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Comparison of two reef sites in the Wakatobi Marine National Park (SE Sulawesi, Indonesia) using digital image analysis

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Introduction

Coral reefs are complex ecosystems characterized by nonlinear relationships between biotic and abiotic components. The availability of light limits the depth distribution of corals, where turbidity and sedimentation can have marked effects on their growth (Meesters et al. 1998) and morphology (Meesters et al. 1996; Kaandorp 1999). Although there have been many studies of coral growth rates (e.g. Dodge and Vaisnys 1975; Bak 1976; Hubbard and Scaturo 1985; Crabbe et al. 2002), there have been few of the influence of sedimentation on the growth rate and morphology of branching corals.

Here, we used digital videophotography and computer image analysis to monitor coral cover, species richness, sedimentation rates, underwater (u/w) visibility, and growth and morphology of *Acropora* colonies at two sites, Kaledupa and Sampela, separated by about 1.5 km in the Wakatobi Marine National Park, SE Sulawesi, Indonesia. There was significantly higher species richness, coral cover and rugosity at Kaledupa than at Sampela.

Our results suggest that the increased sedimentation and consequent lowered light levels at Sampela have altered the growth rates and morphology of the *Acropora* corals there. The scleractinian coral community of Sampela is severely impacted by sedimentation, mostly from a Baujo village, which can lead to the suffocation of corals and to decreased growth and calcification rates resulting from reduced light penetration.

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Methods

The sites studied were located at Kaledupa, a reef experiencing little or no human use, and Sampela, a heavily used reef. Both are close to a Baujo village community near the island of Hoga, where a Marine Research Station run by Operation Wallacea is situated. Hoga is in the Wakatobi Marine National Park, part of the Tukang Besi archipelago, a remote island group off SE Sulawesi in Indonesia (Dioum 2000). The work was conducted between 1 June and 1 October 2001, with the *Acropora* colony growth measurements being made over 6 weeks starting from 1 August 2001. Latitude and longitude of sample sites were determined with a hand-held GPS receiver. Species richness was determined for benthic species cover at three permanent quadrats (1 m^2), chosen randomly at each site at 10-m depth. Coral density was calculated as numbers of hard corals per m^2 in the same permanent quadrats at each site at 10-m depth. Salinity was measured in parts per thousand using a hand-held salinometer. Rugosity was calculated by using a 6.07-m length chain laid over three replicate sections of transects (see Table 1) at each site at 10-m depth. The straight-line distance occupied by the chain was measured, and the rugosity index calculated by dividing the total length of chain by the straight-line distance (McCormick 1994). Euphotic depth (u/w visibility) was estimated using a Secchi disk. Sedimentation rates were determined using standard sediment traps (English et al. 1997) at three locations in 10-m depth at each site over a 7-day period, and are expressed as g dry weight m^{-2} day^{-1}. Salinity, temperature, and u/w visibility were measured at the same time as the *Acropora* growth measurements and did not vary significantly over the measurement intervals.

Three randomly allocated transects, each 10-m long and separated by at least 5 m, were laid at both sites, on the reef crests (5-m depth) and on the reef walls, at 5, 10 and, at Kaledupa only, at 15-m depths. (The maximum depth at Sampela was 12 m.) Each transect was videographed using a Sony digital PC110E camera in an Ikelite u/w housing, and Pro Video-Lite II illumination. Coral cover over each transect was determined using the method of Osborne and Oxley (1997). Computer digital image analysis was done using the UTHSCSA (University of Texas Health Science Center, San Antonio, Texas) Image Tool image analysis software for Windows.

Three *Acropora valenciennesi* colonies growing at 10-m depth were chosen haphazardly at each site, and six branches tagged on each colony. The colonies were chosen randomly with no bias as to their health or morphology. The three colonies at each site were located within an area of about 20 m^2.

Table 1. Environmental and biotic characteristics of two reef sites in the Wakatobi Marine National Park, Indonesia. Values are given as means ($n=3$) ±SD

Sites	Kaledupa	Sampela
Latitude (S)	05°28′261″	05°29′044″
Longitude (E)	123°43′465″	123°45′074″
Species richness	18.33±4.5	12.66±2.08
Coral colony density	18±5	13±3.5
Salinity (ppt)	34	32
Temperature (°C)	27	27
Rugosity index	20.06±1.85	13.94±0.95
Estimated horizontal u/w visibility (m)	15	7
Sedimentation rate (g dry weight m^{-2} day^{-1})	5.35±0.68	20.16±1.71

Growth rates were measured both physically, by using a flexible tape, and digitally, using a calibration scale in the visual field of the digital video. Physical measurements of tagged *Acropora* branch lengths (typical numbered tags shown in Fig. 1), and image analysis of branch lengths in the three replicate colonies (10-m depth) at each site over a 6-week period, differed by less than 5%, as long as the camera axis was aligned to within ±15° to the perpendicular of the branch and the calibration rule was in the visual field. Reproducibility of length measurements was ±5% for branches within 1 m of each other in a given colony. Vertical branching angles near the growing extremities were measured on four branches on each colony, and angles calculated by digital image analysis. Statistical values represent means ±SE, with probabilities calculated by one-way ANOVA.

Results and discussion

Table 1 shows the environmental and biotic characteristics of the sites examined in this study. Table 2 shows the percentage coral cover for both massive and branching corals at the two sites.

The first site, close to the island of Kaledupa (Table 1), is in pristine condition, and appears to have no obvious anthropogenic or sedimentation damage. Figure 1A shows an *A. valenciennesi* at this site, located in area of high cover of coral and other benthic organisms. The second site, Sampela (Table 1), is on the reef surrounding the Baujo village of Sampela. This reef is of great economic importance to the village, and the important food resource is extensively impacted. Table 1 shows that the sedimentation rates are about four times higher at Sampela than at Kaledupa. Figure 1B shows an *A. valenciennesi* at the Sampela site, located in an area of high sedimentation. There was significantly higher coral species richness at Kaledupa than at Sampela ($P<0.05$). There was significantly ($P<0.05$) less cover of both massive and branching corals at all depths at Sampela than at Kaledupa. Sampela had a significantly lower rugosity index ($P<0.02$) than Kaledupa.

Sediment being deposited on the Sampela reef consists of fine sublittoral sands similar in composition to the sediment surrounding Sampela village. In contrast, the material collected from Kaledupa was much coarser, consisting of coralline material and algal spores (Smith and Crabbe, unpublished data). The Sampela reef appears to be degrading and has a large amount of bare substrata and dead coral cover. There are also a number (five over a 500-m stretch) of coral slips (defined as the downward movement of coralline material) on the Sampela reef wall. This is of considerable significance because the reef is currently acting as a protective barrier for Sampela village. Interestingly, surface areas of non-branching corals were significantly lower ($P<0.005$) on the 5-m reef crest at Sampela than Kaledupa, owing to coral mining (Crabbe, Karaviotis and Smith, unpublished data) further limiting the protective reef barrier.

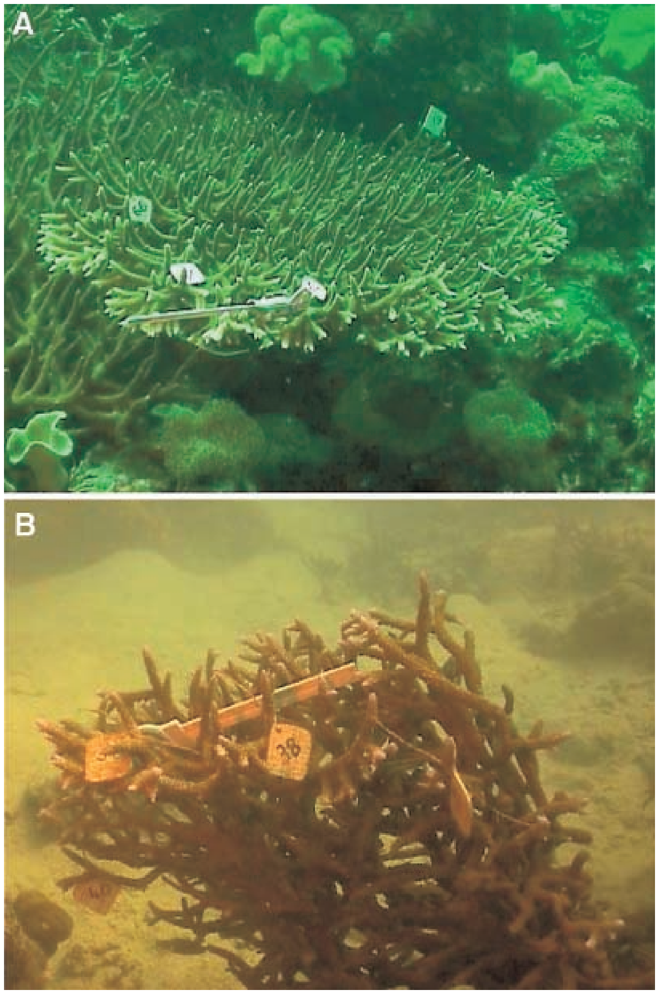

Fig. 1 A. *Acropora valenciennesi* colony at Kaledupa reef site Indonesia, surrounded by good benthic cover. Note tags on branches and calibration rule. **B** *Acropora valenciennesi* colony at Sampela reef site Indonesia, in area of high sedimentation, surrounded by bare substratum and poor benthic cover. Note tags on branches and calibration rule

Mean linear extension rates of *A. valenciennesi* were almost twice as fast at the Kaledupa site (120±20 mm/year) as at the Sampela site (66±15 mm/year), only ca. 1.5 km distant. Both these values are within known ranges for *Acropora* growth including *A. formosa* and *A. palmata* species (e.g. Harriott 1998), although there are no published data on *A. valenciennsi*. Salinity

Table 2. Mean coral cover (%) at two sites in the Wakatobi Marine National Park, Indonesia. *n/a* Not applicable. Values are given as mean ($n = 3$) ±SD

Sites		Kaledupa		Sampela	
Colony type		Massive	Branching	Massive	Branching
Depth (m)	15	12.66 ± 3.09	1 ± 1.41	n/a	n/a
	10	11 ± 1.41	2.66 ± 2.49	6.66 ± 0.94	0.33 ± 0.47
	5	14 ± 2.16	7.66 ± 4.18	7.33 ± 0.94	0
	5 crest	17 ± 2.82	4.8 ± 2.13	4.66 ± 3.09	0

(32–34 ppt) and temperature (27 °C) were similar at both sites and all depths, and did not vary significantly over 24-h periods.

The vertical branching angles of *A. valenciennesi* differed between the two sites. At Kaledupa, the mean branching angles near the growing extremities were 124 ± 17° ($n = 12$), whereas at Sampela they were 161 ± 9° ($n = 12$).

Multispectral remote sensing can be used to monitor large areas of coral reef efficiently (Mumby et al. 2001). Here we show that digital videophotography and computer image analysis can be used to monitor the growth and morphology of individual branching coral colonies, in addition to standard measures of coral density, species richness and coral cover, at closely spaced sites with differing anthropogenic or other impacts.

The scleractinian coral community of Sampela is severely impacted by sedimentation, which can lead to the suffocation of corals while also decreasing light penetration, resulting in decreased growth and calcification rates, and altered branching coral morphology (Wellington 1982). These effects are possibly seen in the lower *A. valenciennesi* growth rates at Sampela relative to Kaledupa, whereas the latter site also has a greater species diversity and coral abundance. Our branching angle measurements of *A. valenciennesi* indicate that at Kaledupa, the *Acropora* growth form is more tabulate, with the final growing points more vertical whereas, at Sampela, the *A. valenciennesi* grows more nearly vertical earlier on in its colony development. This suggests that the sedimentation and consequent lowered light levels altered coral morphology.

We anticipate that there is a net loss of reef material from Sampela, indicated by the coral slips and the reduced coral growth rates, suggesting limitation of calcium carbonate accumulation. If this loss is not checked it could result in the loss of the protective reef barrier that would be to the detriment of the sublittoral sand flats and the Sampela village.

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