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RECOLONIZATION OF A CORAL REEF DAMAGED BY A STORM ON PHUKET ISLAND, THAILAND

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ABSTRACT

In May 1986, a shallow water reef on the south east end of Phuket Island was damaged by a storm surge from the south at the beginning of the southwest monsoon. Immediately after the storm, no living corals could be found in the upper zone of the reef, and only a few could be found in the lower zone. Sixteen months after the storm, live coral coverage was still zero along a transect in the upper reef zone but had recovered to 16.9 % in the lower reef zone. During the initial recovery, two years after the storm damage, the live coral coverage had increased to 2.9 % and 20.5 % in the upper and lower reef zones, respectively. *Acropora, Pocillopora, Montipora, Porites* and *Favites* were the major genera and the first three had fastest growth rate. Recovery in the upper zone occurred as a result of coral larval resettlement, while both resettlement and regeneration played a role in the lower zone.

Today, 5 years after the damage, the reef has recovered with live corals in 52.3 % and 43.6 % of the upper and lower zone transects, respectively. *Acropora formosa* and *A. hyacinthus* have been the only successful species in the upper zone, while the lower zone harbours more species. It is suggested that 6-7 years are needed for the reef to recover to a good condition.

INTRODUCTION

Coral reefs in the Andaman Sea has been affected by several natural and man-made disturbances. *Acanthaster planci* infestation, dynamite blasting and sedimentation from off-shore mining are the major causes of disturbance (Chansang et al., 1986, 1987). Storm damage is rare, since most reefs developed sheltered from the southwest monsoon wind direction which is stronger than the northeast monsoon wind (Phongsuwan and Chansang, 1986). However, early in the southwest monsoon season of May 1986, a small shallow water reef of approximately 150 m length and 50 m width at the southeast end of Phuket Island was destroyed by a storm surge from the south. Branching *Acropora* were washed ashore and the coral fragments piled nearly 2 m high along the shore. Only some massive corals remained scattered on sandy bottom covered with thin layer of sediment.

Since the particular reef is small, it was found convenient to investigate changes of the whole reef. The reef was affected by sedimentation from various sources such as run off from the nearby town and deep-sea port construction. Thus, it is of interest to describe the recovery of this reef under the stressful condition of sedimentation.

MATERIALS AND METHODS

The early stage of coral recolonization was recorded from September 1987 to June 1988. Percentage of coral cover, coral recruit density, mortality and growth rate of coral recruits were observed in this initial phase. The long term recovery, i.e. percentage coral cover was monitored again in May 1991.

The study area was divided into two zones: the upper zone encompassing a totally flat floor at about 2 m depth (nearly exposed at low tide), and a lower zone where high coral colonies interspersed with a flat floor at about 3.5 m depth at mean tide. A line transect method (Loya, 1978), with 15 m line parallel to shore was used to assess the areal cover of live and dead corals and nature of substrate. Each measurement was done precisely at centimeter level. The lines were marked permanently with iron rods.

Coral recruit density was observed within areas of 10 m^2, in which dead coral rubble formed the flat firm substrate near the transects in each zone. In this manner permanent quadrats of 2 x 5 m^2 were placed in the lower zone and 10 quadrats of 1 m^2 in an irregular pattern due to the hard substrate, in the upper zone. All young corals were identified to genera, counted, and the diameter measured. Coral recovery data were achieved from these young corals.

Other young corals outside the permanent quadrats were tagged randomly for observation of 2 dimensional growth rate as well as survival. Measurement was taken of the maximum diameter if a coral colony was more or less circular in shape. The area of such coral was calculated as the area of a circle. In case of an irregularly shaped coral, maximum length and maximum width were measured and the area calculated on the assumption that the coral colony was eliptical. The conditions of attachment of these corals were divided into 3 categories: exposed, sheltered in crevice, and growing on a steeply inclined substrate. These observations were made both in the upper and lower zones. The growth of these juvenile corals was measured periodically (e.g. 2-3 month interval). In the long term monitoring, size measurement, and photographic records were made within the permanent quadrats to assess the large scale cover area of irregularly shaped coral colonies such as *Acropora*. The area of such coral was calculated relative to the total quadrat area.

To assess the biomass accumulation of benthic organisms, rough plastic plates of 10 x 10 cm and 3 mm thickness, were set in pairs, each pair separated by 1 cm. The pairs were placed vertically on dead *Acropora* fragments in the lower zone. The objective was to assess the monthly biomass accumulation throughout a year, and total accumulation for 8 months and 1 year, respectively. Ten pairs of plates were used in each assessment.

Sedimentation rate was assessed by using sedimentation traps constructed from glass bottles, 5 cm diameter and 15 cm long, held with steel rods about 20 cm above the substrate in the lower zone. Sediments were collected from 8 bottle traps, and dry weight measured at weekly intervals.

RESULTS

Line transect and quadrat assessment

In September 1987, 16 months after the storm, no live corals were found along the 15 m line transect in the upper zone which contained 52.7 % dead massive corals, 32.7 % dead *Acropora* fragments and 14.6 % sand substrate. In the lower zone, 16.9 % live corals, including 5 genera were found (Table 1) interspersed with 75.1 % dead corals and 8 % sand.

In the survey of the transects repeated 2 years after the storm event, live coral cover of 6 genera had become 2.9 % in the upper zone and 20.5 % in the lower zone (see Table 1). In the latest monitoring in May 1991, live coral covers of 52.3 % and 43.6 % were found in the upper and lower zone, respectively. *Acropora formosa* was the most abundant species in the upper zone while no dominant species formation could be identified in the lower zone.

In the permanent quadrats, the lower zone substrate consists of cemented dead *Acropora* fragments. This habitat contains various crevices. In consequence, the assessment of the settlement of young corals could only be made accurately on the top surfaces. In June 1988, the quadrats consisted of 168 coral recruits of 14 genera, with diameters up to 5 cm (Table 2). On the assumption that all colonies were circular in shape, the total area covered was about 0.83 % of the 10 m^2 study area. *Porites*, *Acropora*, *Favites*, *Pocillopora* and *Montipora* were dominant according to number of colonies and percentage cover. When monitored in May 1991, the coral cover in the quadrats had increased to 12.84 %. *Acropora formosa*, the most abundant species, contributed 7.86 %.

Table 1. The 15 m transect assessment in the upper (up) and lower (low) zones in September 1987, June 1988 and May 1991.

Coral genera	Sep. 87				Jun. 88				May 91			
	Number of colonies		% cover		Number of colonies		% cover		Number of colonies		% cover	
	up	low	up	low	up	low	up	low	up	low	up	low
Porites	-	6	-	13.6	4	6	0.67	16.6	1	3	0.13	7.2
Acropora	-	1	-	0.27	4	2	0.80	1.07				
-A. aspera									2	-	1.53	-
-A. formosa									11	-	36.8	-
-A. hyacinthus									3	-	8.2	-
-A. nobilis									1	2	3.0	6.0
Fungia	-	1	-	0.73	-	4	-	0.73	-	1	-	0.8
Pocillopora	-	1	-	0.34	2	2	0.14	1.13	-	2	-	1.0
Montipora	-	2	-	2.00	5	2	0.93	0.80	1	7	1.27	9.34
Agaricia	-	-	-	-	-	1	-	0.20	-	-	-	-
Favites	-	-	-	-	3	-	0.27	-	1	2	0.2	3.67
Favia	-	-	-	-	1	-	0.07	-	-	-	-	-
Platygyra	-	-	-	-	-	-	-	-	1	3	0.27	1.0
Hydnophora	-	-	-	-	-	-	-	-	1	1	0.87	0.2
Cyphastrea	-	-	-	-	-	-	-	-	-	1	-	2.47
Diploastrea	-	-	-	-	-	-	-	-	-	1	-	3.27
Echinophyllia	-	-	-	-	-	-	-	-	-	1	-	1.0
Galaxea	-	-	-	-	-	-	-	-	-	1	-	0.13
Goniastrea	-	-	-	-	-	-	-	-	-	3	-	3.47
Leptastrea	-	-	-	-	-	-	-	-	-	1	-	0.27
Merulina	-	-	-	-	-	-	-	-	-	1	-	0.27
Psammocora	-	-	-	-	-	-	-	-	-	1	-	0.47
Millepora	-	-	-	-	-	-	-	-	-	1	-	1.33
Symphyllia	-	-	-	-	-	-	-	-	-	1	-	1.73
TOTAL	-	11	-	16.9	19	17	2.9	20.5	22	33	52.3	43.6

Within the 10 m^2 quadrats in the upper zone, young corals were growing on loose *Acropora* fragments or on dead massive corals which were covered with fine filamentous algae and fine sand when surveyed in 1988. A total of 191 colonies of 14 genera, with diameters ranging from 0.7-10 cm, covered 1.64 %. The recovery had increased to 38.43 % in 1991. *Acropora formosa*, constituting 31.08 % of the quadrat area, was the most successful species.

Assessment of growth rates of the new recruits

In the upper zone, a total of 51 juvenile corals, including 25 *Acropora*, 8 *Pocillopora*, 7 *Porites*, 5 *Montipora*, 5 *Turbinaria*, and 1 *Montastrea* were mapped outside the quadrats and their growth and mortality were monitored. In the same manner, 54 juvenile corals, including 11 *Acropora*, 10 *Turbinaria*, 9 *Porites*, 7 *Pocillopora*, 5 *Montipora*, 5 *Favites* and single

Table 2. Coral assessment from the 10 m^2 permanent quadrat in June 1988 and May 1991, showing coral density (individuals 10 m^{-2}) and percentage cover in 10 m^2 area in the upper (up) and lower (low) zones.

Coral genera	June 1988				May 1991			
	Density		% cover		Density		% cover	
	up	low	up	low	up	low	up	low
Porites	38	48	0.278	0.214	1	55	0.066	0.661
Acropora	61	21	0.051	0.178	*	*	37.663	7.861
Favites	21	41	0.052	0.153	5	21	0.093	0.194
Pocillopora	19	10	0.259	0.104	1	6	0.224	0.230
Montipora	38	8	0.492	0.092	3	39	0.352	2.892
Turbinaria	1	25	0.001	0.010	1	18	0.016	0.077
Favia	3	7	0.013	0.031	1	23	0.021	0.180
Pavona	2	1	0.456	0.016	-	-	-	-
Platygyra	1	1	0.007	0.007	-	9	-	0.066
Leptastrea	2	1	0.009	0.007	-	1	-	0.003
Hydnophora	-	1	-	0.007	-	6	-	0.202
Podabacia	-	1	-	0.005	-	6	-	0.051
Goniopora	-	2	-	0.005	-	2	-	0.096
Echinophyllia	-	1	-	0.003	-	1	-	0.024
Fungia	1	-	0.013	-	-	2	-	0.085
Cyphastrea	2	-	0.008	-	-	3	-	0.030
Goniastrea	1	-	0.003	-	-	-	-	-
Agaricia	-	-	-	-	-	1	-	0.003
Galaxea	-	-	-	-	-	1	-	0.038
Montastrea	-	-	-	-	-	12	-	0.117
Psammocora	-	-	-	-	-	1	-	0.007
Symphyllia	-	-	-	-	-	2	-	0.019
mussid	1	-	0.002	-	-	-	-	-
TOTAL	191	168	1.644	0.832	>12	>208	38.435	12.836

* Number of colonies could not be estimated because colonies fused together.

colonies of *Montastrea, Physogyra, Echinophyllia, Fungia, Platygyra, Goniastrea* and *Leptastrea* were recorded. Growth rates are shown in Figs.1 and 2.

Montipora, Acropora and *Pocillopora* were the fastest growing genera while *Turbinaria* was the slowest. The growth rate of the first three genera tended to increase from the first to third period of the investigation. When the growth rates on the lower and upper zone were compared, there was a tendency that growth rates in the upper zone were higher (Fig. 2).

Biomass accumulation of reef organisms

All 8 sets of plastic plates manipulated for monthly biomass accumulation (from October 1987 to May 1988) consisted of 10 groups of organisms, i.e. crustose calcareous algae, filamentous blue-green algae, bryozoa, juvenile oysters, juvenile gastropods, juvenile crustaceans, spirorbid worm, foraminifera, barnacle and juvenile corals. Among these groups the

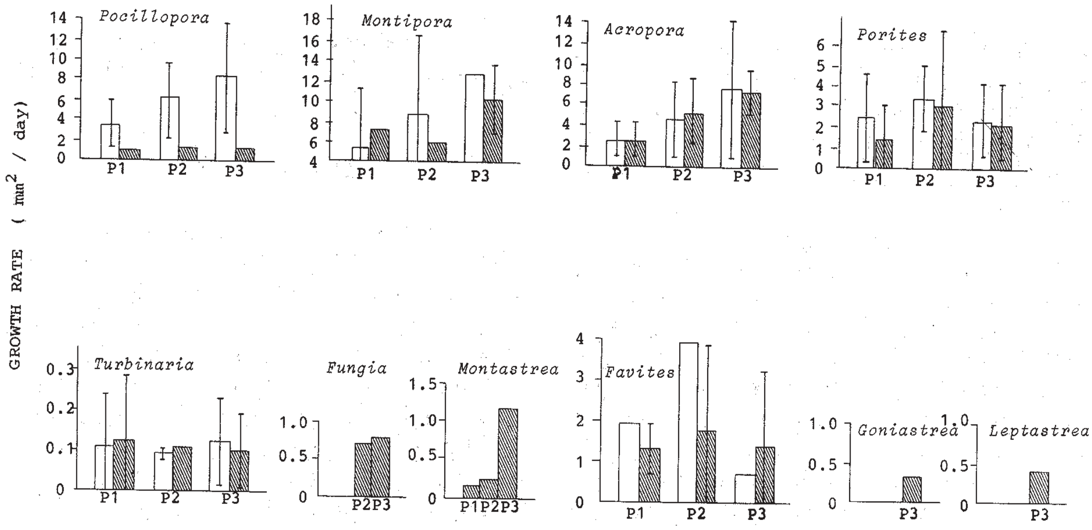

Fig. 1. Mean growth rates ±SD (mm²/d) of juvenile corals in the upper (◻) and lower zones (▨) during 3 periods: p1=8 Oct.-20 Dec.87; p2=21 Dec.87-29 Mar.88; p3=30 Mar.-20 Jun.88.

calcareous algae were major organisms on the plates. The dry biomass in each month is shown in Fig. 3. The highest biomass appeared during the driest months, February to March, when the numbers of sunlight hours are highest.

Only fouling organisms from the plates collected in October 1987 were estimated either as a percentage of area covered or number of individuals. The crustose coralline algae grew more densely on plate edges. This cover was higher on the outside (56.7 ± 20.3 %) when compared with the inside (33.7 ± 9.8 %) of

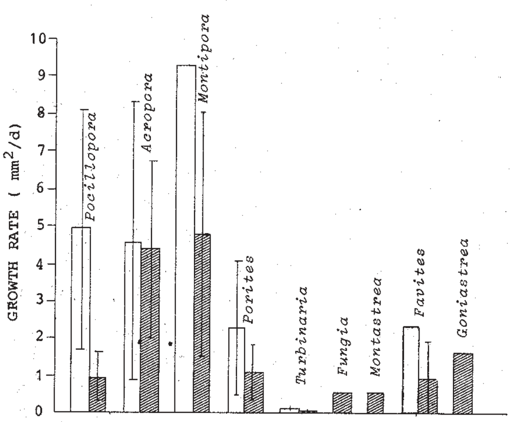

Fig. 2. Mean growth rates ±SD of juvenile corals in the upper (◻) and lower zones (▨) assessed from Oct.87 to Jun.88.

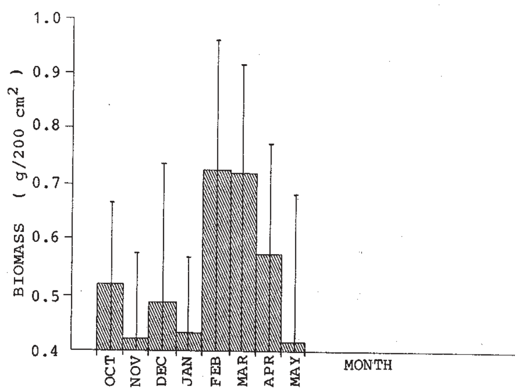

Fig. 3. Monthly biomass accumulation of benthic organisms settled on plastic plates during Oct.87-May 88.

each plate. Spirorbid polychaete worms settled in large numbers. The numbers varied greatly from 0 to 520 individuals (average 47.1 ± 115.5) on the outside of the plates and 2 to 179 individuals (average 49.4 ± 50.1) on the inside of plates.

The remaining organisms were found in small numbers. Juvenile corals were very scarce. Only 2 colonies of *Pocillopora* with 8 polyps and 2.3 mm diameter, and one *Montipora* with 1 polyp and 0.8 mm diameter were found on the outside of 2 plates in November 1987; one unidentified coral, with 1 polyp and 2.2 mm diameter on the inside of plate in February 1988 and an unidentifiable genus, with 7 polyps and 1.6 mm diameter on the inside of plate in April 1988.

The average biomass accumulation (11.11 ± 2.50 g 200 cm^{-2}) of those plates left for 8 months was about 15-30 times higher than the one month group. This was because of the high growth rate of calcareous algae and oysters. No free space appeared on the surfaces of plates left for 8 months, while the 1 month plates had approximately 0-40 % of bare surface on the outer side or 30-65 % on the inner side.

Other organisms found after 8 months exposure were ascidian, *Haliotis* and young brittle star. There were only 2 colonies of coral, *Montipora*, with a single polyp of 0.7 mm diameter on the outside of plate and ahermatypic coral of 1.5 mm diameter on the inside.

Sedimentation rates

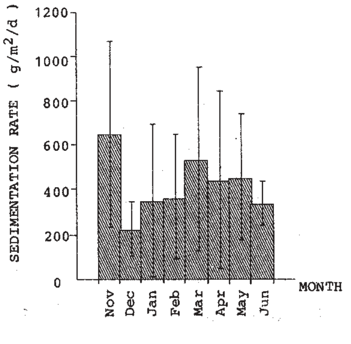

Fig. 4. Monthly sedimentation rate in the lower zone from Nov.87 to Jun.88.

The sedimentation rates varies from about 100 to 1,100 g $m^{-2}d^{-1}$. The monthly mean values are shown in Fig. 4.

DISCUSSION

Since the study site has never been quantified in terms of coral area cover prior to the storm, it is impossible to give the extent of damage in terms of figures. However, the coral cover was more or less 70 % prior the storm event (pers. obs.). The present study was done immediately after the storm. No living coral could be found in the upper zone of the reef. Although large massive coral, such as *Porites lutea* with a diameter of 2.5 m was turned upside down in the lower zone, it remained alive, thus some corals could be found on the lower zone.

The data obtained 16 months after the storm damage show that recolonization took place (mainly by larval settlement) especially in the upper zone. This was not as a result of regeneration from the survivors as has been reported in some reefs (e.g. Pearson, 1981), since all fragments were washed ashore. The largest young coral recorded in October 1987 was an encrusting, two branched *Acropora* of 43.3 x 27 mm (surface area = 918.2 mm^2). Assuming a constant growth rate of 4.43 ± 2.30 mm^2d^{-1} (see Fig. 2), this colony may take 4.5-14 months to grow. This means this colony started to grow 2-11.5 months after the storm event. Wallace et al.(1986) reported that no perceptible time lag occurs before coral larvae can settle, and she found recolonization about 4 months after damage caused by *Acanthaster planci*. The general situation of the reefs is likely to be different in each case of recolonization. After the storm in Phuket, the reef was covered with fine silt for several months and also constantly affected by siltation from a deep-sea port construction. However, the present recruitment started earlier than observed at the Great Barrier Reef which took 2.5 years after a hurricane (Connell, 1973, quoted from Pearson, 1981).

The density of young corals in the upper zone tended to be higher than that in the lower zone, as found at Lizard Island (Harriott, 1985), although the substrates for coral attachment were not as stable as in the lower zone. Pearson (1981) suggested that unstable substrates resulted in a lower chance of coral survival. The higher recruitment rate in the upper zone of the Phuket reef may be due to the higher intensity of sunlight, as well as the fact that sediment was removed more effectively by wave action than in the lower zone.

Differences of early growth rates were not tested statistically due to the small number of corals of each genera. However, growth rates tended to be higher in the upper zone. Bak and Engel (1979) reported that most coral species have monthly growth rates of 1-3 mm diameter in Curacao and Bonaire. The present growth rates were approximately 6-50 times higher in *Pocillopora, Montipora* and *Acropora*, the most rapid growing corals in Phuket. This may be caused by two factors: 1) primary production is high in Phuket water because of outlet of organic nutrients from mangroves and shallow bays (Sundström et al.,1987) and 2) the comparison was made between different groups of corals and different depths, [Bak and Engel (1979) studied at 3-37 m depth]. In addition, the growth rate data presented in Figs. 1 and 2 do not include growth data of corals whose growth was limited, for example by partial mortality.

Four colonies in the upper zone and 7 in the lower zone (10.6 % in total) died during the investigation period. This included 2 *Pocillopora*, 4 *Acropora*, 1 *Montipora*, 2 *Turbinaria*, 1 *Platygyra* and 1 *Echinophyllia*. They were mostly growing in the open space. This mortality rate was lower than found in recolonized reefs after *A. planci* outbreak in the Great Barrier Reef (Wallace et al., 1986) and in the Caribbean after storm damage (Bak and Engel, 1979). Competition for space between coral recruits did not occur during this stage. The mortality may be as a result of being smothered by increasing loads of sediment. Brown et al. (1986) reported sedimentation rates of approximately 20-400 g $m^{-2}d^{-1}$ from November 1983 to November 1984. The sedimentation rate in this study varied from about 100 to 1100 g $m^{-2}d^{-1}$ (Fig. 4). This amount could completely cover and kill corals of the whole reef. Parnrong (1985) reported that at the sedimentation rate from 81.4 $\pm$ 2.5 to 327.9 $\pm$ 9.4 g $m^{-2}d^{-1}$, respiration activity of *Porites lutea* decreased and 50 % of them were completely covered within 2 days in a tank with running sea water. However, in the real situation of this reef, sediment did not permanently settle on corals, because it was resuspended by wave action, which was most effective in the upper zone.

Grazing scars were rare on the plastic plates, indicating low grazing activity. Only 2 small *Haliotis* and 2 brittle stars were found on the inside of the plates. Schools of the herbivorous fish, *Scarus*, enhancing the survival of coral recruits (Birkland, 1977; Harriott, 1985) have been observed.

High amounts of benthic organisms of the present study, such as calcareous algae, filamentous algae, tunicates and bryozoans could rapidly overgrow and smother the coral recruits (Birkland, 1977). This could occur intensely in the crevice complex formed by *Acropora* branches in the lower zone. Tunicliffe (1983) suggested the urchin *Diadema* to be an important grazer on algae. The high production of filamentous algae, and lack of urchins in this reef, could be responsible for the limited coral recruitment in the lower zone.

Similarly, the coral recruitment rate on the plastic plates was limited. Almost all recruits on these plates were *Pocillopora damicornis* which spawns monthly (Mr. Tony Harland, pers. com.). Wallace and Bull (1981) also found low coral recruitment on plastic plates.

From the long term observations during 5 years, it is obvious that recovery in terms of coral area cover has been more extensive in the upper zone than in the lower zone. This finding indicates that sediment load in the lower zone leads to low rates of coral recruitment. In comparison, coral diversity appeared lower in the upper zone (see Table 2). This may be caused by less availability of bare substrate for slow growing species following dense colonization by fast growing *Acropora* which covered the area. *Acropora* can grow and tolerate the high wave energy prevailing in the upper zone.

The recovery in the permanent quadrat in the lower zone was less successful when compared to the transect site. Probably the undamaged parts at the transect site facilitated the recovery in some way. In the quadrats only new recruitment could take place.

Coral reef recovery following storm events has been reviewed by Pearson (1981), who emphasized that rate of recovery is dependent upon the severeness of the storm event. In the present case the rate of recovery is almost the same as reported by Alcala and Gomez (1990) for a reef destroyed at Pescador in the Philippines. In the latter place live coral cover increased from 4.5 to 44.8 % in a 4 year period, i.e. approximately 10 % per year. However, the recovery rate should be faster after the first 2-3 years when budding plays the major role in growth. From this rate it is suggested that the reef at Phuket should recover to a good condition, with more or less 70 % live coral cover, in 6-7 years.

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