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Coral Reef Ecosystem Studies: Integrating Science and Management in the Caribbean

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Coral reefs are one of the most important marine habitats in shallow tropical seas. Reefs provide structure and act as focal points for secondary production. As a consequence, coral reefs provide a number of important ecosystem services (Moberg and Folke 1999). Reefs protect shorelines from coastal erosion and provide habitat for fish and millions of other organisms making them the most biodiverse marine ecosystem. These in turn support commercial and recreational fishing, diving and boating activities, tourist activities, shelter harbors and are a source of biomedicinal compounds. A recent study on the east coast of Puerto Rico (ETI 2007) estimated that economic value of coral reefs at $1.853 billion, or $4.2 million/linear km of coastline. Increasing pressure from human populations, coastal development and changing environmental conditions have produced differential degrees of reef degradation (Pandolfi et al. 2003; Carpenter et al. 2008), especially in the Caribbean, where they have undergone profound ecological changes in recent decades (Gardner et al. 2003; Mora 2008).

The beginning of the decline in Caribbean coral reef ecosystems is difficult to identify, and surely the processes contributing to this were variable in space and time. Yet, with the epizotics that killed most *Acropora palmata* stands in the 1970's, the loss of the long-spine sea urchin, *Diadema antillarum* in the early 1980's (Lessios et al. 1984), followed closely by severe declines in reef fishery catches (e.g., Appeldoorn et al. 1992), the signs that something was systematically wrong, in hindsight, were obvious. Still, there were no major calls to action. No doubt one contributing factor was that until the 1980's studies of coral reefs were carried out by a select and isolated group of academic scientists, whose connections with management agencies and policy makers were limited at best. At that time, scientists were still dealing with characterizing changes, some on decadal scales, and parsing out what might be natural cycles versus responses to anthropogenic stress; and there was no region-wide view of the decline as symptomatic of a larger problem.

The rapid decline of *Diadema* represented the first attempt to describe phenomenon on a regional scale and its subsequent impact. A link to this event and regional overfishing was soon postulated (Hay 1984). The coral bleaching event in 1987 again stimulated a region-wide effort to document its extent and impact (Williams and Buckley Williams 1989), and its link to sea level temperature rise was quickly recognized (Goreau et al. 1993). By the mid-1990's, with ecological regime shifts occurring in the most stressed areas (Hughes 1994) and basin-wide changes due to high levels of fishing (Jackson 1997) well documented, the problems facing Caribbean coral reefs were extensive, systematic and well recognized. By 1998, the United States took action at the national level. Executive Order #13089 established the U.S. Coral Reef Task Force, and Congress funded the Coral Reef Institutes and later passed the Coral Reef Conservation Act, which finally established a comprehensive program to monitor, assess and manage coral reef ecosystems. The vast majority of the expanse of U.S. coral reef ecosystems occurs within the Atlantic, with the U.S. Caribbean (Puerto Rico, U.S. Virgin Islands and Navassa Island) accounting for 8% of the Atlantic total (Rohmann et al.

2005). As national efforts were geared up, one of the first things learned from these efforts was the depth of our ignorance, especially with respect to offering science-based management advice within the socio-economic contexts and national and local regulatory regimes affecting tropical coastal environments.

One of the factors contributing to this was the complexity of the coupled biological-sociological system. At the time, it was recognized that the integrity of coral reefs was threatened by numerous anthropogenic and natural stresses including sediments, nutrient enrichment, climate change (bleaching), overharvesting, and storms (e.g., Hughes 1994, Kleypas et al. 1999, Roberts et al. 2002), and that coral diseases were emerging as a significant cause of reef degradation in the Caribbean (Harvell et al. 1999). Compared to other marine ecosystems, coral reefs were thought to be particularly vulnerable to watershed-based stresses related to coastal development because coral reefs are usually best developed "beyond the influence of continental sediments" (Wells 1957) and flourish as 'closed systems' based on the internal recycling of nutrients (e.g., Hatcher 1997). Economic activities, such as overharvesting were seen as particularly deleterious because they disrupted the complex biological interactions involving predation, herbivory, and competition upon which the high biodiversity of coral reefs depends (Connell 1978). Reefs could also be indirectly affected via stresses to their associated mangrove and seagrasss communities because many keystone reef species use these adjacent habitats for recruitment and nursery areas. In addition to the separate effects of various stressors, synergistic interactions among stressors could further enhance adverse effects (Hughes and Connell 1999). For instance, the resiliency of some reefs to nutrient inputs (e.g., Sorokin 1990, Szmant 1997) were thought to be compromised by overharvesting of the grazers that control frondose macroalgae that, in turn, can outcompete corals (Littler and Littler 1984). Yet, following this example, unknown at the time were the relative importance of different grazers and their ability to control various components of the algal community, the direct and indirect impacts of algae on corals, how fishing had altered the grazing community and whether the system could be returned to a state of health if fishing were controlled, and to what degree.

Within this context, the U.S. National Oceanic and Atmospheric Administration's Center for Sponsored Coastal Ocean Research initiated competitive research programs to study the decline of coral reef ecosystems, the processes contributing to these and potential management actions that could contribute to reversing the decline. Unlike previous efforts, from the beginning the approach was envisioned as being "long-term" (though not necessarily by the standards of reef ecology) and multidisciplinary. The resulting Coral Reef Ecosystem Studies (CRES) projects began in 2002, with one of the initial awards given to the University of Puerto Rico - Mayagüez. Led by the Department of Marine Sciences, the program represented a collaborative effort involving 16 principal investigators representing six academic institutions, two NGO's and three federal agencies and counted on expertise on the biology and ecology of coral reefs, nutrient chemistry, physics, modeling, fisheries and anthropology. The project was driven by three basic premises of reef function. 1) The integrity of coral reef ecosystems depends upon low transports of watershed-based materials to the marine environment and lack of their transport across the insular shelf. This premise was central to hypotheses concerning watershed-based impacts, and involved studies of erosional processes, physical oceanography, water column processes, tissue nutrients, and sediments. 2) Cross-shelf movements of organisms play a vital role in the structure and function of coral reef systems. This premise was the focus of connectivity studies and most relevant to hypotheses related to the changes in faunal components as well as the evaluation of no-take Marine Protected Areas (MPAs), one of the primary management options addressed by the project and the one with the greatest focus on the human dimensions of coral reef ecosystems. 3) Internal (*in situ*) processes play a major role in the structure and function of coral reef communities. This premise was most closely aligned with hypotheses related to the evaluation and prioritization of ecological stresses and involved research in the interrelated areas of demography, coral disease, and species interactions.

The principal field site for the CRES project was the coral reef ecosystem adjacent to the Department of Marine Science's Magueyes Island Marine Laboratory in La Parguera, southwest Puerto Rico. However, other locations were utilized for MPA comparisons and coral disease studies, including the Luis Peña Canal Marine Reserve at Culebra Island off eastern Puerto Rico and the St. John National Park and newly created Coral Monument in the U.S. Virgin Islands. Coral reefs in the Parguera region have been studied by individual scientists for nearly 50 years, principally from the marine lab of the Department of Marine Sciences, University of Puerto Rico. Yet, despite this rich history, the CRES program represented the first time that a long-term, multidisciplinary and coordinated study was conducted with both high temporal and spatial resolution. The timing of these activities were serendipitous yet distressing as the work was able to capture the full brunt of the impacts affecting the reefs at La Parguera, including disease, bleaching, algal overgrowth, sedimentation, and overfishing impacts, particularly at the shelf edge reefs formerly characterized by high coral cover (Ballantine et al. 2008).

The UPRM CRES project extended over a period of seven years, culminating in a symposium held February 11-13, 2009 in La Parguera, where over 30 presentations were given covering work done within the CRES program and the larger context of reef conditions within the region as a whole and their connection to management. This volume presents 18 contributions from that symposium. While representing only a fraction of the publications resulting from the CRES program to date, with many more expected, the contributions included here encompass the full range of activities and disciplines included within the program. Thus, this volume is a fair representation of the scope of work, while only hinting at the greater significance of the program as a whole, to both science and its application to management.

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