Vol. 176: 11–15, 1999 | MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser | Published January 18

Damage and recovery of four Philippine corals from short-term sediment burial

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ABSTRACT: Recovery of corals after full burial with littoral sediment (16% silt, 46% fine sand and 38% coarse sand; 28% $CaCO_3$) was monitored in 2 field experiments at the reefs off Lucero, Bolinao (Pangasinan, NW Philippines), from April to May 1996. In the first experiment at 2 m depth, *Porites* was buried for 0, 6, 20 and 68 h; a second experiment was done at 5 m depth and 4 common taxa (*Porites*, *Galaxea*, *Heliopora* and *Acropora*) were buried for 20 h. At 2 m depth, *Porites* was not affected by 6 h burial compared to the controls that were not buried. Increasing burial time had increasingly more serious effects. Burial for 20 h resulted in increased discoloration of the coral tissue. After 68 h of burial, up to 90% of the tissue bleached in the first days. About 50% of this tissue disappeared subsequently and bare coral skeleton became exposed or were covered with algae. After a few weeks, however, recovery took place: the bare areas were recolonized from surrounding surviving tissue or from highly retracted polyps in the affected area. In the corals that had been buried for 20 h no more significant differences from the controls were observed after 3 wk. For those that were buried for 68 h, this was the case after 4 wk. At 5 m depth, all *Acropora* died after the 20 h burial treatment, but the other taxa recovered in a comparable way to the *Porites* in the first experiment at 2 m depth. It is concluded that complete burial will cause considerable whole-colony mortality in at least *Acropora*, and thus may result in a permanent loss of coral taxa from reefs that are subject to such intense sedimentation events. Less sensitive taxa incur substantial damage but significant recovery was observed after a month.

KEY WORDS: Siltation · Partial mortality · Tissue necrosis · Bleaching · *Porites* · *Acropora* · *Galaxea* · *Heliopora* · SE Asia

INTRODUCTION

Reef-building corals (Scleractinia) incur damage at various scales resulting from biotic and abiotic causes (Pearson 1981, Meesters et al. 1996, Connell et al. 1997, Lewis 1997). Sedimentation is cited as one of the main destructive forces for coral reefs (Pearson 1981, Hubbard 1986, McManus 1988, Hodgson 1990, Rogers 1990, Babcock & Davies 1991). Enhanced sediment loading of coastal waters generally results from terrestrial deforestation (McManus 1988, Hodgson 1990) or marine construction works and dredging (Rogers 1990, Brown 1997). Sediment is deposited on coral reefs in large quantities after extreme river discharges or typhoons (Hubbard 1986, Rogers 1990, Aronson et al. 1994, Riegl 1995, Nowlis et al. 1997).

Excessive sedimentation may lead to full burial, and several examples of burial have been reported from different areas in the world (Caribbean: Hubbard 1986, Rogers 1990, MacIntyre et al. 1994, Nowlis et al. 1997; SE Asia: McManus 1988). Existing literature on the effects of such burial and on the recovery potential for and time scales of coral regeneration describes variable results: some taxa reportedly die after a few hours of burial (Thompson 1980, Rogers 1990), while Rice & Hunter (1992) stated that 7 d of burial caused 50% mortality in the least tolerant species they tested. The latter authors only recorded whole-colony mortality. Nowlis et al. (1997) found that 30 to 55% of a

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reef was covered by terrestrial mud 1 mo after a severe typhoon had hit St. Lucia. This mud cover was reduced to 15–20% in 3 mo. Hence, relevant time scales for the burial itself as well as for the responses vary between hours and months.

Our purpose was to include intermediate stages of tissue degradation and to assess (1) the effects of complete but comparatively short-term burial treatments of different duration (hours to days) on colonies of 1 common taxon, *Porites*, (2) the effects of short-term (20 h) burial on 4 common SE Asian coral genera (*Acropora*, *Galaxea*, *Heliopora*, *Porites*), and (3) the potential for post-burial recovery at intermediate time scales (weeks).

MATERIAL AND METHODS

Coral colonies were buried and observed for damage and recovery in 2 experiments off Lucero village, Bolinao, province of Pangasinan (NW Philippines): one on the reef flat (2 m depth, 16° 23.23' N, 119° 54.41' E) and one on the adjacent deeper spur and groove zone (5 m depth, 16° 25.17' N, 119° 53.87' E). The experiments were conducted from mid-April to late May 1996 (dry season). The sediment was collected near shore from the channel between the reef and the Catubig river mouth (16° 22.99' N, 119° 54.85' E). It was composed of 16% silt (<63 µm), 46% fine sand (63 to 260 µm) and 38% coarse sand (>260 µm), and the dry sediment contained 28% $CaCO_3$. This carbonate content suggests that it is a local mixture of marine and terrestrial material since sediments of the overall Bolinao siltation gradient vary from 6% carbonate at the river mouths to 93% at the reef flat (Terrados et al. 1998, Kamp-Nielsen, Wesseling & Vermaat unpubl. data). Since the taxonomy of Philippine *Porites*, *Acropora* and *Galaxea* is complex (Veron 1986, Uychiaoco & Aliño unpubl.), we have identified these taxa at the genus level only. For briefness, we will also refer to *Heliopora coerulae* Pallas here by its genus name. We used the following growth forms: massive *Porites*, branching *Acropora*, branching *Heliopora* and submassive *Galaxea* (as described by Veron 1986).

In the first experiment, at 2 m depth, 40 *Porites* colonies (4 blocks of 10 m × 10 m area with 10 colonies each) were tagged and labelled, colony area was measured according to Meesters et al. (1996, 1997), and the percentage surface cover of a number of different categories of tissue condition (Table 1) was measured visually, aided by a grid. Observers cross-calibrated their evaluation of tissue condition categories. PVC rings 15 cm in height and 30 cm in diameter were placed around the colonies and pegged into the substrate. Two or three replicates within a block (leading to 10 replicates in total per treatment) were randomly allocated to each of 4 burial periods: 0, 6, 20 and 68 h. The plastic rings were filled up with sediment, burying the corals to 1–5 cm depth, and at the end of the burial period this material was removed by careful fanning with a plastic slate. Percentage cover of each of the various health categories (Table 1) was then estimated for each colony at regular intervals during 4 wk until the end of the dry season.

Table 1. Categories of coral tissue conditions used to describe the state of health of the colonies (modified from Rogers et al. 1994). All categories are expressed as percentage of colony area. The 3 categories 'bare coral skeleton' were classified as such on surface appearance. No cores were made for inspection of deep tissue withdrawal within the skeleton (as observed by e.g. Coles & Fadlallah 1991); hence, no final conclusion could be drawn on the condition or morbundity of any remaining but invisible tissue

Abbreviation	Condition
BLEA	Bleached coral, white, with tissue remaining
BCS/W	Bare white clean coral skeleton without tissue
BCS/TURF	Bare coral skeleton without tissue but with some algal turf grown over the skeleton
BCS/A	Bare coral skeleton covered with algal turf: skeleton not visible
DISCO	Discolored (purple, bluish, pink, yellow, light-brown) or partly bleached tissue but not completely white
MUCUS	Mucus coat
SS	Sediment spot; small sediment-filled spot or hole
OK	Remaining healthy tissue (calculated by summing the percentages of all other categories per colony and subtracting this from 100%)

In the second experiment, at 5 m depth, basically the same procedure was followed. Here 5 specimens each of *Porites*, *Acropora*, *Heliopora* and *Galaxea* were buried for 20 h. For each taxon, 2 additional colonies were monitored as blanks.

Due to time constraints not all necessary observations could be made on the same day. Observation data were pooled into 7 time intervals that are indicated by the day on which most measurements were made, i.e. on the modal day. Measurements made before sediment application are considered preburial controls and pooled into time interval −1. Observations made directly after removal of the sediment are placed in time interval 0. Time interval 4 contains measurements from 4 to 6 d after treatment, time interval 8 from 7 to 10 d, time interval 15 from 13 to 15 d, time interval 19 from 19 to 23 d and time interval 27 from 27 to 30 d after treatment.

Because repeated observations were made on the same colonies, the data are analysed with repeated measures ANOVAs for the separate effects of time and treatment (Potvin et al. 1990). Although Mauchly's sphericity test was generally significant, the Huynh-Feldt Epsilon statistic did not deviate markedly from 1 (less then 25%, Potvin et al. 1990); hence, application of a repeated measures ANOVA was justified. Only results for univariate tests are shown, but levels of significance were similar to those obtained from the multivariate tests. Subsequently, within each time interval, 1-way ANOVAs were carried out to compare differences in cover categories among treatments (Expt 1) and among species (Expt 2). Multiple comparisons among means were made with modified least significant difference tests maintaining an experiment-wise error rate of $p < 0.05$. Data were $\log_{10}(x + 1)$-transformed when requirements for parametric tests were not met (homogeneity of variances, normal distribution). After transformation, the data from the second experiment still did not meet the requirements for parametric testing because of zero variance in some of the taxa. Therefore non-parametric Wilcoxon tests were done, maintaining the experiment-wise error rate at 0.05. Means are presented ±1 standard error throughout this article.

RESULTS

In Expt 1, the factors time (repeated measures) and treatment as well as their interaction were significant for all tested cover categories (Table 2). We conclude from these ANOVAs (1) that different burial periods caused different responses in shallow water *Porites*, (2) that these responses changed with time, i.e. after an initial postburial response the colony surface passed through different stages, and (3) that this temporal change was different for the different treatments. This pattern is supported by the subsequent multiple comparisons (Fig. 1); for example, the average area with healthy tissue returned more rapidly to pre-burial values after short burial.

Short-term burial (6 h) had no significant effect on the remaining percentage of healthy tissue (Fig. 1A), but more prolonged burial (20 and 68 h) drastically reduced healthy areas on the *Porites* colonies. During the subsequent period, recovery took place and after a month the proportion of healthy area in these 2 treatments had approached the levels present in the controls (1-way ANOVA comparing 20 and 68 h burial treatments after 27 d with controls after 23 d: $p = 0.06$).

The patterns observed in the affected tissue categories (bleached, discolored, bare skeleton) differed among treatments. Generally, the corals that were only buried for 6 h showed no difference with the controls. The 20 and 68 h burial treatments produced different responses, particularly in the first days after burial. *Porites* colonies that had been buried for 20 h had a significantly higher proportion of discolored tissue in the first days after treatment. In the same period, the colonies of the 68 h treatment had significantly more bleached tissue (Fig. 1B, C). After 1 to 2 wk we observed large patches of bare skeleton in these previously bleached areas (Fig. 1C, D): the early maximum of 58 ± 15% of colony area bleached was followed after 2 wk by a maximum areal proportion of 45 ± 15% of bare skeleton. In contrast, the discolored tissue of the 20 h burial recovered. Multiple comparisons of the areal proportion of bare skeleton revealed no difference between treatments after 19 and 27 d (Fig. 1D), which largely supports the pattern observed in the percentage live tissue (Fig. 1A).

In Expt 2, all taxa were significantly affected by the burial, but the change over time was only significant in *Heliopora*, probably because of the considerable scatter present in the data (Table 2, Fig. 2). For all genera the percentage healthy tissue decreased to less then 20% immediately after the treatment (Fig. 2). Within post-burial observation periods, differences in the amount of healthy tissue between the control colonies and the treated colonies were always significant for *Acropora* ($p < 0.04$), but only so in the early postburial period for *Heliopora* and *Porites*, whilst *Galaxea* showed no sig-

Table 2. Summary of the univariate repeated measures ANOVAs on data from Expt 1 with shallow water *Porites* and from Expt 2 with 4 different taxa. Treatments in Expt 1 are 3 different durations of burial and a control; in Expt 2 only 1 burial period is compared with the control. Given are the levels of significance (p) for the effects of burial duration (treatment), post-burial time (repeated measures) and their interaction

Parameter	Treatment effect (p)	Repeated measures effect (p)	Interaction (p)
Expt 1			
% bleached colony area (BLEA)	0.001	0.000	0.005
% discolored coral tissue (DISCO)	0.006	0.000	0.001
% bare coral skeleton with algae (BCS/A)	0.018	0.007	0.001
% healthy coral tissue (OK)	0.000	0.000	0.000
Expt 2: % healthy tissue			
Acropora	0.000	0.711	0.829
Porites	0.003	0.072	0.032
Galaxea	0.001	0.481	0.343
Heliopora	0.015	0.001	0.001

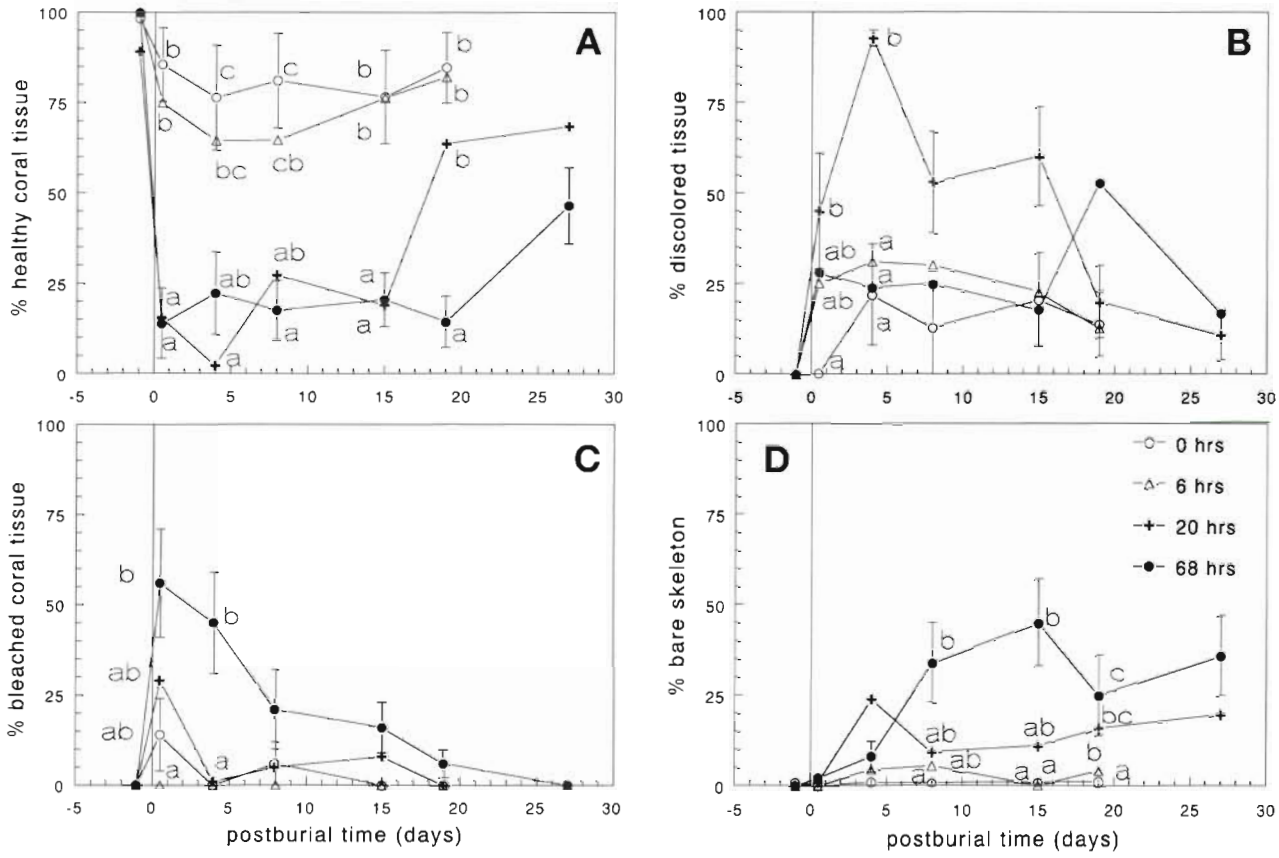

Fig. 1. *Porites*. Post-burial development of the percentage of coral area covered by different tissue quality categories after variable burial duration in Expt 1 (A) Percentage of remaining healthy surface area, (B) percentage of area covered by discolored tissue, (C) percentage of bleached area, (D) areal percentage of bare skeleton (summed categories BCS/A, BCS/W, BCS/TURF from Table 1). For reasons of clarity, SE bars are shown only for the control and 1 treatment. Multiple comparisons were made within each time period and different letters indicate significant differences among treatment means within such a period. Where no significant differences exist between means, no lettering is given. Replication was 10 per treatment, divided over 4 blocks

nificant burial effects ($p > 0.07$ after 4 d post-burial). *Galaxea*, *Heliopora* and *Porites* started to recover within a week. Buried *Acropora*, however, did not recover during the period of observation and therefore probably was completely dead. No significant differences in healthy tissue were observed between the *Porites* at 2 m depth and at 5 m depth that were buried for 20 h ($p > 0.11$ for any post-burial period).

DISCUSSION

In the present experiments *Porites* corals survived complete but short-term burial (6 h) quite well. Longer periods of burial (here 20 and 68 h) resulted in increased areas with discoloration, bleached tissue and bare skeleton in the first days after removal of the burying sand. Particularly the longest burial period (68 h) caused substantial areas of bleached tissue that subsequently turned into bare skeleton (more than 40% after 2 wk, Fig. 1D). However, after 3 to 4 wk, considerable recovery from the surrounding healthy coral tissue was observed, commencing a week earlier in the corals buried for 20 h than in those that were buried for 68 h. Apparently bleaching is more serious than discoloration, as only bleached areas subsequently turned bare. Since we observed a sequence of bleaching, superficial tissue loss and subsequent regrowth, recovery of bare parts of colony surface was probably realised by regrowth from surrounding healthy tissue, or from re-surfacing of deeply withdrawn tissue (cf. Coles & Faladdah 1991).

In deeper water, *Porites* corals responded similarly to 20 h burial as those from shallower water, and recovery was complete after about a month. *Galaxea* and *Heliopora* recovered over comparable time spans, but the buried *Acropora* colonies did not recover after an immediate and complete death. The presently applied natural sediment was a fairly coarse grained mixture of terrestrial and marine materials (cf. Thompson 1980, Rogers 1983, Rice & Hunter 1992, Riegl 1995). This may explain the considerable survival capacity observed

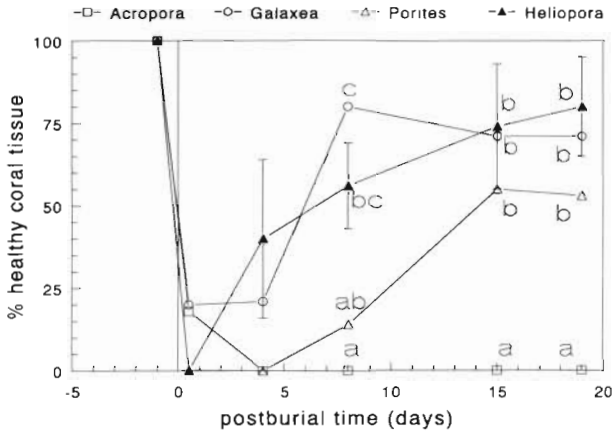

Fig. 2. *Acropora*, *Galaxea*, *Heliopora* and *Porites*. Post-burial development of the percentage of healthy coral area after 20 h of burial in corals in Expt 2 at 5 m depth. For reasons of clarity, SE bars are shown only for 1 of the coral genera. Multiple comparisons were made within each time period and different letters indicate significant differences among treatment means within such a period. Where no significant differences exist between means, no lettering is given. Replication was 5 per species, and 2 for controls

here, since Thompson (1980) reported that burial under fine drilling mud resulted in higher mortality than burial under coarse carbonate sands.

The observed among-species variation in sensitivity is in line with the findings of Thompson (1980), Rogers (1983), Rice & Hunter (1992) and Riegl (1995). Thompson (1980) also found that *Porites* was comparatively insensitive to burial. We conclude that in reefs subject to intense sedimentation that includes possibly infrequent burial events, decline or absence of sensitive taxa like the presently tested *Acropora* is probable. Less sensitive taxa suffer less dramatically, but probably require several weeks up to months for recovery.

Acknowledgements. This paper is part of the EC STD-3 project 'Responses of Coastal Ecosystems to deforestation derived siltation in South East Asia', for practical purposes acronymed CERDS (TS3*-CT94-0301). The project has been assigned to the LOICZ programme as project no. 27. We thank Wilfredo 'Al' Licuanan for advise in the field experimental design, Venus Olaivar for fabrication of field materials, Fernando 'Jhun' Castrence Jr, Rodrigo 'Lagoy' Castelo, Gabriel 'Ambing' de Guzman and Elmer 'Piriong' Dumaran for field assistance and Hazel Arceo for assistance in data processing. Erik de Ruyter van Steveninck, Michiel Hootsmans and Peter van der Wateren critically read the manuscript.

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Editorial responsibility: Otto Kinne (Editor), Oldendorf/Luhe, Germany

Submitted: February 16, 1998; Accepted: October 8, 1998
Proofs received from author(s): January 7, 1999