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ASSESSMENT OF LIVE CORAL COVER AND RECENT CHANGE ON THE REEFS OF THE ADANG–RAWI ISLANDS, TARUTAO MARINE NATIONAL PARK, THAILAND

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ABSTRACT

During 1993 to 1995 a team from the Wildlands Studies Program (San Francisco State University, College of Extended Learning) mapped live coral cover (lcc) in the Adang–Rawi Island Group of Tarutao Marine National Park, Satun Province, Thailand. These granitic, continental-shelf islands in the Andaman Sea support intact fringing reefs in most locations. Visual estimates of lcc were made by swimmers, locations were established by means of a hand-held global positioning system and data were mapped using CAMRIS geographical information system software. Results of the Wildlands Studies survey were compared with data obtained by the Phuket Marine Biology Center 8 years earlier. In general, coral cover was well correlated between studies, establishing that methods were comparable and that coral cover is predictable on a temporal scale of years to decades. Significant increases in coral cover did occur on some reefs, however. These were mostly reefs located in sheltered places and dominated during the WS study by rapidly-growing corals of the genus Acropora, indicating recovery from some disturbance prior to the PMBC survey. The only reef with significantly diminished coral cover had a significantly higher proportion of massive corals, relative to the island group as a whole. The simplest model to explain this pattern of change is one in which exposed reefs are subject to high rates of disturbance, while sheltered reefs are most of the time undergoing a gradual recovery from infrequent catastrophic disturbance.

INTRODUCTION

The Adang–Rawi Island Group consists of 25 small granite islands in the Andaman Sea about 65 km off the west coast of Satun Province, Thailand. These islands are included in Tarutao National Park and are located at about 6° 30' N. latitude, 99° 15' E. longitude. They support well-developed fringing coral reefs in most offshore locations with a diversity of taxa and growth forms typical of the Eastern Indo–Pacific Region (WELLS, 1988).

During the period 1993 to 1996, we mapped coral in the Adang–Rawi islands and established a series of survey plots to investigate local patterns of dominance among different coral growth forms. More recently, we have developed a map of live coral cover using the CAMRIS (Computer Aided Mapping and Resource Inventory System) software package. This paper reports the results of our survey and compares coral cover today with

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conditions reported by the Phuket Marine Biological Center (PMBC) during a survey conducted in 1986 (PHONGSUWAN & CHANSANG, 1987). We hope that this comparison can provide useful information about the effects of various "natural" and human-caused disturbances on the coral reefs of this area and provide the foundation for further studies on the ecology of coral reef communities in the Andaman Sea.

Geomorphology of the Study Area

The Adang–Rawi islands belong to the peninsular ranges of southern Thailand, and have been insular at least since the beginning of the most recent interglacial period, about 7,000 years ago (WELLS, 1988). Surrounding seas attain a maximum depth of less than 40 m. The outer island group, including Rawi and Adang, consists of Triassic granite, while islands closer to the mainland, including Tarutao Island, are composed of Paleozoic limestone and sandstone. These geological differences have a significant effect on both the terrestrial and marine environments. On the near-shore islands, soils derived from limestone have a poor water holding capacity so that vegetation is mostly drought deciduous. Beaches are composed of fine sand, and much of the coast consists of undercut headlands. Coral reef development is modest there. The granitic Adang–Rawi islands, further from the mainland, support evergreen forest on retentive soils. Here the sand is coarse and the islands, though mountainous, slope evenly to the sea so that beaches are present in most places. Shorelines consist of narrow beaches interrupted by headlands of eroded granite boulders or sloping cliff faces. Offshore, reef flats of varying width and coral condition give way in favorable locations to reef slopes dominated by massive or branching corals with a high proportion of live coral. Water clarity is greater among the outer island group.

Rawi Island (3,100 ha) is the most physiographically diverse of the outer island group with inland valleys and large flat areas, but Adang Island (3,000 ha) attains a higher elevation (703 m). Both of these islands have perennial fresh water streams and stands of undisturbed evergreen dipterocarp forest. The Adang–Rawi island group also includes 23 other islands large enough to support woody vegetation, and numerous small rocks and shoals (Figure 1–2). Tides are semi-diurnal and the average spring tide range is 2.4 to 2.7 m (PHONGSUWAN & CHANSANG, 1992).

Annual precipitation averages about 2600 mm, and is seasonally variable. About 70% occurs during the May to October southwest monsoon while the period November to April has northeasterly winds and a dry climate. December to March can be virtually rainless. Data collected for Phuket Island (190 km to the NNW) records sea temperatures that vary seasonally between 25° and 29° C. (PHONGSUWAN & CHANSANG, 1992).

Coral Distribution

Coral reefs of the Adang–Rawi island group have been studied taxonomically by PHONGSUWAN (1986) who found 138 species of scleractinian corals in 47 genera on "typical reefs" and among coral communities on rock surfaces. This generic diversity is similar to that identified for the Eastern Indian Ocean region in biogeographic studies such as STEHLI & WELLS (1971), but falls short of the number identified for the region by VERON (1985) [both references cited from VERON, 1995].

The distribution of different reef types and coral growth forms was described by PHONGSUWAN & CHANSANG (1987) of the PMBC. They also measured the proportion of live coral cover by area and the ratio of live to dead coral along reef slopes throughout the island group as of January 1986. Our coral map represents an effort to supplement PHONGSUWAN & CHANSANG's existing significant body of work with a finer resolution description of this area based on observations taken 8 years later.

Typical reefs of the Adang–Rawi islands consist of a reef flat of variable width, the surface of which is a complex mosaic of intact living and dead coral colonies, coral-derived rubble and sand. On the reef flat, live coral is dominated by massive forms, but branching corals are nearly always present to some degree and may be locally dominant in sheltered locations. Several other growth forms occur here as well. The distribution of live coral on reef flat surfaces is highly variable across a broad range of spatial scales, imparting to the reef flats a fractal character that makes spatial analysis a special challenge. Further offshore, reef slopes are gently inclined and are dominated by massive coral colonies that may grow up against one another to form a continuous surface. PHONGSUWAN ET AL. (1987) describe the zonation of coral taxa and growth forms along a transect from reef flat to reef slope. Due to a shallow continental shelf in this part of the Andaman Sea, no significant reef walls or surge channel formations occur in the Adang–Rawi islands. Shorelines that face open ocean to the southwest are exposed to the southwest monsoon, a source of intermittent high winds and destructive waves during May to October. These seasonally high energy shorelines may lack well-developed reefs, but support communities of coral on granite (PHONGSUWAN ET AL., 1987).

Park–People Relations

The Adang–Rawi islands comprise the outer part of Tarutao Marine National Park, a protected marine area of 1,490 km^2 that includes 260 km^2 of land. Most islands are uninhabited due to national park management policy and a lack of fresh water. Indigenous residents belong to one subgroup of a fishing culture popularly referred to in Thai as *Chao Le,* in English as "Sea Gypsy." These people call themselves *Irak Lawoi* as distinguished from the other group of *Chao Le,* the *Mawken,* who live farther north. They speak a language related to Malay (EITEL, 1994; FRASER, 1966). Lipe Island (400 ha) has the largest human population, with approximately 800 permanent residents and a few tourists during the winter dry season. A smaller settlement exists on the east side of Adang Island, and some of the resident *Irak Lawoi* seasonally occupy temporary encampments in various places along the shores of Adang and Rawi. A national park sub-station at the south end of Adang Island supports a few park employees and their families as well as a small concessionaire. A second substation has recently been built on the southeast shore of Rawi. The Thai Fisheries Department maintains a station on Lipe Island as well.

Human-caused disturbances to the reef ecosystem are evident in the Adang–Rawi islands, although the magnitude appears to be less than that normally found in areas closer to human population centers. A history of confrontation exists in Tarutao Marine National Park and armed conflicts occurred between park workers and local residents as recently as the early 1980's (ALEXANDER, 1983). Today the relationship between Tarutao Marine National Park and its indigenous residents appears peaceful. National park staff and local fisherman both report that cooperation has improved, and our personal observations during the past five years corroborate this. But some impact to the protected marine ecosystem continues since both subsistence and commercial fishing activity is practiced here. On the positive side, illegal dynamite fishing appears to have declined to a low level, and commercial trawling boats, while still present in the park, have begun to show greater compliance with the park directive to limit trawling to locations more than 3 km offshore. Trawling activity is a source of ecological concern because these boats, working in pairs, drag nets that capture nearly all but the smallest marine organisms in their relatively fine mesh.

The ecological cost of subsistence fishing is probably less significant, although these activities may appear more evident from a visual inspection of the coral reef since trawlers work farther offshore in environments seldom visited by divers. Fishing methods practiced on a small scale by local people include catching fish in sunken traps and harvesting giant clams (*Tridacna* sp.). Sunken fish traps are less damaging than trawling nets to communities of benthic organisms and the larger mesh size of the enclosure enables small fish to escape. In order to harvest giant clams, the collector, breathing air from a compressor hose, stands on the bottom and pries his quarry from the reef with a metal bar. Besides its effect on the target species, this activity visibly scars the reef, although the magnitude of the ecological damage not known.

Compared to many other places in southern Thailand, the ecological effects of tourism in the Adang–Rawi islands remain small, since the area is relatively inaccessible. Current sources of concern are damage to coral caused by boat anchors and by careless swimmers, littering, and the illegal collection of protected marine organisms. To date, 42 mooring buoys have been installed by the national park staff near some of the most attractive reefs. It is hoped that these will minimize anchor damage caused by tourist vessels, although storm damage and theft of mooring buoys has been a continuing problem. Pollution and eutrophication of near-shore waters due to improper sewage disposal could also become a problem if unrestrained growth of low-budget tourist accommodations is allowed to occur here as it has at other coastal locations throughout South Thailand.

Natural disturbances also affect reef condition. Storms of the southwest monsoon can completely destroy the live coral on an exposed reef flat and severely damage deeper reef edge habitats, creating a disturbance which requires at least 6 to 7 years to recover (PHONGSUWAN, 1991). High winds during the dry northeastern monsoon may also produce wave energy powerful enough to break coral or bury it in sand. Movement of sand by ocean currents appears to be a significant source of reef disturbance. For example, during the past 8 years, sand transported in a westerly direction around the southern end of Adang Island has completely surrounded a pier and, during the past 4 years, has transformed several hundred meters of rocky, south-facing shoreline to sandy beach. Loss of sand from the north side of Lipe Island, across a shallow, 1.5 km wide channel, has threatened homes and left another pier isolated in open water some distance from shore. Records indicate high live coral cover along the southern end of Adang Island 8 years ago (PHONGSUWAN, 1986). Today, isolated patch reefs grow up from a sandy bottom in this same location and live coral cover is quite low.

During the mid-1980's, an infestation of crown-of-thorns starfish *Acanthaster planci* was reported in the Adang–Rawi islands (PHONGSUWAN & CHANSANG, 1992), although difficulties in censusing this coral-eating starfish and in quantifying coral predation confound assessments of its importance as a source of disturbance. There has been much written on the population dynamics and control of *A. planci* but little agreement as to the cause of outbreaks, the degree to which they might be self-limiting, and how and whether they should be controlled (JOHNSON ET AL., 1990). *A. planci* is present on reefs of the Adang–Rawi group, but our casual surveys suggest that its abundance is much lower than was reported during the outbreak of the mid-1980's.

Studies have shown that the coral reefs of the Adang–Rawi islands are vulnerable to several kinds of disturbance. But the specific nature and intensity of these disturbances appears to be highly variable, a pattern that is increasingly recognized as a general ecosystem property. It is no simple task, therefore, to infer from current conditions the nature or magnitude of the historical events that account for variation in live coral cover observed during our 1993–1996 visits.

METHODS

Mapping Live Coral Cover

On three annual visits each of 21 days' duration, January–February 1993 to 1995, we mapped live coral cover (lcc) on fringing reefs and rocky offshore locations for all the islands of the Adang–Rawi group (Figures 1–2). Our objective was not to describe the taxonomic composition of the coral community, since this work is better left to specialists (VERON, 1995). Rather, we attempted to rapidly assess the condition of the reef by quantifying live coral cover and identifying major coral growth forms.

To accomplish our survey, we towed two mask and snorkel-equipped swimmers alongside a small boat (one to starboard, one to port), moving at approximately 60 m/min. Swimmers used hand signals to communicate information about coral condition to team members in the boat. Other information relayed by the swimmers included the nature of the non-coral substrate (rock, sand or calcareous rubble), the occurrence of *Acanthaster planci* and signs of human disturbance such as fishing traps or discarded nets. As the swimmers observed the reef, a team member on board monitored a global positioning system (Garmin GPS 50 Personal Navigator) which provided location data. By combining information provided by the two swimmers and the GPS unit, we obtained lcc estimates at a resolution of 0.01 minutes of latitude and longitude, approximately equivalent at these near equatorial latitudes to an 18x18 m square.

During our initial rapid surveys, we attempted to map the perimeter of each island by making at least one survey-run along the reef slope. In places where the reefs were especially broad, we made several survey-runs at different distances from shore in order to map an area rather than a line. After three field seasons, our coverage of reef edge and rocky offshore locations was nearly 100%, although some areas of expansive reef flat and shallow, sandy bottom locations remain only partially surveyed.

Managing mapping error caused by substrate variability has been a concern throughout the project. One source of error is limited coverage of the area mapped. During the mapping surveys each swimmer observed a strip of substrate that ranged in width from 2 to 5 m, depending on water depth. With swimmers about 2 m apart (on opposite sides of the boat), the width surveyed by both swimmers ranged from 4 to 7 m. To obtain a lcc estimate, swimmers integrated their observations over about 3 seconds, a traversed distance of about 3 m. Thus, at any moment, the two swimmers' hand signals represented lcc integrated over 12 to 21 m^2 of substrate, depending on water depth. Since the swimmers' signals were recorded as data each time the GPS location changed by 0.01' latitude or longitude, data assigned to the 18x18 m "sampling point" was actually derived from observations of a small fraction (4% to 6%) of that area. Since the distribution of live coral varied on spatial scales that range across several orders of magnitude from centimeters to hectares (SALE, 1991), our lcc estimates, derived from observations of less than 10% of the area mapped, are best regarded as statements of probability at a resolution 0.01 minutes of latitude or longitude (about 18 m). In other words, some fraction of a specified area 18 m on a side has a substrate equivalent to that which we recorded, with the maximum likelihood that we recorded the lcc class which is most abundant at that location. An additional source of error results from the limited accuracy of the GPS unit: its signal may be intentionally degraded by the U.S. Department of Defense which controls the satellites (HURN, 1989).

Surveyed locations were assigned a value of 1 to 4 according to the proportion of total area occupied by live coral (Figure 3). Each of the two swimmers independently relayed this value to the on board data recorders. If the numbers were different, the average value was taken as lcc for that location. Since some places were mapped more than once, lcc values associated with a particular 18x18 m 'sampling point' may represent coral cover estimates averaged over more than one visit.

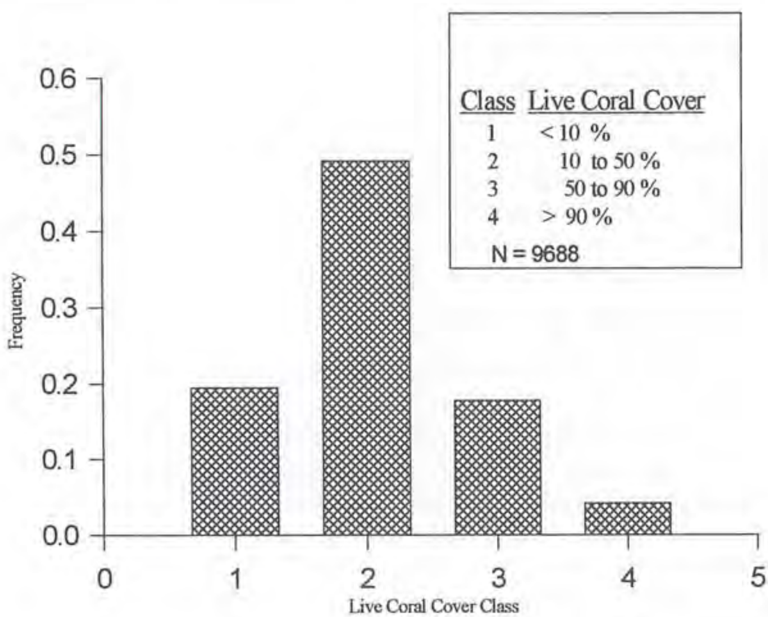

Figure 3. Frequency of live coral classes on fringing reefs of the Adang–Rawi Island Group. The modal cover class is about 25%. Areas of very high live coral cover are infrequent.

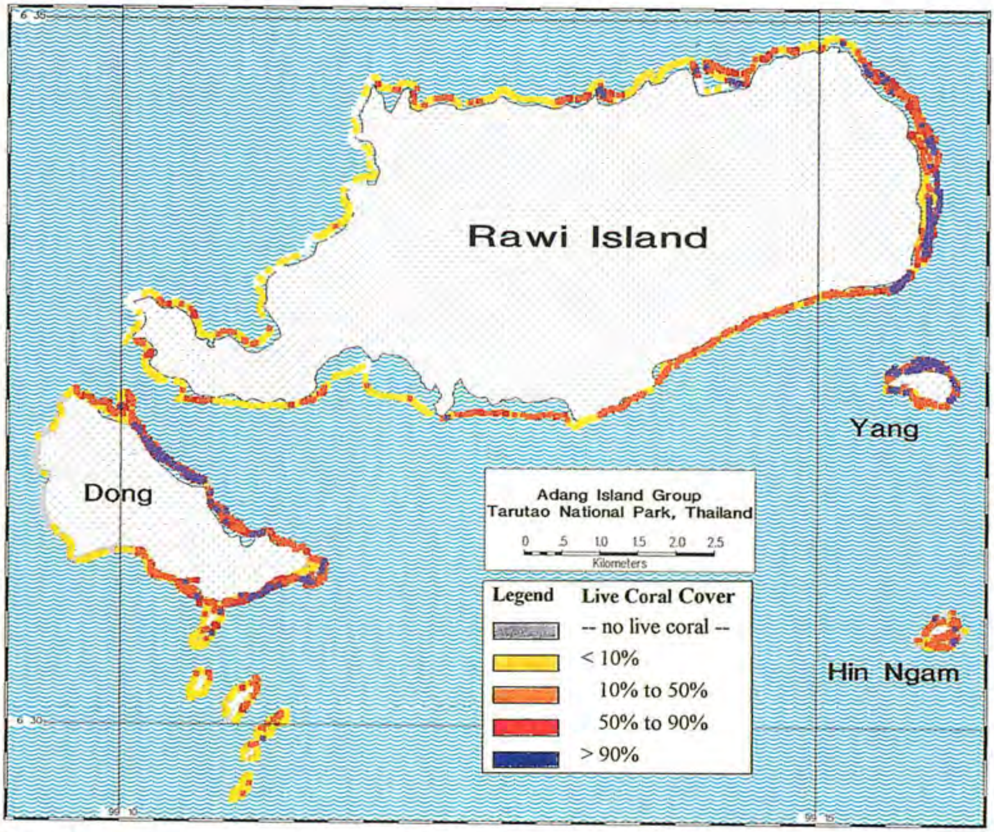

Figure 1

Figures 1–2. Maps illustrating the proportion of live coral in different locations along fringing reefs of the Adang–Rawi Island Group. Figure 1 depicts the western porion of the island group, Figure 2 (next page) depicts the eastern portion. Colors indicate percent live coral cover. The size of each point is exaggerated to make the maps easier to read.


Bisee
Adang
Island
Yang
Hin Ngam
Lipe
Adang Island Group
Tarutao National Park, Thailand
0 .5 1.0 1.5 2.0
Kilometers
Legend
Live Coral Cover
-- no live coral --
< 10%
10% to 50%
50% to 90%
> 90%

Figure 2.

Despite certain limitations, we believe that the mapped data presents a fundamentally sound, if somewhat subjective, description of live coral cover in the Adang–Rawi islands at a finer scale than might be achieved using other methods. The map is functional in the sense that it allows users to easily locate places of high or low coral cover.

To produce the map, data were initially transferred by hand onto graph paper at a scale of 1:18,000. A more recent version of the coral map has been produced using CAMRIS software (FORD, 1993).

The coral map contains a great deal of descriptive information which can be used to generate hypotheses about the environmental factors that control reef formation, and about the relationship between coral and the distribution of fish and other marine organisms. The data on live coral cover have additional value as a management tool and as a source of baseline data to monitor change in the reef environment over time.

Comprehensive Survey Plots

Although our coverage is extensive, the rapid nature of our mapping survey limits the amount of information we can attach to each sample point. Thus, our map data does not include information about the relative abundance of different coral growth forms, nor does it estimate the ratio of live to dead coral or the frequency of associated fish species. In 1995–96, to better understand these important ecological variables, we made a more detailed survey of selected locations throughout the island group. Survey locations were circles of approximately 30 m radius, monitored for 15 to 20 minutes by 4 to 8 mask and snorkel-equipped swimmers. For each of the 82 survey locations, we determined the substrate type (reef flat, reef slope, coral on granite or sand), estimated the frequency of different coral growth forms, and recorded the species richness of certain fish taxa generally associated with scleractinian corals.

Comparison with Previous Studies

PHONGSUWAN & CHANSANG's 1986 Phuket Marine Biology Center (PMBC) survey of fringing reefs in the Adang Rawi Island Group enables us to investigate how live coral cover changed between 1986 and 1994, the year in which we did most of our mapping. The PMBC team used the Manta Tow technique in which observers are pulled by an outboard motor boat moving at a speed of 75 m/min. Descriptive data were recorded at 2-minute intervals and this information was relayed every 10 minutes to a data recorder in the boat. Survey data covers segments of the coastlines of all the major islands of the Adang–Rawi group with observations collapsed to a single lcc estimate (mean and standard deviation) for each section of reef. Information includes percent cover of live coral, dead coral and soft coral as well as the substrate type. Although the PMBC team measured only reef slopes and we included some reef flat locations, it is still possible to compare our respective findings.

If the reefs have not changed during the 8 years 1986 to 1994, or if change has been even and directional throughout the island group, then our lcc data should correlate in a reef by reef, pair-wise comparison to that of PMBC. If the data do not correlate, then either the sampling methods in the two studies are not compatible or else reefs here are so dynamic that live coral cover in 1986 has no power to predict live coral cover eight years later. For this to be true, reefs would have to be subject to rapid, stochastic change on spatial scales of a few hectares and temporal scales of a few years. In other words, coral growth patterns would have the capacity to erase their own history in a relatively short period of time.

RESULTS AND DISCUSSION

Our mapped survey results show that fringing reefs with moderate (10–50%) live coral cover are typical for islands of the Adang–Rawi group. Although some rocky shorelines with a southwest aspect are completely lacking coral cover, more often the rocky shorelines have at least a small amount of coral on granite. In some places, broad reef flats extend from sandy beach to the fringing reef-edge and in these locations the reef flats typically have a lower lcc (<50%) than the reef edge (lcc usually >50%; occasionally near 100%). Places where high lcc extends over a broad area tend to lie in sheltered coves, mostly along shorelines with a north to northeast aspect. Figure 3 illustrates the frequency distribution of live coral cover classes throughout the island group.

Despite the importance of the SW monsoon in this area, we found no obvious relationship between gross aspect and lcc. It is likely that local features of the shoreline and the presence or absence of sheltering islands are more important than gross aspect in determining the wave energy to which a particular reef is subject.

Thus the most extensive areas of high coral cover during our 1993–1995 mapping effort are located on the north side of Yang Island, the northeast side of Dong Island, the southeast corner of Rawi Island, protected by nearby Yang and Adang Islands, and sheltered coves at the southwest corner of Adang. Clearly the presence of sheltering islands and smaller-scale shoreline features has a significant affect on lcc. We also found healthy fringing reefs with high lcc along the east and west sides of Adang Island, although in both of these places, the nearshore reef flats were in poor condition.

Figures 1 and 2 show the distribution of live coral cover throughout the island group.

Comparison with PMBC 1986 Survey Data

Our comparison shows a significant correlation between reef condition measured by the PMBC team in 1986 and the WS team in 1994 ($r=0.477$; $N=59$; $p<0.001$). This correlation (Figure 4) demonstrates that historical effects do persist: reef conditions in 1986 have some power to predict conditions 8 years later. However, it is not appropriate to draw conclusions from the slope of the regression curve, since each team used its own subjective method to estimate live coral cover.

Although the distribution of points is correlated—here each point represents a reef—there is a great deal of scatter. We attribute this to several general causes, some of which are ecologically meaningful and some which are not. First, sampling error due to the heterogeneity of the reef substrate certainly reduces the strength of the correlation. Second, small, stochastic change in the reefs over the 8-year interval would also reduce the correlation. These two sources of error are probably inseparable in this study. Third, the

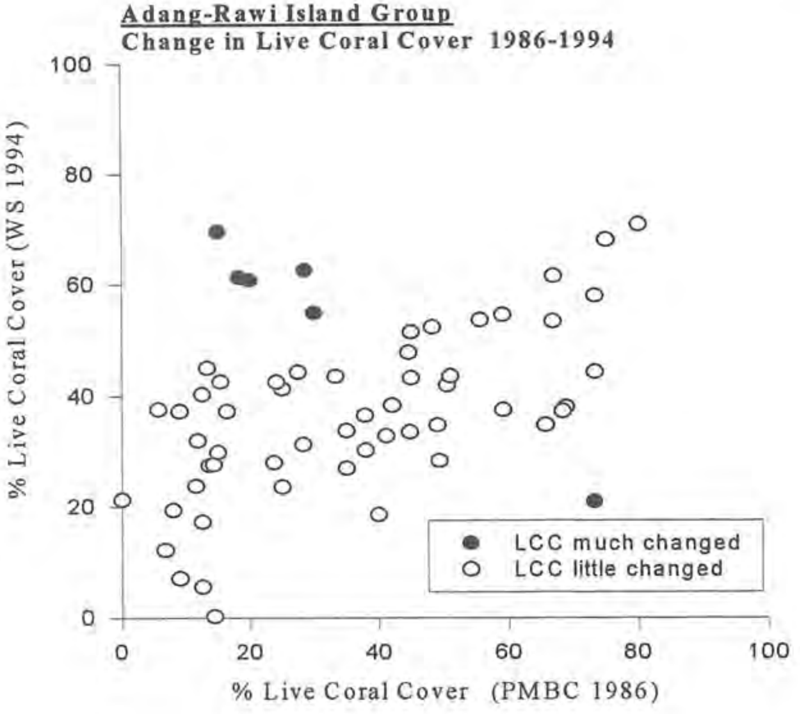

Figure 4. Relationship between live coral cover measured by the PMBC Team in 1986 and the Wildlands Studies in 1994. Outlying points, representing reefs much changed during the interval between surveys, are represented by dark circles. Other points are signifcantly correlated (P<0.001), indicating a correspondence between live coral cover in 1986 and 1994. That is, lcc in 1986 has some power to predict lcc in 1994 on most of the fringing reefs surveyed. In this comparison, the slope regression is not biologically meaningful since the two surveys were conducted independently of each other, using slightly different survey methods.

Wildlands Studies team combined data from both reef flat and reef edge locations to obtain an overall lcc estimate for a reef, while the PMBC team measured only the reef edge. To address this source of bias, we discarded from the comparison the two reefs (Adang 6 and Adang 11) where measured reef flat lcc and reef edge lcc were most dissimilar.

In addition to these three rather uninformative sources of variation, it appears that some of the outlying points in our pair-wise comparison of reef condition over an interval of 8 years result from major changes in live coral cover. Indeed, when we remove six of the most distant outliers, the correlation among the remaining points increases substantially ($r=0.672$; $n=53$; $p<<0.001$). All but one of the reefs which lie significantly outside the putative correlation show a substantial *increase* in lcc since 1986. The five most extreme points in this direction represent three reefs comprising the northern half of Yang (Yang 1, 5, 6) where lcc changed from 20–30% in 1986 to 54–63% in 1993–95, and two sections along the northeast side of Dong (Dong 4, 6) where lcc changed from 15–18% in 1986 to 61–70% in 1993–95.

We believe that these reefs, which comprise essentially the whole northern half of Yang and the long northeast side of Dong, show evidence of substantial increases in lcc over 8 years from 1986 to 1994. It may be significant that a dominant growth form in all five of these locations is branching coral *Acropora* sp., a fast-growing, early successional form which PHONGSUWAN (1991) describes as being able to fully recover from complete storm destruction in 6 to 7 years. Our observations of coral colonization of cement blocks placed on reef flat locations off the west shore of Adang Island in 1993 show that *Acropora,* once established, can increase the diameter of its branching mass from 5 cm to 15 cm in one year.

A sixth major outlier, on the south side of Lipe Island (Lipe 5), reflects a substantial loss of live coral cover from 73% in 1986 to 21% in 1993–95, an event corroborated by local residents and members of the WS team who made a preliminary visit to this area in 1992.

These results suggest that coral reefs in the Adang–Rawi islands are potentially very dynamic on time scales of a few years, and are capable of rapid recovery following a major disturbance. It seems likely that here, as in other ecological systems (CONNELL, 1978), frequent local disturbance may maintain non-equilibrium conditions that support a higher architectural and biotic diversity. For example, branching growth forms appear to dominate places where the coral has changed rapidly over a short period of time and massive forms tend to dominate those areas where live coral cover is relatively constant.

Having identified some reefs that show evidence of substantial change over an 8 year interval, we used our comprehensive survey plots to determine what characteristics these reefs might share. We investigated variables such as the aspect and physiography of the shoreline and the relative abundance of massive and branching growth forms.

Reefs with the biggest increases in lcc were situated in places sheltered from the southwest monsoon, with a lower energy coastline. This includes the reefs on north Yang and northeast Dong where lcc increases were from 30% to 55% and from 15–20% to 60–70%, respectively. Other locations of northern aspect also showed increases in lcc. On Adang and Rawi, lcc increased three-fold or more in some places as did lcc in sheltered locations of smaller islands such as Ta Rang, Bissee and Lipe.

Figure 5 illustrates the response of reefs to aspect. In favorable (sheltered) locations, most change is in the direction of increased lcc. Exposed locations, on the other hand, are equally divided between increased and decreased lcc.

Are there any differences in the relative abundance of branching and massive coral growth forms on the reefs that changed between 1986 and 1994, compared to the overall distribution of growth forms throughout the island group? We compared data from all 82 coral survey locations, distributed throughout the island group, to those particular survey locations taken from reefs that show substantial change (Table 1). Four of the changed reefs (Yang 1, Yang 6, Dong 6 and Lipe 4) had enough survey plots ($N \geq 3$) for a statistical comparison. Of these four, we found that two of the three reefs that showed large *increases* in lcc (Yang 1 and Yang 6) had significantly more branching coral and less massive coral than the survey plots overall ($p<0.05$; Mann Whitney Rank Sum Test). On the other hand, Lipe 4, the reef that showed the biggest *decrease* in lcc during the period 1986 to 1994, had significantly less branching coral and more massive coral than average.

These observations suggest an explanation for the dynamics of change in live coral

Table 1. Coral Cover in Comprehensive Survey Plots, 1995–96. Massive corals dominated survey plots throughout the Adang–Rawi Island Group. However, those reefs that showed an increase in live coral cover between 1986 and 1994 were dominated by branching corals. The single reef that showed a large decrease in live coral cover had an even greater than average proportion of massive corals in 1994.

Location	N in lcc	change	% lcc (1996) (avg +/- std)	% massive (1996)	% branching (1996)
All Plots	82		52 +/- 27	66 +/- 31	24 +/- 25
Yang #6	4	(+)	81 +/- 19	14 +/- 6.5	65 +/- 17
Yang #1	3	(+)	50 +/- 14	12 +/- 6.2	70 +/- 22
Dong #6	4	(+)	74 +/- 25	55 +/- 23	36 +/- 21
Lipe #5	5	(–)	45 +/- 18	93 +/- 4.0	4 +/- 1.3

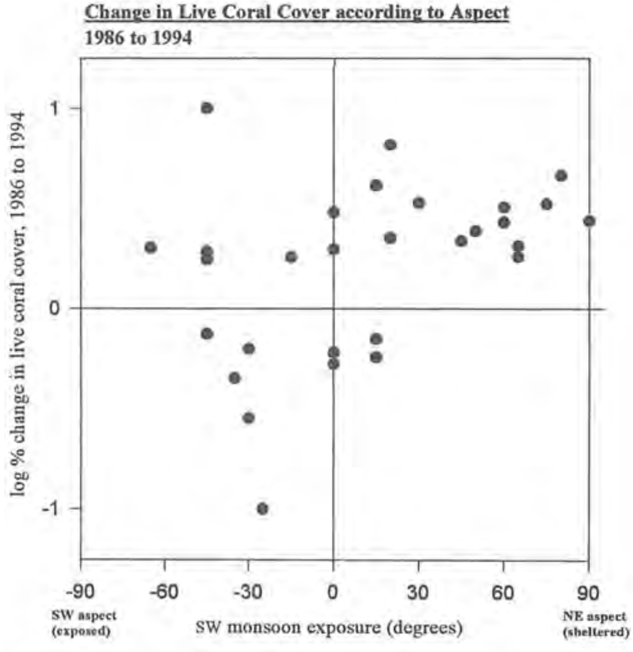

Figure 5. Response of reefs to coastal aspect. Reefs facing northeast are defined to have the maximum shelter angle of 90°, those facing southwest have the minimum shelter angle of –90°. The vertical axis is log of change. Negative values mean live coral cover (lcc) has declinded, positive mean lcc has increased. diagram shows that in favorable (sheltered) locations, most change is in the direction of increased lcc. Exposed locations, on the other hand, are equally divided between increased and decreased lcc.

cover. Exposed places are subject to a high frequency of disturbance that excludes the fast-growing but delicate branching corals. Instead, these places are dominated by massive forms that grow slowly but can withstand higher wave energy. Continuous, slow coral growth is punctuated by frequent small disturbances and rare large disturbances. Under such a disturbance regime, change on a scale of several years is stochastic and non-directional. Thus, reefs in places subjected to high disturbance show no directional change: at any given time, about the same proportion show increased and decreased live coral cover.

Sheltered reefs have a different dynamic. They are prone to infrequent but severe disturbances that are likely to destroy the reef (PHONGSUWAN, 1991), but which are usually followed by an extended period of recovery, as reef edge locations and offshore flats are colonized by rapidly growing, branching species. When instantaneous, catastrophic disturbance is infrequent, the most likely observation will be one of directional increase in lcc. Thus, the reefs on the north side of Yang Island, currently dominated by branching corals, appear to be still recovering from some disturbance which occurred prior to 1986. And they will probably continue to do so until they either reach a state of equilibrium, unusual for coral reefs (CONNELL, 1978; SALE 1991), or until the next catastrophe. Whether these disturbances are due to anthropogenic influences, self-limiting predator outbreaks, or physical disturbances like storm damage, has yet to be determined. This explanation for the dynamics of coral change in sheltered and exposed locations best accounts for the differences we noted between the 1986 PMBC survey and our 1994 Wildlands Studies survey.

CONCLUSIONS

The large-scale distribution of live coral in the Adang–Rawi island group is typical of islands located in the shallow waters of the Andaman Sea. Although it is evident that these reefs are prone to disturbance, the causes of these disturbances are difficult to discern. Wave damage and sand deposition caused by the storms and high winds of the wet southwest monsoon (May to October) and the dry northeast monsoon (December to April) probably cause the greatest reef damage. Biogenic causes such as outbreaks of crown-of-thorns starfish *(Acanthaster planci)* and anthropogenic causes related to subsistence and commercial fishing activity and tourism may also disturb the reefs to some degree. Tourism, poised to increase in the region, could become a serious threat to the coral reef community in the future and will require careful management and cooperation between park authorities and local commercial interests. It is significant that the reefs most attractive to snorkeling tourists (e.g, Yang Island) are those which support the most delicate, vulnerable coral growth forms.

Comparison of live coral cover in 1986, measured by a team from the Phuket Marine Biology Center, and in 1994, measured by the Wildlands Studies team, shows little change in live coral cover in those places exposed to prevailing winds and dominated by massive corals. By contrast, reefs in sheltered places, dominated by delicate branching corals, show a higher coral cover in 1994 than they did in 1986. We propose that this pattern occurs because the exposed reefs are subject to a high frequency of disturbance relative to the eight year interval between the two surveys and that their resident corals (dominated by massive forms) are adapted to this disturbance regime. Sheltered places, on the other hand, allow delicate branching corals to proliferate under conditions that may be tranquil for long periods of time. But these sheltered places are still subject to infrequent catastrophic disturbances of the kind that might accompany a large storm, an outbreak of *Acanthaster planci,* or an episode of destructive fishing activity. After such a disturbance, the affected reef will begin an extended period of regeneration during which live coral cover will increase to a high level. If the pattern of disturbance on a sheltered reef is catastrophic but infrequent relative to an eight year survey interval, and if the recovery process is prolonged and directional, then an increase in live coral cover would be the pattern most likely to be observed between two surveys eight years apart. This is indeed the pattern we observed.

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REFERENCES

ANONYMOUS. 1975. Map of Tarutao National Park (1:50,000), Prepared for the Second Report of Tarutao National Park. *The Environmental Education and Research Project,* Mahidol University, in Cooperation with National Park Division, Royal Forest Department (Thailand).

ALEXANDER, D. 1983. This battleground called Tarutao. *International Wildlife Magazine* 13: 6–10.

CONGDON, G. 1982. The vegetation of Tarutao National Park. *Nat. His. Bull. Siam Soc.* 30: 135–198.

CONNELL, J. H. 1978. Diversity in Tropical Rain Forests and Coral Reefs. *Science* 199: 1302–1309.

DONE, T. J., R. A. KENCHINGTON AND L. D. ZELL. 1981. Rapid large area reef resource surveys using a Manta Board. *Proceedings of the 4th International Coral Reef Symposium 1: Manila.* pp. 299–308.

EITEL, M. 1994. Chao Le of Ko Tarutao National Park: Myths, Identity and Lifestyles Among Battlefields and Nesting Grounds (unpublished manuscript).

FORD, R. G. 1993. CAMRIS: Computer Aided Mapping and Resource Inventory System. Ecological Consulting, Inc. 2735 NE Weidler St. Portland OR 97232.

FRASER, T. M. 1966. *Fishermen of South Thailand: the Malay Villagers.* Holt, Rinehart and Winston, Inc., New York.

GALZIN, R., S. PLANES, V. DUFOUR AND B. SALVAT. 1994. Variation in Diversity of Coral Reef Fish between French Polynesia Atolls. *Coral Reefs* 13: 175–180.

GRAY, D. 1991. *National Parks of Thailand.* Communications Resources (Thailand) Ltd., Bangkok, Thailand.

HURN, J. 1989. *GPS, a Guide to the Next Utility.* Trimble Navigation Limited, Sunnyvale, CA.

JOHNSON, D. B., P. J. MORAN AND S. DRIML. 1990. Evaluation of a crown-of-thorns starfish *(Acanthaster planci)* control program at Grub Reef (central Great Barrier Reef). *Coral Reefs* 9: 167–171.

PHONGSUWAN, N. 1986. *Taxonomic Study of Scleractinian Corals (CoelenteratañAnthozoa with notes on structure and condition of reefs in the Adang–Rawi Group, Tarutao National Park, Southern Thailand.* M.S. Thesis, Prince of Songkla University, Thailand.

PHONGSUWAN, N. 1991. Recolonization of a coral reef damaged by a storm on Phuket Island, Thailand. *Phuket Marine Biology Center Research Bulletin* 56: 75–83.

PHONGSUWAN, N. AND H. CHANSANG. 1987. Coral Reef Resources of the Tarutao National Park, Thailand. In *Coral Reef Management in SE Asia, Biotrop Spec. Publ. 29.*

PHONGSUWAN, N. AND H. CHANSANG. 1992. Assessment of Coral Communities in the Andaman Sea (Thailand). *Proc. of the 7th Int'l Coral Reef Symposium, Guam* 1: 114–121.

SALE, P. F. 1991. *The Ecology of Fishes on Coral Reefs.* Academic Press, Inc. San Diego, CA.

STEHLI, F. G. AND J. W. WELLS. 1971. Diversity and age patterns in hermatypic corals. *Syst. Zool.* 20: 115–126.

VERON, J. E. N. 1985. Aspects of the biogeography of hermatypic corals. *Proceedings of the Fifth International Coral Reef Congress,* Tahiti 4: 83–88.

VERON, J. E. N. 1995. *Corals in Space and Time: The Biogeography and Evolution of the Scleractinia.* Cornell University Press, Ithaca, NY.

WELLS, S. M. 1988. *Coral Reefs of the World. Volume 2: Indian Ocean, Red Sea and Persian Gulf.* UNEP/IUCN Conservation Monitoring Centre, Cambridge U.K.