Pattern of Algal Succession in the Tropical Subtidal Coral Reef Community at Koh Taen, Mu Ko Thale Tai National Park, the Gulf of Thailand.

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ABSTRACT

The pattern of algal succession was investigated at a subtidal reef, Koh Taen, Mu Ko Thale Tai National Park, Gulf of Thailand. Patches (20×20 cm) were cleared from dead massive corals and monitored from May 2017-May 2018. The results showed the early succession pattern during this study. Red turf algae and *Padina* in *Vaughaniella* stage were early colonizers, followed by *Lobophora variegata*. Red turf algae were the dominant taxa, with the highest percentage cover throughout the year. It might be because these algae can reproduce throughout the year, with rapid growth and has quick colonization abilities, in contrast with other species that have distinct reproductive periods and has slower colonization abilities. Additionally, red turf algae can trap sediment that might prevent settlement of other algal species. Algal species diversity after clearing was reduced, and then recovered after 3-4 months. Coral settlements were found in cleared patches, but these died after one month of settlement.

Keywords: Algal succession, Coral reef, Disturbance, Recruitment, Turf algae

INTRODUCTION

Disturbance is an event or force that removes living biomass from a habitat or disrupts the community by influencing the usable space and food resources, or modifying the environment in such ways that can change the habitat to a mosaic type (Pickett and White, 1985; Townsend and Hildrew, 1994; Kim *et al*., 2017). Disturbances caused by natural and anthropogenic activities are important factors influencing subtidal communities in terms of species abundance, species richness, and species composition (Stachowicz and Hay, 1999; Nystrom *et al*., 2000; Diaz-Pulido and McCook, 2002; Jompa and McCook, 2002; Sotka and Hay, 2002; Bruno and Selig, 2007; Bruno *et al*., 2009; Vermeij *et al*., 2010; Hurd *et al*., 2014). However, the impact of disturbance on community and the pattern of community recovery after disturbance vary both in space and time, depending on frequency, magnitude, and intensity of disturbance, size of disturbed patches, location, time and seasonality (Foster, 1975; Benedetti-Cecchi and Cinelli, 1993; Kim and DeWreede, 1996), as well as seasonal availability of propagules and life-history traits of dominant species (Kim *et al*., 2017).

In a subtidal coral community, coral reefs are subjected to disturbances such as decreased grazing, eutrophication, and elevated sea water temperature that cause coral bleaching and coral mortality (Brown, 1997; McClanahan *et al*., 2002; Sotka and Hay, 2009). Disturbance has influenced the species diversity, community structure and dynamics of reefs (Diaz-Pulido and McCook, 2002). Reefs have undergone disturbances that might cause

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a change from coral to algae dominance (coral-algal phase shift) because there are dead coral skeletons which are favorable substrates for algae to colonize (Littler and Littler, 1984; Glynn, 1993; Hughes *et al*., 2007). Colonizing algae might inhibit coral settlement, coral growth (McCook *et al*., 2001), and delay the regeneration of coral tissue (Diaz-Pulido *et al*., 2009). Disturbed or bleached corals might recover or die, depending on the magnitude and frequency of disturbance, and the species of coral and algae involved (McCook *et al*., 2001; Diaz-Pulido and McCook, 2002; Jompa and McCook, 2003). However, the pattern and dynamics of algal succession in tropical subtidal coral reef communities are not well understood. Additionally, the ability and potential of a community to recover from disturbance are still unclear.

In Thailand, degraded coral reefs along the Andaman Sea and the Gulf of Thailand have been reported, and this situation has been caused by natural (strong waves, disease, coral bleaching) and anthropogenic (loss of herbivory and nutrient enrichment) disturbances for decades (Cheevaporn and Menasveta, 2003; Yeemin *et al*., 2006; Reopanichkul *et al*., 2010; Plathong *et al*., 2011). These reefs have undergone a shift from coral to algae dominance (Yeemin *et al*., 2006). However, much less is known about changing coral-algal dynamics and algal succession patterns after disturbance. A better understanding of community dynamics and the potential of reefs to recover from disturbances is needed. Thus, the aim of this study was to determine the algal succession pattern in a subtidal coral reef community in the southern Gulf of Thailand.

MATERIALS AND METHODS

Study site

The study was carried out at the subtidal reef crest at Ko Taen, Mu Ko Thale Tai National Park, (9° 19′ 20″ N, 99° 46′ 80″ E), Gulf of Thailand, Southern Thailand. There are two seasons in this area: the wet season, dominated by the northeast monsoon (October-January) and the dry season, dominated by the southwest monsoon (February-September). Tides along the gulf coast are semi-diurnal, and tidal range varies from 0.8 to 3.0 m (Coppejans *et al*., 2010). In this area, there were approximately 60 species of marine benthic algae found, including 23 species of Chlorophyta, 19 species of Ochrophyta, 16 species of Rhodophyta and two species of Cyanobacteria (Coppejans *et al*., 2010; Prathep *et al*., 2011), with four common genera: red turf algae, *Padina*, *Sargassum* and *Turbinaria*. The massive coral *Porites* was the dominant coral genus. *Abudefduf vaigiensis*, *Abudefduf bengalensis*, *Abudefduf sexfasciatus*, and *Neoglyphidodon nigroris* were dominant herbivorous fish species at this study site (personal observation).

Experimental design and methods

For the succession study, dead coral patches (20×20 cm) were cleared by hand chiseling and scraping with wire brush in April 2017 to remove all organisms as much as possible. Uncleared areas with natural conditions (initially having 10 percent coverage of healthy coral) were marked as control. Ten natural patches and ten cleared dead coral patches were marked and labeled with concrete nails and surrounded with nylon thread.

In all permanent patches, percentage cover of each algal species was estimated and monitored monthly from May 2017 - May 2018. Photos of all patches were taken using an underwater digital camera (Olympus TG-5, Japan). Unknown algal specimens were collected and taken to the laboratory for identification using algal taxonomic identification guides (Coppejans *et al*., 2010).

Statistical analyses

Percentage cover of three dominant algal species was analyzed using repeated measures analysis of variance (RM-ANOVA). One-way ANOVA was separately applied for each of three dominant algal species. Species diversity was calculated using Shannon-Weiner index. SPSS for Windows version 16.0 was used for statistical analyses.

RESULTS AND DISCUSSION

In control patches, twenty-one algal species were found, with four dominant taxa: *Padina* in *Vaughaniella* stage, *Lobophora variegata* (J.V. Lamouroux) Womersley ex E. C. Oliveira, *Cladophora* sp. and red turf algae (Table 1). Red turf algae were dominant with the highest percent cover of 50.10±9.57 % (Figure 2). The coverage of red turf algae fluctuated over time, while the coverage of *Padina* in *Vaughaniella* stage, *L. variegata*, and *Cladophora* sp. was approximately 20 % for each species throughout the year. For the massive coral *Porites* spp., coverage remained near 10 % throughout the study, with a slight increase from 10.10±0.23 % in April 2017 to 12.30±4.70 % in May 2018 (Figure 2). However, there was no significant difference in coral cover among months ($p>0.05$). Algal species diversity in the control patches ranged from 0.98-2.13; diversity increased during the first five months and then decreased afterwards. The greatest species diversity ($H'=2.13$) was found in August 2017 (Figure 1). There was no significant difference in algal species diversity among months ($p>0.05$) (Table 2).

Table 1. Algal species and occurrence on a coral reef in the Gulf of Thailand. C: common (>10 % in at least 1 sample); R: rare (<10 %); X: no occurrence

Taxa	Abundance	
	Control patches	Cleared patches
Division Chlorophyta		
Caulerpa verticillata	R	X
Cladophora sp.	C	R
Dictyosphaeria sp.	R	R
Green turf algae	R	R
Parvocaulis sp.	R	R
Rhipidosiphon sp.	X	R
Division Rhodophyta		
Amphiroa sp.	R	X
Ceramium sp.	R	R
Ceratodictyon spongiosum	R	X
Champia sp.	R	X
Chondrophycus sp.	R	R
Hypnea spp.	R	R
Polysiphonia sp.	R	R
Red turf algae	C	C
Red crustose algae	R	R
Class Phaeophyceae		
Dictyota sp.	X	R
Lobophora variegata	C	C
Padina sp.	C	C
Sargassum spp.	R	R
Turbinaria conoides	R	R
Turbinaria decurrens	R	R

Table 2. Percentage cover of three dominant algae (red turf algae, *Padina* in *Vaughaniella* stage, *Lobophora variegata*), and coral (*Porites* spp.) in cleared patches of a reef in the Gulf of Thailand. ***$p<0.001$; ns, non significant.

Source of variation	Red turf algae			*Padina* in *Vaughaniella* stage			*Lobophora variegata*		
	df	MS	F	df	MS	F	df	MS	F
Within subjects									
Month	8	888.181	1.276^{ns}	8	690.306	2.017^{ns}	8	185.687	4.786^{***}
Error	56	695.847		56	342.278		56	8.795	

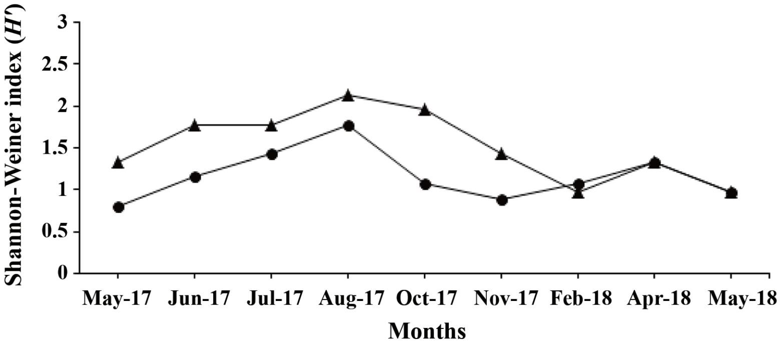

Figure 1. Algal species diversity (Shannon Wiener) in control and cleared patches of a coral reef in the Gulf of Thailand, from May 2017 - May 2018. (▲= Control patches; ●= Cleared patches)

In the cleared coral patches, nineteen algal species recruited, with three predominant species: *Padina* in *Vaughaniella* stage, *L. variegata*, and red turf algae (Table 1) (Figure 2). These three algae taxa were the first colonizers that recruited after one month of clearing. Red turf algae quickly and extensively colonized the cleared patches with the highest percentage cover (56.33±10.59 %). *Padina* in *Vaughaniella* stage and *L. variegata* had a low percentage cover until the end of the study. Their highest cover was 25.00±11.02 % and 17.22 ±5.84 %, respectively (Figure 2). Algal species diversity in the cleared patches ranged from 0.80-1.78, and the greatest species diversity (H'=1.78) was found in August 2017 (Figure 1). The diversity increased during the first four months and then decreased afterwards. The patches began to recover in May 2017, one month after clearing, and took three to four months to reach levels similar to the control plots (Figure 2). Coral juveniles settled in the cleared coral patches in August 2017, however they disappeared after one month of settlement.

This study showed an early stage of succession. Red turf algae were the dominant species that recruited and colonized the cleared patches within one month after clearing, and covered the patches until the end of the study. Meanwhile, the other two species recruited the cleared patches with a very low percentage cover throughout the year. The difference might be due to the ability of red turf algae to grow quickly and rapidly colonize cleared spaces, and then persist for a few years, suppressing the recruitment of other algae (Kendrick, 1991; Diaz-Pulido and McCook, 2002; Fong and Paul 2011; Duran *et al*., 2016). Red turf algae also have a highly competitive ability that might reduce the growth rate of the later-arriving species (Connell, 1973). Additionally, from field observations, the cleared patches were covered with sediments. It has

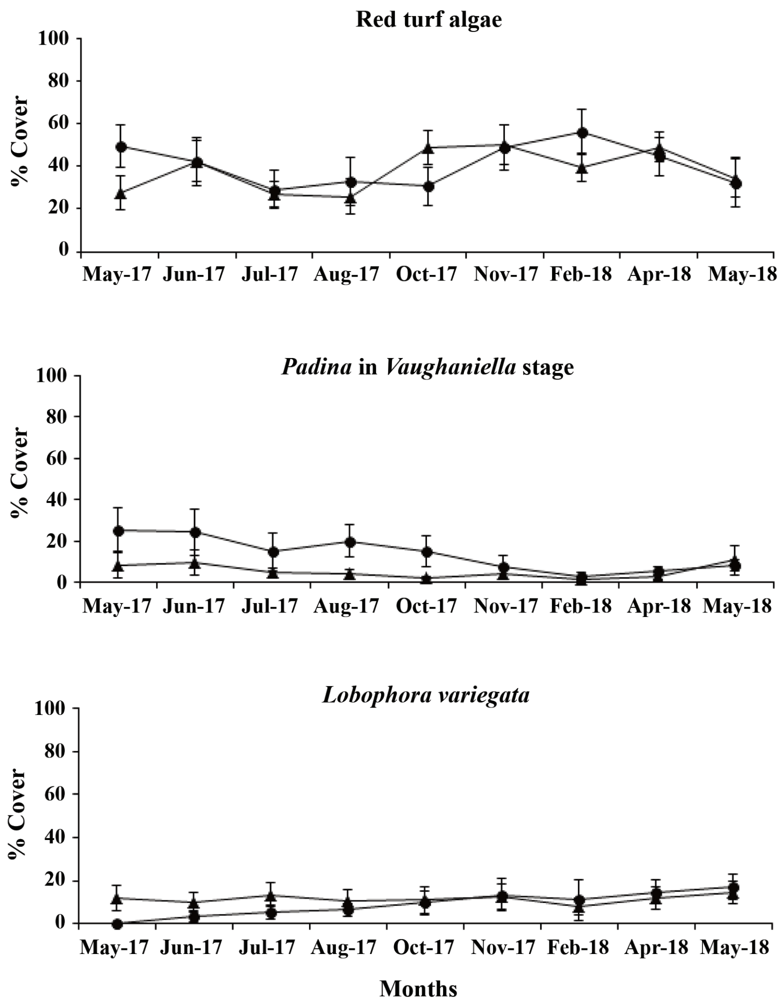

Figure 2. Percentage cover of the three dominant algal species; Red turf algae, *Padina* in *Vaughaniella* stage, and *Lobophora variegata* in control and cleared patches from May 2017 - May 2018 (mean±S.E., n = 10): ▲ = Control patches; ●= Cleared patches.

been found that turf algae can trap and hold sediments to form a mat, causing an unsuitable surface and inhibit algal and coral settlement and colonization (Sousa, 1979; Sousa *et al*., 1981; Diaz-Pulido and McCook, 2002; Eriksson and Johansson, 2003; Birrell *et al*., 2005). *Padina* in *Vaughaniella* stage and *L. variegata* were also among the first colonizers, and recruited the cleared patches, but the percentage cover was low for both species throughout the year. This might be because they are not good competitors, slower colonizers, and have slower growth rates (Mayakun *et al*., 2010); however, they might play a greater role in community dynamics later.

In this study, the results seem to support the inhibition model proposed by Sousa (1979), stating that the pioneer or early species modify or make an environment less suitable for later successional species to recruit. For the successional trends, algal colonization in this study followed a typical successional pattern, dominated by turf and filamentous algae (Diaz-Pulido and McCook, 2002).

Red turf algae had a high percentage cover both in the control and cleared patches, while the other two species had very low coverage, which might be the result of the resident herbivorous damselfishes such as *Neoglyphidodon nigroris* (personal observation). These damselfishes can exclude other herbivorous fishes from their territories and maintain dense stands of red filamentous algae and turf lawns (Ceccarelli *et al*., 2001; Arnold *et al*., 2010). Damselfishes prefer red filamentous algae because they are palatable and high in nutrients, easily digested, and have high productivity (Frédérich and Parmenntier, 2016).

Many studies reported that turf algae might inhibit and delay coral settlement and recruitment by occupying the available space and trapping sediment (Birrell *et al*., 2005). In addition, the chemicals produced by filamentous algae can kill coral tissue (Jompa and McCook, 2003).

In recent years, disturbances and coral bleaching have occurred frequently, and these directly influence benthic communities. The disturbed or bleached coral reefs are likely to be dominated by turf and filamentous algae, which might influence reef recovery. Thus, this research can provide a better understanding of community dynamics and the algal successional pattern, and the consequences of disturbance or bleaching.

CONCLUSION

Our results showed the early successional pattern in a subtidal tropical coral reef. Red turf algae, *Padina* in *Vaughaniella* stage, and *L. variegata* were pioneer groups colonizing the cleared patches. Red turf algae were the dominant group and covered the patches during one year with the highest percentage cover. After establishment, red turf algae inhibited coral settlement and slowed the recovery of the reefs. Our results provide information on algal successional patterns and the recovery of the reef community after disturbance, which is useful in assessing the effects of disturbance of clearing on algal succession on tropical coral reefs. However, further studies would allow us to get a better understanding of the effects of other disturbances on algal succession and the recovery of coral reefs.

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