Fifty Years of Change in Coastal Ecosystems of the Wider Caribbean and the Eastern Tropical Pacific—with an Eye on the Future

Cincuenta Años de Cambio en los Ecosistemas Costeros del Caribe y el Pacífico Oriental Tropical — Con Un Ojo el el Future

Cinquante Ans de Changement dans les Écosystèmes Côtiers de la Région des Caraïbes et du Pacifique Tropical oriental — Avec un Oeil sur L'avenir

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EXTENDED ABSTRACT

Introduction

In this extended abstract I will survey through personal experience some of the unique events that encompassed the region over the past five decades and see what lessons can be drawn from them. I cover a lot of ground, and citations are included as entry points to the scientific literature. I concentrate on the Wider Caribbean as I know it best, but the general trajectory of change and potential management approaches which I discuss are the same for the Eastern Tropical Pacific.

In my lifetime, the population of the world has increased more than three times from 2.3 billion, and it has more than doubled from 3.7 to 7.6 billion in the 50 year interval covered by this talk. There is no question that human population growth, the drive for economic growth, and the disproportionate use of the world's resources by industrialized nations are the primary drivers of environmental decline. The control of these influences will be a major part of whatever future solutions may be possible.

The Wider Caribbean has a Unique and Alarming Environmental History

Pacing the explosive growth of the human population which began in the late 19th and early 20th centuries, the decline of Caribbean coral reefs and their associated coastal ecosystems including seagrasses and mangroves has been in progress for several hundred years, (Jackson et al. 2001, Pandolfi et al. 2003, Pandolfi et al. 2005). The recent period of rapid decline was first noticed 4 to 5 decades ago coincident with the start of my career with Smithsonian in Panama and then at the West Indies Laboratory of Fairleigh Dickinson University in St. Croix. If someone had told me then that in only 40 years the relatively luxuriant coral reefs of the region would be as diminished as they are today, I would have thought that they were completely crazy. We now recognize that decline of coral reefs is not confined to the Caribbean but is global in extent and growing in severity.

The more than 33 nations and dependencies of the Caribbean region have long supported field stations and coastal laboratories in relatively undisturbed locations. The laboratories are archives of data and local knowledge forming a baseline against which past and future changes can be measured. The Association of Marine Laboratories of the Caribbean (AMLC), one of the oldest scientific associations in the region, was established in 1958 to facilitate international communication through an annual forum for sharing ideas, information and technology. Similarly, the Gulf and Caribbean Fisheries Institute (GCFI) has grown dramatically in recent years with many of the same traditions.

Researchers at these laboratories pioneered the study of the dynamics of coastal ecosystems. Various programs including CARICOMP, Atlantic and Gulf Rapid Reef Assessment (AGRRA) and the Global Coral Reef Monitoring Network (GCRMN) and many local efforts monitored the status and trends of coastal ecosystems (CARICOMP 2001, Jackson et al. 2014). Others investigated the drivers of change and achieved considerable understanding of, for example, the coral-algal balance on reefs (Hughes 1994), the importance of herbivores (Hughes et al. 1999, Kuffner et al. 2006, Ogden and Lobel 1978), the impact of fishing (Jackson et al. 2001), top-down predator control (Mumby et al. 2007), the role of nutrients (Szmant 2002), coral diseases (Harvell et al. 2004), field and physiological studies of coral bleaching (Brown 1997) and more recently the potential future impact of ocean acidification (Albright et al. 2008).

Caribbean scientists have examined the connection with land (Rogers 1990), the inter-connectivity with other coastal ecosystems including seagrass beds and mangroves (Nagelkerken 2009, Ogden et al. 2014) and connectivity by pelagic larvae (Cowen 2000). These studies and many others have been done in the context of a thorough understanding of the geological history of the Caribbean reefs, the growth of reefs through the Pleistocene and Holocene and the origin and evolution of Caribbean corals (Adey 1977, Hubbard et al. 2005, Knowlton and Budd 2001).

Three epic, pan-Caribbean events stand out as a stark warning of the future in the region. In the early 1970s Antonius (1977) reported on black-band disease (BBD) and remarked at white blotches or bands on acroporid corals. In the late 1970s Gladfelter (1982) discovered white-band disease (WBD) moving relentlessly along a front on Tague Bay Reef, St. Croix. WBD slowly spread across the Wider Caribbean over the next decades and was implicated in the region-wide decline of the major reef builders, elkhorn and staghorn corals. In hindsight, we could have done a better job of tracking WBD, but at the time there was poor telephone service and snail mail. Later, other diseases were discovered, some linked to pollution, and for a time there was a "disease of the week" in the Florida Keys, many of which implicated increased stress and disruption of the coral dependencies on micro-organisms including intracellular zooxanthellae symbionts, but also microbes in the surface mucous layer of corals. The latter is one of the most important and active areas of coral research today (Ritchie 2006).

In contrast to WBD, the 1983 - 1984 mass mortality of the long-spined black sea urchin, *Diadema antillarum*, was a more familiar pandemic, moving rapidly across the region to eventually encompass virtually everywhere *D. antillarum* are known to live, except the eastern Atlantic. Lessios et al. (1984) solicited regional observations and determined that over approximately a year the pandemic spread with remarkable fidelity to the prevailing ocean currents. This event convinced ecologists that the pre-mortality densities of *Diadema* on shallow Caribbean reefs, upwards of 10 - 20 or more /m^2, were unnaturally high as a result of the overfishing of its many predators and competitors.

The *Diadema* mass mortality reorganized the thinking of every marine ecologist in the region. Interestingly, its major ecological impact of disastrous overgrowth of reefs by benthic algae, was predicted by earlier observations and small scale grazing experiments (Carpenter 1990). But to this day it is difficult to admit that the cause is unknown and can only be guessed from studies of other echinoderm mass mortalities in which a variety of micro-organisms were implicated. While we might be excused for poorly documenting the mass mortality in 1983 - 1984, we have no excuse for not tracking its recovery which is now in progress in many locations.

Through the 1980s, and up to the present moment, coral bleaching is a manifestation of seasonally high sea water temperatures linked to relentlessly increasing concentrations of greenhouse gases and episodic ocean-atmosphere phenomena such as El Niño. Following the first widely reported and alarming coral bleaching event of 1983, a group of scientists testified at U.S. Congressional hearings on the probable causes and potential solutions for coral bleaching. A NOAA official at the hearing was ridiculed by the Senators for not be able to say what the temperature of the Caribbean was. As he explained, NOAA satellites measured only the skin temperature of the sea and observations were often interrupted by clouds. At the time, the longest ecologically significant temperature record was a daily bucket temperature taken by the ferry boatman at the University of Puerto Rico Marine Laboratory on Mayagüez Island. In 1987, an international workshop defined a coral bleaching research agenda that heralded the need for systematic ocean observing in the Caribbean, beginning with temperature (Ogden and Wicklund 1988).

Since these early days, the link between atmospheric carbon dioxide, mostly from the burning of fossil fuels, and ocean warming and potential ocean acidification has been firmly established. The last major global bleaching event was in 1997 - 1998, but at this moment a record El Niño is in progress which has raised seawater temperatures across the tropics to unprecedented highs. For the first time in recorded history Australian scientists have documented bleaching and coral death across huge regions of the Great Barrier Reef. Ironically, this is happening following the Paris Climate Conference (COP 21) in December 2014. While the participating nations agreed to hold atmospheric CO_2 reductions below 450 ppm and global warming to less than 2°C. by the end of the century, there is little optimism that the signatories will be able to achieve these reductions.

The bottom line is that the decline of coral reefs and coastal ecosystems in the Caribbean and in the Eastern Pacific has been a result of multiple stresses the most important of which are anthropogenic in origin and include poor land-use practices, particularly runoff and pollution, over-fishing, and climate change.

Marine Protected Areas (MPAs) are Necessary but not Sufficient

The pioneers of marine conservation, notably Tom van't Hof, originally of Caribbean Research and Management of Biodiversity (CARMABI) in Curacao, implemented early MPAs and communicated widely their design and political considerations. The Saba Marine Park in the Netherlands Antilles and the Hol Chan Marine Reserve in Belize were among the first and regionally the most influential. Starting from these small beginnings, MPAs expanded across the region as the Great Barrier Reef Marine Park became an influential model for tropical marine conservation and management (Kelleher *et al.* 1995). A compilation of MPAs for the Lesser Antilles and Central Caribbean listed 75 functional MPAs (Geoghegan et al. 2001). However, many of these are still so-called "paper parks" with little or no protection or management other than their boundary lines on the chart.

Early studies of a class of MPAs called "no-take marine reserves," prohibiting all extractive use, documented the relatively rapid response of demersal fishes to fishing protection. Almost everywhere in the world, no-take reserves produced more and bigger fishes in approximately three to five years (Halpern 2003). However, longer term studies of corals have shown that declines continue through a failure of recruitment. For example, Toth et al. (2015), working in the Florida Keys National Marine Sanctuary on a series of four small no-take zones compared to adjacent fished reference sites, showed after 13 years of study no effect of Sanctuary no-take protection on coral cover, macro-algal abundance, or coral recruitment. Perhaps not surprisingly, fish, corals, and other major groups react differently to no-take protection, related to the geographic scale of ecological processes, particularly recruitment, that drive their dynamics. It is clear that implementation of small marine protected areas, even no-take marine reserves, has not been sufficient (Allison *et al.* 1998). Networks of existing MPAs have been proposed to increase the geographic scale protection, but the benefit of such *ad hoc* "networks" is likely to be administrative efficiency rather than substantial environmental gains.

White-band disease, the *Diadema* mortality and coral bleaching provide ample evidence that the Caribbean region and likely the Eastern Tropical Pacific functions as a large marine ecosystem (LME, Sherman et al. 2005). The ocean currents of the Wider Caribbean connect ecosystems over large areas through the planktonic transport of larvae of many organisms (Cowen et al. 2000, Baums et al. 2006). While the patterns vary with reproductive strategy and timing, transport of larvae increases the resilience of populations through recruitment following disturbances. In addition, the key ecosystems of the Caribbean, coral reefs, seagrasses and mangroves are physically, chemically, and biologically connected (CARICOMP 2001, Nagelkerken 2009, Ogden et al. 2014).

Marine Spatial Planning (MSP) is a First Step in Ecosystem-Based Management (EBM)

More comprehensive ocean governance using marine spatial planning and an ecosystem-based management approach is needed that encompasses the geographic scales of marine biodiversity, human impacts and the ecological processes that sustain coral reefs and associated ecosystems. The large size and political complexity of the Caribbean suggest that smaller sub-regions may be better suited for MSP. In several recent studies, the Caribbean has been sub-divided into a number ecoregions (Chollett et al. 2012, Rivera-Monroy et al. 2004, Spaulding et al. 2007) and these can help focus site selection for MSP. It is critical that MSP efforts incorporate local people and political entities as practical and political considerations may trump scientific criteria in site selection. The key is to select regions where planning and implementation efforts have the political support to provide a reasonable chance of success which may become a model for other regions.

Following the selection of a suitable site, MSP involves assessment and assembly of existing spatial data and information in GIS formats including, key resources, benthic habitats, biological diversity, oceanography, bathymetry, and sediments. Human uses are also mapped including shipping lanes, pipelines and cables, minerals leases, protected areas, fishing zones, and aquaculture sites, to name a few. The sources of this information include publications, databases and local and traditional knowledge. The public meetings required to collect the latter play an important part in building a political constituency for this inclusive process. The GIS overlays show areas where information is abundant and areas where there are significant gaps. Continually updated maps from spatially organized databases allow assessments of changes and provide parameters for models to help predict the future under different scenarios of management and environmental change. The importance of maps in engaging the stakeholders, illuminating complex use problems, and suggesting solutions cannot be overemphasized (Carollo et al. 2009, Ogden 2010).

As in land-use planning, MSP concentrates on places of importance to people and provides a mapping and analysis framework for visualizing the finite nature of resources and the need for governance, principally through zoning, of the human enterprise on the ocean (Crowder et al. 2006). Young et al. (2007) outline four key principles to implement governance:

i) Create governance arrangements that minimize mismatches between biophysical systems and socioeconomic activities,
ii) Develop procedures that recognize multiple-uses of ocean areas and can mediate conflicts,
iii) Insure that all interested parties have a voice in decision-making in MSP and governance from the beginning, and
iv) Design governance to monitor results of management policies and to change them as necessary as understanding of the dynamics of the place advances.

There are several governance projects in the Caribbean which serve as examples. The Meso-American Barrier Reef System (MBRS) project used a spatial planning approach to define biophysical characteristics, human uses and potential conservation management measures within a four-country region of the western Caribbean (Kramer and Kramer 2002). The planning process was inclusive and thorough, but the political complexity of the region has hampered implementation of internationally coordinated ecosystem-based management and governance.

At a larger scale, the Caribbean Large Marine Ecosystem (CLME) Project based at the Secretariat of the Intergovernmental Oceanographic Commission for the Caribbean (IOCARIBE) in Cartagena, Colombia is a developing example of a multilevel governance network linking regional inter-governmental initiatives together. While the project to date has concentrated on organization, conceptual designs and political considerations to approach comprehensive governance of the Caribbean LME, it will use MSP to define management concerns and identify use areas to implement governance (Fanning et al. 2007, Mahon et al. 2009).

MSP was first used during the planning effort that established the Great Barrier Reef Marine Park in 1972. It has been used in Europe, notably in the extensively exploited North Sea, and in various locations in Asia to balance economic and environmental objectives. A step-by step guide to MSP presents clearly and with many examples its importance and how to do it (Ehler and Douvere 2009). These examples and sources show that while the tools and approaches of MSP can be outlined, each location is unique in terms of its biophysical characteristics, engagement of the stakeholders and the local and national political apparatus.

The Wider Caribbean and Eastern Tropical Pacific are Economically Dependent on a Healthy Environment

The most important sectors of the economies of the nations of the Caribbean and the Eastern Tropical Pacific are fisheries and tourism. Fisheries have great cultural importance, but these are the most tourism dependent economies in the world. Much has been made of valuing ecosystem services. For example, the World Wildlife Fund recently reported a study valuing the services delivered to humankind by the global ocean at $24 trillion per year. A Florida economic study sponsored by the Florida Ocean Alliance evaluated the annual cash flow from healthy oceans (recreational and commercial fishing, boating, beaches, ports and harbors, coastal parks and so on) at $562 billion per year, but this startling figure didn't move the legislative requests for funding management and conservation projects. The economic valuation of ecosystem services makes better sense within the context of an MSP effort which engages the stakeholders of that region and demonstrates in financial terms which everyone can understand what might be lost if ocean resources are not managed effectively.

A Challenge to GCFI and MarViva

Too often our work ends, rather than begins, at a publication or a report. We now should know that we must take our results directly to policy-makers in a more effective way. The Caribbean and the tropical Eastern Pacific have a number of regional scientific or science-based organizations: GCFI, MarViva, AMLC, CRFM, GCRMN, AGRRA, CARICOMP-2, CLME, IOCARIBE, and Parlatino, to name a few. GCFI and MarViva could be a focal point in organizing with others an international "*Coastal Ecosystem Spokes Team*" which could design a presentation to regional governments at the level of the ministry of environment or tourism giving the facts of the decline of Caribbean coastal ecosystems over the last 20 - 50 years, the potential economic losses and options for management. To begin this process gaining cooperation of influential regional organizations such as the Caribbean Hotel and Tourism Association (CHTA) or the Caribbean Tourism Organization (CTO) would be a good first goal. Within each nation these agencies are shortcuts to the highest levels of government. I also urge GCFI, MarViva and partners to:

i) Support improved networking of regional management, conservation, and scientific organizations
ii) Get involved in existing programs in regional governance such as the Caribbean Large Marine Ecosystem (CLME) project,
iii) Support coordinated, networked ocean observing based at marine laboratories and other coastal management and conservation institutions,
iv) Urge members of establish open working relationships with their respective governments and keep them informed of the results of scientific studies of the impact of coastal pollution, over-fishing, climate change, and ocean acidification.

The Bottom Line

Simply stated, the drivers of the dramatic changes that have swept the Caribbean are:

i) Pollution from poor land-use and waste disposal practices,
ii) Over-fishing resulting in great changes in the trophic structure of coastal ecosystems,
iii) Climate change, and
iv) Population growth.

It won't be easy, but the first two drivers are open to management at the local and regional scale. Climate change and population growth are global impacts requiring global action. Faced with this, some people have decided that management is futile, as these last two drivers will over-ride all other considerations. This may prove to be true, but we are not good at predicting the future. There is some evidence that if we can successfully expand our governance of the sea to the scale of ocean processes, we can build ecosystem resilience to climate change. But whether it works or not, the effort will not be wasted. Even if the ocean as we know it is doomed, if life is to remain on earth we will always need to draw resources from the sea and will be sustained by its contributions to the maintenance of the global system. Great challenges spawn great ideas and these are popping up all the time. So let's just get busy and do what we already know is the right thing.

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SELECTED INTERNET SOURCES

AGRRA (Atlantic and Gulf Rapid Reef Assessment): http://www.agrra.org/.

Caribbean Large Marine Ecosystem Project: http://www.cavehill.uwi.edu/cermes/clmeInfo.html.

GCRMN: http://www.car-spaw-rac.org/?The-GCRMN-Caribbean,637.

Healthy Reefs for Healthy People: http://www.healthyreefs.org/.

Marine Spatial Planning (UNESCO): http://www.unesco-ioc-marinesp.be/.

Natural Capital Project: http://www.naturalcapitalproject.org/.

National Policy for the Stewardship of the Ocean, Our Coasts, and the Great Lakes: https://www.whitehouse.gov/administration/eop/ceq/initiatives/oceans.

NOAA Marine Sanctuaries: http://sanctuaries.noaa.gov/about/pdfs/se_gom.pdf.