Monitoring the Impact of Tropical Cyclone on Coral Reef Community and Its Recovery Using Landscape Mosaic Technique at Racha Yai Island, Phuket

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ABSTRACT

Coral reef ecosystems are being degraded through multiple disturbances that are becoming more frequent and severe. This study examined storm impact on coral reef and its recovery using landscape mosaics technique. This technique demonstrated an off-the-shelf underwater camera and the Adobe Photoshop software, end-users in developing countries with limited resources could use the video mosaics technique for reef monitoring and documenting storm impacts. The landscape mosaic technique was used to document the tropical storm impact on coral communities at Racha Island within 3-5 m of water depth. This video-mosaic method provided a spatially landscape view of the reef benthos. The images from the landscape mosaic method revealed that after the storm on November 2012, 20% of the coral cover disappeared within the first month and continued to die off within the six month after the storm. Two years after storm, the results from the images still revealed some slightly increases in the percentage of coral cover but not significant. Most of the coral destroyed by the storm were foliaceous coral - i.e. *Montipora* sp. This study clearly demonstrates that the physical disturbance on coral reef, community changes and its recovery can be monitored using the two-dimensional landscape mosaic technology.

Keywords: video survey, landscape mosaics, *Montipora*, coral recovery, coral reefs, Phuket, Thailand

INTRODUCTION

An association between climate change and increasing storm frequency and intensity has been suggested (Grinsted *et al*., 2013). Storm winds are strengthened by warm waters resulting in increases in rainfall, severe flooding and high levels of terrestrial runoff. Strong storms such as hurricane and typhoon have catastrophic impacts on coral reef worldwide, commonly influenced by the magnitude and duration of storm events, proximity to the reefs, depth on the reef, physical characters of reefs, community composition, coral morphology, and colony size (Gleason *et al*., 2007; Park and Suh, 2012; Yu *et al*., 2012). Strong storms can have physical and biological impacts on coral

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reefs. Physical impacts generated by strong storms include damages due to changes in sedimentation processes, damages due to increased turbidity, damages due to decreased salinity, and damages due to change in sea level (Lugo-Fernández and Gravois, 2010). Biological impacts include a disruption of reef zonation (Grauss *et al*., 1984), the reduction of coral cover (Gardner *et al*., 2005) and algae cover (McClanahan, 2002), the mitigation of coral bleaching (Manzanello *et al*., 2007), the creation of opening space for coral growth and recruitment (Rogers, 1993; Treml *et al*., 1997) and the enhancement of coral dispersal (Gardner *et al*., 2005). Many studies reported changes in ecology and morphology of reefs brought about by tropical storms (Mah and Stearn, 1986; Massel and Done, 1993).

Due to the worldwide decline of coral reef communities occurring at an alarming rate, many countries have initiated monitoring programs to document changes in reef communities (Oliver *et al*., 1995; Chumkiew *et al*., 2011). The long-term trajectories and recovery pattern of coral communities following disturbances are poorly understood (Gardner *et al*., 2005). With the recent technological advances, many monitoring programs now incorporate underwater photography or video into their survey design so that images can be analysed out of the water to measure metrics such as percent coral cover and coral colony sizes for monitoring coral reefs communities (Chumkiew *et al*., 2011; Jaroensutasinee *et al*., 2015). The objective of this study was to apply landscape mosaics technique for monitoring the impact of a storm on coral reef and its recovery at Racha Island, Thailand.

MATERIALS AND METHODS

Study site

This study was conducted at Racha Island, Phuket province, Thailand (Latitude 7.60488 °N, Longitude 98.37660 °E) (Fig. 1). Coral reefs in this area are typically shallow (1-15 m depth) fringing reefs (Bainbridge *et al*., 2011; Jaroensutasinee *et al*., 2011, 2012 a,b). The tides are semi-diurnal with a range of 0.6 (neap tide) to 3.1 m (spring tides).

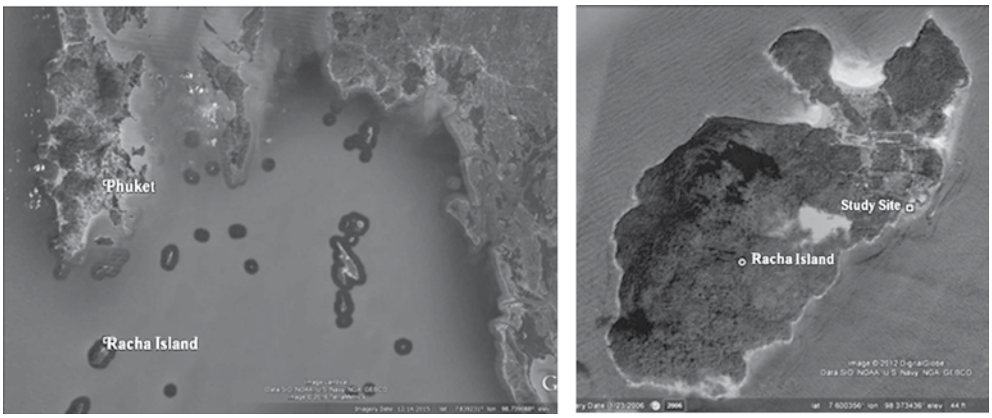

Figure 1. Racha Island, Thailand (Images from Google Earth TM).

Landscape mosaic survey

In this study, the landscape mosaic technique was used to document the tropical storm impact on a population of the laminar coral (*Montipora* sp.) and its recovery at Racha Island within 3-5 m of water depth (Jaroensutasinee *et al*., 2015). The storm passage was on November 2011, we compared four landscape mappings: (1) before storm passage (July 2011), (2) two months after storm passage (February 2012), (3) six months after storm passage (June 2012) and two years after storm passage (November 2013). Four video mosaics of the same reef area were created using different survey focal lengths (Table 1).

Survey focal length was chosen to minimise lens distortion, maximise field of view and increase overlapping regions of the stitching images. The first (July 2011) and second (February 2012) video surveys were collected with Canon Power Shot G11 still camera with housing. The third (June 2012) and fourth (November 2013) video surveys were collected using the same camera model with dome lens. Without dome lens, the camera restored the original 28 mm focal length instead of the 37 mm focal length produced by the flat port of the housing. In the field, the camera was deployed in a down-looking position. Diver swam approximately 1-2 m above the reef area in a lawnmower pattern of side-by-side strips. The method was composed of three steps: (1) capturing the series of parallel underwater videos to still images, a set of key frames was used based on an image superposition criterion (typically 65-80%) using the FrameShots™ software, (2) rotating half of the underwater videos 180º- i.e. when divers swam back, (3) stitching overlapping images and blending the overlapping areas together with the Adobe Photoshop™ CS6.

Benthic characterisation

To quantify the benthic cover from video mosaics, a sample grid was established so that 20 sub-sections of 1.00 m^2 - i.e. the same dimensions as the quadrats used by the standard protocol - were used. Each sub-section was assigned a unique number and drawn a sample by choosing 20 sub-sections from the complete set at random. The images were analysed using CPCe software developed by the National Coral Reef Institute.

Data analysis

For differences among main categories, two-way ANOVA and post-hoc Dunnett T3 tests were used to test for significant

Table 1. Description of the four different mosaics constructed based on digital video collected at Racha Island, Thailand at the depth of 3-5 m

Survey	Date	Re-sample Image size (pixels)	Focal length (mm)	Altitude (m)	Area covered (m^2)
1	09/07/2011	(640 × 480) ~0.3 MP	37	1.0	~100
2	05/02/2012	(640 × 480) ~0.3 MP	37	1.5	~100
3	24/06/2012	(640 × 480) ~0.3 MP	28	2.0	~100
4	27/11/2013	(640 × 480) ~0.3 MP	28	2.0	~100

differences between type of substrate covers - i.e. coral, macro-algae, dead coral, sand, pavement, and rubble, times and its interaction between type of substrate cover and times. For the differences within subcategories, two-way ANOVA and post-hoc Dunnett T3 tests were used to test for significant differences between times, its interaction and (1) within coral types - i.e. *Millepora platyphylla*, *Porites lutea* and *Montipora* sp., (2) within dead coral types - i.e. dead coral with algae, old dead coral, and recently dead coral, and (3) within sand, pavement and rubble. One-way ANOVA and post-hoc Dunnett T3 tests were used to test for the passage of November 2011 storm affecting *Montipora* sp., dead coral with algae, old dead coral, and sand. All statistical tests were two-tailed and significance level was considered as $\alpha = 0.05$. All statistical analyses were performed using SPSS software.

RESULTS

The video mosaics taken in July 2011, February 2012, June 2012, and November 2013 were generated (Fig. 2a-d). After the passage of November 2011 storm, most *Montipora* sp. colonies were removed and

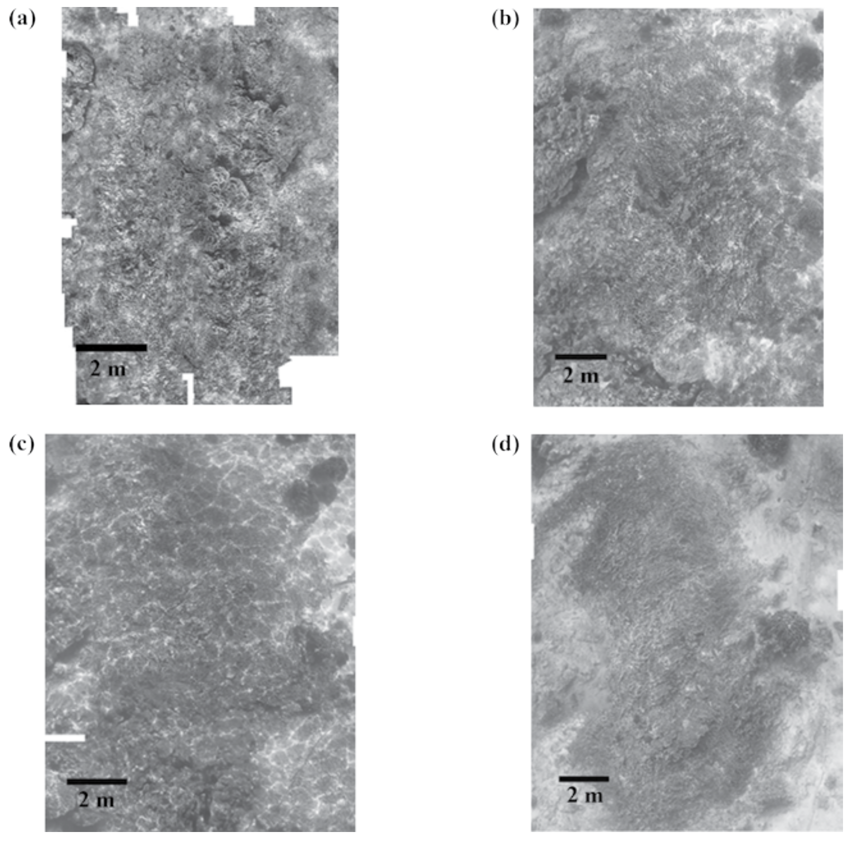

Figure 2. Landscape mosaic constructed with video collected from hand-held digital camera during 2011-2013 at Khonkae Bay (depth 3-5 m); (a) landscape mosaic in 09 July 2011, (b) landscape mosaic in 25 February 2012, (c) landscape mosaic in 24 June 2012 and (d) landscape mosaic in 27 November 2013.

absent from the plot (Fig. 2a-b). There were four main substrates found: macro-algae (1.23%), sand, pavement and rubble (14.54%), live coral (17.30%) and dead coral cover (66.28%) (Fig. 3a). There were some differences between main substrate categories but no difference between times and its interactions (Two-way ANOVA test: substrate: $F_{5,560} = 20.972$, $P<0.001$, time: $F_{3,560} = 0.032$, *ns*; interaction between substrate and time: $F_{9,560} = 1.131$, *ns*, Fig. 3a). Post-hoc Dunnett T3 tests showed that the percentage of dead coral cover was the highest percent substrate cover and the percentage of macro-algae was the lowest (Fig. 3a). Turf macro-algae found at the site before the storm and two months after the storm with the average of 1.23%. The percentage of turf algae cover before the storm passage was higher than six months and two years after storm passage (One-way ANOVA test with post-hoc Dunnett T3 test: $F_{3,47} = 6.624$, $P<0.005$, Fig. 3a). The averaged percentage of pavement, rubble and sand cover were 0.13%, 4.91% and 9.50%, respectively.

When comparing between before and after storm passage, the averaged percentage of pavement, rubble and sand was lowest before the storm passage (One-way ANOVA test with post-hoc Dunnett T3 test: $F_{3,149} = 4.450$, $P<0.05$, Fig. 3a). There were some differences between sand, pavement, and rubble cover, times and its interactions (Two-way ANOVA test: sand, pavement and rubble cover: $F_{2,153} = 18.293$, $P<0.001$, time: $F_{3,153} = 5.729$, $P<0.005$; interaction between types and time: $F_{5,153} = 2.562$, $P<0.05$, Fig. 3b). The percentage of pavement cover was the lowest, the percentage of rubber was intermediate and the percentage of sand was the highest (Fig. 3b). The averaged percentage of coral cover before the storm passage was higher than six months after the storm hit the site (One-way ANOVA test with post-hoc Dunnett T3 test: $F_{3,149} = 3.187$, $P<0.05$, Fig. 3a). There were three coral species found: *Millepora platyphylla* (1.10%), *Porites lutea* (6.49%) and *Montipora* sp. (11.15%) (Fig. 3c). There were some differences between coral types, times and its interactions (Two-way ANOVA test: coral types: $F_{2,153} = 6.467$, $P<0.005$, time: $F_{3,153} = 4.687$, $P<0.005$; interaction between coral types and time: $F_{6,153} = 9.813$, $P<0.001$, Fig. 3c). The percentage of *Montipora* sp. and *Porites lutea* cover was higher than the percentage of *Millepora platyphylla* cover. The percentage of *Montipora* sp. before the storm passage was highest (31.89%), washed away during the storm (3.11%) and slow recovered after two years (9.07%) (One-way ANOVA test with Post-hoc Dunnett T3 tests: $F_{3,47} = 11.250$, $P<0.001$, Fig. 3c). *Millepora platyphylla* and *Porites lutea* did not differ in their percentage cover before and after the storm passage (One-way ANOVA test: $F_{3,47} = 0.451$, *ns*; $F_{3,47} = 1.392$, *ns*, Fig. 3c). The average percentage of dead coral cover did not different (One-way ANOVA test: $F_{3,149} = 0.135$, *ns*, Fig. 3a). There were three categories of dead coral recently dead coral cover (1.90%), dead coral with algae cover (3.43%), old dead coral cover (61.16%). There were some differences between dead coral categories but there was no difference among four times and its interactions (Two-way ANOVA test: substrate: $F_{2,141} = 243.454$, $P<0.001$, time: $F_{3,141} = 0.601$, *ns*; interaction between dead coral and time: $F_{6,141} = 0.992$, *ns*, Fig. 3d). The percentage of old dead coral cover was the highest and the percentage of recently dead coral was lower than dead coral with algae cover (Fig. 3d). Recently

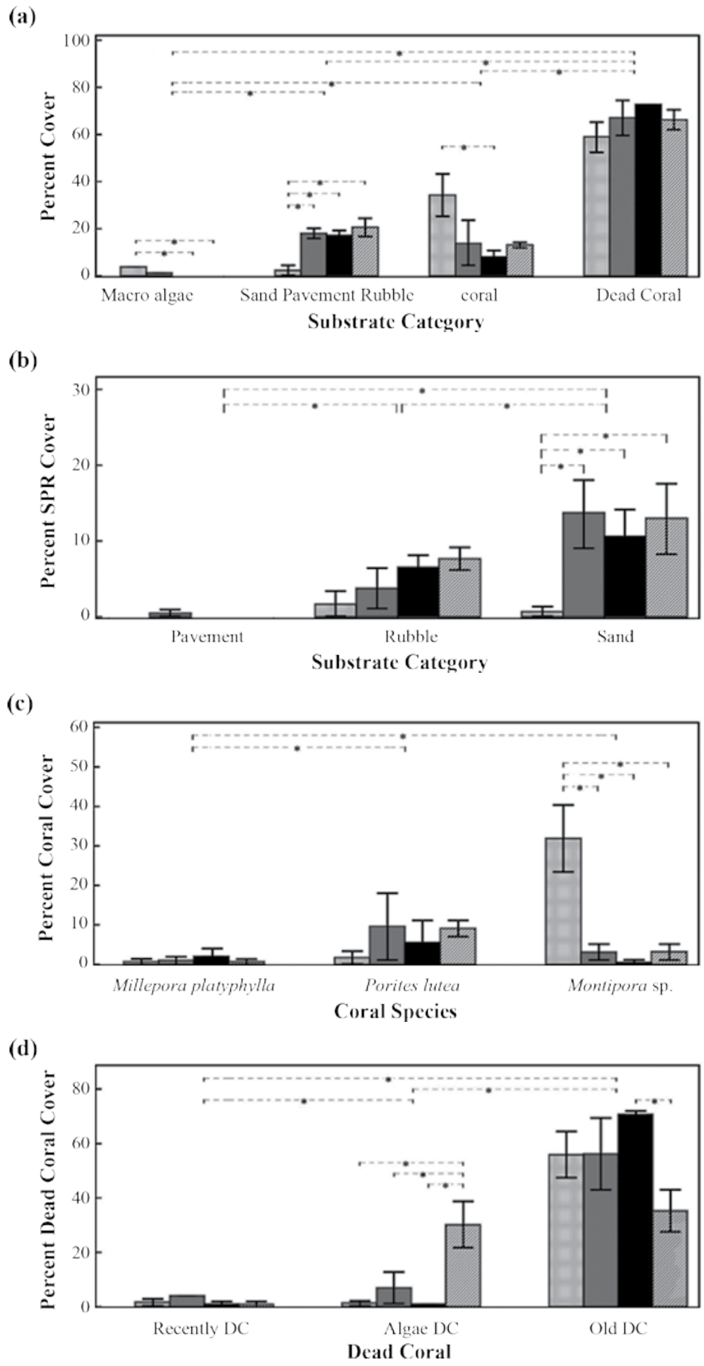

Figure 3. Mean ± SE of benthic substrate categories (%) as estimated by re-sampled from the landscape mosaic over four times measurement. Dashed, grey, black, and cross boxes represent benthic cover during July 2011, February 2012, June 2012, and November 2013, respectively. (a) percent of main benthic substrate categories, (b-d) the subcategories of (a), (b) percentage of sand, pavement, and rubble, (c) percentage of coral species cover, and (d) percentage of dead coral.

dead coral, dead coral with algae and old dead coral did not differ in their percentage cover before and after storm passage (One-way ANOVA test: $F_{3,47} = 2.156$, *ns*; $F_{3,47} = 1.010$, *ns*; $F_{3,47} = 0.186$, *ns*, Fig. 3d).

DISCUSSION

In this study, landscape mosaic mappings of coral reefs at Racha Island taken within 3-5 m of water depth revealed that up to 26% of the coral reef disappeared after the storm passage on November 2011. Branching coral colonies - i.e. *Montipora* sp. were the most which disappeared after the storm. On the other hand, massive colonies of *Porites lutea* were less affected by storms, could better survive transportation by storms, and could colonize new habitats.

After the storm, a large proportion of broken corals faced immediate mortality due to mechanical abrasion, sand scouring and piling up. Most coral fragments that were still alive 1-2 weeks after the storm died within five months (Knowlton *et al*., 1981). This delayed mortality of storm-generated coral fragments is well documented in many places such as in Belize, the U.S. Virgin Islands, and Guadeloupe. Our results from the photo-mosaics technique also documented the delayed mortality of storm-generated coral fragment. There were the significant declined in the percent of sand, pavement and rubble from 2.32% before the storm passage to 20.62% after two years of storm passage.

Many studies report that the succession of benthic algae bloom after storms and cyclones (Harmelin-Vivien, 1994). The succession tends to start with green algae bloom in one to two weeks, followed by red algae lasting for two to four months, and finally replaced by brown algae lasting for six months (Bouchon *et al*., 1991). However, our results did not support these previous findings. There was no algal bloom at the coral reef site on Racha Island. The possible reason is that Racha Island is located 40 km away from the mainland, far from human activities, nutrient load, sedimentation load, and pollution that might cause water quality deterioration. Therefore, no phase-shift from coral to algal bloom would support coral reef recovery.

The recovery of coral and coral communities recognized three different processes: (1) the regrowth of surviving coral fragments, (2) the regeneration of partially damaged coral colonies, and (3) the settlement of coral larvae onto damaged reef surfaces. In this study, landscape mosaic mappings of coral reefs at Racha Island revealed no significant reef recovery after two years post-storm passage. There were some increases in the percentage of coral cover from the regeneration of partially damaged coral colonies, however, these slight increases were not statistically significant. No measurable recovery of live coral has been reported in many places such as St. Croix one year after Hurricane Hugo (Roger *et al*., 1993), British Honduras reefs three years after Hurricane Hattie (Stoddart, 1963), and upper reef zone of Phuket Island 16 months after storm surge (Phongsuwan, 1991). Long-term coral monitoring of storm impact using this photo-mosaic method can help us to improve our understanding about coral reef and reef community changes.

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