chaetomorpha antennina (Bory) Kützing												X	X	X	X	X	X	X
	Dictyosphaeria cavernosa (Forsskål) Børgesen			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Filamentous green algae	X		X			X			X									
	Rhipidosiphon javensis													X	X				
	Ulva sp.																	X	
	Valoniopsis pachynema (Martens) Børgesen	X	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X
Pheaophyta	*Dictyota* sp.					X		X	X	X	X				X	X			
	Filamentous brown algae	X					X			X									
	Padina spp.	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
	Sargassum polycystum C. Agardh				X														
	Turbinaria spp.		X	X	X		X	X				X	X	X					
Rhodophyta	*Acanthophora spicifera* (Vahl) Børgesen					X	X						X	X	X				
	Amphiroa sp. (L.) Lamx.							X	X										
	Crustose red algae				X	X	X	X	X	X			X				X		
	Filamentous red algae	X		X	X		X												
	Gelideilla acerosa (Forsskål) Feldmann and Hamel		X	X	X	X		X	X					X	X				
	Gelidium sp.				X	X		X		X	X	X	X	X	X		X	X	X
	Gracilaria salicornia (C.Agardh) Dawson		X	X	X	X		X	X	X				X			X		X
	Halymenia durvillae Bory de saint Vicent													X			X	X	
	Hypnea pannosa J.Ag.							X						X					
	Jania sp.							X			X							X	
	Laurencia spp.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Polysiphonia sp.													X	X				

and taken to the laboratory for identification to species using various taxonomical keys [28, 29, 30, 31, 32, 33]. Voucher specimens were deposited at the Prince of Songkla University herbarium.

Statistical Analysis

Percentage cover was analyzed by ANOVA for each season using a nested design with degrees of exposure as the main factors and shore level nested within the main factor. Repeated measures were used to test temporal changes, interpretation was as a first approximation of seasonal effects. Cochran's C- test was used before each analysis, to assess whether variances were homogeneous, and various data transformations were applied when necessary. Multiple comparisons were made following Zar [34] when there were significant differences between treatments. Statistical results are presented based on the transformed analyses, but, for clarity, graphical output was based on the untransformed means.

RESULTS

Diversity and Distribution

All four major groups of marine macroalgae were found, with more than thirty macroalgae species on the sites (Table 1). Rhodophyta were the richest group, while only two blue-green algae, *Brachytrichia* sp. and *Lyngbya* sp., were found. The richest diversity, made up of more than 18 species, was at the lower level of the semi-exposed shore during the dry season. The lowest diversity, with only 9 species, was found on the lower levels of the sheltered shore during the wet season.

Padina and *Laurencia* were the most common genera, with significantly higher percentage cover than other algae. Also, it is worth noting that two common seagrasses, *Cymodocea rotundata* and *Thalassia hemprichii*, mixed together along the transect lines on coarse sand at the upper and mid-shore levels.

The diversity and distribution of macroalgae were influenced by the degree of wave exposure, shore elevations and season (Table 1). However, *Dictyosphaeria carvernosa*, *Valoniopsis pachynema*, *Padina* spp. and *Laurencia* spp. were common over all ranges of wave exposure in both wet and dry seasons. Filamentous algae were recorded only during the wet season, but *Cladophora* sp., *Chaetomorpha antennina*, *Rhipidosiphon javensis*, *Halymenia durvillae* and *Polysiphonia* sp. were only found during the dry season.

Spatial and Temporal Variations in Populations

Seventeen species of algae showed significant differences in percentage cover with respect to degree of wave exposure, shore elevation, season and their interactions (Table 2). *Brachytrichia* sp., *Boergesenia forbesii*, crustose red algae, filamentous brown and green algae, *Turbinaria* spp. and *Valoniopsis pachynema* were highly seasonal with a greater percentage cover in the wet season, but *Lyngbya* sp. had a greater percentage cover during the dry season (Figure 2). *Lyngbya* bloomed during the dry season and increased its percentage cover to 12.2%, twelve times greater than in the wet season and higher than other algae.

There were also patterns related to degree of wave

Table 2. Summary of significant results (F-ratio) from analysis of variance showing effects of (1) different levels on these shores (nested within degree of exposure) in two seasons, (2) with seasonal effects assessed by repeated measures on species abundance of macroalgae. Algal species that are not presented have no significant relationship; otherwise, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; ns not significant.

Species	Wet season		Dry season		Repeated measures		
	Degree of exposure	Shore level	Degree of exposure	Shore level	Season	SeasonX exposure	SeasonX shore level
Boergesenia forbesii	6.08**	5.12**	2.02 ns	0.76 ns	18.55***	4.38*	2.09 ns
Boodlea composita	6.15**	1.28 ns	10.5***	0.37 ns	2.05 ns	13.0***	1.64 ns
Crustose red alage	12.4***	2.01 ns	0.87 ns	0.74 ns	31.1***	10.8***	1.77 ns
Dictyosphaeria cavernosa	9.51***	0.96 ns	5.69**	1.29 ns	0.67 ns	2.59 ns	1.67 ns
Dictyota sp.	4.03*	1.36 ns	0.08 ns	0.69 ns	0.33 ns	2.90 ns	1.83 ns
Filamentous Brown algae	8.80***	1.73 ns	-	-	25.24***	8.73***	3.52**
Filamentous Green algae	2.06ns	1.67ns	-	-	7.44**	2.06ns	2.48*
Filamentous Red algae	0.84 ns	0.95ns	-	-	25.1***	7.33***	2.96***
Gracilaria salicornia	3.53*	0.40 ns	3.23*	1.83 ns	0.09 ns	1.32 ns	1.57 ns
Gelidium sp.	6.88***	13.1***	2.52 ns	0.58 ns	0.94 ns	1.08 ns	5.95***
Jania sp.	4.52*	4.47*	0.63 ns	0.76 ns	0.59 ns	1.95 ns	3.73**
Lyngbya sp.	2.71 ns	3.68*	5.76**	1.74 ns	109***	7.84***	1.90 ns
Padina spp.	10.8***	1.75 ns	1.98 ns	0.02 ns	1.93 ns	9.82***	2.64*
Turbinaria spp.	1.28 ns	9.60***	0.57 ns	4.68*	12.5***	0.66 ns	3.99***
Valoniopsis pachynema	5.72**	0.25 ns	2.23 ns	6.05**	18.8***	7.57***	0.52 ns

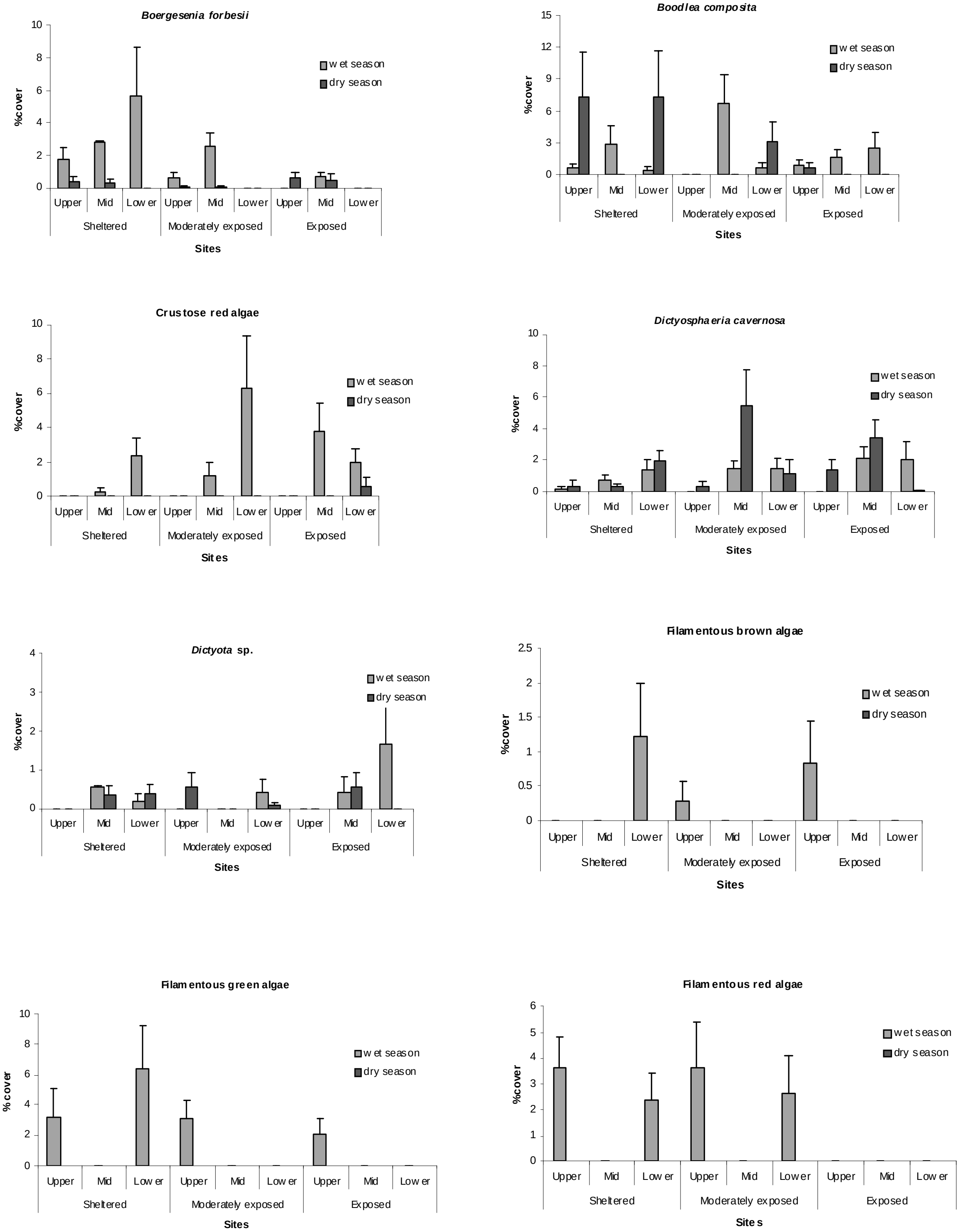

Fig 2. Effects of wave exposure, sheltered, moderately exposed and exposed shores in two seasons on algae percentage cover which showed significant relationships.

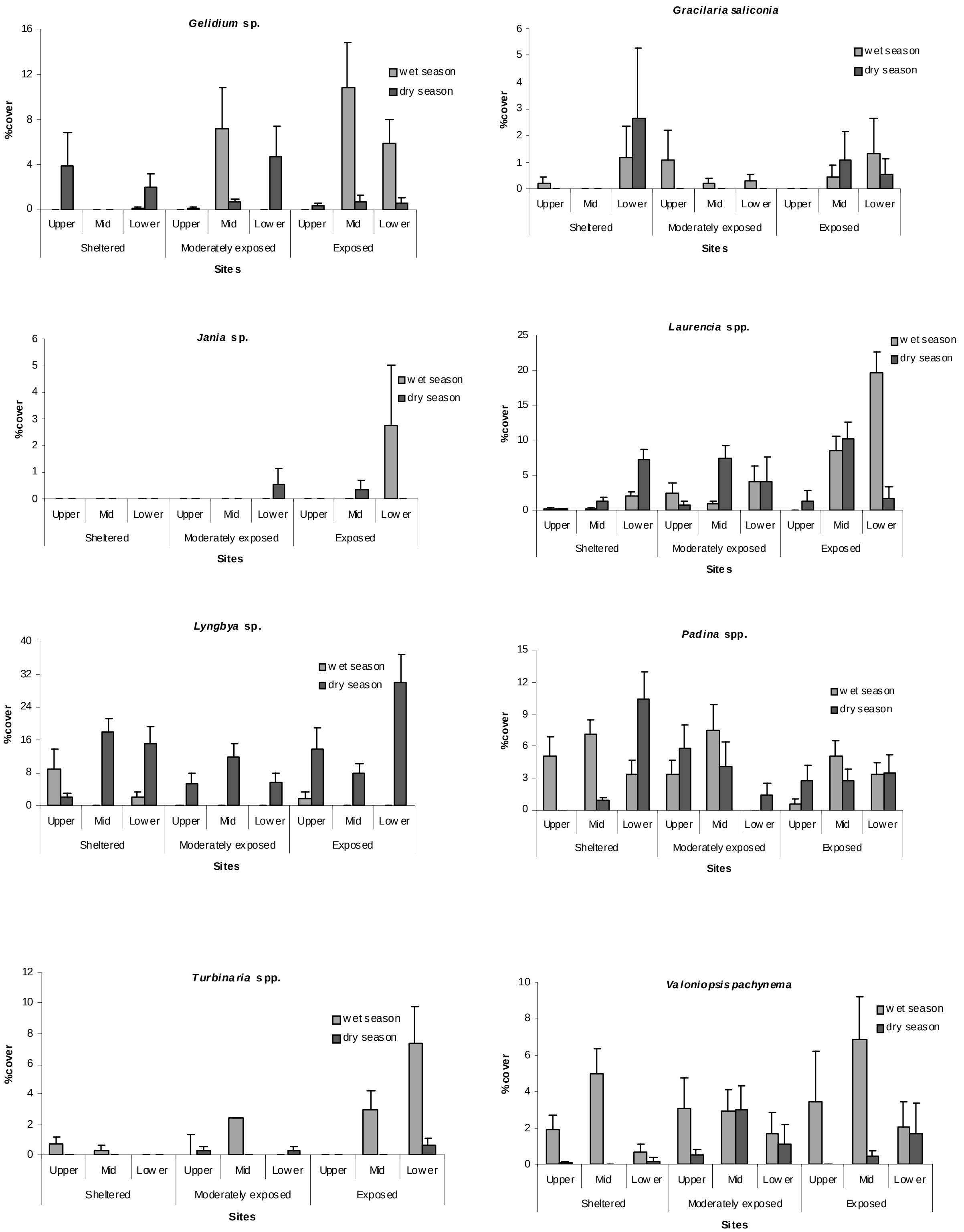
Gelidium sp.
Gracilaria saliconia
Jania sp.
Laurencia spp.
Lyngbya sp.
Padina spp.
Turbinaria spp.
Valoniopsis pachynema
wet season
dry season
%cover
Upper
Mid
Lower
Sheltered
Moderately exposed
Exposed
Sites

Fig 2. *Cont'd.*

exposure: an increased percentage cover with decreasing wave exposures (*Boodlea composita*), an increased percentage cover with increasing wave exposure (*Laurencia* spp., *Valoniopsis pachynema* and crustose red algae.) and some such as *Brachytrichia* sp., filamentous red algae and *Jania* sp. were absent at a certain degrees of wave exposures (Figure 2). However, while there were no uniform patterns related to shore elevation, most algae had greater percentage cover in the mid and lower shore levels.

Discussion

The majority of the seaweed species in the world are red algae, with more than 4,000 described species [35]. In the tropics, there is greater diversity of red algae than in the temperate regions. Thus, at Sirinart Marine National Park, we are likely to find a greater diversity of red algae than other groups of algae. Brown algae, however, showed a greater percentage cover than other seaweeds, although there were only a few individual fronds observed. This is due to their larger thallus size. *Sargassum polycystum* and *Turbinaria* spp., for example, are more than 20 cm. long, while red algae are mostly small or filamentous plants e.g. *Amphiroa* sp., *Jania* sp. or *Polysiphonia* sp.. Therefore, brown algae are likely to support a higher productivity on the coastal rocky shore of this study than other algae.

The results showed that the highest diversity was found at the lower level of the moderately exposed shore during the dry season, with only few species influenced by shore elevation. Also, 75% of macroalgae, more than 12 species, were strongly influenced by high wave motion during the wet season, compared to only 31% in the dry season. Therefore, the richest diversity, more than 18 species during summer is likely to be caused by less disturbances from wave action. Waves of two-to-three meter heights were observed during the wet season at all sites. These strong waves could wash away seaweeds as well as new germlings. Also, wave action is known to inhibit spore settling and recruitment of algae and other marine organisms [36, 37], and thus influence the composition of the community. Therefore, the calmer wave conditions during the dry season would cause less disturbance and allow a stable community with higher diversity to develop [38, 39].

Exposed shores are known to be occupied by fewer marine organisms due to high wave action [40]. However, some algae are adapted to these available spaces[41]. For example, *Laurencia* spp. and *Valoniopsis pachynema*, formed many patches of short clump turfs. Individual fronds of *Laurencia* spp. and *V. pachynema* aggregated together, thus decreasing the area exposed to strong wave motion. In addition, the red crustose algae, another dominant alga on the exposed shore, accumulate calcium carbonate and encrust onto the rock. These algae are tougher and their flat form is less affected by strong wave motion. They, therefore, can better withstand the strong waves of the exposed shore. By contrast, *Boodlea composita* and the fragile filamentous algae, showed greater abundance on the sheltered shore. Also, *Boodlea's* leaf-like thallus is more complete on the sheltered shore than on the semi-exposed or the very exposed shore, where some thalli were broken and frayed.

Laurencia and *Padina* are the most common genera found across all sites in all seasons. *Laurencia* spp. grows as a clump, which helps them to resist desiccation when the tide is out [42]. Moreover, *Laurencia* spp. are known to have secondary metabolites, which make them unpalatable for herbivores [43, 44,45]. The success of *Padina* spp. might be a result of calcium accumulation, which would not be preferred by herbivores. Also, their fan-shaped blades could hold some water [46], allowing them to resist longer periods of desiccation when the tide is out. These adaptations and mechanisms of both algae could explain their success found in this study.

Surprisingly, most algae showed a greater percentage cover in the wet season than in the dry season. This, however, might be a result from their accumulated growth during the dry season. During the dry season, macroalgae are likely to have higher rates of photosynthesis than in the wet season due to greater amount of irradiance [6, 47], thus they would have the energy for greater growth. Growth of macroaglae in the tropical zone, however, is likely to have a slower rate than macroalgae in the temperate zone[48]. Thus, it would take rather a long time to have a significantly increased percentage cover of macroalgae population. Thus, a greater percentage cover of most algae was found in the beginning of wet season, after 6 months of dry season with higher productivity. Then, when the SW monsoon started, it washed most algae away, thus we found a lower percentage cover of macroalgae in the early summer. However, more frequent sampling and longer monitoring would allow us to understand more about the seasonal dynamics of this shore.

This study showed that there were variations in the diversity and distribution of macroalgae between sites and seasons. Degrees of wave exposure during the wet season highly influenced the percentage cover, diversity and distribution of macroalgae. Statistical analyses indicate that shore elevation does not influence the macroalgal population significantly. Although, biological interactions such as herbivory, competition and predation are known to play important roles on community structure in other areas [49, 50], such studies are still very scarce in Thailand and Southeast Asia. Thus, intensive investigation and experimental ecology of both physical and chemical factors (e.g. sedimentation or nutrient concentration) and biological factors (e.g. grazing or competition) will allow us to understand more about seaweed diversity and distribution in the Sirinart Marine National Park in Phuket, Thailand, and of tropical coastal shores in general.

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