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CORAL DISEASE: BASELINE SURVEYS IN THE ANDAMAN SEA AND GULF OF THAILAND

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ABSTRACT: Within the last decade, coral disease has become an issue of concern around the world. However, little is known about the presence of coral disease in Thailand. This pilot study aimed to establish a baseline for future long-term monitoring comparison on reefs of southern Thailand. A total of 87 surveys were conducted from November 2007 to August 2008 using the semi-quantitative Belt Method. Disease occurred on 66% of reefs surveyed in the Andaman Sea and 77% of reefs surveyed in the Gulf of Thailand in levels ranging from rare (0–3 cases per survey) to abundant (25–50 cases per survey). It is important to note that while disease was observed on a high percentage of reefs, the relative frequency of disease observations within a reef was low in comparison to the Caribbean or Great Barrier Reef. About 29% of reefs or 25 sites exhibited disease in levels above rare, all of which were located off heavily developed beaches and/or heavily toured areas. Overall, eight coral genera, comprising 18+ species, were observed to be affected by four disease categories: pink line syndrome, white syndrome, black band disease and the Thai aspergillosis variant. This broad-based disease survey is the first of its kind in Thai waters. Increased awareness and future long-term monitoring of coral disease is needed to fully understand disease dynamics on the reefs of Thailand.

Key Words: coral disease, baseline survey, Belt Method, Andaman Sea, Gulf of Thailand

INTRODUCTION

Throughout the past thirty years, coral disease has become an increasingly important issue concerning researchers around the world. Field observations suggest that coral disease has increased in both incidence and outbreak severity since the mid-1990's (Richardson, 1998; Harvell *et al.*, 1999; Sutherland *et al.*, 2004). The majority of observations are reported in the Caribbean and Great Barrier Reefs, while the Indo-Pacific seems to be less affected (Sutherland *et al.*, 2004). Little is known about the presence or prevalence of coral disease in Thailand.

To diving enthusiasts, the reefs of Thailand have long been considered some of the best in the world. Yet survey data, based on the proportion of live to dead coral cover, established that 25% of reefs in the Andaman Sea were already in poor condition in the early 1990s (Phongsuwan and Chansang, 1992). Reefs along the Andaman coast are also still in the process of recovering from the Tsunami of 2004 (Phongsuwan *et al.*, 2005). Anthropogenic disturbances due to tourism, coastal development and other industries are evident on many reefs (Brown and Holley, 1982; Brown *et al.*, 1990; Chansang *et al.*, 1992; Clarke *et al.*, 1993; Brown, 2007). In a comparison of dissolved nutrient levels, sites in Phuket were on par with sites in the Florida Keys and Barbados that tend to eutrophication (Brown *et al.*, 1999). Elevated particulate loads are also present in inshore waters (Scoffin *et al.*, 1992; Panutrakul, 1996).

Coral disease was first observed in the Indo-Pacific (Antonius, 1985). Black band and "white band" diseases predominated early observations (Antonius, 1985; Coles, 1994; Littler and Littler, 1996). Pink-line syndrome, affecting only *Porites sp.*, is thought to be caused by the cyanobacterium *Phormidium valderianum*

(Ravindran and Raghukumar, 2006). Antonius and Lipscomb (2000) identified the first eukaryotic disease, a protist infection, widely distributed across the Indo-Pacific. Porites ulcerative white spot (PUWS), a novel disease affecting *Porites* sp. was first described in the Philippines (Raymundo *et al.*, 2003). Haapkyla *et al.* (2007) conducted a baseline coral disease survey of Wakatobi Marine Park, Indonesia, the first of its kind in the region. Compared to the more heavily monitored Caribbean and Great Barrier Reefs, however, the state of coral disease throughout the Indo-Pacific is thought to be under-documented (Raymundo *et al.*, 2003).

Fewer still are observations within Thailand. In an initial comprehensive review of disease in the Indo-Pacific, Green and Bruckner (2000) reported no disease observations in Thailand. In October 2005, an outbreak of an aspergillosis variant was identified in the Similan Islands, marking the first observation of this disease outside of the Caribbean (Phongpaichit *et al.*, 2006). Other records of disease observations in Thai waters are limited to the coral disease database on ReefBase, the most recent observation dating from 2003 (http://www.reefbase.org).

The relatively unknown condition of Thai reefs with respect to coral disease presents a unique opportunity to establish a baseline data set. The majority of information on coral disease has been compiled post-outbreak (Santavy *et al.*, 2001; Ward and Lafferty, 2004; Selig *et al.*, 2006). Researchers speculate as to the normalcy of low levels of coral disease on reefs, but the need for baseline data is evident (Harvell *et al.*, 1999, 2002, 2004). This pilot study aimed to establish a baseline data set for future long-term monitoring comparison on the reefs of southern Thailand.

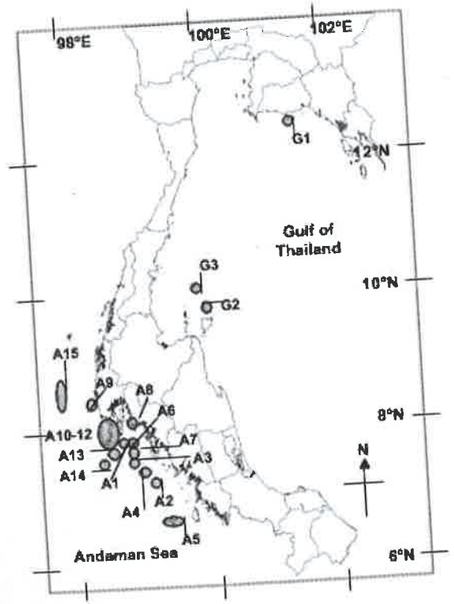

Figure 1. Relative locations of site groups. A1, Eastern Dive Sites; A2, Hin Daeng/Muang; A3, Ko Bida; A4, Ko Ha; A5, Ko Adang/Rawi; A6, Ko Phi Phi Don; A7, Ko Phi Phi Lei; A8, Krabi/Ao Nang; A9, Phang Nga; A10, Phuket East; A11, Phuket South; A12, Phuket West; A13, Racha Noi; A14, Racha Yai; A15, Similan Islands. G1, Ko Man Nai; G2, Ko Phang Nga; G3, Ko Tao.

MATERIALS AND METHODS

Study Sites

A key objective was to survey the broadest area possible. A total of 87 sites were surveyed, 74 in the Andaman Sea and 13 in the Gulf of Thailand (Fig. 1, Table 1). Sites were grouped based on relative proximity and selected based on continued monitoring ability. Study sites varied greatly in depth, reef type, level and nature of disturbance. Between sites, depth ranged from one meter for snorkeled sites to 25 meters for deep dive sites, but within site depths varied no more than 5 meters.

Disease Survey Methodology

In total, 87 surveys were conducted from November 2007–August 2008, 74 in the Andaman Sea and 13 in the Gulf of Thailand. Due to the reported 'nonexistence' of disease (personal communications) and general lack of prior data, the Belt Method developed by Antonius (1995) was selected as the most efficient way to cover large areas of reef. The Belt Method is a semi-quantitative time count technique. Disease observations over a thirty-minute time swim are categorized based on observation frequency. Time swims were conducted perpendicular to the reef slope. Starting points were determined by the initial

Table 1. Disease condition average per site group. Average consists of the sum of all disease condition rankings per individual site divided by the total number of sites in that group. For example, site group A-4, Ko Ha, consisted of four sites in total, two at 0 cases observed and two at condition 1, which averages to a condition of 0.5 over all sites. * Indicates site group average above rare.

Fig. 1 Site Key	Site Group	# Sites	Condition Avg.	Genera Affected
Andaman Sea				
A-1	Eastern Dive Sites	2	0	
A-2	Hin Daeng/Muang	2	0	
A-3	Ko Bida	2	0	
A-4	Ko Ha	4	0.5	*Porites*
A-5	Ko Adang-Rawi	16	1.9*	*Acropora,Echinopora, Porites*
A-6	Ko Phi Phi Don	6	1.67*	*Acropora, Porites, Diploastrea*
A-7	Ko Phi Phi Lei	2	0	
A-8	Krabi/Ao Nang	2	1	*Acropora, Porites*
A-9	Phang Nga	4	1	*Acropora, Hydnophora, Porites*
A-10	Phuket East	2	0.5	*Porites*
A-11	Phuket South	8	0.67	*Acropora, Porites*
A-12	Phuket West	7	1.71*	*Acropora, Favia, Diploastrea, Porites*
A-13	Racha Noi	3	0.33	*Porites*
A-14	Racha Yai	2	0.5	*Porites*
A-15	Similan Islands	13	0.54	*Acropora, Anella*
Gulf of Thailand				
G-1	Ko Man Nai	3	0.67	*Porites, Echinopora*
G-2	Ko Phang Ngan	3	0.67	*Porites*
G-3	Ko Tao	7	2*	*Acropora, Pavona Diploastrea, Porites*

descent for dive surveys. For snorkel surveys, starting points were determined by the extent of the reef, beginning on one end of the reef track. For small islands or submerged rocks surveys were again conducted perpendicular to the slope, but trajectories were altered to the circumference of the site. The amount of reef covered per survey was dependent on percent coral cover. Distance covered varied from approximately 300 to 500 meters by 2 meters, resulting in anywhere from 600 to 1000 m^2 per site, with shorter distances reflecting a higher percent coral cover and longer distances reflecting lower cover.

Data Analysis

Routine data collected consisted of disease observed, genus affected, colony depth and photo documentation. Predation of *Acanthaster planci*, *Drupella* sp., or any fish were identified and not included in this study. In order to differentiate predation or physical damage from general white syndromes, specific symptoms were looked for. White syndromes were diagnosed as progressive tissue death that had no identifiable cause. A gradation was readily observed from healthy tissue to an area of tissue sloughing, followed by an area of freshly exposed skeleton and finally algae covered skeleton with an increasing algae cover proportional to the amount of time the skeleton had been exposed. *A. planci* damage was distinguished as a wide stripe of sloughing tissue or skeleton. It usually had a heavy mucous coating and in most cases the predator was still in the vicinity of the damaged colony. *Drupella* sp. predation was characterized by the presence of large numbers of snails along the band of tissue sloughing. Fish predation is easily differentiated as isolated bite marks with no subsequent tissue sloughing.

Physical damage was not included in this study, unless it resulted in a subsequent disease event. For example, in clean breaks where tissue sloughing was not observed, the colony was simply marked as damaged. However, in some cases, physical damage resulted in subsequent white syndrome symptoms. For example, fishing line and rope were frequently observed tangled in *Acropora* sp. In some instances, the coral had grown over the rope and no damage was observed. In others though, the colony displayed the progressive tissue sloughing as observed in white syndromes. These colonies were marked as diseased. Coral bleaching was infrequently observed during surveys and did not interfere with disease identification because tissue was present in all cases.

Based on field observations, disease type was sorted into four categories (Fig. 2). White syndrome (WS) refers to any undistinguishable plague, shut down reaction or band perceived to be actively affecting a specific colony as described above. While the Caribbean experiences a wide variety of white diseases, white syndromes observed in the Indo-Pacific region have not been well defined. The putative pathogen is unknown and it is not clear if the symptoms represent multiple diseases or even if the syndrome is infectious (Willis *et al.*, 2004). Pink-line syndrome (PLS) affected only the genus *Porites* as described by Ravindran and Raghukumar (2002, 2006). This was characterized as a deep pinking of the tissue that did not result in any swelling. It was readily distinguishable from trematode infection, which results in considerable polyp swelling as described by Aeby (2003). The final two disease observations were black band disease (BBD) first observed in the Indo-Pacific by Antonius (1985) and the aspergillosis variant (ASP) *Aspergillus versicolor* reported by Phongpaichit *et al.* (2006).

Disease observations were analyzed based on the Belt Method ranking system (Antonius, 1995). Per 30-minute time swim, 1–3 cases is indicative of condition 1 (rare), 4–12 of condition 2 (moderate), 13–25 of condition 3 (frequent), 26-50 of condition 4 (abundant), 51–100 of condition 5 (epidemic), 100+ of condition 6 (catastrophic). Random consistency checks of these ranges proved accurate in repetition of initial observation results.

RESULTS

Of the 87 surveys conducted, disease occurred on 66% of reefs surveyed in the Andaman Sea and 77% of reefs surveyed in the Gulf of Thailand in levels ranging from rare (0–3 cases per survey) to abundant (25–50 cases per survey). About 29% of reefs or 25 sites exhibited disease in levels above rare. Furthermore, of these 25 sites in the elevated range group, all were located off heavily developed beaches and/or heavily toured areas. Four specific site groups exhibited an overall disease condition average above rare: Ko Phi Phi Don, Phuket West, Ko Adang-Rawi and Ko Tao. Within these site groups, disease was also observed to affect a greater number of genera than in sites with a lower condition average (Table 1, 2).

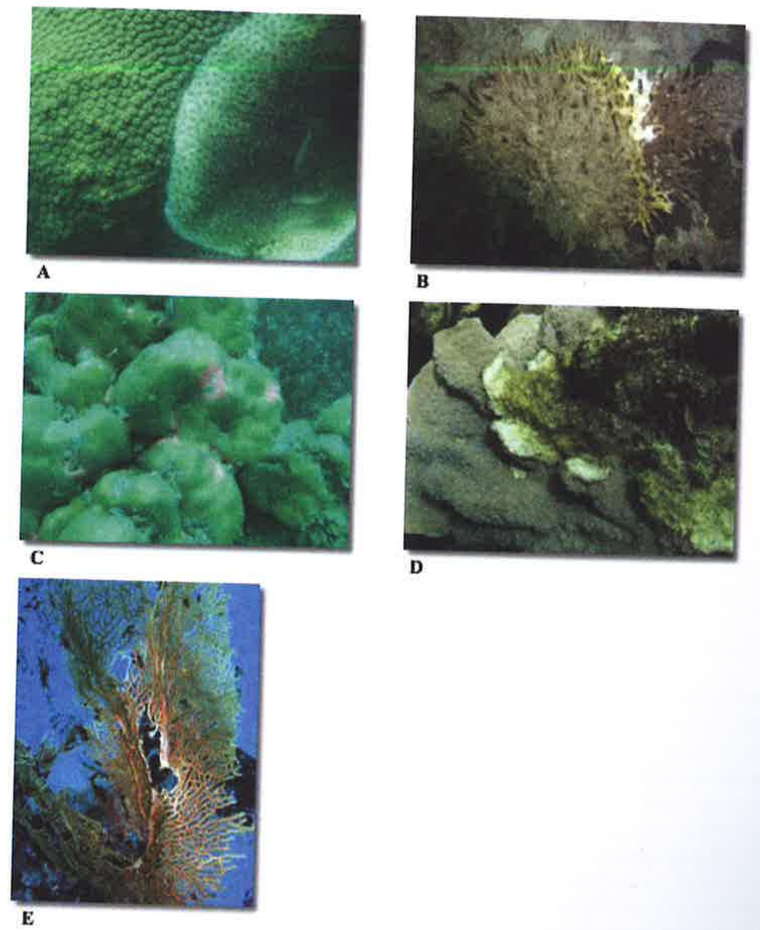

Figure 2. Type photographs used for the identification of the four disease groups. A,B = White syndrome (WS) on *Diploastrea heliopora* and *Acropora solitaryensis,* respectively; C = Pink Line Syndrome (PLS) affecting only *Porites*; D = Black Band Disease (BBD) on *Echinopora lamellosa*; E = Aspergillosis variant (ASP) on *Anella mollis.*

Table 2. Disease conditions for site groups with overall averages above rare. ASP, aspergillosis; BBD, black band disease; PLS, pink line syndrome; WS, white syndrome. Observations based on semi-quantitative belt method (Antonius, 1995): 1–3 cases per scan-condition 1(rare), 4–12 cases-condition 2(moderate), 13–25 cases-condition 3(frequent), 26–50 cases-condition 4(abundant), 51–100 cases-condition 5(epidemic), over 100 cases-condition 6(catastrophic). Individual disease columns list the condition of that disease for a specific site. Condition overall is total number of cases of any syndrome per scan. Overall condition per location (bold) is the overall condition per site average.

	Condition of Each Syndrome Observed				*Condition Overall*
Site Name	*ASP*	*BBD*	*PLS*	*WS*	
Adang-Rawi					**1.9**
Ko Adang East	0	0	1	0	1
Ko Adang North	0	0	2	0	2
Ko Adang South	0	0	2	0	2
Ko Adang West	0	0	3	1	0
Ko Bitsi East	0	0	3	0	3
Ko Bitsi West	0	1	1	0	2
Ko Bu Tong North	0	0	4	0	4
Ko Bu Tong South	0	0	3	0	3
Ko Hin Ngam South	0	0	2	0	2
Ko Ka Ta North	0	0	2	0	2
Ko Lipe East	0	0	1	0	1
Ko Lipe North	0	0	1	1	2
Ko Lipe South	0	0	0	0	0
Ko Rawi East	0	0	0	0	0
Ko Rawi South	0	0	2	0	2
Ko Talang North	0	0	2	0	2
Ko Phi Phi Don					**1.67**
Ao Nui	0	0	1	1	1
Hin Phae	0	0	0	1	1
Laem Tong	0	0	0	1	1
Lolana Bay	0	0	1	1	2
Ko Pai	0	0	2	1	2
Ko Yoong	0	0	3	1	3
Ko Tao					**2**
Ao Hin Ngam	0	0	0	1	1
Ao Leuk	0	0	1	1	1
Chumphon Pinnacle	0	0	2	0	2
Lighthouse Bay	0	0	2	0	2
Mae Haad	0	0	0	3	3
Shark Island	0	0	1	0	1
Twin Peaks	0	0	4	0	4
Phuket West					**1.71**
Bang Tao North	0	0	0	1	1
Bang Tao South	0	0	0	2	2
Kata North	0	0	2	2	2
Nai Yarn	0	0	1	2	2
Patong North	0	0	0	2	2
Patong South	0	0	0	1	1
Sirinat North	0	0	0	2	2

Specific disease observations chiefly consisted of PLS and WS. PLS was the most frequently observed, occurring on 44% of reefs, or 38 of the 87 sites. WS was observed at 32 sites and was also the most pervasive, affecting 15+ species (Table 3). BBD was only observed at one site, Ko Bitsi West in the Adang-Rawi group. A single observation occurred within the time swim, while a second was observed outside of the time limit. The ASP variant was only observed in the Similan Islands.

Due to the difficulty of identification in situ and the broad nature of this survey, the identification of affected corals was carried to the species level when possible. Massive types of *Porites sp.* are difficult to identify in situ and no species were delineated for this genus. Overall, eight genera comprising 18+ species were observed to be affected by disease, these were *Acropora*, *Anella*, *Diploastrea*, *Echinopora*, *Favia*, *Hydnophora*, *Pavona* and *Porites* (Table 3).

Table 3. Species affected by each disease category. ASP, Aspergillosis variant; BBD, Black Band Disease; PLS, Pink Line Syndrome; WS, White Syndrome.

	ASP	BBD	PLS	WS
Acropora austere				X
A. clathrata				X
A. florida				X
A. hyacinthus				X
A. muricata				X
A. nasuta				X
A. secale				X
A. solitaryensis				X
A. valida				X
Acropora spp.				X
Anella mollis	X			
Diploastrea heliopora				X
Echinopora lameliosa		X		X
Favia rotundata				X
Favia speciosa				X
Hydnophora microconus				X
Pavona dessucata				X
Porites sp.			X	X

DISCUSSION

The Belt Method proved valuable for evaluating the general state of disease across sites surveyed. Due to logistics constraints, the optimized radial arc transect method developed for multiple species/multiple diseases surveys was not feasible for this initial study (Santavy *et al.*, 2001). Belt transects were considered, but other studies have concluded that transects are too limiting when the initial disease condition is an unknown (Haapkyla *et al.*, 2007).

The unknown condition of coral disease also necessitated conservative field observations and categorizations. Only those diseases/ syndromes that were observed to be actively involved in colony mortality were included in this study. All conditions observed in this study have been implicated in previous studies as being detrimental to reef health. Other conditions were observed in the field, such as skeletal anomalies, parasitic infestations (most commonly in *Porites* sp.) and other dead or overgrown patches but were not included in these results as these conditions were not perceived to be actively contributing to colony death. The majority of published disease surveys vary widely in their definitions of disease and standardization is needed (Richardson, 1998; Raymundo *et al.*, 2003).

For the majority of sites, disease observations were rare Due to the semi-quantitative nature of the survey method, the

percent of colonies infected at each site could not be calculated. If a transect method had been adopted, it is likely that cases of disease at all but the more heavily affected sites would have been missed. Therefore, while it is critical to understand that levels of disease on sites surveyed is low in comparison to other regions, it is also important to note that it is present for the purpose of establishing a baseline. Other baseline studies from relatively pristine areas in the Pacific have reported similar results (Aeby, 2006; Haapkyla *et al.*, 2007). In the Andaman Sea, 66% of reefs exhibited disease in low levels. A baseline survey conducted over 73 sites in the Northwestern Hawaiian Archipelago similarly reported disease at 68.5% of sites in low levels (Aeby, 2006).

This broad-based disease survey is the first of its kind in Thai waters. Reef composition most likely played a role in the dominant disease observations. PLS affects only *Porites*, sp., and the reefs of the Andaman Sea are generally dominated by this genus, followed by *Acropora* sp. (Phongsuwan and Chansang, 1992; Phongsuwan, *et al.*, 2001). In the Adang-Rawi group, the *Porites* dominance is even more pronounced with 58% of the total coral cover made up of *Porites porites* (Phongsuwan, *et al.* 2001). This dominance is reflected in the occasionally abundant levels of PLS observed on the reefs of this group (Table 2). Raymundo *et al.* (2005) established that *Porites* sp. is a major host of diseases in the Philippines.

As previously stated, four site groups displayed somewhat elevated levels of disease. Furthermore, these site groups were all located near more developed areas in southern Thailand. Phuket was the first island to be heavily developed beginning in the 1970's. Today the 543 km^2 island sees upwards of 4.5 million visitors each year. Observations of white syndromes around Ko Phi Phi Don, while not as abundant, are as consistent across sites surveyed as observations in Phuket West (Table 2). As the most popular tourist destination in the Andaman Sea, after the land-clearing effect of the tsunami, formerly forested areas have been re-developed into more hotels and resorts. In 1983 Ko Tao had only one bungalow operation catering to backpackers. Today there are more than 100 and garbage removal and sewage processing facilities were not constructed to deal with the heavy tourism influx to the island each year. The Adang-Rawi group, while currently the least developed of the four, lies outside the boundary of the national park and is poised to become the next big tourist destination of the far south.

In other studies, increases in coral disease have been correlated with deteriorating water quality. In the Caribbean, researchers have demonstrated that increases in nutrients can speed the progression of black band disease, yellow band disease and aspergillosis (Bruno *et al.*, 2003; Voss and Richardson, 2006). Increased prevalence of black band disease and white plague type II have been correlated to increased sewage run-off exposure (Kaczmarsky *et al.*, 2005). In Fiji, black band disease was observed on massive corals exposed to terrigenous sediment stress due to run-off from an adjacent, overgrazed island (Littler and Littler, 1996). In a recent study, Fabricius described coral tissue loss and increased mortality in the presence of increased organic material due to sedimentation (2005). Other environmental phenomena have been implicated as well. Warming trends and extreme ENSO events may be contributing to the increase in global coral disease observations (Harvell *et al.*, 2002; Rosenberg and Ben-Haim, 2002; Jones *et al.*, 2004; Selig *et al.* 2006). In another study, coral disease pathogens were found in algae-associated microbial communities (Nugues *et al.* 2004). Predatory organisms can also be vectors of disease. Antonius and Riegl reported a correlation between coral disease and *Drupella cornus* predation in the Red Sea (1997). However only two individual species, one fireworm and one nudibranch, are proved culprits in this capacity to date (Sussman *et al.*, 2003; Dalton and Goodwin, 2006). A combination of factors most likely influenced disease observations in this study. Increased awareness and future long-term monitoring of disease will better elucidate coral disease dynamics on the reefs of southern Thailand.

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