A mechanistic approach to understanding and predicting hydrodynamic disturbance on coral reefs

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ABSTRACT

To understand and predict community dynamics in habitats where physical disturbance is a major cause of mortality, we must understand the frequency and intensity of these events, as well as their differential effects on the community's structural species. Using a tropical coral reef as a study system, the aim of this thesis was to quantify the mechanical vulnerability of the habitat-forming structural species, scleractinian corals, and build a framework to estimate size- and species-specific mortality rates based on the return time and magnitude of hydrodynamic disturbances.

To accomplish this aim, a geometric model and classical engineering theory were used to identify the factors upon which colony strength depends. These factors were 1) the tensile strength of the limiting material at the colony/substrate interface, 2) the projected shape of the colony perpendicular to water motion and 3) the maximum water velocity per wave cycle. To investigate the first of these factors, the strength of coral skeleton from three morphologically disparate species (submassive *Acropora palifera* [Subgenus *Isopora*], corymbose *Acropora gemmifera* and tabular *Acropora hyacinthus*) and the strength of the reef substrate were investigated spatially at a hydrodynamically-exposed shallow reef platform (Lizard Island, Australia) to determine whether overall colony strength (i.e., a colony's ability to withstand physical stress) is limited by skeletal strength or the reef substrate to which it is attached. To investigate the second factor, colonies of the three study species were photographed from the exposed reef crest along belt transects shoreward towards the relatively sheltered reef back and mechanically quantified using a novel technique for calculating the maximum predicted stress (MPS) at the base of a colony as a function of its projected shape for a given water velocity (MPS can be thought of as an objective quantification of mechanical

vulnerability). Finally, to examine the third factor, a 37-year meteorological record of hourly wind conditions, in conjunction with a field-calibrated oceanographic modelling procedure, was used to comprehensively quantify maximum water motion (i.e., displacement, velocity and acceleration per wave cycle) on the study reef platform at scales ranging from seconds to decades and from metres to the entire reef. Using the measurements of each colony's limiting strength (factor 1) and MPS (factor 2), the maximum water velocity that each colony is predicted to be able to withstand was calculated. The expected mortality rates of colonies from physical disturbances were calculated by fitting the exponential probability density function to the frequency distribution of times between wave events which produced maximum water velocity (per wave cycle; factor 3) greater than that which the colony is predicted to be able to withstand at a given location on the reef.

The carbonate substrate of coral reefs served as the limiting factor to the strength of mechanically threatened coral reef colonies and raises the question of why corals invest resources into building skeletons that are stronger than mechanically necessary. The robust, submassive *Acropora palifera* has a significantly lower MPS than the corymbose *Acropora gemmifera*, which in turn has a significantly lower MPS than the competitively superior, yet more mechanically vulnerable, tabular *Acropora hyacinthus*. In addition to these inter-specific differences, these three species display distinctly different intra-specific patterns of MPS when examined with relation to colony size. *Acropora palifera* demonstrates approximately equal MPS values regardless of size, whereas *Acropora gemmifera* and *Acropora hyacinthus* become significantly more mechanically vulnerable with increased size. In addition, the lognormal distribution of MPS values of the mechanically inferior species, *Acropora hyacinthus*, was truncated at the reef crest, suggesting the imposition of a mechanical threshold by a recent hydrodynamic disturbance which caused colonies with an MPS above the threshold to have been dislodged from their position on the reef. Superimposition of the disturbance thresholds modelled from the meteorological record onto the three study populations illustrated that larger colonies of *Acropora hyacinthus* are indeed predicted to be mechanically removed at regular intervals from the reef at Lizard Island, and such removal regimes are predicted to occur in a manner consistent with present distributions of this species on the reef. Finally, estimated mortality rates for coral colonies in general (i.e., based on their MPS) vary significantly over the reef's hydrodynamic gradient and suggest that a mechanical refuge exists approximately 40-60m back from the reef crest. This refuge is in addition to the expected refuges found at the reef base and reef back, each of which should theoretically promote mechanical, and therefore morphological, diversity.

This study has developed a framework for which the change in community structure of scleractinian corals caused by recurrent physical disturbance can be estimated. Building on this framework will significantly enhance ecological understanding of the relationship between physical disturbance and biodiversity on coral reefs, and will facilitate the estimation of general future community changes resulting from changes in the intensity and frequency of physical disturbance that may be associated with global climate change.

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