Executive Summary - Coral Resilience Work

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Development of diagnostics for resilience in reef-building coral organisms, populations, and communities under the Marine Management Area Science Program 2005-2010

Les Kaufman
Principal Investigator

Introduction

Framework-building stony corals lay the foundation of modern coral reefs. Without a healthy coral community covering a majority of space on the sea bottom, many of the values and services that people derive from coral reefs are diminished or unavailable. Over the last thirty years, coral cover has declined precipitously across the greater part of the world's coral reef estate, due to a combination of local and global anthropogenic stressors. To reverse this trend, efforts- as yet less than adequate- are under way to stem the causes of global climate change, while also reducing or eliminating local human impacts. Even under the best of local circumstances, climate change now subjects coral reefs in many areas to catastrophic bleaching events. This is now so widespread, and occurs so frequently, that coral reef health has become largely a question of the ability of a reef to resist being damaged, or to recover from damage that can not be resisted. Mechanisms of resistence and resilience in coral are similar, but resilience is the more likely place for adaptation by all the members of the extended coral holobiont- including humans- to play a role.

In adaptive management of the tropical nearshore it is necessary to be able to measure the health or integrity of a coral reef in order to know if its welfare is being enhanced or eroded by management practices. Thus a diagnostic for resilience is required. In MMAS we sought to contribute new diagnostic methods and to employ them at the nodes in future work. There are various types of resilience and it is manifested at a variety of scales. We attacked sought diagnostics at the levels of (1) the coral organism, (2) the coral population, and (3) the coral community. In each case we developed new approaches to measure reef resilience, some highly novel, that can eventually be incorporated into routine coral reef monitoring programs along with the more traditional measures of benthic cover and species composition.

The Coral Organism

Tropical framework-building corals are perceived by us as colonial anemones that share a common limestone skeleton that is superficially plant-like in growth form. In fact, the coral colony is better thought of as a holobiont- that is, a composite of many organisms, each with its own genome, some of which are capable of a modicum of autonomous existence, and others- including the cnidarian host, entirely dependent upon one or more symbiotic relationships. Included in the extended holobiont are a wide range of bacteria, dinoflagellates, and the host coral, plus filamentous green algae, sponges invertebrate and vertebrate species that live commensally within the skeleton, and frequently interact with the cnidarian host as an irritant or possibly as mutualists.

Holobiont resilience is a product of the capacities and interactions among all of its constituent biological entities.   The greatest amount of research attention has been paid to the host-dinoflagellate relationship, as this is at the root of coral bleaching. Resilience at the organismal level is manifested as adaptive changes in gene expression (heat-shock proteins, upregulation of many other stress response genes) and behavior (e.g. polyp bail-out, sexual reproduction, tissue healing and skeletonization). In toto, the genomic component of the stress response capacity is called the defensome.

Given recent advances in genomics, it is now possible to characterize the full defensome sequence, to identify the coding and non-coding portions of the genome, and to associate specific genes with particular functions or pathways, including those related to stress response and resilience. And so, that is what we did. Under seed funding from MMAS, we formed a consortium to study the coral defensome, and then use this information to diagnose stress profiles in coral colonies that are of particular interest.   This information provides a read on the speed and nature of corals' genomic responses to stresses, both local and global in origin, as well as offering data that can be of use in local forensics. Because this work is still expensive and demanding, we began by choosing a handful of coral species that occur over wide ranges, that play important roles in reef construction, and that can be kept in the laboratory for experimental studies.

In assembling our target coral species, we also drew together a consortium of researchers with like interests, each of whom was already engaged in research on the coral defensome at a fairly advanced stage. The project is affectionately referred to as "The Coral Whisperer", and it was mentioned elsewhere in this report.

The senior investigators, their areas of speciality, and the species on which the are focusing are:

Les Kaufman	coral ecology, predation, wound healing, and competition *Pocillopora damicornis, Acropora cervicornis, Montastrea spp.*
John Finnerty	cnidarian functional genomics and evolution *Nematostella* (model reference cnidarian), *Pocillopora damicornis*
Steven Palumbi	genomics of thermal adaptation in the coral host *Acropora hyacinthus group, Porites lobata*
Andrew Baker	host-symbiont relationships, symbiont phylogeoraphy, thermal adaptation *Montastrea faveolata, Acropora cervicornis*
Bob Richmond	forensic and management applications of coral genomics; *Pocillopora damicornis, Porites lobata*

Two recent additions to the consortium are:

Steven Vollmer	coral disease, *Acropora cervicornis* (Caribbean)

Chris Langdon coral response to ocean acidification, *Porites lobata, Montastrea faveolata, Acropora cervicornis*

To focus our work, we elected to move in parallel on the different species paying particular attention to two kinds of stress: (1) thermal stress associated with high sea surface temperatures, and (2) the combined stress imposed by coral predators, overfishing, and eutrophication, as manifested in the difficulties faced by corals in repairing routine damage to tissue and skeleton (as from parrotfishes, sea urchins, or damselfishes) when growing near dense human populations.

Work on (1) was carried out principally by Palumbi in American Samoa with in situ experiments, and by Baker and Langdon under ex-situ experiments in Miami. For work on (2), we first developed a standard coral lesion protocol for *Montastrea faveolata* with assistance from Dr. Erich Mueller in the Bahamas (PIMS) and Burton Shank in Belize. Rates of lesion repair were examined in and out of no-take zones; a possible effect was observed in the Bahama Land and Sea Park. The lesion protocol was also tried on several other coral species, including lab studies of *Pocillopora damicornis* at Boston University by Finnerty and Kaufman (heavy lifting by their graduate student, Ms. Nikki Traylor-Knowles). Langdon and Baker then adopted the Mueller protocol for experimental runs on CO2 effects on rates of lesion repair in *M. faveolata*.
These experiments are near completion. In addition, Ms. Traylor-Knowles conducted a well-replicated lesion repair experiment in Taiwan this past summer (2010) to characterize the full lesion repair defensome of *Pocillopora damicornis*. Sequencing is now under way, including what we hope will produce the first full genome sequence for this coral species (one of the first handful corals in general).

At the official close of the GBMF grant for the first five years of MMAS, we have several publications, have sequenced a growing list of genes important in the defensome, and have performed the first "global climate change treadmill" experiments for exposure to high temperature, high CO2, and lesion repair in our target coral species. We have also begun to submit grants for continuing funding to other agencies and foundations, with a bit of early success.

The Coral Population

Coral reef recovery following major disturbance is dependent upon three factors: (1) the supply of larvae able to settle in a given area; (2) the availability of suitable substratum on which coral planulae will settle: and (3) the ability of newly-settled corals to survive once they have settled. Measuring these three parameters in the field is extremely difficult. One of the difficulties involves the challenge of seeing tiny young corals underwater, against a heterogeneous background and amidst algal turf or canopy. In order to facilitate the counting of very young corals, we have adopted a technology developed by Charles Mazel, in which special filters are used to photograph corals, revealing brilliant fluorescence that some species are famous for. The trick is to be able to do this routinely, during the daytime, quantitatively, and inexpensively via photogrametry to minimize bottom time and maximize the opportunity for careful scrutiny of small colonies once above water. We are experimenting with three camera systems representing different compromises in portability, resolution, and cost, to determine the most effective way to generate replicable data from this method. Thus far we have run field trials of two of these systems; the third will be assessed soon. The next step is to run parallel photogrammetric and *in situ* counts to compare fidelity and variance between the two approaches.

When combined with standard visual counts of small coral colonies (generally 2 to 10cm in diameter) this method should make it possible to estimate survivorship curves for the early phases of coral recruitment through establishment as a young colony with a high chance of subsequent survival and contribution to reef framework and fish habitat.

The Coral Community

The development of ways to measure coral community resilience is an active area in coral reef research, but has been very largely focused on resilience to bleaching as opposed to other stressors, or especially, combined stressors. MMAS approached this problem in two very different ways. The first was to try to characterize reefs in various phases of regeneration as a cross-sectional sample, looking for subtle relationships among descriptive variables that might previously have been missed. This was carried out principally in Belize and Fiji, is part of the dissertations of Burton Shank and Jean Francois Bertrand, and is now in the process of being worked into manuscripts.

The other approach was to track a recovering reef longitudinally, in a place where local human impacts were minimal so as to obtain the purest possible signals for regeneration from a discrete perturbation in the absence of reiterative confounding factors. For this we conceived the Central Pacific Reference Area (described elsewhere in this report) and have been tracking recovery in the Phoenix Islands Protected Area from a catastrophic bleaching event in 2002-3. The first manuscript on PIPA based on work supported under MMAS is in preparation now, and a scientific workshop was held in Boston in September 2010 to expand the range of disciplines and parameters to be studied by the team through repeat visits to PIPA. We are hoping for one every two years.