

Brief communication

Modelling variations in corallite morphology of *Galaxea fascicularis* coral colonies with depth and light on coastal fringing reefs in the Wakatobi Marine National Park (S.E. Sulawesi, Indonesia)

M. James C. Crabbe^{a,*}, David J. Smith^b

^a Luton Institute of Research in Applied Natural Sciences, Faculty of Creative Arts, Technology and Science, University of Luton, Park Square, Luton, Bedfordshire, LU1 3JU, UK

^b Department of Biological Sciences, University of Essex, Wivenhoe Park, Colchester CO4 3SQ, UK

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Abstract

Coastal environments in the tropics can suffer from high sedimentation and low light levels. *Galaxea fascicularis* is a hermatypic coral that is relatively resilient to stress from bleaching and from sedimentation. Corallite dimensions – width, height, corallite densities and inter-corallite distances – of *Galaxea fascicularis* colonies varied significantly with depth, and so with incident light at the Sampela reef in the Wakatobi Marine National Park, S.E. Sulawesi, Indonesia. Modelling studies based on our data showed that corallite width decreased with the amount of incident light, while corallite height increased with the amount of incident light (r^2 values of 0.835 for width and 0.869 for height). In all colonies, inter-corallite distance decreased significantly with the amount of incident light ($r^2 = 0.89$). Colony width/height ratio increased in a linear fashion with inter-corallite distance for all colonies studied ($r^2 = 0.65$). Current flow as judged using tags did not appear to be a factor in variations of corallite dimensions. Our results suggest that under low light conditions, distribution and size of corallites may optimise heterotrophic nutrition, while in conditions where light is not limiting, distribution and size of corallites may be optimal for photosynthesis.

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1. Introduction

Reduced water quality as evidenced by increased light attenuation or concentration of inorganic nutrients coupled with unsustainable exploitation pose the greatest threats to coastal communities, including coral reefs (Airoidi, 2003). Much knowledge has been gained about the community structure of light-limited and non-light limited coastal reefs, and the species that may be common on each reef type. Less is known about how important coral species on light-limited reefs respond to reduced light concentrations (Iglesiasprieto and Trench, 1994; Levy et al., 2003). If reefs are to be protected, and management to be appropriate, more information is required on how corals respond and cope with reduced light quality (Rogers, 1983).

Galaxea fascicularis is a hermatypic coral that is relatively resilient to stress from bleaching (Marshall and Baird, 2000)

and from sedimentation (Wesseling et al., 1999; Philipp and Fabricius, 2003). Here we relate modelling the measurements of corallite dimensions, corallite densities and inter-corallite distances of *Galaxea fascicularis* colonies with the ambient light intensities at the Sampela reef in the Wakatobi Marine National Park. We hypothesise that the species morphological adaptations allow it to cope successfully with low light in habitats of heavy sedimentation.

The Wakatobi Marine National Park is situated in the Tukang Besi archipelago, a remote island group of about 200,000 ha off S.E. Sulawesi in Indonesia. We have studied three sites near the island of Hoga: Kaledupa (a reef experiencing little or no human use), Sampela (a heavily used reef 400 m from a Bajau village) and Hoga (a reef site intermediate in use between Kaledupa and Sampela), each separated by about 1.5 km (Fig. 1; Crabbe and Smith, 2002, 2003, 2005). Rates of sedimentation at Sampela (mean = 20.16 ± 1.71 g dry weight $m^{-2} d^{-1}$, $n = 26$) are significantly higher than at Kaledupa (mean = 5.35 ± 0.68 g dry weight $m^{-2} d^{-1}$, $n = 22$, $p < 0.0001$) or Hoga (mean = 7.54 ± 0.76 g dry weight $m^{-2} d^{-1}$, $n = 22$, $p < 0.0005$),

* Corresponding author. Tel.: +44 1582489265; fax: +44 1582489212.
E-mail address: james.crabbe@luton.ac.uk (M.J.C. Crabbe).

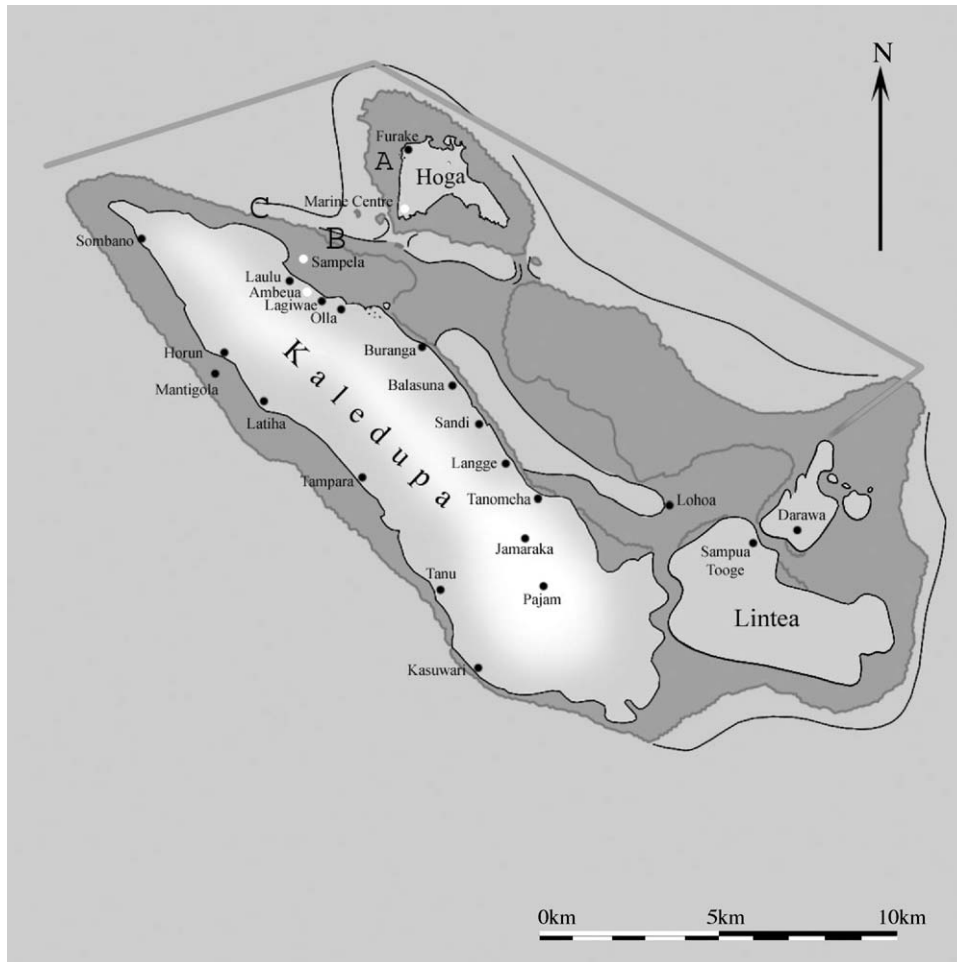


Fig. 1. Diagram showing the sites studied in the Wakatobi Marine National Park. (A) Hoga site (low sedimentation rate); (B) Sampela site (high sedimentation rate); (C) Kaledupa site (low sedimentation rate).

with rates being approximately 3.8 times higher at Sampela than at Kaledupa (Crabbe and Smith, 2003; Crabbe et al., 2004). *Galaxea fascicularis* is a resilient coral species (Marshall and Clode, 2003), that is spread throughout the study sites, with the largest individual colonies being found at the Sampela site.

2. Methods

The biotic and environmental measurements and characteristics of the study sites have been described previously (Crabbe and Smith, 2002, 2003; Crabbe et al., 2002, 2004; Crabbe, 2003). Light levels incident on the reef walls were measured at 1 m intervals to a maximum depth of 15 m, averaging three measurements collected at 9 a.m., midday and 3 p.m. over a 1-month period (July–August 2003), using a Solex SL100 lux meter (Fisher Scientific, Manchester, UK) in an Ikelite underwater housing (Cameras-underwater, St. Ives, UK). We studied two large colonies (diameter >5 m) and three smaller colonies (diameter <0.5 m) on the Sampela reef wall. Corallite dimensions and inter-corallite distances were determined by physical measurements (using a Vernier scale) and by image analysis of digital photographs using Image Tool software (University of

Texas Health Science Center, San Antonio, Texas, TX, USA) as described previously (Crabbe and Smith, 2002). Dimensions of 10 corallites chosen haphazardly in 625 cm² quadrats (nine replicate quadrats were sampled per colony) were measured in situ. The quadrats were at least 1 m apart. The work was conducted between July 29 and August 20, 2003.

3. Results and discussion

Galaxea fascicularis colonies are not a major component of the total coral community at any of the three sites studied (Fig. 2), with no significant differences between upper reef slope and reef crest at Sampela and Kaledupa ($p > 0.05$). Only at Hoga was there significantly greater percentage cover on the reef crest than on the reef slope ($p < 0.01$). However, direct observation in situ showed that *Galaxea* was dominant on some parts of the reef wall and colonies often exceeded 10 m in circumference (occasionally over 50 m in circumference as measured by a flexible tape) often associated with a number of sub-colonies. Total coral colony density was $18 \pm 5 \text{ m}^{-2}$ at Kaledupa, $12 \pm 1 \text{ m}^{-2}$ at Sampela, and $13 \pm 3.5 \text{ m}^{-2}$ at Hoga (Crabbe and Smith, 2002; Crabbe et al., 2004). The

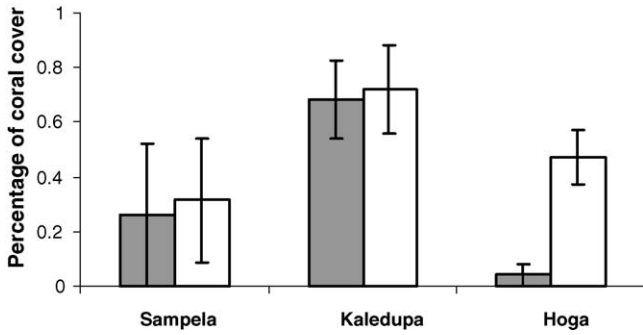


Fig. 2. The percentage contribution of *Galaxea fascicularis* to the total live coral community present on the upper reef slope (10 m at low tide) and reef crest at Sampela, Kaledupa and Hoga reef sites. Means \pm S.E.M. ($n = 3$) are presented. (■) Upper reef slope; (□) reef crest.

patchy dominance of this species in certain areas, coupled with its apparent ability to adapt to varying light regimes along depth and sedimentation gradients highlights problems with using haphazardly placed line intercept transects to give representative figures for coral cover (Wielgus et al., 2004).

Light levels incident on the Sampela reef wall were markedly decreased relative to levels incident on the Kaledupa and Hoga reefs (Fig. 3), and accorded with visibility measurements using a Secchi disk (Crabbe and Smith, 2002; Crabbe et al., 2004). However, it should be noted that our light measurements are in lux, and so may not fully reflect the PAR (Photosynthetic Active Radiation) utilised by the zooxanthellae (Lesser and Farrell, 2004). The slightly higher lux levels at the lower depths at Sampela are probably due to reflection from the sandy bottom at ca. 12 m, whereas at both Hoga and Kaledupa the walls descended to over 30 m depth. Corallite dimensions – width, height, corallite densities and inter-corallite distances – of all five *Galaxea* colonies studied varied significantly with depth, and so with incident light. Corallite width decreased with the amount of incident light, while corallite height increased with the amount of incident light. This is typically shown for one of the large colonies (Fig. 4), with r^2 values of 0.835 ($n = 9$,

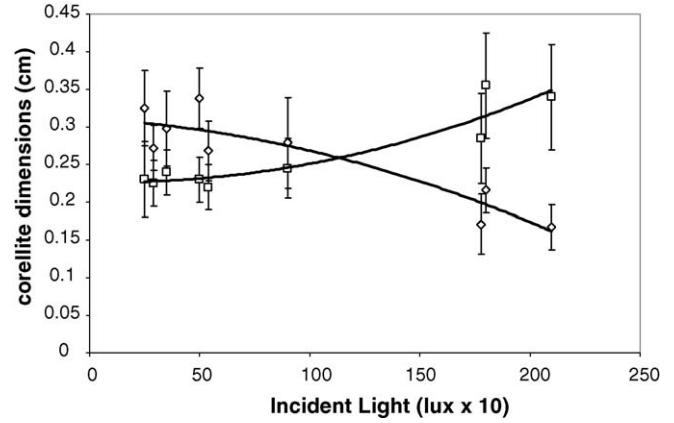


Fig. 4. Corallite dimensions at different incident light levels within a single colony of *Galaxea fascicularis* growing on the Sampela reef. Light levels are in lux. Means of corallite dimensions \pm S.D. ($n = 10$ corallites) are presented. (□) corallite height; (◇) corallite width. The curves are exponential best fits to the data.

$p < 0.04$) for width and 0.869 ($n = 9$, $p < 0.03$) for height. All other colonies studied showed similar relationships and r^2 values, with p always < 0.05 . In all colonies, inter-corallite distance decreased and corallite density increased significantly with the amount of incident light; a typical example is shown in Fig. 5, with $r^2 = 0.89$ ($n = 9$, $p < 0.02$) for inter-corallite distance and $r^2 = 0.85$ ($n = 9$, $p < 0.03$) for corallite density. All other colonies studied showed similar relationships and r^2 values, with p always < 0.04 . Colony width/height ratio increased in a linear fashion with inter-corallite distance for all colonies studied, as shown in Fig. 6, where $r^2 = 0.65$ ($n = 9$, $p < 0.04$).

Corallites of *Galaxea fascicularis* have been found to reorient in the direction of maximum irradiance (Hidaka and Shirasaka, 1992), and light energy has been found to trigger calcium uptake in this species (Al-Horani et al., 2003; Marshall and Clode, 2003). However, corals growing in shallow environments can take on different morphologies from corals growing in turbulent environments (Todd et al., 2004), and it is possible that

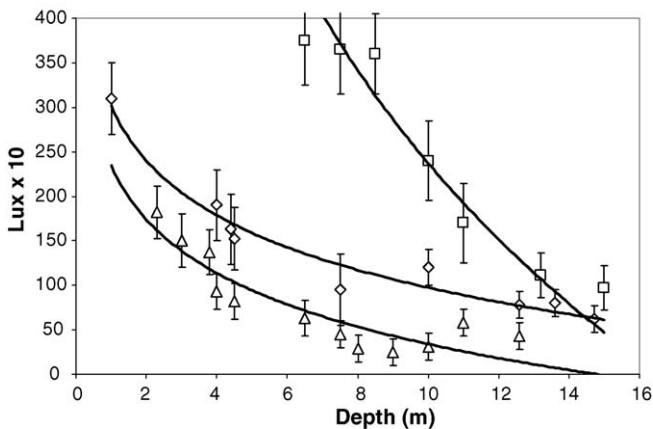


Fig. 3. Incident light levels at different depths on reef walls at three sites in the Wakatobi Marine National Park, Sulawesi. Means \pm S.E. ($n = 5$) are presented. (□) Kaledupa; (◇) Hoga; (△) Sampela. The curves are logarithmic best fits to the data.

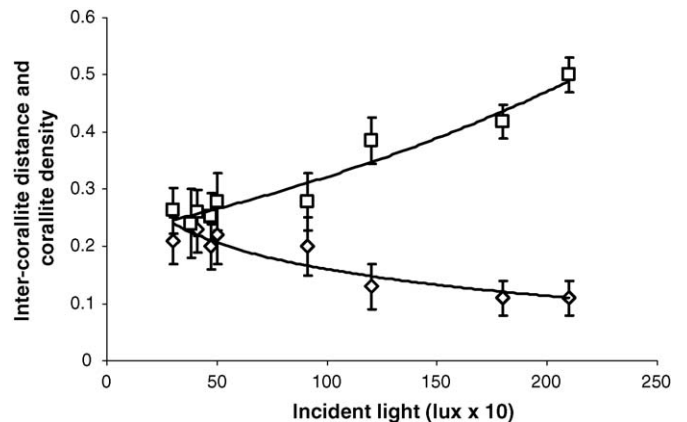


Fig. 5. Inter-corallite distances and corallite densities at different incident light levels within a single colony of *Galaxea fascicularis* growing on the Sampela reef. Means \pm S.D. ($n = 10$ corallites) are presented. (□) corallite densities (presented as numbers of corallites per unit area (taken as $25 \text{ cm}^2 \times 5 \times 10^{-3}$)); (◇) inter-corallite distances (presented as cm).

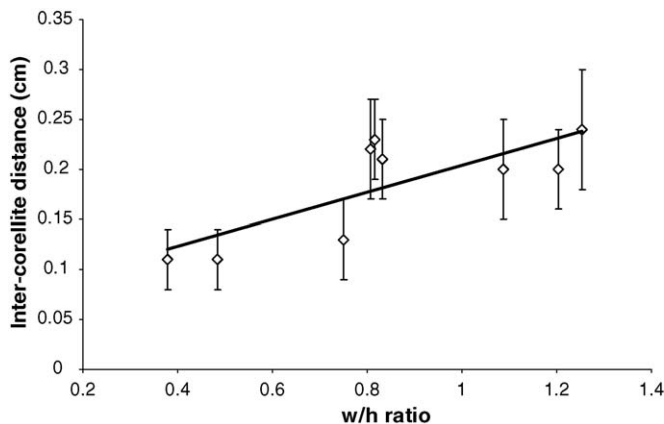


Fig. 6. Variation of inter-corallite distance with corallite width/height ratios over the five colonies of *Galaxea fascicularis* studied growing on the Sampela reef. Means \pm S.D. ($n = 10$ corallites) are presented. The graph shows a best fit straight line to the data.

the morphology changes could be due to light-water motion-sediment interaction. Our qualitative measurements of current flow at different depths of the *Galaxea* colonies using timed flow of 3 cm \times 1 cm plastic tags suggested that there were no significant differences in flow over 12 h time periods between the top and bottom of the colonies. While we have not directly measured currents at different depths, we have measured depth-average currents over a 3-week period while the corallite measurements were being made. At the Sampela site the depth-average current is 12 cm s⁻¹, which is not significantly different from the Kaledupa or Hoga sites. Also, there are no significant differences in the direction of current flows at different times of the day between the sites (Crabbe and Smith, unpublished work). Our results suggest that *Galaxea fascicularis* has at least in part developed strategies to optimise energy utilization from heterotrophic feeding and photosynthesis, and that these different strategies can be implemented within a single colony. Under low light conditions, distribution and size of corallites may optimise heterotrophic nutrition, while in conditions where light is not limiting, distribution and size of corallites may be optimal for photosynthesis (Anthony and Fabricius, 2000). The crossover point between strategies for *Galaxea fascicularis* occurs at light levels around 1000 lux (Fig. 4). Small tightly packed corallites would increase the amount of surface area available for zooxanthellae, thereby maximising photosynthetic potential (i.e. the amount of energy that can be gained via photosynthesis by an individual corallite and the colony). There may be a mechanism, possibly involving calcium uptake and oxygen secretion (Marshall and Clode, 2003) by which more corallites are produced and are done so more rapidly than in colonies that are subjected to lower ambient light. In such light conditions, individual polyps may meet a greater proportion of their energetic requirements by heterotrophy means and therefore the corallites need to have a better developed food capturing mechanism (i.e. a larger number and size of tentacles) in proportion to increased corallite dimensions as measured here. Larger corallites would also result in a less of a chance of individual corallites becoming smothered by the high sedimentation on the Sampela

reef (Crabbe and Smith, 2002; Crabbe et al., 2004). This has been found in *Favia speciosa*, where morphological variation in polyps appeared to be either a plastic, or selected for, response to high levels of sediment, and consequently low light (Todd et al., 2001).

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