Project 6. Population dynamics of coral populations under environmental change

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Location: Mesoamerican CoE, Australasian CoE, East African Coe, and Philippines CoE

Key results

This project examined the population dynamics of coral populations at a scale which is highly novel relative to previous studies. In addition to establishing the monitoring of coral reefs at the four Centres of Excellence across the CRTR Program, this project delivered a number of important research outcomes and conclusions. Outcomes included corrections developed to eliminate biases that occur because of boundary effects when measuring the size of benthic organisms, as well as a series of relationships between 2-dimensional and 3-dimensional estimates of coral growth. Several important ecological phenomena were also identified, including two modes of partial mortality affecting coral species in the Caribbean; with some species rapidly losing colony integration while others maintained integration and sacrificed marginal tissue. Research within this group also identified the critical observation that mild thermal stress events showed different responses than extreme events: during extreme events, small colonies do better than larger colonies, while during mild events, colony size did not influence bleaching. In both cases massive corals were found to be more sensitive than branching corals. The research within this project also identified the important influence of substrate reflection, for example from sand, increasing available light and exacerbating the risk of coral bleaching. Indeed, corals growing on and near sand showed more intense bleaching than those growing on or near substrate with lower reflectivity. The group also made some interesting long-term observations, such as sea urchin densities on the western reefs of Zanzibar increasing 6 to 10-fold since 1996; with fish on the same reefs increasing considerably in the last three years.

Background

The overall objective in this project was to assess coral-population dynamics within the context of coral bleaching and subsequent effects. Given the importance of comparing between regions, in terms of the ability to generalise about the ecological behaviour of coral reefs, the team decided to focus work around 3 CoEs in the initial stages: Puerto Morelos (Mexico), Heron Island (Australia), and Zanzibar (Tanzania). This project also undertook activities in the Philippines and Palau. This CoE-centered approach allowed for a focus on coral dynamics which were easily accessible, and where the research activity could evoke collaboration among the other working groups with the Coral Reef Targeted Research Program.

We focused on quantifying both state (i.e., coral cover, macroalgal cover, size-frequency distributions) and process (or vital-population rates) variables (including coral recruitment rates, individual growth rates, partial mortality rates, and survival). We were also interested in the macro-processes, such as predation, herbivory, and oceanography that influenced the corals' vital-population rates. Our approach allowed us to determine which vital rates were responsible for the state of the reef, and allowed us to derive novel yet pragmatic models that would predict population changes and the future state of the reefs.

Objectives

One of our primary goals was to understand: Which coral species were physiologically more tolerant to thermal stresses than others, and why? Which interacting variables and processes are driving coral population structure? Which processes are primarily responsible for coral population change? Does differential coral population response to, and recovery from, thermal stress vary among regions and habitats? What role do remnants play in recovery processes? Is annual recruitment vital in all habitats? Which habitats recover more rapidly than others? Which coral species will adjust to global climate change? Can differential and local management practices influence thermal-stress response and recovery?

Our primary task was to assess the dynamics of coral populations and associated coral reef organisms by defining the key ecological processes that regulate the populations (Figure 15). Understanding these processes, assessing their spatial variation and their relationship with state variables, including size-frequency distributions, leads to predictive models of population trajectories, relative population size distributions, and community change under different climate change scenarios. We predicted that size-frequency distributions coupled with partial mortality information could provide a reliable indicator of coral stress and provide insight into the future of coral reefs.

Specifically we examined:

1. Spatial patterns in coral population size-frequency distributions and temporal changes of the populations at three CoEs;
2. Scale dependence of key process variables, including rates of recruitment, partial mortality, and mortality;
3. Relationships between processes and state variables and whether size-frequency distributions reflected population performance;
4. Effect of macro-processes, including herbivory (i.e., density and composition of urchins and fishes), on coral population vital rates and diseases.

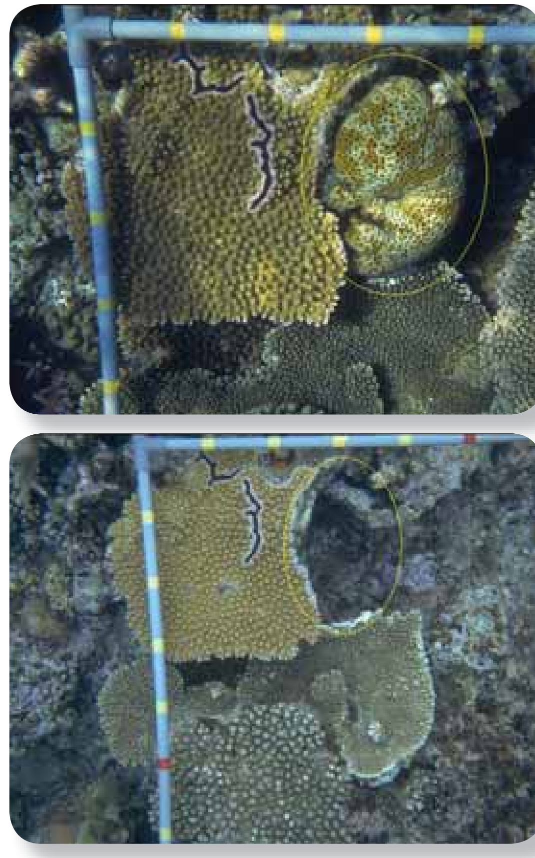

Figure 15. Total mortality of a coral colony over a year period. Photo: R. van Woesik

Methods

The sampling strategy captured state and process variables at a spatial scale of 10s of kilometers (herein called a Location). Sampling aimed at establishing 6-7 sites per location. Sites were spaced approximately 2 km apart, representing a 10^3 m spatial scale, with random stations nested within sites. Sites were systematically selected based on the targeted depth regime where sampling efforts were focused on one depth zone (2-5 m), rather than stratifying the design by depth and reducing the spatial area to be sampled. Stations were randomly selected and nested within sites, representing a 10^4 m spatial scale and were 75 x 25 m. However, these dimensions remain plastic depending on the reef morphology, while maintaining a total area of 1875 m^2. Stations were the effective sampling units. Within each station we ran at least 5, 50 m transects that were re-randomized each sampling period, and used to estimate state variables (i.e. size frequency distributions, benthic composition). Three randomly selected 16 m^2 quadrats were placed in each station, and marked for relocation purposes (Figure 16), and used to assess processes (i.e. recruitment, growth, partial mortality, mortality etc.) across time (repeated measures design). Both quadrats and belt-transects are effectively sub-samples from which we derived estimates of means for each station at each sampling event (because the station was the effective sampling unit).

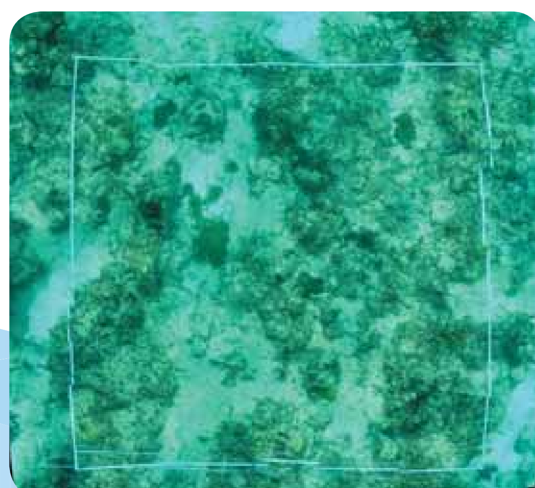

Figure 16. Permanent quadrat in Puerto Morelos, Mexico (~ 50, 1 m^2 photos were overlapped to generate a 16 m^2 mosaic using Matlab® software). Photo: Nuno Garcia

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Results and discussion

a. Advancements in coral reef sampling

Throughout this project various techniques for monitoring populations have been used and tested. Zvuloni et al. (2008) elucidated the biases that can arise in the application of popular and traditional sampling methods (e.g. quadrat, belt-transect, and line-intercept). Simple mathematical corrections were developed that provide unbiased estimations for previously collected data acquired by these widely used methods. In addition, alternative sampling methods were identified that do not suffer from these shortcomings. Eliminating these types of sampling errors provide better assessments of the status of a given coral reef, and provide precise comparisons among coral reefs in different regions. This work is equally relevant in other ecological contexts, not just corals.

Limitations with photographic analyses have also been recognized as a 3-dimensional (3-D) reef is turned into a 2-dimensional (2-D) photo. For some growth morphologies such as branching corals, this significantly affects growth measurements. Holmes et al. (2008) found a significant difference in growth when comparing 2-D and 3-D measurements for two branching species. These findings suggest that growth measurements are only reliable when measured in 3-D, and 2-D measurements can be corrected to provide reliable coral estimations.

b. Population dynamics

Key process variables (i.e. partial mortality, whole colony mortality, recruitment, and growth) have been identified and investigated to some degree in each region. In the Caribbean, partial mortality appears to be a primary mechanism of coral-cover degradation (Figure 17). Two modes of partial mortality were identified: (1) peripheral-partial mortality, occurring between live tissue and substrate, and (2) centralised-partial mortality, occurring within the colony, completely surrounded by live tissue. All species investigated (*Diploria strigosa, Siderastrea siderea, Porites astreoides, Agaricia agaricites* and *Montastraea cavernosa*) were affected by peripheral mortality, while *P. astreoides* and *S. siderea* were more likely to also exhibit centralized mortality.

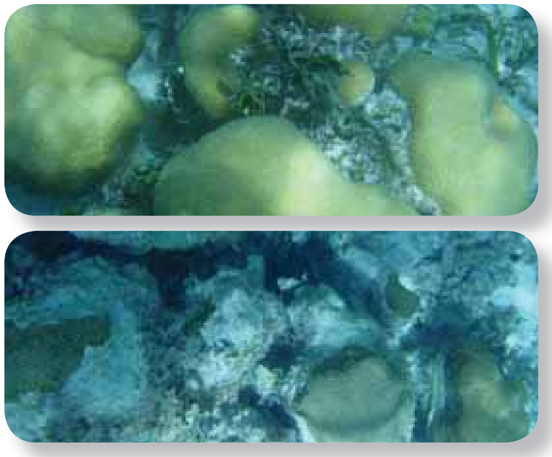

Figure 17. Partial mortality of *Montastraea* one year to the next in Puerto Morelos, Mexico. Photo: J. Gilner

c. Response and recovery from bleaching events

These same process variables were investigated on Heron Island in response to a mild thermal stress event. Mortality, recruitment, and growth were examined for four targeted coral taxa (*Pocillopora damicornis, Stylophora pistillata, Favites/Goniastrea,* and *Favia* spp.) to determine sensitivity to a mild thermal-stress event (in January-May 2006 on Heron Island in the Great Barrier Reef). The mild thermal stress event showed a different response than major thermal stress events. The mild stress showed that coral-colony size did not influence bleaching response, and massive corals were more affected by bleaching than branching corals. Because massive corals were primarily surrounded by sand, it was hypothesized that light reflectance from sand increased incoming irradiance and hence elevated stress. During extreme thermal-stress events small-coral colonies were least effected, as were massive and encrusting colonies. Therefore, various thermal stress anomalies show different bleaching responses.

d. Thermal stress, bleaching, and diseases

The prevalence of black-band disease (BBD) was strongly associated with high-water temperature. BBD infected coral colonies exhibited aggregated distributions on small spatial scales (up to 1.9 m). Newly-infected corals appeared in proximity to existing infected corals. Previously infected corals were more susceptible the following summer season. Therefore, water-borne infection is likely to be a significant transmission mechanism of BBD.

e. Coral-community structure

The patterns of coral community composition and diversity were examined around Zanzibar at three spatial scales ranging from transects (≤ 20 m), stations (< 100 m), to sites (< 1000 m). Two sites of the four, Chumbe and Mnemba, are located within marine protected areas (MPAs) and the other two sites, Bawe and Changuu, are not protected.

Figure 18. Permanent quadrat to assess coral-community structure and herbivory by sea urchins in Zanzibar. Photo: A. Zvuloni

Additive partitioning was used to examine diversity within and between the three spatial scales, where individual-based rarefaction was used as a null model. We show that each of the sites is different in species composition, except Bawe vs. Changuu. Chumbe and Mnemba, the most diverse sites, exhibited α (local) and β (turnover)-diversity as expected by random, whereas Bawe and Changuu were different than expected. In general, given the regional species pool, diversity among sites was significantly higher than expected. These results suggest that nonrandom processes interact on an among-sites scale (i.e., ca. kilometers), and in Bawe and Changuu they also interact on a within - and between-transects scale. The nonrandom outcome helps identify appropriate boundaries for studying mechanisms that generate and maintain biodiversity within this region. In considering coral diversity in Bawe, the number of rare species and singleton species (only found in one locality) suggests that Bawe should be declared a Marine Protected Area (MPA).

f. Macro-processes

i. Herbivory by sea urchins

We assessed the impact of sea urchin populations on coral communities around the island of Zanzibar. Twice a year, between 2007 and 2008, surveys of urchin populations (species, densities and size-frequency distributions) were performed at the same six locations used for coral and fish monitoring. Urchin bioerosion experiments were conducted separately for each of the study sites. Dominance of two urchin species was evident: *Diadema setosum* and *Echinometra* sp., in five out of six stations, with *D. setosum* dominating the western side of Zanzibar and *Echinometra* sp. dominating the eastern side (Figure 19). Average densities of *D. setosom* and *Echinometra* sp. ranged from 0-30 and 0-88 individuals m^{-2}, respectively. Eastern sites showed 2-4 times more sea urchins than the western sites. Urchin species assemblage did not change significantly throughout the duration of the study, nor did it change in comparison to 1996 (McClanahan et al. 1999), whereas sea urchin densities at Changu and Chumbe increased 6-10 fold since 1996. Mnemba showed the lowest sea urchin densities (1.2 urchins m^{-2}) and the highest abundance of urchin-preying fish. Molecular and morphological studies conducted on *Echinometra* sp. from 8 locations around the island of Zanzibar and 3 locations in the northern Red Sea suggest that urchins from the genus *Echinometra* are a suite of new species.

Figure 19. Dominant sea urchins in Zanzibar. A *Echinothrix diadema*, B *Echinometra* sp, C *Diadema savignyi* and D. *setosum*. Photos: O. Bronstein

ii. Fish communities

Zanzibar's economy relies heavily on fishes, which are used both for food and as an attracting component in the coral reef tourism industry. We studied the coral reef fish community structure around Zanzibar to establish a base-line for future monitoring of fish interactions with corals and sea urchins (herbivory, predation). In April 2009 we compared four sites around the island. Two sites are marine reserves (Chumbe in the west side of the island and Mnemba in the east) and another two (Changu and Bawe, located on the west side) are not protected and are heavily fished. We visually sampled fish in replicated 25 by 2 m transects, identifying fishes to the species level and estimating their abundance and length (Figure 20). We used point sampling along transects to estimate habitat parameters. We sampled 7046 individuals from 153 species belonging to 30 fish families. Using a null model we found that alpha diversity was lower than expected by chance but also that the sites were highly heterogeneous. The fish community structure differed remarkably between the sites with the two non- managed sites being the most similar. The fish-community structure was influenced by the amount of living coral cover, particularly branching coral colonies and substrate structural complexity. Regardless of low coral cover, the number of fish species was highest at Mnemba (a protected site). The amount of large exploitable fish (> 20 cm) was highest in the protected sites (16% of all fish in Chumbe and 6% in Mnemba as oppose to ca. 3% in the non protected sites). Mnemba had the highest number of sea urchin predators and the fewest sea urchins. Comparing this study with previously reported data from the same area which was affected by the 1998 bleaching event, we show that fish density increased dramatically in the last three years.

Figure 20. The grunt fish Blackspotted rubberlip (*Plectorhinchus gaterinus*) is a component of the reef fisheries in Zanzibar. Photo: E. Brokovich

Key literature generated with Full/partial project support:

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