

# SEDIMENTATION DAMAGE TO REEF CORALS

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## ABSTRACT

A 12-month study was made of the effects of coastal logging in a Philippine drainage basin, on soil erosion, sediment transport, and the subsequent effects of marine sedimentation on coral reefs located in an adjacent bay. Logging significantly increased soil erosion and sediment transport to the bay. Over 80% of surface erosion came from logging roads. Sediment deposition increased only at the coral reefs closest to the river mouth on most days. During peak river discharge, however, sediment plumes spread over the bay and high rates of sedimentation occurred at all reefs except the control station. Coral cover and number of species declined significantly during the study period. Experimental tests of sedimentation tolerance among 50 species of coral revealed a tolerance hierarchy based on growth form, corallite diameter and polyp extensional ability. The abundance of corals shown by experiment to be highly susceptible to injury from sedimentation declined significantly over the 12-month period. The study demonstrated that coastal logging can damage coral reefs by increasing sediment deposition rates above the tolerance thresholds of some coral species.

## INTRODUCTION

Sedimentation in the sea is a natural process that results from erosion of the land and transport of soil to the sea, or from resuspension of sediment previously deposited along coastal margins or on the seabed. Many human activities, particularly land clearing associated with farming, logging and road construction, are believed to accelerate erosion and subsequent marine sedimentation. This anthropogenic sedimentation is a form of pollution. Scleractinian corals are known to be injured by exposure to sedimentation (Rogers, 1990), and sedimentation pollution appears to be widespread and increasing in severity. Sedimentation pollution may pose the single most serious threat to the health of coastal coral reefs in the world.

Few studies have attempted to link the cause of anthropogenic sedimentation, in the terrestrial ecosystem, with the effect on organisms in the marine ecosystem. This paper summarizes the results of a 12-month study of the effects of coastal logging in the Philippines on soil erosion, and the follow-on effects of marine sedimentation on coral reefs located within a nearby bay (Hodgson 1989; 1990a; 1990b). A detailed analysis of this case from the perspective of ecological economics has been reported separately (Hodgson and Dixon, 1988).

## METHODS

### Terrestrial

The study was carried out in a forested watershed and adjoining bay in El Nido, Palawan (Figure 1). A six-month site investigation commenced in mid-1985 followed by a 12-month period of quantitative data collection that ended on 31 December 1986. Land use, particularly the extent of logging, was measured from aerial photographs and confirmed by ground truthing. From January to December 1985, the pristine dipterocarp forest was selectively logged, with most activity occurring during the dry season (August-December). Logging was temporarily halted between January and December, 1986.

Rain gages and adjacent erosion plots were built on 30% slopes and used to measure erosion rates in pristine forest, coastal forest and on a logging road (Figure 2). An automated gaging station was constructed to measure the flow of the major river (Manlag draining the logging area). Sediment load in the Manlag River and a nearby river draining pristine forest land were measured using standard USGS procedures (Guy and Norman, 1970).

### Marine

Eight permanent stations were monitored on coral reefs in Bacuit Bay (Figure 2). Station 8, near the bay entrance served as a control station. Water current patterns were studied using drogues during both monsoons. Weather conditions and water quality parameters were measured twice monthly. At each station, sediment deposition was measured once per month using replicate traps located at a depth of 3 m and placed 1.5 m above the seabed. Both terrestrial and marine sediments were analyzed for particle-size distribution, calcium carbonate and organic content.

At each station, five 10 m transects were established on the reefs at a depth of 3 m. The transects were surveyed in January and December 1986 using the chord-intercept technique (Loya, 1972). Coral colony-size was also measured and the size of any injured patches was recorded (partial mortality).

The effects of sedimentation on 50 species of corals from 14 Families were studied in the laboratory and the field. In Bacuit

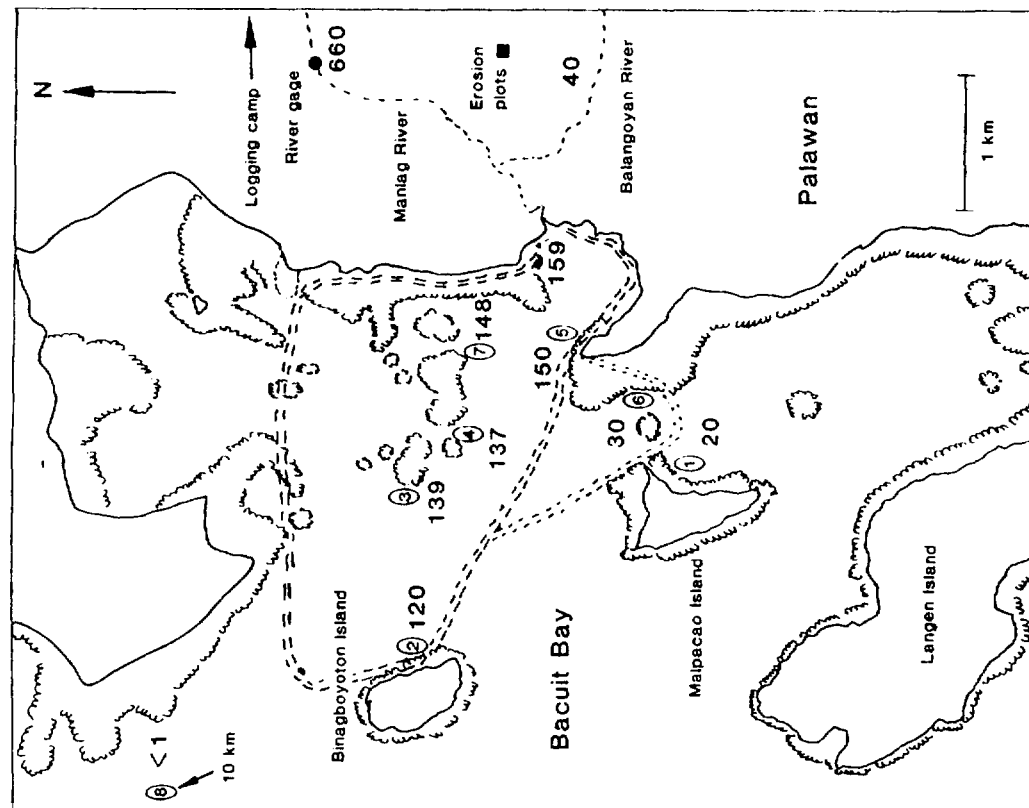


Figure 2. The study area showing the location of terrestrial and marine monitoring stations (1-8). The control station (8) was located near the bay entrance and is not on the map. The border of a typical sediment plume is marked by a broken double line and sediment concentrations in the river and sediment plume are given (mg/l).

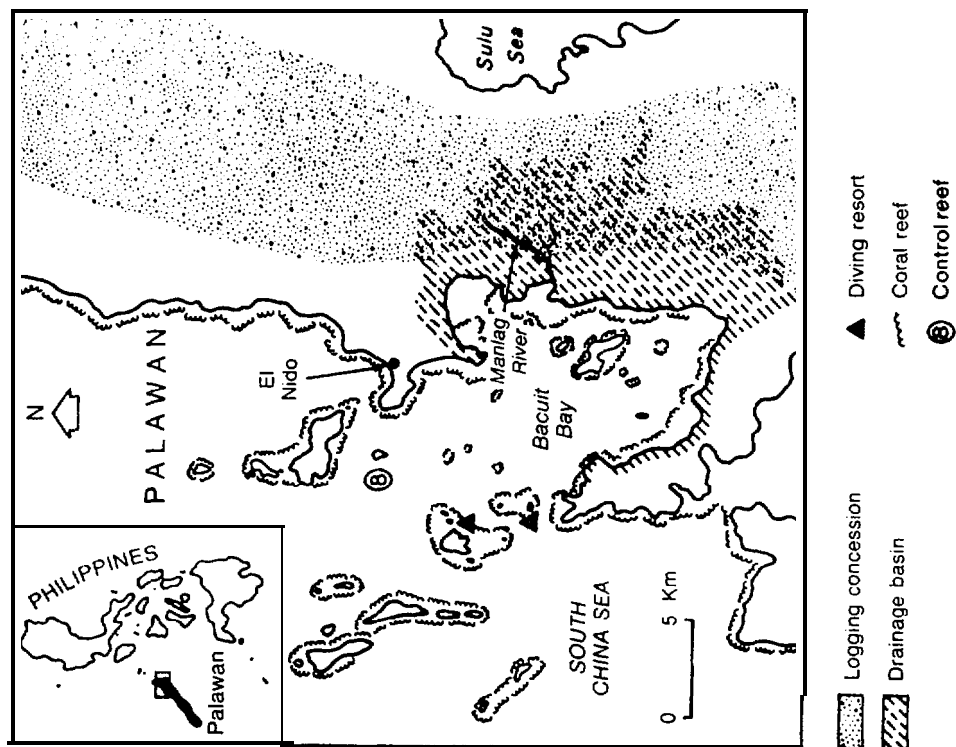


Figure 1. The study area in El Nido, northern Palawan showing coral reefs in Bacuit Bay, the drainage basin, and logging concession.

Bay, reciprocal transplants were made between corals at a pristine reef (Station 8) and the reef nearest to the mouth of the **Manlag** River (Station 5), the source of anthropogenic sedimentation. Mortality and the percentage of injured tissue were monitored regularly. Experiments conducted in aquaria were used to **assess** the tolerance of 22 species of **coral** to sedimentation. A variety of additional studies **were carried out** to investigate the process of sedimentation damage to corals and the effects of sediment *on* the settlement of coral **planulae** (Hodgson, 1989; Hodgson, 1990a, b).

## RESULTS

### Terrestrial

At the beginning of the study, when logging had temporarily ceased, 87% of the watershed was still forested and about 6 % had been **logged** (Table 1).

Table 1. Land use in the **Bacuit Bay Drainage Basin** in **January 1986**

Land Use	Area (km <sup>2</sup> )	% of Drainage Basin
All Forest	72.8	93.0
Primary	37.0	47.3
<b>Scrub/Secondary</b>	27.1	34.6
Logged	4.8	6.1
Mangrove	3.9	<b>5.0</b>
All Agriculture	<b>5.5</b>	7.0
<b>Swidden/cashew</b>	3.6	4.6
Rice paddy	<b>1.1</b>	<b>1.4</b>
Coconut plantation	0.8	1.0
Total	78.3	100.0

Drainage basin soils are acidic; the average particle-size distribution is 23% sand, 41% silt and 36% clay, Rainfall in **1986** was 3400 mm, of which about 85% fell from June through November. The annual erosion rate from the road (**3.2 15 kg/m<sup>2</sup>**) was 5( times the rate in the cut forest and 120 times that from the pristine forest. Mean **Manlag** River discharge was 112,402 **m<sup>3</sup>/day (5,74: m<sup>3</sup>/day/km<sup>2</sup>)**. Mean suspended sediment concentration in the **Manlag** River was 327 **mg/l** and annual sediment discharge was 39,154 tonnes (2,000 **tonnes/km<sup>2</sup>**). During five one-week monitoring periods (February, May, June, August and December), the **Manlag** River sediment concentration (730 **mg/l**) was significantly higher ( $p < 0.005$ ) than that in the *river (Balangoyan)* draining adjacent **pristin** forest (45 **mg/l**).

### Marine

#### Physical Parameters. —

During 1986, mean wind speed was 2.7 m/s and the wind direction closely followed monsoon directions (southwest from **May through** October; northeast from November to April). Annual means of other marine parameters are given in Table 2.

Table 2. Marine Parameters **during 1986: mean (standard error)**

Parameter	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	Stn 7	Stn 8
Temp °C	29 (1)	28 (2)	28 (2)	29 (2)	29 (1)	29 (2)	29 (1)	28 (1)
Salinity (ppt)	34 (1)	33 (2)	33 (3)	33 (3)	33 (2)	33 (2)	33 (3)	34 (1)
Waveheight (m)	0.1 (0.3)	0.1 (0.1)	0.5 (0.4)	0.3 (0.3)	0.4 (0.3)	0.2 (0.3)	0.2 (0.2)	0.4 (0.3)
Sediment deposition (mg/cm <sup>2</sup> /d)	1.4 (0.8)	0.5 (0.4)	1.8 (1.1)	1.7 (0.9)	31.6' (19.0)	6.8 (5.9)	2.1 (1.3)	0.6 (0.4)
Secchi depth (m)	7.5 (3.8)	9.5 (4.9)	8.0 (3.7)	6.4 (2.3)	3.4 (1.8)	5.4 (1.8)	4.5 (2.5)	13.1 (5.4)

<sup>1</sup>p < 0.05 Tukey test

There were some significant differences in wave height among stations (see Hodgson, 1989), however, there was no difference between Station 5 (closest to the terrestrial sediment source) and 8 (control). Sediment deposition was significantly higher ( $p < 0.05$ ) at Station 5 than at all other stations. In the trapped sediment, percent calcium carbonate was significantly lower at Stations 5, 6 and 7 than at Stations 1, 2, 3 and 8. Turbidity was significantly higher ( $p < 0.05$ ) at Station 5 than at Stations 1, 2, 3 and 8.

The results of routine monitoring indicate that mean temperature and salinity were similar at all stations, however, during periods of high discharge from the Manlag River, low salinity and temperature sediment plumes spread out across the bay for periods lasting up to several days (Figure 2). Depending on the state of the tide, wind direction and speed, and rate of Manlag River discharge, these plumes would occasionally reduce salinity and temperature to a depth of 1 m at Stations 1-7. The concentration of suspended sediment in surface waters during such an event is indicated in Figure 2.

It was not possible to monitor all sediment plumes (peak discharge often occurred at night), however, daily sediment concentrations and discharge rates measured at the Manlag River gaging station allowed estimates to be made of suspended sediment and sediment deposition at all marine stations except the control (Station 8) during peak discharge days. During 1986, there were seven high-discharge days during which sediment deposition at Stations 1-7 probably ranged between 16 and 51  $\text{mg}/\text{cm}^2/\text{day}$ .

### *Biological Parameters.* —

The results of the aquarium and field experiments with 50 species of corals showed that there was a hierarchy of tolerance to sedimentation that was related to each species' growth form, corallite size and ability to extend polyps above the colony surface. Sediment deposition of 20  $\text{mg}/\text{cm}^2/\text{day}$  was sufficient to injure many species of Bacuit Bay corals. Coral species having a large corallite diameter and extensible polyps were found to be the most resistant to sedimentation damage while those with small corallite diameter, low polyp extensibility and ramose growth form were the most susceptible.

Between January and December 1986, coral cover was reduced at all stations except the control (Figure 3); this reduction was significant ( $p < 0.0005$ ; anova). Recently killed coral increased significantly at Station 5 from near zero to almost 40% of the substrate ( $p < 0.01$ ; Tukey test). There was a significant positive relationship between loss of coral cover at each site and mean sediment deposition (natural log transformed;  $p < 0.02$ ;  $r^2 = 0.62$ ;  $y = 6.28x + 1.3$ ).

In addition to a reduction in coral cover, there was a significant decrease in number of species ( $p < 0.0001$ ; anova) and genera ( $p < 0.05$ ; anova), however, changes in the Shannon diversity index ( $H'$ ), Pielou evenness (F) and mean colony size were not significant. Partial mortality significantly increased ( $p < 0.0007$ ; anova). There was a significant reduction in cover of coral species with the three phenotypes shown by experimentation to be susceptible to sedimentation injury ( $p < 0.0001$ ; anova).

## DISCUSSION

### Terrestrial

Although intuitively obvious, only a few studies have demonstrated that logging increases soil erosion (Hamilton and King, 1983). The present study was possibly the first to quantify the links between erosion and sediment transport from a logging area, and sedimentation in a tropical marine ecosystem. The erosion and sediment transport results presented here are conservative because prior to the start of monitoring, logging had stopped and only a small portion of the total available concession had been harvested.

To estimate the contribution of roads to erosion, it is necessary to take into account the cut and till slopes that are generated during road construction on steep slopes. Using this method, logging roads in El Nido comprised 6% of all forest land, but were estimated to contribute 84 % of all surface erosion.

### Marine

Marine organisms have a wide variety of adaptations that protect them from deleterious effects of sedimentation. Contrary to conventional wisdom, corals commonly grow in turbid water environments and have a variety of mechanisms that protect them from sedimentation damage (Hubbard, 1973; Hubbard and Pockock, 1972; Hodgson, 1989; Rogers, 1990; Stafford-Smith, 1990; Stafford-Smith and Ormond, 1992). In general, sediment deposition is more harmful to corals than high turbidity (Edmondson, 1928). When the rate of sediment deposition exceeds the clearance rate, tissue necrosis follows a well-defined series of microbe-mediated stages until the skeleton is exposed (Hodgson, 1990b). A number of studies have investigated the tolerance of scleractinian corals to sedimentation (see Rogers, 1990; Stafford-Smith, in press). Building on previous work, the present study demonstrated that corals span a wide hierarchy of sedimentation tolerance. Corals with large diameter corallites and high extension ability polyps are most resistant to sediment damage because they can clear their surfaces of sediment accumulation, even when the sediment is composed of large heavy particles. The linkage of certain phenotypic characters such as small polyps and ramose growth form in the speciose Acroporidae makes it difficult to resolve the importance of some individual characters.

There is little evidence to support hypotheses other than sedimentation as the cause of the changes recorded at Bacuit Bay reefs in 1986. In particular, the losses of coral cover consisting of species predicted by experiments to be most susceptible to sedimentation injury is considered strong supporting evidence that sedimentation was a primary causative agent.

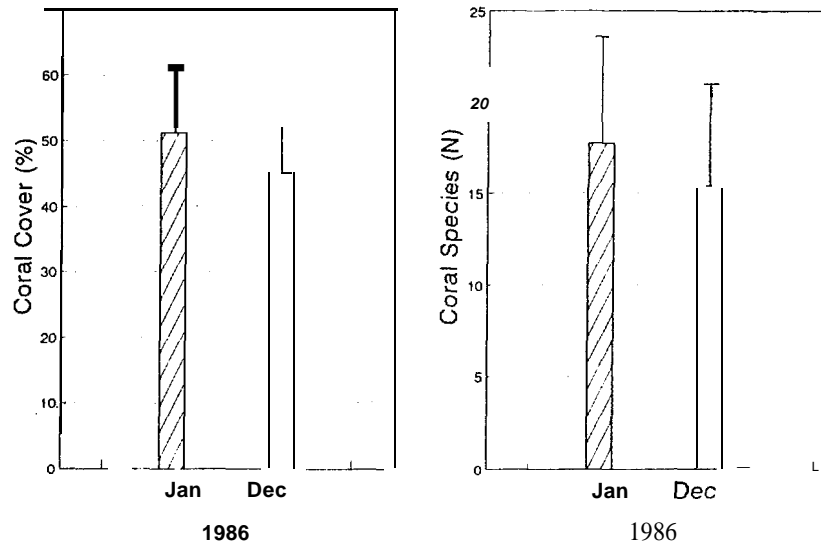


Figure 3 There was a significant decline in mean coral cover and number of species at Stations 1-8 between January and December 1986. Error bar shows S.D., n=5, 10m transects.

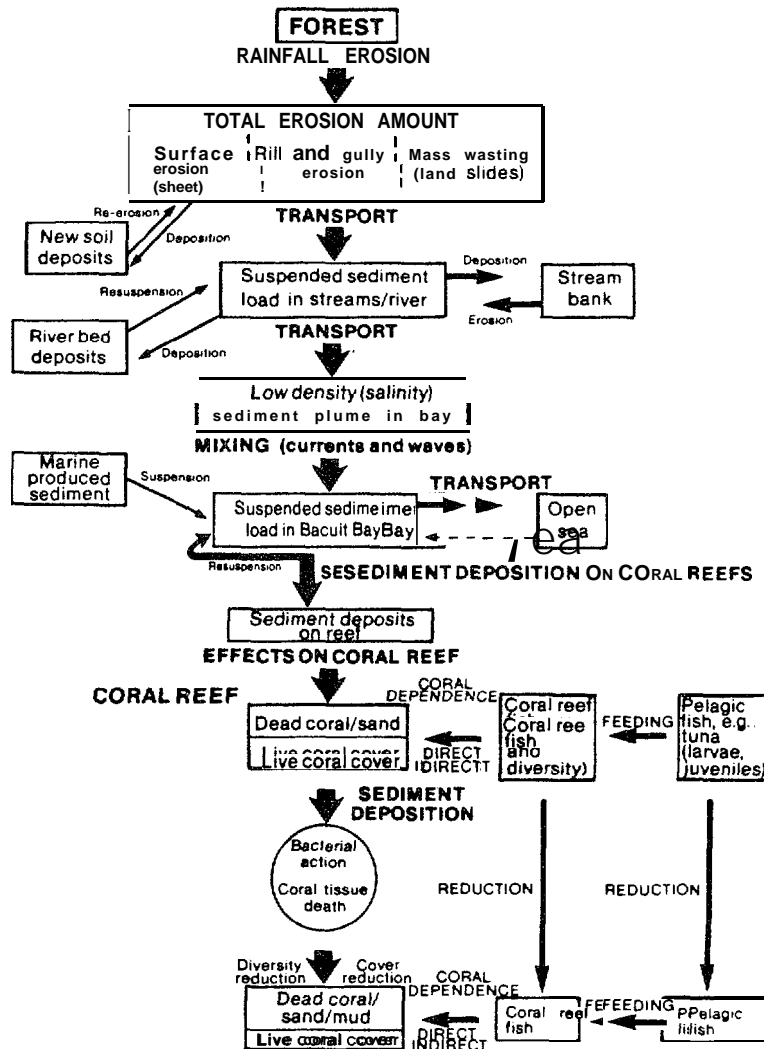


Figure 4. This flow chart indicates the possible pathways of sediment eroded from the El Nido forest, and some potential effects on coral reef communities.

## CONCLUSIONS

Logging in the El Nido forest was shown to significantly increase surface erosion of which more than 80% was attributable to roads. Cost-effective erosion control within logging concessions would best be achieved by focusing on the reduction of erosion from roads. Logging significantly increased sediment transport from the drainage basin to **Bacuit** Bay. Although sediment deposition on most days was significantly increased on Jy at reefs close to the river mouth, on peak discharge days sediment plumes spread out over the bay and deposition was increased to potentially damaging levels ( $> 20 \text{ mg/cm}^2/\text{day}$ ) at all except the control station. Coral cover and number of species declined significantly during the study and the most **likely** cause was sediment deposition. Coral species shown by experiment to be susceptible to sedimentation injury showed significant mortality. The most susceptible coral species are probably among the least tolerant marine organisms to sedimentation. The study demonstrated the link between the terrestrial and marine ecosystems, and that coastal logging can damage coral reefs by increasing erosion, sediment transport and deposition (Figure 4). The results from El Nido are conservative because only a small fraction of the available forest was logged, logging was not active during the study, and the water volume in **Bacuit** Bay is relatively large when compared with the discharge volume from the drainage basin. The study confirmed the hypothesis that coastal logging can damage coral reefs and suggests that other forms of land clearing would pose a similar threat. There is potential for large economic losses due to sedimentation damage to coral reefs (**Hodgson** and **Dixon**, 1988).

## ACKNOWLEDGEMENTS

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