Journal of Natural History

ISSN: 0022-2933 (Print) 1464-5262 (Online) Journal homepage: http://www.tandfonline.com/loi/tnah20

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To cite this article: Suchana Chavanich , Voranop Viyakarn , Pramot Sojisuporn , Absornsuda Siripong & Piamsak Menasveta (2008) Patterns of coral damage associated with the 2004 Indian Ocean tsunami at Mu Ko Similan Marine National Park, Thailand, Journal of Natural History, 42:3-4, 177-187, DOI: 10.1080/00222930701847915

To link to this article: http://dx.doi.org/10.1080/00222930701847915

Journal of Natural History
Vol. 42, Nos. 3–4, January 2008, 177–187

Patterns of coral damage associated with the 2004 Indian Ocean tsunami at Mu Ko Similan Marine National Park, Thailand

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(Received 28 July 2007; final version received 1 December 2007)

On 26 December 2004, a severe earthquake in Sumatra caused a series of tsunami waves to strike southwestern coastal areas of Thailand. In this study, we investigated the patterns of tsunami-related damage to coral reefs at Mu Ko Similan Marine National Park. The results showed that the percent of damaged corals ranged from 7.2% to 39.7% of the total live coral cover, and the intensity of the coral damage was high at depths deeper than 10 metres at most study sites. In addition, massive and tabulate coral forms were the most susceptible to tsunami damage. The surveys also revealed that a high degree of coral damage occurred where the reef slope gradually dropped away from the shoreline. Therefore, coral communities and coastal profiles can be major factors influencing the movement of the currents generated by the tsunami and consequently may affect the pattern of coral damage by the tsunami.

Keywords: *tsunami*; *coral reef*; *coastal profile*; *coral lifeform*; *shore*

Introduction

On 26 December 2004, a severe earthquake occurred in the Indian Ocean approximately 250 km west of Sumatra, Indonesia with a magnitude of 9.3. It caused a series of tsunami waves, and within 1.52 hours, the tsunami waves reached southwestern coastal areas of Thailand, located on the northeast of Sumatra (Siripong 2006). Six provinces of Thailand – Ranong, Phangnga, Phuket, Krabi, Trang and Satun – were affected by the tsunami (Department of Marine and Coastal Resources 2005; Siripong 2006). The highest run up in Thailand (15.68 m) was seen at Pakarang Cape in Phangnga Province while the longest inundation distance (3 km) occurred at Bang Nieng in Phangnga Province (Siripong 2006). After the incident in Thailand, rapid assessment surveys were conducted by the Department of Marine and Coastal Resources and nine academic institutes to investigate coral damage in the affected areas. The preliminary results showed that overall coral damage was low, although damage was found as deep as 27 m (Chavanich et al. 2005; Department of Marine and Coastal Resources 2005; Pennisi 2005). From the immediate surveys of 174 sites, only 13% of the sites were severely damaged (Department of Marine and Coastal Resources 2005; Pennisi 2005; Wilkinson et al. 2006). Types of coral damage included broken, overturned, sediment-covered and collapsed colonies (Brown 2005; Chavanich et al. 2005; Coral Cay Conservation

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ISSN 0022-2933 print/ISSN 1464-5262 online

DOI: 10.1080/00222930701847915
http://www.informaworld.com

2005; Department of Marine and Coastal Resources 2005; Wilkinson et al. 2006; Phongsuwan and Brown 2007; Satapoomin et al. 2007). In addition, in some areas, a significant amount of sand, up to two metres deep, was transported away from the area (Chavanich et al. 2005). The tsunami not only smothered but also abraded the seafloor habitat (Birowo et al. 1983; Chavanich et al. 2005).

It is unclear why the tsunami caused more damage in some locations than in others. Several studies reported that the damage to coral reefs by the tsunami in Thailand was unpredictable and localized (Phongsuwan and Brown 2007; Satapoomin et al. 2007). Nevertheless, aspects of reefs and shores including coastal profiles and coral colonies growing on unconsolidated substrates are factors possibly influencing the pattern of coral damage caused by the tsunami (Baird et al. 2005; Brown 2005; Campbell et al. 2007; Satapoomin et al. 2007). However, no detailed studies were undertaken to validate the linkage between the pattern of coral damage and those factors. In this study, we investigated the patterns of tsunami-related damage to coral reefs, the coastal profiles and the coral composition where damage occurred.

Materials and methods

Mu Ko Similan Marine National Park in Phangnga Province, the southern islands of Thailand, was surveyed during January 2005 to examine the patterns of coral damage after the tsunami on 26 December 2004. From the numerical model, this area experienced tsunami waves from 5 to 15 metres high (Sojisuporn, unpublished data). Data were collected within one month of the tsunami while tsunami-inflicted damage was still evident. Thus, it was not difficult to categorize whether the damage was caused by the tsunami or was pre-existing. Six study sites around two islands, Ko Similan and Ko Ba-Ngu, located in Mu Ko Similan Marine National Park were investigated (Figure 1). In this particular area, trash and debris were not evident on the reefs after the tsunami. Hence, patterns of coral damage were solely from the impact of 2004 tsunami waves. At each site, ten 150–200 m long transects were established perpendicular to the island shoreline, and aligned from the shallowest areas (the beginning of the reef flat) to the deepest parts (the base of the reef slope) of the reefs. Data were collected every 2 m along the transect at points where the measuring tape touched corals or substrates. Data included 1) substrate cover type (live coral, tsunami-damaged coral, dead coral (not caused by the 2004 tsunami), sand, coral rubble, rock and others), 2) coral lifeform (foliose, branching, tabulate, massive and others), 3) types of tsunami damage (broken, overturned, sand covered, recently killed and others), and 4) water depth. These data categories were based on the reef characteristics in the study areas. The data gathering method was specifically developed and modified from the guidelines for rapid assessment and monitoring for tsunami damaged coral reefs (ICRI/ISRS 2005). In addition, to estimate the percentage of live coral cover before the tsunami, the percentages of undamaged and tsunami-damaged corals were combined. Pearson correlation tests were used to examine the relationship between the percentage of tsunami-damaged coral cover and the percentage of pre-tsunami coral cover. Tests were done using Systat 9.0.

Coastal profile data collected during the field surveys at each site is shown in Figure 2. Two distinct coastal profiles characterized the selected sites. At three locations, the reef sloped away from the shoreline with a gentle gradient (Snapper Alley Point, Water Fall and Christmas Point) to the base of the reef slope which was

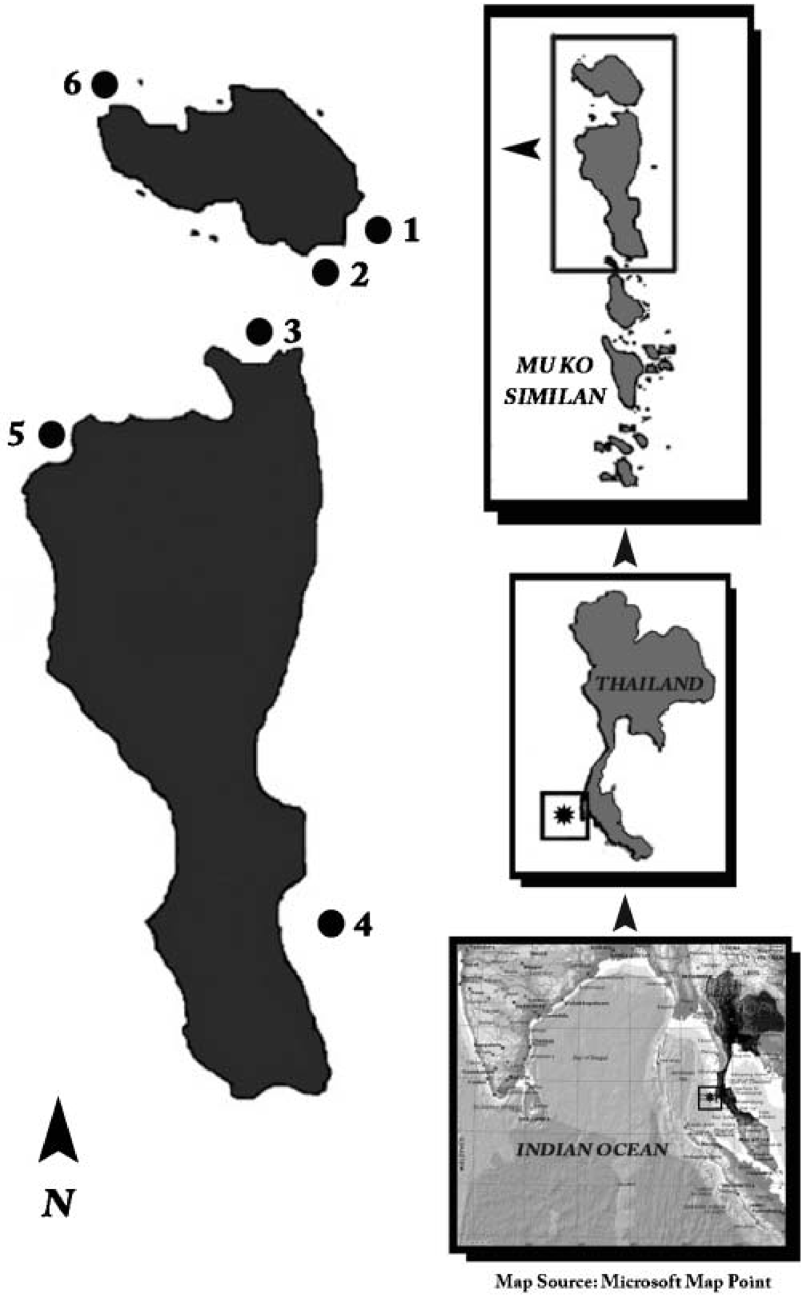

Figure 1. Map of the study sites (1=Grandmother Rock, 2=Snapper Alley Point, 3=North Point, 4=Beacon Reef, 5=Water Fall, 6=Christmas Point).

approximately 150–200 metres from the shoreline. In contrast, at the remaining three sites (Grandmother Rock, North Point and Beacon Reef) the lower reef slope showed a very steep gradient to the reef base which was between 150–180 metres from the shore.

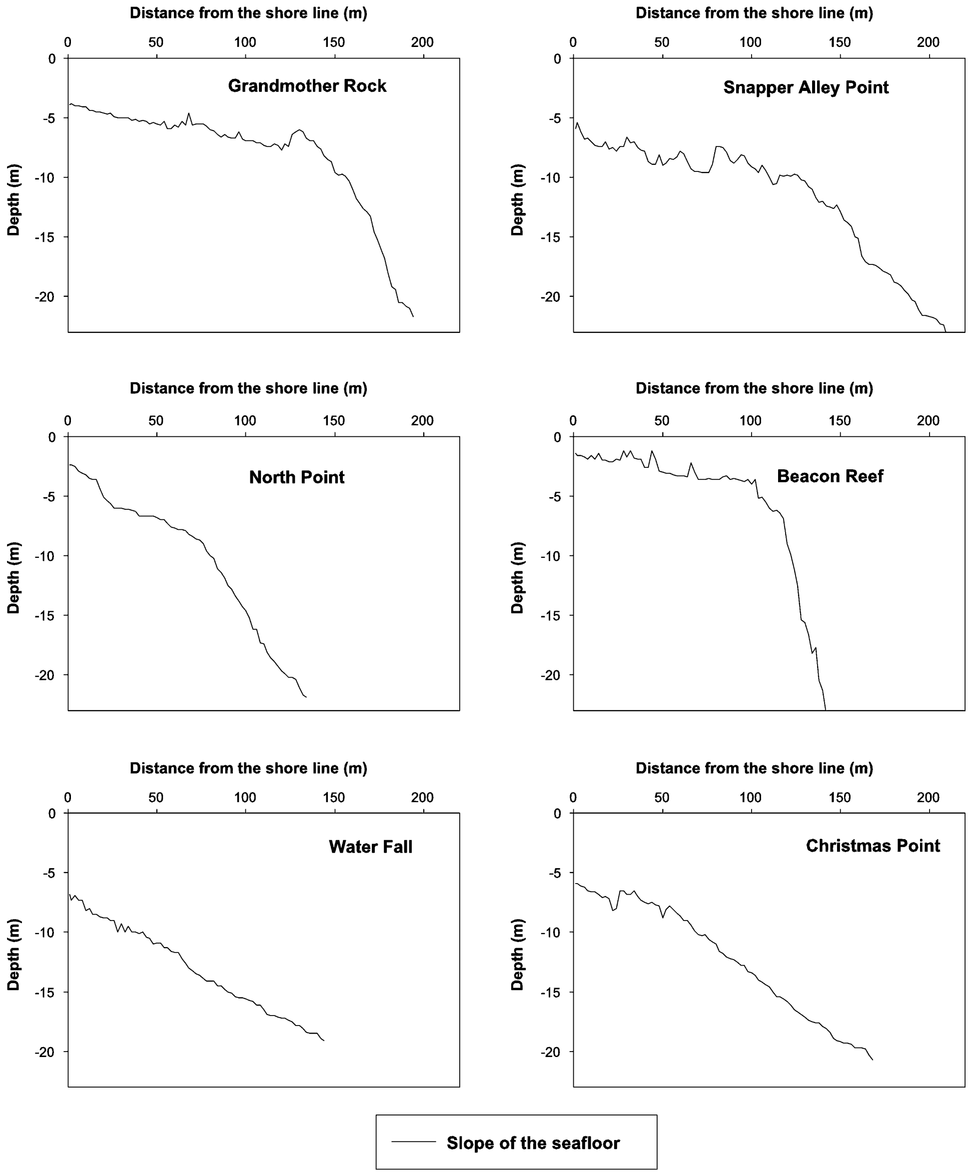

Figure 2. Cross sections of coastal profiles at six sites (0 depth=surface sea level).

Results

The proportion of tsunami damaged corals at different sites was very variable ranging from 7.2% at Beacon Reef to 39.7% at Snapper Alley Point (Figure 3). The greatest damage occurred at Snapper Alley Point followed by North Point, Water Fall, Christmas Point, Grandmother Rock and Beacon Reef. The results indicated that five of the six reef sites had a higher intensity of damage at depths deeper than 10 metres compared to the damage in shallow water (Figure 3). Four major types of damage were recorded at the study sites; broken, overturned, sand covered and

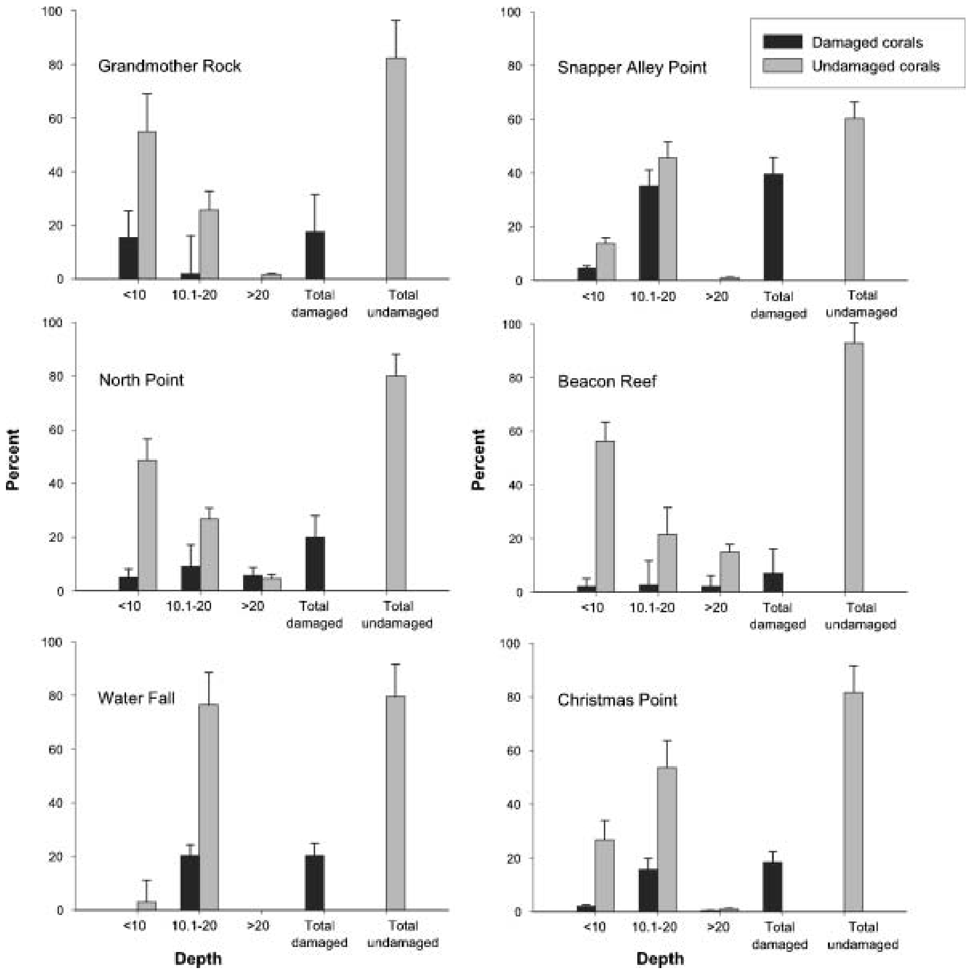

Figure 3. Percent live coral cover on tsunami-damaged corals and undamaged corals at three different depths (<10, 10.1–20, >20 m) in six locations.

recently killed coral colonies. The intensity of each damage type varied among sites (Figure 4). Higher proportions of broken coral (61.5% of total damage) and sand-covered coral (30.8% of total damage) were found at Beacon Reef where the percent coral damage was the lowest (7.2% of total pre-tsunami live coral cover) compared to other sites (Figures 3 and 4). In addition, the highest percentage of overturned corals (40.9% of total damage) occurred at Snapper Alley Point where the highest percentage of coral damage was detected compared to other sites (Figures 3 and 4). From the surveys, four major coral lifeforms in the area were foliose, branching, tabulate and massive (Figure 5). The foliose form was less susceptible to the tsunami than other coral lifeforms while the forms most affected by the tsunami were the massive and tabulate forms (Figure 5, Table 1). From Table 1, all four types of damage were detected in the tabulate and massive forms, but not in the foliose and branching forms. In addition, in the foliose form, no sand-covered and overturned colonies were found, and sand-covered examples were not detected in any branching

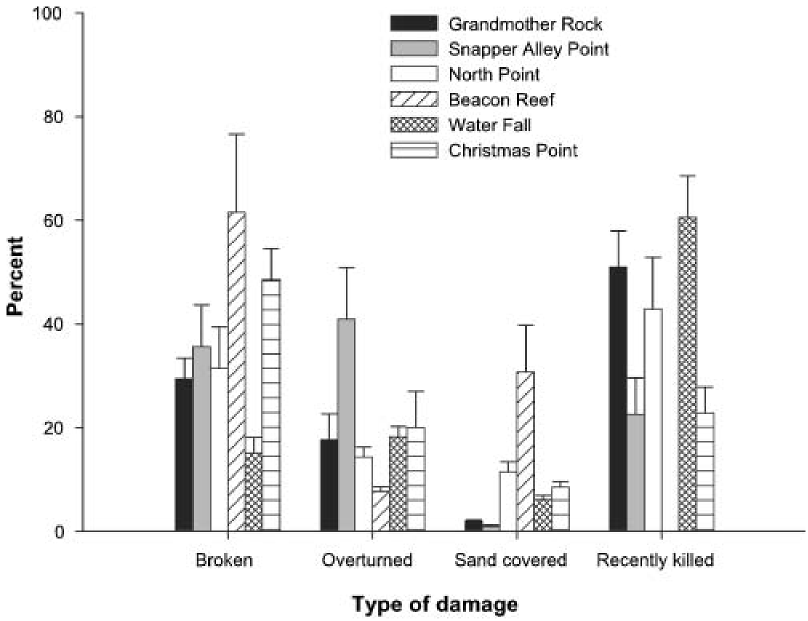

Figure 4. Types of coral damage caused by the tsunami at six different sites.

forms. The results also showed that some corals were dead within a month of the tsunami (Table 1). Moreover, our observations found that the damage to corals at the six study sites occurred in situ and was a result of corals being moved by the tsunami.

Coral community composition at each site is summarized in Table 2. The results showed that pre-tsunami live coral cover in the study areas ranged between 37.2% and 57.4% of total substrate cover (Table 2). Statistical analyses, using the Pearson correlation test, showed that there was no correlation between the percent coral damage caused by the tsunami and the percent pre-tsunami live coral cover ($p>0.05$).

Discussion

In Thailand, strong and powerful currents and waves generated by the tsunami during 26 December 2004 caused great loss and destruction to buildings and infrastructure. The impact of the 2004 earthquake and tsunami on reefs varied between sites and countries (Wilkinson et al. 2006). In Simeulue Island, Indonesia, the earthquake caused large areas of reefs to be uplifted by 1–2 m above sea level, and killed the reefs (Foster et al. 2005; Searle 2006; Wilkinson et al. 2006). However, the overall results from both preliminary and intensive surveys showed that the tsunami damage to Thai coral reefs was low; only 13.2% of the reef sites were severely damaged (Allen and Stone 2005; Brown 2005; Chavanich et al. 2005; Coral Cay Conservation 2005; Department of Marine and Coastal Resources 2005; Wilkinson et al. 2006; Phongsuwan and Brown 2007; Satapoomin et al. 2007; this study).

At Mu Ko Similan Marine National Park, the most damaged area was at Snapper Alley Point (39.7% coral damage), followed by Water Fall (20.4% coral

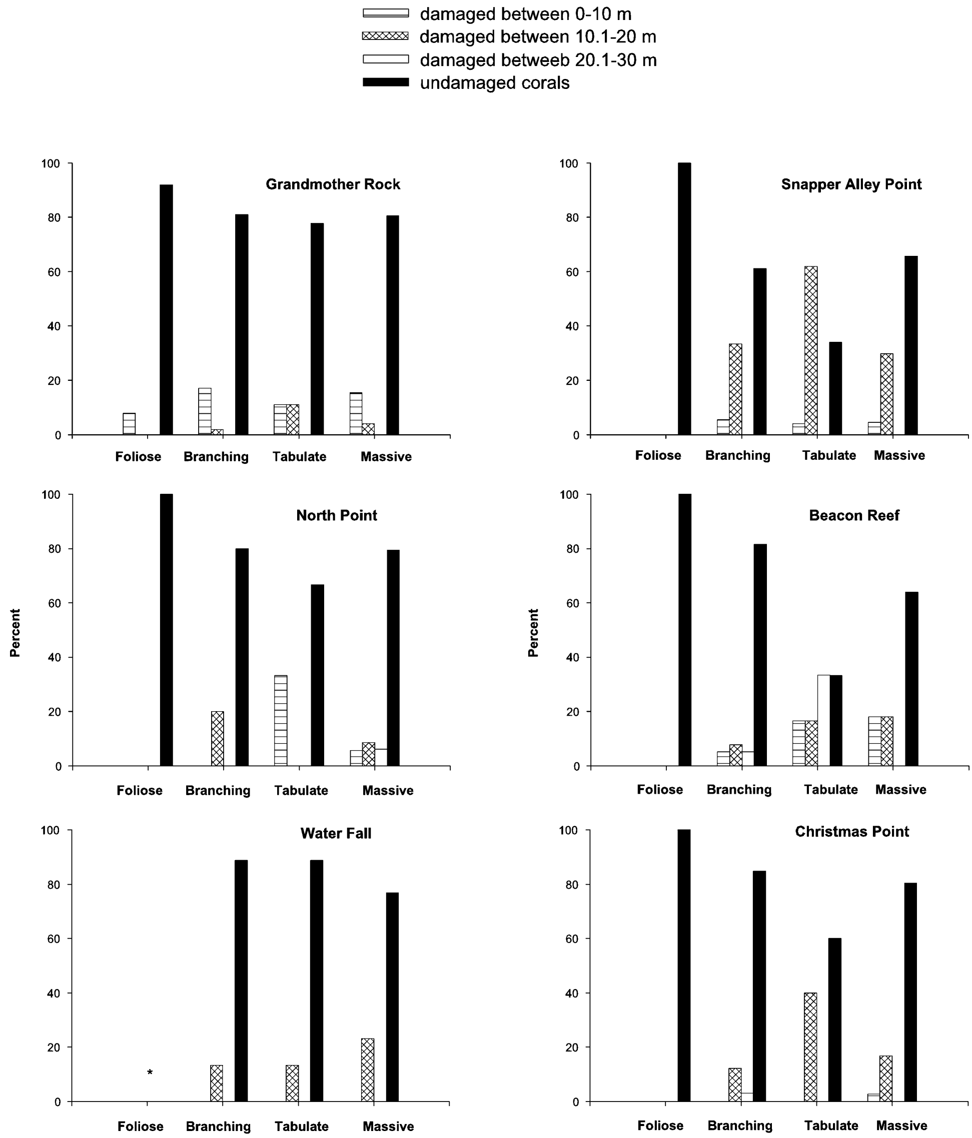

Figure 5. Percent tsunami-coral damage for each coral lifeform at various depths at six sites.

damage) and North Point (20.0% coral damage) (Figure 3). The relative damage estimated from this study was lower than the value recorded by the Department of Marine and Coastal Resources (2005). This is due to different survey methods being used. The Department of Marine and Coastal Resources used a visual estimation method while this study was based on quantitative surveys using line transects. The results from the present study showed that most coral damage occurred at depths where the reef slope gradually dropped away from the shoreline. Therefore, corals lying between those areas were the most affected by the tsunami. Interestingly, comparing coastal profiles with the pattern of coral damage caused by the tsunami,

Table 1. Percent coral cover on undamaged and damaged corals and types of coral damage in each coral lifeform at different sites (GRM=Grandmother Rock, SAP=Snapper Alley Point, NP=North Point, BR=Beacon Reef, WF=Water Fall, CP=Christmas Point).

Coral lifeforms	Sites	Undamaged corals (%)	Types of coral damage: Broken	Overturned	Sand covered	Recently killed
Foliose	GRM	92.00	6.00	0.00	0.00	2.00
	SAP	100.00	0.00	0.00	0.00	0.00
	NP	100.00	0.00	0.00	0.00	0.00
	BR	100.00	0.00	0.00	0.00	0.00
	WF	–	–	–	–	–
	CP	100.00	0.00	0.00	0.00	0.00
Branching	GRM	81.00	17.00	2.00	0.00	0.00
	SAP	61.10	33.60	0.00	0.00	5.30
	NP	80.00	20.00	0.00	0.00	0.00
	BR	81.60	18.40	0.00	0.00	0.00
	WF	86.70	6.64	3.33	0.00	3.33
	CP	84.80	3.04	9.12	0.00	3.04
Tabulate	GRM	77.80	0.00	11.1	11.10	0.00
	SAP	34.00	26.00	40.00	0.00	0.00
	NP	66.70	0.00	0.00	0.00	33.30
	BR	33.30	16.68	16.68	33.35	0.00
	WF	86.70	0.00	13.30	0.00	0.00
	CP	60.00	0.00	20.00	0.00	20.00
Massive	GRM	80.50	1.20	3.30	0.00	15.00
	SAP	65.60	9.90	12.80	0.45	11.25
	NP	79.50	5.58	3.10	2.48	9.34
	BR	63.97	0.00	0.00	36.03	0.00
	WF	76.90	2.56	2.56	1.71	16.27
	CP	80.40	9.80	3.50	2.10	4.20

Table 2. Percent cover for different substrates: post-tsunami live coral cover, tsunami-damaged coral cover, dead coral (before the tsunami), sand, rubble and rock at six study sites.

Habitat composition	Grandmother Rock	Snapper Alley Point	North Point	Beacon Reef	Water Fall	Christmas Point
Pre-tsunami live coral cover (%)	37.2	44.4	40.0	57.4	44.7	47.9
Post-tsunami live coral cover (%)	30.6	26.6	32.0	53.3	35.6	39.1
Tsunami-damaged coral cover (%)	6.6	17.5	8.0	4.1	9.1	8.8
Total dead coral cover (%)	12.5	11.1	14.4	13.3	18.5	10.6
Sand (%)	37.1	13.5	15.5	18.4	4.4	2.3
Rubble (%)	13.2	25.0	29.6	10.9	32.4	39.2
Rock (%)	0	6.3	0.5	0	0	0

it appeared that those sites which had a gentle gradient suffered greater damage at depth than those with a steep gradient. At Mu Ko Surin Marine National Park, Thailand, more coral damage was found in deeper zones where the slope was steep (Coral Cay Conservation 2005; personal observations), and there was a correlation between live coral cover before the tsunami and the proportion of damage caused by the tsunami (Coral Cay Conservation 2005). However, in this study, there was no correlation between percent tsunami-damaged corals and percent pre-tsunami live coral cover.

Broken, overturned, sand-covered and dead corals constituted the major types of coral damage. The types of damage varied between the areas depending on the composition of coral lifeforms at the locations. The overturned category tended to be found in massive and tabulate coral forms while the broken category was most often seen with the branching corals (Table 1). Sand covered colonies were most frequently massive and tabulate forms. It is interesting to note that study sites either did not have sandy beaches on the shore or nearby, or had very small areas of sandy beach before the tsunami. Moreover, there was no detection of sand erosion along the shores at the study sites after the tsunami (personal observations). Therefore, sand that covered corals most likely originated from the seafloor. It is probable that the tsunami wave carried the sand from the seafloor and deposited it on reefs and shallow areas. Chavanich et al. (2005) described areas on the seafloor of Mu Ko Similan Marine National Park where large quantities of sediment had been moved elsewhere.

Results from the current study showed that massive and tabulate corals were the most susceptible to tsunami damage at almost every site (Table 1). Coral morphology clearly has an influence on the types of coral damage inflicted by the tsunami. Large sized corals were also more susceptible to tsunami damage than the smaller colonies. In contrast, foliose forms were least affected by the tsunami. Typically, branching forms are considered to be the most fragile; however, during the tsunami, the branching morphology allowed strong currents to pass through the coral structure whereas poorly anchored massive and tabulate species overturned (Baird et al. 2005).

Within a month of the tsunami, recently killed corals were found in every coral lifeform category (Figure 4, Table 1). Even though some corals recovered or regrew upwards at other sites (Coral Cay Conservation 2005), in the present study, some corals, particularly massive and tabulate forms, did not survive.

The geographic position of shores and islands can also influence tsunami-induced damage to corals. When the tsunami reached the Similan Islands, it travelled from the west to the east (Sojisuporn, unpublished data), and was forced to squeeze through a narrow channel between islands with increasing force. Snapper Alley Point and North Point are located along the walls of the channel (Figure 1) and therefore, corals in those two areas were more affected by the tsunami.

It seems that tsunami damage to corals is both variable and unpredictable, as found in other studies (Baird et al. 2005; Campbell et al. 2007). In some areas in Thailand, coral damage was found at shallower sites where corals were patchy, and grew on unconsolidated substrate or sand. For example, at Pakarang Cape, north of Khao Lak, and Ko Prathong, Phangya Province in Thailand, large blocks of corals were deposited on the shore after the 2004 tsunami (Goto et al. 2007; personal observations). In other areas, debris and trash which fell onto the reefs after the tsunami also influenced damage on shallow reefs such as in Phi Phi Island (Department of Marine and Coastal Resources 2005). Thus, this may be the reason why the high intensity of coral damage was seen in the shallower areas, and therefore, the patterns of coral damage in those areas were not the pattern solely affected by the tsunami waves.

In summary, in areas where corals grow on consolidated substrates, and debris and trash did not fall onto reefs after the tsunami, composition of coral lifeforms and coastal profiles can be the major factors influencing the pattern of coral damage by tsunamis. Other factors, such as reef types and reef boring organisms, may also contribute to the linkage between the tsunami and the pattern of coral damage; however, more detailed studies are needed to validate those factors.

Acknowledgements

We would like to thank Supachart Soopanich for field assistance and Chareon Nitithamyong for initial encouragement. Piya Koeysin, Chalothon Raksasab, Se Songploy, Lalita Putchim, Thepsuda Loyjiw, Nipat Somkleeb and Udomsak Darumas helped in collecting field data. We also thank Hugh Kirkman, Barbara Brown and anonymous reviewers for editing and comments on the manuscript. This work was supported by Ratchadapiseksomphot Endowment Fund of Chulalongkorn University, the Ministry of Natural Resources and Environment, Thailand, National Geographic Society (7986-06), and PADI Project AWARE (2Q06.15).

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