MMAS Project Synthesis

A Chapter in the MMAS Final Report to the Gordon and Betty Moore Foundation

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I. Introduction

The Marine Management Area Science program was created to support and enhance the practice of marine adaptive management along tropical coastlines. Here, dense and often poor human populations share space and resources with the highest biological diversity known to man. This document is a technical summary and synthesis of lessons learned under MMAS in its initial five years, under a grant from the Gordon and Betty Moore Foundation. MMAS encompassed the efforts of 100+ senior investigators working on about 50 related and sometimes overlapping projects. The program evolved gradually as individual projects were sequentially brought on line and woven together over the 5 years. Many MMAS participants saw the program through the eyes of their individual interests. Admittedly, few remained aware of the overarching goals and synthesis objectives of MMAS all the while that they were participants. For that reason, with the close of the grant, we are creating a series of products that provide an integrated glimpse of the MMAS program, and the insights that it has begun to yield.

The idea of adaptive management in its modern incarnation is often traced to Aldo Leopold, but adaptive management's taproot is sunk thousands of years deep among a sweep of indigenous cultures. The concept is simple. Both the environment and human behavior are constantly changing, so the environmental outcomes of new human behaviors (policies) are hard to predict. Plus, the risk of environmental harm is today very high because people can mobilize vast technological and financial resources and can rapidly alter the face of the biosphere, with myriad consequences that we fail to anticipate, and for which we are ill prepared. Thus, environmental risk reduction and adaptability are both very important in setting new policy. A policy that is too risk-averse could fail to sustain society. One solution is to try new policies out on a trial basis before they are implemented more broadly, and in any event, to monitor all that unfolds in the wake of any new policy so that both its desirable and undesirable outcomes can be taken into account. Each time something new and important is learned in this way, new policies are implemented that, it is hoped, will promulgate greater good and less harm than their predecessors. Marine management areas offer a special opportunity for adaptive management. An MMA is not only an interim spatial solution that distributes human behaviors across an area of ocean; it is also an hypothesis about the processes and outcomes that each type of management regime will trigger. In this way, the program for monitoring policy outcomes in a coastal zoning scheme becomes more than just a mechanism for accountability -- it becomes the practice of testing management hypotheses.

<u>History of The MMAS Program</u>

The concepts central to MMAS were conceived at the 2003 Defying Ocean's End conference in Cabo, Mexico. Following program development in collaboration with the Gordon and Betty Moore Foundation, a grant was made to Conservation International in 2005 to "*combine(s) social and biological science to study management of multiple-use and protected marine areas*" (Conservation International 2006). Since 2006, the MMAS Program has been working in four selected sites or "nodes" within the global marine ecosystem on six thematic areas as they relate to MMA use. Belize, Brazil, Fiji and the Eastern Tropical Pacific Seascape (ETPS) are the selected nodes in which several projects have been implemented in the following theme areas: 1) management effectiveness, 2) connectivity, 3) resiliency, 4) economic and cultural valuations, 5) conservation and economic development, and 6) enforcement. In late 2010, the grant concluded, but not before it catalyzed several important developments at CI in accord with a new institutional mission. MMAS laid the foundation for a marine conservation science program at CI under the Division of Science and Knowledge, focused on biodiversity and the ecosystem services that it supports. Though originally imagined as strictly a research program, MMAS evolved into a pragmatic, policy-oriented initiative through the addition of a "Science To Action" (S2A) component. The decision was made about a third of the way into the project that 15% of the expenditures under each program element would be applied to translational activities. That is, we would put the science that we generated into use in the policy arena. S2A is now a central tenet of CI's modus operandi. Since 2005, MMAS has conducted more than 50 studies in over 70 MMAs in 23 countries, using an integrated approach of natural and social sciences. Nearly every one of these studies was conducted with a clear eye toward conveying results into policy by translating and disseminating them in a form useful to legislators and decision makers.

In the MMAS project we used the concept of the *"total ecology"* of a MMA, which consists of the biophysical, human, and institutional ecologies mapped onto one another. The *biophysical ecology* we define as the non-human, biophysical environments and systems related to a specific MMA. The *human ecology* we define as those humans and human behaviors that affect, are affected by, or are otherwise concerned with a specific MMA. Finally, we define the *institutional ecology* as those institutions that govern or affect the behavior of those people in the human ecology; that is, the institutions through which policy 'solutions' must be formulated for the MMA. The *"total ecology"* of a given MMA is these three different ecological systems mapped onto one another: Laws and policies affect the people who affect the marine environment, and changes in the services provided by the marine environment trigger changes in laws and policies in response. Many similar, sister conservation programs that launched at about the same time as MMAS acknowledged the importance of a total ecology in other words, but none of these targeted the total ecology- that is, the human-natural coupled system as a whole- as a specific focus of conservation research and application.

The MMAS program was composed of four major study areas or "nodes" that conducted a similar set of studies of MMA function in parallel, plus a group of supportive, basic studies valuable in one way or another to all four nodes. Each of the four nodes in MMAS was chosen for study partly because its associated human community had already self-elected to implement coastal zoning. The details vary, as do the strengths and weaknesses of each node as a component in the larger program. Brazil, Panama, and Fiji all had CI staff and offices in place or nearly so at project inception, putting Belize at a relative disadvantage throughout the project. On the other hand, the geography and geological history of Belize made it the stand-out node in terms of the stratified experimental design necessary to separate local management effects from global processes such as climate change. Panama offered a very strong partner and pre-existing data in the form of STRI, the Smithsonian Tropical Research Institute, but the research of STRI investigators was narrower in concept than the vision for MMAS and our work entailed a lot of context-setting and mutual enlightenment. Fiji began with a relatively poor research infrastructure, but good colleagues at the University of the South Pacific, and most important, a national movement toward resurrection of the traditional marine tenure system in Fiji. Even better, this movement was led by a individuals who made up a well-run network of traditional protected areas, FLMMA, that provided a ready and appropriate partner unlike those in any other node.

However, in none of the four nodes was adaptive management the explicit guiding paradigm. Rather, the MMAs had been formed, on the whole, to divide the sea into one set of areas for different kinds of exploitation, and another for special protection. The goal was to reduce conflicts under multiple use, to conserve for future use, and to provide resilience to the resource base for people. MMAS adopted these four nodes, and then declared and treated them as adaptive management experiments. This was done both to frame the program as a scientific study, and in the hope that the idea of adaptive management- as one of the most historically successful of all conservation approaches- might catch on.

A key element of the MMAS program was a Science Advisory Committee consisting of ten experienced and respected interntional marine conservation scientists of various stripes, chaired by the Principal Investigator. The creative contributions and overall role played by the SAC in the evolution of MMAS research were of great importance to the success that the program has enjoyed.

Here we review some of the concepts examined under MMAS, cite specific projects that explored one or another of these concepts, and assess what we have learned about the paradigm of adaptive management along tropical coastlines. As already indicated, we are cognizant that MMAS was superficially similar to other large marine conservation science projects going on at about the same time, and in some of the very same places. What made MMAS unique was its driving philosophies: the integration of social and natural science, its organization around the idea of an adaptive management experiment, and the notion of linking multiple communities similarly engaged around the world into a global learning community. Indeed, we like to think that some of the similarity among programs (e.g. MMAS, MBRS (Mesoamerican Barrier Reef Study, Global Environment Facility), CRTR (Coral Reef Targetted Research, The World Bank), Healthy Reefs for Healthy People (Belize)) derived from our sister projects taking a few hints from us, as we certainly did from them.

II. The Flow of Science to Policy

The cycle of adaptive management proceeds through a series of steps:

1. Identification of a conservation problem that has been generated by natural events or human behaviors or concerns.

2. General characterization of the target system, including the development of a rich understanding of biophysical, socio-economic and governance system structure and driving processes.*

3. Setting of management objectives within the context of a total ecosystem perspective (natural plus built infrastructures, human and surrounding biological systems fully, dynamically linked).
4. Development of policy alternatives, and development of criteria (which flow from the management objectives) to evaluate these alternatives.
5. Choosing options to pursue. Here participants assess the components of total estimated value (costs and benefits) expected from a policy action, and how different policy options compare in their ability to maximize the overall attractiveness of the value package (both the total economic value, and the relative importance of values that derive from specific ecosystem services, such as food provisioning, maintenance of productive ecosystems, maintenance of environmental health, aesthetic services, etc.)
6. Implementation of an option (in this case a MMA, which is a defined set of spatially distributed management alternatives).
7. Monitor and analyze the efficacy, and the effects (including unintended and unexpected effects) of the MMA system.*
8. Adapt/revise policy on the basis of the most current information and analyses.

Steps 1, 3, 5, 6, and 8 are all actions that are taken by a society and its governing bodies- scientists can inform these steps, but may not participate *as scientists* in actually making these decisions beyond their role as ordinary citizens. From the manager's perspective, steps 2, 4, and 7 are places where science can enter the picture and provide the information tools and products that are required by the decision-making community to do its job. Usually, the need for marine zoning first becomes apparent because of some problem that people are trying to solve- fishery depletion, habitat degradation or conflicting uses in the same area of coast or ocean. Rarely (if ever) is zoning actually formulated as an adaptive management experiment.

Rather than simply providing information products to decision makers, scientists find it useful to think of themselves as the observers in a ceaseless experiment: i.e., the essence of adaptive management. When the word experiment is used in a policy and management context it may invoke violent reactions, because no one wants to be experimented upon. Nonetheless, trial-and-error experiments in living with nature are, in fact, the basis of how human society moves forward over time and adapts to changing circumstances. Having a MMA or coastal zoning scheme affords us the opportunity to try several different experiments, or alternative management regimes, all at once, as well as to examine how they interact with each other, and how the entire quilt functions in providing ecosystem services to its dependent human societies.

In Step 2 of the flow from science into policy, the scientists set out to inventory all of the key moving pieces of the system, and to develop a rich, dynamical understanding of system structure and driving processes. MMAS was designed to be broadly interdisciplinary, striving to capture the "total ecology" of MMA settings. Thus, "inventory" meant not only an accounting of physical environments, living habitats, and non-human species, but also all the key elements of human society, culture, and governance. The second objective, understanding key processes, is even more challenging. Conducting separate studies of economic or biophysical dynamics is challenging enough, but conducting such separate studies in isolation was not sufficient. In

MMAS, we wanted to at least begin to understand how these two facets of the system – structure and process -- worked together in the larger context of local, regional, and global dynamics.

The next point of entry for science, Step 4, follows the laying out by stakeholders and decision-makers of various policy alternatives, followed by the systematic comparison and evaluation of these alternatives using carefully defined criteria. Scientists assist by providing a means to conduct this evaluation and to forecast the likely outcomes if one or another policy is elected for implementation. In other words, they can lead participants in running "what if" thought experiments, based on scientific data and information.

Both in its original conception and as it played out, the bulk of MMAS efforts were focused on Step 7, monitoring and analysis of the efficacy and effects of MMAs. Efficacy means the extent to which an MMA is actually achieving its desired objectives. Effects refers to the full suite of functional consequences attributable to an MMA policy, including both anticipated and unexpected outcomes- the latter by far the most interesting, and potentially the most troublesome.

The flow described above is with reference to an area management experiment. Meanwhile, there are many aspects of basic and diagnostic science that can enhance management, and should be pursued, but are unlikely to be a focus of attention within any one MMA. 20% of the MMAS investments were in this "global studies" category. Among the most influential was a "Global Management Effectiveness" study carried out by Tammy Campson with Bob Pomeroy, that examined critical factors in MMA success in a set of 15 comparative locations that included both non and non-node study sites, and analyzed them using a regression approach. Tammy also asked whether the results from all of the study sites collectively behaved as if there were a set of common underlying principles guiding the outcomes of an MMA as perceived by local stakeholders. The answer was "yes", and the composition and significance of these latent vectors are now being examined.

<u>A Note on Data Integration and Modeling in MMAS</u>

It was our hope in MMAS to assemble and study the program data stream within the framework of a powerful dynamic modeling and visualization platform of some kind. We realized that this platform did not yet exist: we would have to develop it. The model would simulate all the key ecological, economic, and social processes currently understood to drive system change and homeostasis. Model inputs would include all available spatial data, plus locally appropriate settings for key biophysical, economic, and governance drivers. The goal was not to model everything- this is pointless- but rather to capture essential system processes capable of generating predictions, and especially, surprises. Think of this as the ecological economic equivalent of a weather or climate model.

After five years, we do not yet have a full-blown model of this sort for any of the nodes, but we've made substantial progress. For the modeling environment, we chose an approach called MIMES (Multiscale Integrated Model of Earth Systems). MIMES is founded on the concept of ecosystem services (Daily et al 1996), and its outputs are expressed in terms of ecosystem service flows and yields (Boumans ***). Under MMAS we developed some of the basic principles for applying MIMES in this way. For example, we developed a basic architecture for calculating trade-offs between ecotourism and fisheries, using the Brazil node as our example.

Also, emerging from that same workshop in Vermont (2008, Gund Institute for Ecological Economics), came eventually a new module by Roel Boumans and others to integrate perverse subsidies into the larger MIMES architecture. However, we did not get to the point of a management-ready MIMES model for any of the nodes. However, MMAS did lay the groundwork for new funding (under GBMF, EPA, and other sources) to carry on model development work in other places, like Massachusetts. Much of the code developed in these related projects will be transferable back to the MMAS sites with appropriate modification.

One way to assist in the consideration of alternatives is to use the virtual world of a MIMES model, facilitated by graphic visualizations and run in real time. MIMES is not yet far enough advanced in our MMAS nodes to do this, but the demand for such a tool was great, particularly in the Belize and Panama nodes. Consequently, we jumped ahead and created a spatial management decision tool in the form of a graphic user interface for MIMES. This simulation game we called "MIDAS" (Marine Integrated Decision Analysis System). We programmed MIDAS for dedicated scenarios that were of interest in Panama (a general model) and Belize, where we constructed interactive scenarios for oil spills, mangrove clearing, risk maps for specific MMAs, and a generalized model for the entire coastal zone and continental shelf. MIMES and MIDAS are under continuing development, drawing upon financial resources for various geographies as they become available (e.g. our team is now working on a MIMES-MIDAS package for coastal Massachusetts, and MIMES models are under construction for North Carolina, Tampa Bay, and St. Croix USVI). In addition, GBMF has recently supported us to draw together the leaders of both MIMES and its sister methodologies (ARIES, InVEST, and cumulative human impacts analysis) to see how their complementary strengths might be combined into a single platform for cross-biome (land and sea, natural and social) system simulation and decision support. Within the five years of the MMAS study, however, it was MIDAS that received most of our attention and subsequent use as a thinking and teaching tool, and mostly in Belize.

III. The Concept of a Marine Management Area (MMA)

MMAs are discrete geographic areas in marine and coastal environments that are designated by law and designed to protect and manage resources and their uses by humans (Bass et al. 2006). They are typically characterized as having multiple management zones that facilitate a wide range of uses and types of users (Green & Paine 1997), although some are in their entirety strict "no-take" areas that prohibit all human extractive activities (Guardera 2007). MMAs have been adopted by many countries around the world as a popular tool in fisheries management and for advancing marine conservation goals (Christie et al. 2003). The explosion in MMA popularity across the globe has been attributed to the fact that in addition to being "*tools for conservation of ecosystems and fishery stocks*", they are also "*valuable centers for tourism, research and education*" (McField 2000).

For our purposes, we defined an MMA as an area of ocean, or a combination of land and ocean, where all human activities are managed toward common goals. This concept is elaborated in one of our S2A documents, "MMAs, What Where and How?" MMAs are a form of *ecosystem-based* management, where all elements – biophysical, human and institutional – of a particular system are considered together. There are several overarching principles under which MMAs should be developed. One such principle is that all human uses and their subsequent impacts on the defined area should be considered, and their management *integrated* in an *adaptive* framework. Another is that the policy and management should be based on the *best science*, both biophysical and social, available. A third is that all *stakeholders* in the defined area and its condition and uses should be consulted and fully involved in the policy and management development and implementation process. When such principles are fully implemented, the uses of the resources and habitats and the resulting benefits both to the environment and to humans can be optimized.

IV. Core Concepts of the MMAS Program, How They Were Instantiated, and What Was Learned

Adaptive Management, central to the conception of MMAS, was featured above. Despite its youth, MMAS succeeded in fostering or contributing to policy change in all four nodes, as well as in the two MMAS reference areas: the Phoenix Islands Protected Area (Kiribati) and the Galapagos Archipelago. These efforts are featured on-line on the web site www.science2action.org. While initial policy responses to new science do not of themselves constitute a full adaptive cycle, given time we could see ongoing adaptive management taking root in the MMAS nodes and other study areas. Much will depend upon the sustainability of local efforts that MMAS has fostered. What MMAS has taught us thus far is that the notion of adaptive management is quite foreign to individuals and institutions with a Western perspective. The adaptive management paradigm stands in opposition to a more widely held view that problems are simple and straightforward, and that science and technology can quickly and permanently fix them, one by one, forever. Furthermore, it seems to be a widely held belief that the ability of technology to solve problems will advance more quickly than the problems themselves arise. None of this is true, of course, and hence the need for adaptive management and the science to support and empower it.

Connectivity

The human enterprise is embedded within a larger, natural ecosystem whose essential functions are driven by crucial connectivities. Patterns of biophysical connectivity are a central component of the ecological landscape. The social systems and economies layered upon landscape have their own essential connectivities, both within the region and between it and a global society. If maintaining the flow of ecosystem services is our goal, then human infrastructure and activities must sit delicately upon the ecological landscape of connectivities, with minimal disruption.

Biophysical Connectivity refers to the processes by which water masses, nutrients, genes, organisms, energy, and biomass move from one place to another, creating a spatial linkage in the flow of information and materials. The design of MMA networks, planning where and how to develop the built environment, and the disposition of shipping lanes and recreational areas are examples of activities that require knowledge of biophysical connectivity if the results are to be sustainable.

Eight MMAS projects contributed explicitly to our understanding of biophysical connectivity in MMA settings. Though conducted in association with the four nodes, these were supportive projects funded under the "global" portion of the MMAS program.

(1) Drs. Josh Drew and Paul Barber led work on genetic connectivity in coral reef fish

populations of Fiji. They found that as a rule, fishes born on Fijian reefs return to Fiji to settle. Indeed, a surprising number of Fijian coral reef fishes are actually endemic species, and not synonymous with their closest relatives in the rest of the Indo-Pacific.

(2) Dr. Stephen Palumbi measured the size of the dispersal kernal in an important group of Fijian reef-building corals. He found that despite the existence of a pelagic larval phase for these corals, as for most marine invertebrates, the majority of larvae disperse no more than tens of kilometers from their birthplace before they settle to take up life on the reef. Dr. Palumbi also discovered that such long-distance dispersal as does exist, is mostly in an east-west direction. The barrier to north-south dispersal of corals (and presumably other marine organisms) in the Pacific means that it is unlikely that nearshore tropical species can rely upon dispersal into higher latitudes as an adaptive response to climate change.

(3) Drs. Mark Hixon, Jim Beets, and Brian Tissot used DNA fingerprinting methods to determine if yellow tang (*Zebrasoma flavescens*), the most important exported fish from Hawaii for the aquarium trade, benefits from the Fish Replenishment Zones established along the Kona coast of the Big Island. They found that, indeed, juvenile yellow tang found outside the FRAs but still on the Big Island were genetically derived from parent stock within FRAs, signifying that spillover from the FRAs was resupplying the Big Island population, that self-recruitment was prevalent in Big Island yellow tang, and that due to this local benefit, the FRAs were actually functioning as intended. Comparative study of a non-exploited species yielded similar results.

(4) Drs. Richard Kliman and John Cigliono examined the population structure of conchs (queen conch, *Strombus gigas*; and milk conch, *Strombus costatus*) in Belize. Their study suggested that the shallow and deepwater populations of the commercially important queen conch were panmictic, indicating that the heavily exploited, shallow water population should be managed as one with the deepwater individuals. Additional data would be needed to confirm this result, but for the moment it established a precautionary baseline for management practices. Not enough data were obtained to determine the extent to which the Belizean queen conch populations are isolated from others in the region.

(5) Dr. Claire Paris modeled the physical oceanography of Glover's Atoll at high resolution, as a drop in to existing lower-resolution models for this region. She then used the model to test the null hypothesis that the endangered Nassau Grouper is panmictic in the MAR region; that is, that progeny from any spawning aggregation are distributed evenly throughout the region upon settlement from the plankton.

(6) Mr. Eli Romero and Dr. Leandra Cho-Ricketts and used distribution, size, and stable isotope data to better understand the movements and habitat dependencies of commercially-targeted reef fishes in Belize as they grow from newly settled juveniles to adults and enter the fishery. This study (which focused on a cross-shelf transect from Placencia to Glover's Atoll) confirmed the importance of seagrass and mangrove habitats to completion of the life histories of economically important species of snapper and grunt. It also revealed that mangroves function as a juvenile refugium but not as a carbon source. Most energetic requirements were met chiefly through seagrass and water column food webs. Mainland mangrove forests- now threatened by coastal development- are especially important to the commercial fisheries. The snappers exhibited contrasting habitat dependence behaviors, but there remained an overall pattern of early juveniles

being most abundant inshore, with larger individuals with increasing distance toward the shelf edge. Glover's atoll appeared to be a self-contained system harboring early juveniles in the lagoon and mature individuals on the outer barrier.

(7) Dr. Rodrigo Moura, Dr. Ken Lindeman, and Mr. Eduardo Marocci conducted a parallel sister project to the Romero and Cho-Ricketts Belize study on the Abrolhos Shelf in Brazil. The results were similar to those in Belize, especially with regard to the importance of mainland mangrove forests. However, the Brazilian study also produced two surprising discoveries. First, one of the principal commercial snappers is actually an endemic species (*Lutjanus alexandri*). Second, the team discovered that steep-sided holes or depressions in the reef platform constitute a previously unknown and important juvenile habitat in this region.

(8) Dr. Phillip Lobel examined the biogeography of fishes in the Belizean portion of the Mesoamerican Reef (MAR) lagoon. His work revealed that the MAR lagoon is quite isolated from the barrier and atoll reef systems, creating an evolutionary cauldron with its own suite of endemic fish species, including several previously unrecognized despite their extraordinary abundance (*Halichoeres socialis*, n. sp.) or coloration (*Hypoplectrus* n. sp.). Also, a new species of sponge goby (*Elacatinus* sp. nov. Lobel and Kaufman in prep.) was discovered on an outer atoll wall at Lighthouse Reef, sparking a systematic search for other new species of both the outer reef and inner shelf and inter-reefal habitats.

In sum, supportive MMAS science on biophysical connectivity revealed that MMAs function in a much more self-contained manner than was appreciated. While the notion of a global network of MPAs remains sound, for a variety of reasons the individual no-take areas must probably be larger, more numerous, more closely spaced, and more carefully stratified by habitat within each region, than we might have hoped.

<u>Human and Institutional Connectivity</u>

When considering a 'region', natural scientists think of biophysical resources such as plants and animals and their habitats—coral reef, barrier island or mangrove forest. But social scientists tend to think more of a group of people, their characteristics, and behaviors. These differing thoughts yield very different maps of the world, which then guide scientific research and marine resource management policies. Since all marine conservation involves, first and foremost, human behavior, we need to begin to draw our 'maps' based on the characteristics of people and their behaviors together with the biophysical resources.

For example, people are connected economically to locations and communities through markets for the products they buy and sell. People are connected to governance institutions – local government, for example –through voting and public meeting and hearing processes. Governance institutions are connected to one another – a fisheries agency to a water quality agency, or a state fisheries department to a federal fisheries department – through law and policy although the fragmentation (lack of communication and cooperation) among such agencies is frequently a problem. All of these are examples of the "connectivity" of human and institutional systems, which is analogous to the connectivity in biophysical systems.

<u>Resilience</u>

The word "resilience" generally refers to the ability of an individual or system to return to its original form following some form of disturbance. It can also mean to recover from adversity; both definitions imply that the recovery is to a nominal or stable state that preceded the perturbation (Holling 1973). "Resistence" is a related but distinct term that refers to the tendency of a system to resist deformation from its normative state in the first place, despite perturbation. In the context of MMA's, there is a human desire for natural systems to exhibit resilience in the face of perturbations caused by people, such as the removal of biomass, destruction of habitats, the release of wastes and toxins, and anthropogenic alterations in weather and climate. The most important aspect of natural resilience in ecosystems is that they continue to provide the ecosystem services that people depend upon, despite the potentially harmful influence of the acts involved in using these services: e.g., fishing, coastal development, mining, deforestation, ecotourism.

Society is part of the larger ecosystem, and in order for ecological resilience to be assured, humans and their social institutions must also exhibit resilience (Baker et al. 2004).

The science of MMA planning and accountability require the invention of means by which resilience can be measured and tracked over time, as well as policy interventions that can be used to manage resilience up or down, while recognizing the necessary trade-offs between resilience designed to maintain a norm, and the flexibility that may be necessary in order to keep open the option of pursuing other, different norms and achieving different metastable states.

Biophysical Resilience

The concept of the MMA as an adaptive management tool is specifically intended to minimize disturbance to the ecosystem and maximize resilience. To take full advantage of this philosophy there must be ways to measure ecological resilience. This can be accomplished by quantifying parameters that reflect system response to the most recent natural or anthropogenic disturbance, or an experimental perturbation can be exacted to create the opportunity to measure the system's response.

MMAS included several discrete attempts to improve the ways that ecological resilience can be measured in the context of an MMA. Nearly all of the nodes were in a state of recovery from a recent major disturbance. Thus it was possible to measure the abundance of organisms whose presence is a reflection of a healthy regenerative process. Most of our work was focused on coral reefs. In modern coral reef environments, the normative state, as well as the state desired by human beings as delivering maximal services, is a robust calcium carbonate framework built by, and nearly entirely covered by living scleractinian corals. These corals are to be healthy, growing, and thus actively building and repairing the structural foundation of the community. There is a large and controversial literature on the definition of ecological health in coral reef environments, and in particular, the best way to understand the processes by which coral reef health declines, and can be restored.

Due to the widespread degradation of coral reefs since at least the early 1980's- particularly in the Caribbean, it is difficult to parameterize a quantitative baseline for what is meant by a "healthy" coral reef. To this end, MMAS teamed up with work that had already been initiated by Dr. Enric Sala, a member of the MMAS Science Advisory Committee. One of the MMAS projects consisted of support to complete the analyses from an expedition to the Northern Line

Islands, Kiribati. The purpose of the expedition was to measure variation in benthic community, fish community, and microbial community along a known gradient of human impact. At one end of the four-atoll gradient was Christmas Island, the largest land mass on a densely inhabited atoll. At the other end was Kingman's Atoll, which has no permanent residents and has never had a large resident population. This work revealed a consistent decline in the biomass of large predatory and herbivorous fishes and live coral cover with increasing human population density, as well as a distinctive shift in the microbial community from one dominated by minute photosynthetic bacteria called *Prochloroccus*, to one dominated by opportunistic pathogenic bacteria, such as members of the genus *Vibrio*.

An unfortunate, but for us fortuitous event took place in 2002, when a remote island group in the southern part of Kiribati, the Phoenix Islands, was subjected to an extremely severe bleaching event. This event took place just after a New England Aquarium-led expedition to the islands documented their status as one of the few remaining, relatively pristine coral reef ecosystems. This afforded us the opportunity to test the hypothesis that a coral reef far removed from immediate human impacts would exhibit high resilience in the face of global climate impacts. Meanwhile, the Government of Kiribati declared the Phoenix Islands Protected Area, bringing the entire region under management scrutiny. The 2012 PIPA expedition, undertaken as an MMAS activity, revealed aggressive recovery of coral communities in PIPA from the bleaching event, but with a twist. First, the recovery appeared to have been made possible largely by the existence of an intact and high-biomass herbivore assemblage. Benthic communities showed high dominance of crustose coralline algae, usually a sign of intense grazing pressure, and thus creating a state conducive to the recovery of scleractinians corals. However, even slight local nutrient impacts, such as from bird colonies or iron deposits from old shipwrecks, could compromise coral reef recovery. While these observations are still only anecdotal, they are cautionary. They indicate that local efforts to curtail human impacts on coral reefs could go a long way to ensuring coral reef health, but it could also be that the bar is rather high for these local efforts to be meaningful or worthwhile.

While PIPA suffered serious setback followed by an apt, Phoenix-like rise from the ashes, the Southern Line Islands in eastern Kiribati remained unscathed, providing a natural control. Based upon comparison among PIPA and the Northern and Southern Line Islands, we devised a way to compare all the coral reef systems of the world on a common set of health axes, and also to reduce coral health to a single number to make it easier to communicate. We call this the "Coral Health Index", or affectionately, "CHI", after the Chinese character signifying the life force or breath of life. CHI is calculated from three elements: the amount of reef surface covered by hard corals and crustose coralline algae (CCA) combined; the biomass of fishes; and the density of *Vibrio*, a genus of gram-negative bacteria that include a host of opportunistic pathogens and generally unwelcome camp-followers. CHI also operates as a measure of coral reef resilience. CCA creates suitable substrata for the settlement of hard coral larvae, and of course lots of baby corals being able to settle on the reef, means money in the bank for its future vitality. Total fish biomass is driven mostly by herbivores and large predators, and herbivores are important to CCA's being able to dominate the benthic community, particularly after a major die-off of hard corals. High *Vibrio* titres can themselves play a role in coral disease.

Originally, CHI was conceived as a way to compare the efficacy of management across the four disparate nodes. To validate the CHI methodology, however, we need to at least compare a very wide range of reefs using similar data along 2 of the 3 axes: i.e., fish biomass and benthic community, realizing that right now, microbial data are only available for a very few sites. The concept of CHI was tested and articulated under MMAS funding, including a booklet about to be completed and several peer-reviewed publications in various stages of completion.

1) measuring resilience at the level of populations

Population resilience is the ability of a local community of organisms of a given species to maintain stable population numbers, avoiding anomalously high or low population levels. In coral reefs, which are currently experiencing substantial degradation, population resilience is perhaps most clearly indicated by the rapidity with which new recruits of coral reef organisms appear and become established following major physical disturbances. In part this is a product of large-scale connectivity among source and sink populations, a process examined extensively in MMAS studies of coral reef fish and coral connectivity. A more immediate indication of the contribution of coral population resilience to coral reef resilience overall is the small-scale connectivity that is reflected in the abundance of young coral colonies. Small coral colonies (1 cm and up in diameter) were enumerated as part of the routine ecological monitoring in MMAS, but tiny, brand new recruits are difficult to detect consistently. To this end we experimented with several underwater camera systems that could highlight young coral colonies using induced fluorescence and special filters for the flash and camera lens. These early experiments were sufficiently promising to justify follow-on work.

2) measuring resilience at the level of genets or individuals

The decline of coral dominance in reef communities can be caused by both acute and chronic processes. Mass bleaching events and epizootics are acute events. Examples include the PIPA 2002 bleaching event, and the White Band Disease that brought Caribbean acroporid corals from dominant to endangered status in the mid-1980's. Chronic stressors include some of local origin, such as sedimentation, nutrient enrichment, toxins, coral predation, and reduced grazing pressures on fleshy algae, in addition to regional and global stressors such as regional plagues, ocean acidification, thermal anomalies, increased storm intensity, and sea level rise. We proposed that chronic processes operating at the level of the genet or individual could be just as important, and could also make corals more susceptible to disease, bleaching, and physical disturbance. MMA's are intended, in part, to alleviate local, mostly chronic stressors. Are they working? Coral morbidity is a complex, interactive process, so merely scoring coral health under different management regimes is unlikely to be all that revealing. What was needed was a way of determining not only that a coral colony was under stress, but by what. This required a new approach, a diagnostic medicine for corals. To this end, we founded the Coral Whisperer project under the MMAS program. The goal of CW is to use translational bioinformatics to predict and detect physiological stress in reef-building corals, in order to: 1) give site managers immediate insight into the health state of "their" corals, 2) alert site managers to a source of the stress early (at pre-lethal levels) in the stress pathway (i.e. temperature, chemical, predation, etc.) and 3) provide for an indicator variable in the determination of individual site management effectiveness. Under our MMAS GBMF grant, CW was a portfolio of several seed projects that together engaged a consortium of investigators: John Finnerty – Boston University; Andrew Baker – University of Miami; Steve Palumbi – Stanford University; Robert Richmond – University of Hawaii; and Les Kaufman – Boston University. Recently, Steve Vollmer of Northeastern University was added in our first bid for programmatic funding from the National

Science Foundation. That proposal was declined but will be resubmitted. The CW consortium has already produced a portfolio of peer-reviewed publications and bioinformatic products, leading to a focus on five species of reef-building corals, representing a range of growth forms, geographical ranges, and life history attributes. The final experiments under GBMF funding are now nearing completion, including our first efforts to systematically profile gene expression patterns in association with specific stressors.

Human and Institutional Resilience

Life biophysical communities, human communities exhibit different degrees of resilience. The health of the people in the community; the security of their livelihoods; the existence of private-sector organizations such as churches and unions are all aspects of human communities that can make them more resilient in the face of challenges and stresses. Similarly, public sector institutions (government) can be more or less resilient. Adequate legislative mandates; clear assignments of authority and responsibility; a well-trained workforce; adequate resources for compliance and enforcement; these are all aspects of governance institutions that can make them more resilient to challenges and stresses.

Among those MMAS studies that contributed explicitly to our knowledge of human and institutional resilience was the work led by Amanda Vincent of UBC on Danajon Bank, in the Philippines. In a series of studies (cite pubs***) of locally established and managed MMAs (mostly small no-take areas), it was found that having an MMA could build social capital, and hence economic resilience, within a community even if the MMA did not increase the biomass of commercial fishes! The reason may have been that the operation of an MMA organizes and empowers people, who may then go on to pursue a variety of related or even unrelated pursuits that benefit the community. A separate MMAS study, but along the same lines, was the Global Management Effectiveness work led by Bob Pomeroy and his graduate student, Tammie Campson. The take-home lessons from MMAS on human and institutional resilience correspond fairly well to the observations on functional and dysfunctional governance of common resources made in the work of Elinor Ostrom, for which she won the Nobel Prize in Economics.

Tradeoffs

Public policy decisions on environmental issues are always political precisely because they always involve tradeoffs among different objective and impacts. Protecting a certain population or biomass of fish or forest is one kind of objective; harvesting those fish or forests for profit is another. Protecting water quality is one kind of objective; using water bodies for waste disposal or repositories for pollutant runoff is another. The challenge of public policy-making is choosing among alternatives which reach these disparate objectives to different degrees, and such choices always involve tradeoffs in what is an essentially political process. In this sense, the establishment of MMAs is an inherently political process, one which involves tradeoffs among different objectives, alternatives and impacts.

While the idea of tradeoffs is familiar to most, the scientific analysis of tradeoffs in the context of tropical coastal communities is not very advanced. The development of MIMES and MIDAS was intended to address this, and MIDAS has already been used in Belize to engage stakeholders in discussion of tradeoffs between the economic benefits of coastal development or oil production, and the various ecosystem services that are put at risk by development and oil.

During a 2008 MIMES workshop, information from the Brazil MMAS node was used to develop a case study in ecosystem service tradeoff modeling, with a focus on extractive versus non-extractive uses of coral reef systems. That work has been recycled into MIMES models by collaborator Dr. Roel Boumans for other tropical nearshore sites, as well as into the Belize MIDAS applications. One thing we learned in doing this is that standard marine monitoring protocols, while they can provide a wealth of data useful in determining if MMAs are functioning as desired, do not provide the insights on ecological and economic processes that are needed for trade-off modeling. In other words, if management decision making is the ultimate pragmatic goal, it is necessary that monitoring target additional, nontraditional parameters that shed light on the realized setpoints for ecosystem service tradeoffs within an MMA.

Global Learning Community

One operating principle of MMAS has been that coastal communities in the tropics share common problems and so should benefit from common solution sets. Furthermore, faster progress should be achieved if geographically disparate communities share their experiences and their data on a regular basis. We had also hoped that the unique opportunity to engage four regions in parallel MMA research efforts would unite them into a learning community, characterized by frequent spontaneous communication among the nodes, including the sharing of data and methods. Five years was not long enough for this to happen, for a variety of reasons. First, field work was launched sequentially across the nodes and reference sites, as was necessary to keep the work of bringing the nodes on-line within the capacity of both the core and field office teams. So really, the four nodes were functional at the same time for only the last 2 or so of the 5 years. Second, the bureaucracy entailed in moving and accounting for funds in a responsible manner greatly slowed many aspects of the science. This was just about worked out by the time the grant ended. But, and most important, acting as one learning community does not come naturally to far-flung individuals who must dedicate much of their time and energy to just keeping their own work going, in environments with limited resources and many obstacles. After the project was up and running, it was possible to hold program meetings that included representatives from the four regional nodes. Time and funds allowed for five such meetings. Two were during the formative stages of the project (both held at GBMF headquarters), and three were held near the end of the project period in Boston, for the purpose of data inter-operability and the joint production of outreach documents. These meetings were so well appreciated that all agreed it would have been wonderful to have held them several times a year. Having done so, however, would have severely compromised funding for the actual work in the field.

Extensive use of electronic communications media was of great assistance, but the trust that fuels close working relationship was greatly boosted by face time, and face time in a global project is extremely expensive. As regional efforts find ways to become more financially sustainable in their own efforts, then it may become easier to nourish global learning communities with regular meeting opportunities, and more importantly, greater incentives to reach out electronically to colleagues with similar experiences in other parts of the world. One incentive frequently mentioned by MMAS participants, is data sharing. Extensive sharing (of ecological data from the four nodes) only began toward the end of the project, when all the nodes were operational, but it was greatly appreciated, and has spurred much discussion and many new ideas.

Interdisciplinarity

In this paper we will describe the "total ecology" of Marine Managed Areas (MMA), which consists of the biophysical, human, and institutional ecologies. We will begin with the biophysical ecology, which we define as the non-human, biophysical resources and environments related to the area in which human behavior is to be managed. We will then discuss the human ecology, which we define as those humans and human behaviors that affect, are affected by, or are otherwise concerned with the MMA. Finally, we will describe the institutional ecology of the MMA, which we define as those institutions that govern or affect the behavior of those people in the human ecology; that is, the institutions through which policy 'solutions' must be formulated. The "total ecology" of any MMA is these three different ecological systems mapped onto one another. An important implication of this perspective is that if we do not proceed with a 'mirror image' of social science to match the biophysical science, we will not have the understanding, information and tools that we need to effectively sustain and manage our coastal and ocean environments and resources – that is, to develop law and policy.

Scale and Boundaries, Embeddedness

One of the chief criticisms of spatial management of any kind, is that lines drawn on maps do not reflect the true connectivities and spatial dynamics of either nature or society, and hence can not work. The situation is not that bad, but the critics have a point. The effects of an MMA are contingent upon size (scale relative to important system processes and boundaries), how artificial boundaries map onto natural ones, the hierarchical structure of ecosystems, and the ways and degrees to which an arbitrarily-bounded MMA is connected to surrounding areas.

Embeddedness emerges as a problem from the moment that MMA function must be measured. The area of an MMA is embedded in, and functionally a part of, a larger ecological landscape encompassing watershed, continental shelf, and open ocean. At the same time, it is also embedded within economic and social hierarchies that owe their behavior to both local and global influences, sometimes equally. The situation is witheringly complex: three dynamic landscapes layered one atop the other, and all with conditions varying from place to place. From the standpoint of the MMA manager, this variation is distributed within an MMA, across a national system of MMAs, and most definitely across a geographical region. The result is that any data meant to indicate MMA performance are likely to suffer very high variance and much spatial idiosyncracy, for reasons having nothing directly to do with area management.

In MMAS, we dealt with the problem of embeddedness in three ways. First, ecological sampling was stratified, with replicated comparisons among management regimes, distributed strategically across a region. This enables investigators to examine the effects of management regimes under a range of conditions representative of that region. For example, in Belize there were five principal long-term study sites: inshore and an offshore sites in southern Belize where the MAR (Mesoamerican Reef) is relatively poorly developed, inshore and offshore sites in the central, well developed portion of the MAR, and one site at an offshore atoll, Lighthouse, in a place as far removed as possible from local human influences. A sixth site was later added at Glover's Atoll. In the end, we found that the MMA on Lighthouse showed the greatest management effects. This could have been because of good enforcement, or remoteness, or simply a good choice of where to locate the no-take area, but we know that it was not only because of underlying habitat variation because the stratified design enabled those effects to be minimized in the course of statistical analysis.

Another, crucial form of embeddedness in which it can work very strongly in favor of conservation, involves the relative impacts of land-based versus marine-based, and local versus global human impacts. It is strong inference that a combination of good land-use practices (including conservation of forest cover), good freshwater management, and good fishery and habitat management can all together nurture the healthiest, most robust and resilient nearshore marine ecosystem possible. It is also likely that under these ideal local management conditions, the ecosystem will fare better through global climate change events (such as severe hurricanes or warming periods) than an otherwise identical area lacking in effective local conservation measures.

The embeddedness of social systems is also of obvious importance. The distribution of power across government hierarchies can either greatly help, or virtually condemn conservation efforts. Comparison among the MMAS nodes is enlightening in this regard, in ways we plan to explore in detail in the peer-reviewed synthesis papers now emerging from this work.

The Role of Stakeholder Involvement

Involvement of stakeholders at all levels (local, regional and national) is critical to the success of MMA development. Besides often having critical 'local knowledge' of coastal and marine resources and environment and local needs and attitudes, the involvement of stakeholders often gives everyone a stake in the outcomes of deliberations. The more people have participated in, and understood, the process through which MMAs are created, the more likely they are to support and help enforce the rules of the MMA. In fact, because of the general lack of resources for monitoring and enforcement in many MMA-adjacent communities, the assistance and cooperation of local stakeholders is critical to the success of the MMA.

Stakeholder involvement in the places studied by MMAS varied in accordance with the system of governance in play. We are elucidating this effect in our continuing analysis of node outcomes. Useful insights in this regard have emerged from the Danajon Bank study (Vincent et al.), and in a regression-based comparison among both node and non-node sites, called the Global Management Effectiveness Study. GME produced a set of "Critical Determining Factors" including governance, economic, and biophysical attributes, that strongly influence MMA success; stakeholder involvement was one of these. The CDF's were employed as the basis of a user-query panel in MIDAS to establish the background conditions in which an MMA is being managed, and to calculate risk factors that management would want to consider reducing.

It is reasonable to also ask how MMAS itself fared in terms of stakeholder involvement in its own projects. The answer is, variable- again largely based on local circumstances and program history- as revealed in evaluative reports written by Michael Wells and Jesse ______. For example, In Brazil, where clearly identified stakeholder communities were deeply involved with a well-consolidated MMA system (i.e. it seemed like one system), there was considerable buy-in and awareness, at least of the MMAS program. In Belize, where local communities are associated with local portions of the national MMA system but do not communicate closely or often, a more concerted outreach program would have been necessary to achieve high levels of awareness of any new element such as MMAS. This could have improved performance in Belize, but might also have detracted from the science accomplished. With the transition from a purely research program to one involving substantial conservation implementation ("Science To

Action"), efforts to engage stakeholders began to improve in all the nodes.

V. Characteristics of and Outcomes from Node MMAs

MMAS offers insight on the integration of social and natural science for MMAs from four primary (Belize, Brazil, Panama and Fiji), two secondary (Phoenix Islands and Galapagos), and an additional ca. 12 tertiary study sites (included with the Global Management Effectiveness study). Synthesis and integration were focused on the four nodes, however, with support from information developed in other, non-node sites and global comparative studies. The results from each node are currently being fashioned into a variety of products, from peer-reviewed scientific papers to policy action items. Here we offer a detailed view of coordinated MMA activities and synthetic outcomes for one node, Brazil, and a brief overview for each of the remaining three.

Belize Node Characterization

MMAS focused on six of the 13 MMAs that together comprise the "marine reserve" system for the nation. MMAS activities in Belize were coordinated by Mr. Lindsay Garbutt, then Executive Director of the NGO Friends of Nature, which later changed its name to Southern Environmental Association (SEA, located in Placencia) upon merging with a sister organization in Punta Gorda, near the Guatemalan border. S2A activities were coordinated by Melanie McField of the Smithsonian Institution. This worked well in general, but communications about the MMAS program within Belize, had they been more extensive and intensive, would have benefited the project. This deficit was symptomatic of the lack of a CI office and staff in the country.

The greatest strength of the Belize node analytically was the opportunity to examine geographical and environmental variation in the effectiveness of MMAs, and in the relationships between people and the marine ecosystem. Although Belize is a small country, the continental shelf ecosystem is extremely complex, comprising a barrier reef system with well-defined inner, middle, and outer shelf environments plus three of the four only true atoll ecosystems in the Atlantic Ocean. So Belize was *the* place to both examine geographical variation in system properties, and to see if knowledge of this variation could be used to jack up the signal strength of management regime effects. We found that it could, as have others more recently, and using different methods. Despite this ploy, our surveys did not show statistically significant differences in numbers or size of fish inside versus outside of no-take areas in five of the six study sites. Only the oldest, Half Moon Caye, showed statistically significant biological effects that could (though not definitively) be attributed to management.

Of the six MMAS study sites in Belize, we have complete interdisciplinary data for only one: Laughing Bird Caye National Park (LBCNP). We also have some overlapping biophysical and social data for Gladden Spit Marine Reserve (GSMR), and collectively the villages in which MMAS social science was conducted, which run along nearly the length of Belize, can be matched to the ecological study sites to which they were most closely related.

Laughing Bird Caye National Park

Laughing Bird Caye National Park was established as a no-take area surrounding Laughing Bird Caye in response to a proposal by a private investor to develop the Caye. The local community environmental group, Friends of Nature, was formed in large part to oppose this development, and eventually succeeded in having the Park created. Recreational fishing is allowed within the

Park boundaries, but no commercial fishing.

Outcomes

Originally we thought that the lack of statistically significant management effects in the benthos or fish communities of LBC might be due to the small size of the Park. Recently, however, we noted an inconsistency between the numbers we obtained from transect lines at our standard monitoring depths and the presence of large predatory and herbivorous fishes in extremely shallow water near the caye. That is, the monitoring data were obtained while diving at a substantial distance from Laughing Bird Caye itself, on the flanks of the rhomboid shoal atop which the reef and caye are perched. It may be that protection is best enforced in shallowest areas right near the Caye, which is a good distance from most of our sampling points. It also hints that protection effects do not manifest homogenously across a designated protected area, which could be true for a variety of reasons.

The very shallow waters near LBC itself are also one of several coral restoration sites, a project being carried out by Ms. Lisa Carne. Some local fishermen who used to fish around the Caye can no longer do so, but report that they fish in other nearby locations. Recreational fishermen and divers are part of a large and growing leisure-tourism industry in Belize. The Friends of Nature organization has proven to be a durable presence in marine conservation in Southern Belize, and has now merged with another similar organization to become SEA, the Southern Environmental Alliance (still based in Placencia, Belize). FON, and later SEA, served as the local coordinating body for MMAS work in Belize, where CI lacks an office.

Brazil Node Characterization

The MMAs in Brazil were all in the vicinity of the Abrolhos Bank adjacent to Bahia State. The CI office in Brazil was the coordinating entity for the Brazil node work, and coordinated the work in all of the different disciplines as well as contributing to the design and implementation of the MMAs themselves. The three specific MMAs on which we focused our work were the Abrolhos National Park and the Cassuruba and Corumbau Extractive Marine Reserves.

Abrolhos National Park

Abrolhos National Park (ANP) was established as a no-take area with use focusing on leisure-tourism. Commercial fishing is not allowed. Several private firms operate charter and tourist boats that take tourists to the islands and reef areas in the Park. There are several unique coralline structures within the boundaries of the boundaries of the Park. A significant impetus for the establishment of the ANP was to prevent offshore oil and gas exploration and development, which is now prohibited within the Park boundary. The CI Brazil Marine Program personnel, along with other scientists from Brazil, were instrumental in the establishment of the Park, as well as leading MMAS studies in this region.

Outcomes

Surveys show more and bigger fish within the Park boundaries compared to areas outside of the Park. However, these apparent benefits were ephemeral: relaxed enforcement led quickly to loss of benefits. Undetermined numbers of local and ‘outside’ (from other areas of Bahia State and other states in Brazil) fishermen who used to fish within the Park boundaries are now prohibited from doing so, and presumably fish elsewhere. The leisure-tourism industry based on visitation to the Park is strong and growing.

Corumbau Extractive Marine Reserve

The Columbau Extractive Marine Reserve was created in response to local concern about outside fishermen fishing, primarily with trawl nets, in the Corumbau area. A local fishermen's organization and the local communities were significant factors in the establishment of the Reserve, the principle of which (extractive reserve) was 'imported' from the Amazon region where it had been applied to native peoples' rights to local natural resources. The rules of the Reserve stipulate that only fishermen from local communities can fish in the Reserve, using traditional gear and methods, mostly small gill nets and handlines.

Outcomes

Surveys show more and bigger fish within the reserve boundaries compared to areas outside of the Reserve. The benefits of the fishery goes to local communities; there are presumably fewer habitat effects from the fishing gear; and the conservation goals for the fishery are met more easily with the reduced participation and effort in the fishery. An undetermined numbers of 'outside' (from other areas of Bahia State and other states in Brazil) fishermen who used to fish within the Reserve boundaries are now prohibited from doing so, and presumably fish elsewhere. A significant outcome of the application of the Extractive Reserve concept is that, with the caveat that the federal government had to step in to create the reserve in federal waters, the local fishermen and communities organized themselves and are essentially self-governing within the boundaries of the Reserve.

The Cassuruba Extractive Marine Reserve

The Cassaruba Extractive Marine Reserve is unique in that it includes a significant amount of estuarine mangrove area where much of the extractive use is by local subsistence fishermen who live in the mangrove area. The CI Brazil Marine Program personnel were instrumental in the establishment of the Reserve.

Outcomes

The establishment of the Cassaruba Reserve is very recent, and the outcomes are not clear at this time.

Fiji Node Characterization

Fiji has a centuries-old tradition of marine managed areas called *Qoli Qoli*. These are areas adjacent to local villages on each island where the local Chiefly clans controlled access to and use of the areas inside the fringing reefs, the reefs themselves, and the nearshore sea outside of the reef. The *Qoli Qoli* system broke down to some extent with the arrival of British Colonial power, which attempted to centralize the fishery management system under nation-wide civil government. More recently, however, the Marine Managed Area movement of which our project is a part has had the effect of revitalizing the traditional *Qoli Qoli* system. The three sites in Fiji for which we have complete interdisciplinary data are Navakavu/Kalokolevu, Malolo and Waitabu. A fourth study area, Rakiraki, was opened in the second year of sampling. While we do not have socioeconomic data for “Ra” as yet, this site is significant to Fiji (and CI) as being the MMAS site about which the first ridge-to-reef conservation corridor is being developed. The corridor runs from indigenous forest in the interior of NE Viti Levu, down rivers rich in indigenous (and largely endemic) freshwater fish and other species, across twinned FLMMA/MMAS sites, past an ecotourism spot where tourists observe spinner dolphin, and out across blue water to a seamount, “E6”, that is frequently visited by live-aboard dive boats.

Navukavu/Kolokolevu is located a few kilometers west of Suva, along the south coastal road. This spot was chosen for study to represent a well-managed “mainland” site (i.e. exposed to high-island runoff). These two adjacent villages encompass three side-by-side management regimes: a tabu area (no-take), a managed extraction area, and an open-access area. Distinct management area effects were detected for the biomass of commercially targeted fish species. An observed pattern in benthic community structure (live coral cover in particular) must be conservatively regarded as a spatial confound until sufficient time series data indicate otherwise. The three areas together are notable for providing the clearest evidence of a serial management area effect in Fiji. The Waitabu site is located on the southern coast of Taveuni, seaward and slightly northeast along the coast from a montane conservation and ecotourism area. It was chosen to represent a well-managed offshore site. The Waitabu study site consists of a simple inside/outside comparison between tabu and open access. Here, too, there is evidence of an apparent management effect, although there is a possibility of a spatial confound with reef face exposure and topography. Helen Sykes, who has been studying this region for several years and whose study area we overlapped with by agreement, earlier found some evidence for a tabu effect here. Malolo lies in the Mamanuca archipelago, west of Nadi on the western coast of Viti Levu. Malolo was originally chosen for study as a poorly or lightly managed offshore site. However, its status changed in two ways during the study. First, the chief passed away and the tabu area was tapped to supply the funeral feast. Second, catastrophic floods in Nadi sent dense sediment plumes out as far as the Mamanucas, with especially heavy impact in the vicinity of Malolo. No tabu effect on fish community composition or abundance was observed at Malolo, not surprisingly. The Rakiraki region study sites encompass two relatively newly enforced tabu areas and open access areas nearby. Curiously, in the one data set from Ra so far, fish abundances are higher outside the tabu areas, possibly indicating energetic fishing in anticipation of the impending closures.

Panama Node Characterization

The primary MMA in the Panama Node is the Coiba National Park in the Gulf of Chiriqui on the west coast of Panama, consisting of Coiba Island and its surrounding waters. MMAS ecological monitoring, carried out in collaboration with the Smithsonian Tropical Research Institute (STRI), encompassed not only the several management zones around Coiba, but also many other island and mainland sites in the Gulf. Coiba Island has a unique history, having been leased by the government of Panama from a private owner for use as a prison since the early 1990s. In the 1990s, Panama decided to abandon the prison, and a struggle ensued between development and conservation interests regarding the future use of the island. In part because the waters surrounding Coiba Island had been off-limits to fishing for most of the last century due to security concerns for the prison, and had therefore essentially been a sort of marine protected area for that time, the decision was ultimately made to create the Coiba National Park. Restricted commercial fishing is still allowed in certain areas of the Park using specific traditional fishing gears, and is restricted to a limited number of fishermen who hold non-transferable licenses based on historic fishing in the Park area. Recreational fishing is allowed in most areas of the Park.

Outcomes

Surveys show more and bigger fish within the Park boundaries compared to areas outside of the Park despite the relative recency of regulation. All fishing had been restricted near Coiba Island for a century, and the island itself is 30 KM from the mainland so it had always been difficult for commercial fishermen from communities in the Gulf of Chiriqui to fish near the island, so the effect of the Park on commercial fishermen has been minimal, especially since those who historically fished within Park boundaries can largely still do so. Recreational fishing in the Park and low-impact tourism to the island itself is part of a growing leisure-tourism industry in the Gulf or Chiriqui.

Emergent Themes and Insights From MMAS

The primary products expected of MMAS were peer-reviewed scientific publications, and various forms of translational documents to carry the science into public awareness, decision-making, and policy. Peer reviewed papers and professional presentations have begun to flow from the five years of work; nearly forty published thus far but many to follow. Translational products have included booklets, posters, policy briefs, the MIDAS decision software, many workshops in the four node regions, and numerous more informal communications through varied political channels in support of key environmental decisions in the nodes. A third type of product that we were hoping for, is less tangible: wisdom. Following is a list of insights inspired and supported by the cumulative results of MMAS thus far. In particular, these are realizations at the nexus of natural and social science issues. They are presented here to provoke thought, in no particular order, and parsed into nuggets that are not mutually exclusive.

The first 13 emergent ideas concern mostly social and cultural issues. The remainder involve the nexus of social and natural science results.

1) The Need for Comprehensive Long-term Planning Observant of Both Political and Natural Units of Landscape Function.

There is a general lack of comprehensive coastal and marine planning for coastal and marine areas, including both planning within the coastal and marine sectors and also between the two. Apart from the establishment of specific MMAs, there is the need for these MMAs to be embedded in a larger, comprehensive policy and management plan at the EEZ, regional and international levels. In 2005, at the “Defying Oceans End” conference, this was referred to as a global ocean “policy closure” (Orbach et al. 2005). In all of the four nodes, a policy envelope of course did, of course, enclose the MMA’s, in the sense that in most EEZ’s there are laws governing resource extraction, mining, transport and other activities. Almost always, however, these are historical accumulations of legislation, frequently overlapping in jurisdiction and unclear or unenforceable in key respects, and neither comprehensive or internally consistent. Furthermore, they are rarely long-term or adaptive; change and the need for innovation and flexibility are not anticipated. Australia, and two states (California and Massachusetts) have moved boldly toward comprehensive ocean policy, and the US is in the throes of doing so; these are the only examples that come to mind. It may well be that a MMA will fail unless it is accompanied by coherent regional ocean policy. We typically think of nation states as the natural units for these policies, but nature itself appears to think otherwise. Ecological and social scales of organization must match to function smoothly, but human nature is at odds with nature itself, because people and nature have parsed the world in orthogonal ways. The same river that divides two peoples politically joins them ecologically, uniting the two sides of a watershed with each other and the sea. National borders follow rivers and low places, while natural borders follow ridges and high places (watershed boundaries). Gulfs (e.g. Mexico, Honduras, Chiriqui), estuaries (Cassuraba, Placencia), ocean basins, and remote archipelagos (Fiji, Galapagos, Line Islands) require a unified governance system of some sort to live harmoniously within the natural landscape that supports them. This is the ancient Polynesian way, ahu-pua'a, and it works. Development pitted against the natural order of things generates instabilities, incurs cost, and undermines the functional capacity of an MMA.

2) The Important Role of Subsistence and low-Capital Society and Economy

It is often difficult, especially for the developed world, to see the value of subsistence and low-capital society and economy, by which we mean societies and economies where much of the production from fishing or farming is consumed directly by the producers without entering markets or where per capita incomes and other measures of wealth are very low. Two things are important to realize, however. The first is that people should be able to determine their own subsistence form and lifestyle. And many people choose subsistence and low-capital approaches. The second is that much of the world, including all of our study sites, contains many such societies and economies that provide quality lifestyles for their members. This is not to say that good health, education, and upward mobility are not important; but that the value of subsistence, low-capital societies and economies and the rights of self-determination should be recognized. In the current order of things, growth economies feed on subsistence economies, undervaluing subsistance and exploiting (and undermining) it to fuel growth.

3) Human Values, Perceptions and Attitudes as Drivers of Policy Processes

Different people will naturally have different perception of problems and issues and their appropriate solutions. These perceptions and attitudes, as much as results from formal "science", determine behavior. As a practical matter, formal scientific information often comes in long after a process has begun – even sometimes after it is completed. People act on the information they have at the time; however, action is unlikely if their perceptions and attitudes do not come together on an agreed-upon course of action. This fact accentuates the important role of communication, education, outreach and consensus-building with whatever information is available.

The MMAS nodes differed in cultural diversity and sociological complexity, levels of shared values, and degree of information connectivity. Brazil exhibited high sociological complexity (multiple cultures and socioeconomic classes) but also high shared values and connectivity. Belize displayed similar sociological complexity, but conflicting values and lower connectivity. Science to action outcomes were not easy to achieve in either node, but this could partly explain the somewhat greater challenge that we experienced in Belize.

4) The Critical Role of Local Community Culture, Tradition, Organization and Involvement

The involvement of local community organizations is critical in the establishment and management of MMAs. Often, the significant differences among community members point to the potential for conflict and negotiation in the process of community empowerment. The traditional cultural understandings and relationship in local communities form the basis for resource management practices. Attempts to weaken or circumvent these traditional understandings and relationships have led to failure of management initiatives. On the other hand, initiatives like FLMMA in Fiji, which seek to strengthen traditional relationships, may start off at an advantage.

5) The Role of NGOs, Especially BINGOs

Although question of influences from outside of the country certainly arise, the fact that certain NGOs, both domestic and international, have established offices in our node countries was critical in producing much of the scientific, political and administrative work necessary to the establishment and implementation of MMAs. This work included science and activism with respect to such activities as offshore oil and gas development and mariculture, support to strengthen local community associations and local councils, in addition to the work with MMAs themselves. NGOs can be important partners in this process along with government agencies, universities, local communities and other stakeholders.

6) The Role of Political and Administrative Organization

Since MMAs are regulated and administered by the government, often with the involvement of several different agencies, public policies for those areas are influenced by the political party that is predominant. Policies directed to the eradication of poverty, development of community infrastructure, empowerment of traditional populations and other topics are often important to the success of MMAs. Which particular agencies and organizations have authority and responsibility makes a difference, as does the leadership of those entities. It is not possible to control large-scale political factors, but attention must be given to them, and to the structure, process and personalities involved in government agency activities, to make progress on coastal and marine conservation.

7) The Role of Larger Social and Economic Forces, in Particular Leisure-tourism Development

It is essentially difficult to see the effects of specific MMAs on coastal communities and people for most if not all of our study communities independent of the general and overwhelming effects of broader social, cultural and economic change. Although specific effects can be pinpointed, they pale in comparison to the effects of these broader changes. In that some of these broader effects, in particular leisure-tourism development, can be traced to the establishment of MMAs overall and the value of MMAs to the leisure-tourism industry, all of these effects are linked together.

8) Connections among, and Cumulative Socio-economic Effects of, Multiple MMAs

Although the effect of each individual MMA on commercial and subsistence fishers may be small, the cumulative effect of increasing number of MMAs can be large. In general, there is often no specific overall plan for the siting or function of these MMAs as a group, nor any account taken of the cumulative impact on commercial or subsistence fishers or the opportunity for both more effective conservation (i.e., corridors) or economic and social (i.e., designated areas where commercial or subsistence fishers CAN fish) stability through such planning. This harks back to the first point: the need for a comprehensive regional policy for ocean and watershed, to allow all involved to appreciate the system, and the distribution of its services and benefits, as a whole.

9) The Role of General, Sector-specific Marine Resource Management

It is generally conceded that marine resource management cannot be accomplished with MMAs alone, but must also involve sustainable management practices for all human uses throughout the world ocean. One sector of particular importance, for example, is marine fisheries. Some of the basic requirements of a sustainable marine fisheries system are:

1) The need for a robust fishing license system;

2) adequate data collection programs;

3) effective monitoring and enforcement;

4) the full use of Traditional Ecological Knowledge in "modern" management;

5) consideration of features such as designated fishing areas and limited access programs tied with local communities.

As often as not, one or more of these requirements are missing, even at our MMAS nodes. There is a global push for MMAs, and major investments are being made to establish them in management climates that are frequently inimical to their success. It is probably still wise to advance the establishment of MMAs, but performance expectations must be very low until the necessary supporting management instruments and capacity are in place, and sustainably so.

10) Multi-Ethnicity

The mix of ethnicities in the coastal zones characterized and defined the cultural involvement with and effects from MMAs in many of our research communities, in particular Belize (Creole, Garifuna, Maya, and Mestizo) and Fiji (Fijian and Tamil, or Indo-Fijian). A great portion of the cultural effect of MMAs in the researcher communities is circumscribed by the role of kinship, community and ethnicity. Multi-ethnicity can easily be perceived as a problem instead of a potential strength. The Corumbau Extractive Reserve in Brazil offers one example of how it can provide strength. In Fiji, multi-ethnicity currently appears in coastal conservation as a weakness; the opportunity is there to change this, and programs at the University of the South Pacific in Suva are on track to do so.

11) The History of Colonialism and Merchantilism

The history of many countries as former colonies, primarily of European nations, and the associated merchantilist economies, is critical to an understanding of current beliefs and attitudes towards natural resource policy and management. Mercantilism, wherein raw goods and natural products are shipped out of the country and processed and more expensive goods are shipped in, thereby creating a cycle of negative domestic economies and dependence, defined and still defines the character of many local, regional and national economics, including fishing. The link with the 'big international non-government organizations (BINGOs)' is interesting here – is this the new merchantilism, 'exporting' the gross benefits of the use of the marine environment to the leisure-tourism industry and creating low-paying, dependent jobs for local communities? To the extent that local communities are involved in independent business enterprise or skilled job in association with the leisure-tourism industry, this effect may be ameliorated.

12) The Relative Powerlessness of Coastal Peoples

A documented world-wide phenomenon is the relative powerless of coastal – in particular fishing – communities because of the physical hazards, low levels and uncertainty of income, and under-representation in the political process. This is generally true of essentially all of our study communities, in particular in the face of powerful economic and political forces such as leisure-tourism development, multi-national petrochemical companies and consortia, and the power of BINGOs .

13) Populism, Nationalism and Environmentalism

The beginning of the environmental movement in some of our node countries was characterized by a coming together of popular, nationalistic, and environmental movements. This has defined the outcomes in such arenas as marine resource management. The question is the mix of the three into the future in any particular country.

IX) Science to Action

A) How much science, and of what kinds are needed for adaptive policy and sustainability?

Managers seek (or should) to reduce uncertainty in the flow of ecosystem services over both the short and the long term. One goal of MMA science is thus to observe and flag deviations from the nominal system states and dynamics necessary to support human needs. This first goal requires a regular monitoring program, and clear management targets tied to measurable indicators and management reference points. A second goal is to understand system dynamics well enough to respond to undesirable system deviations, and to forecast future states; i.e. to construct alternative policy scenarios and their likely outcomes, and to keep these future alternatives fresh over time through continued study of the system and analysis of the time-series data sets from monitoring. So, both monitoring and basic research produce actionable results. The two are mutually supportive in allowing scientists to create a coherent picture of the health and prognosis for ecosystems that include the human presence.

Despite their importance to human welfare, MMAs usually have scarce resources from which to draw for even the most immediately useful science. In this sense the occasional, pulsed contributions from private foundations- such as the GBMF award for MMAS- play a special and critical role. These brief, intensive periods of well-resourced work can expand the knowledge base on which decisions are made and develop decision tools of enduring value, but are not a substitute for regular, in-situ monitoring by a local staff. In this sense, huge international grants do not "solve" chronic local problems. They can, however, better equip local managers to design and operate a science program appropriately scaled to their needs and resources.

There are two extremes of management-science relationships are possible: data-rich and data-poor. In data-rich management, monitoring efforts are both extensive and intensive, and are adequately replicated to detect even a modest change in the status quo. Obviously data-rich is also well-financed. However, financial and personnel resources rarely allow for enough data to be collected, and in the right way, to have a reliable early detection system. Even then, high patchiness and variability in coral reef environments means that statistical power to detect undesirable deviations in mgmt area performance might be too low to see a signal until great changes have already occurred. This capacity is essential if the management strategy is to allow impacts and competing functions to occur right up to the edge of what a system can tolerate- in other words, to squeeze every last drop of value out of the system as quickly as possible. An alternative philosophy of conservativism and long-time horizons would not need anywhere near this much data, because it is easier and cheaper (though less lucrative in the short-term) to adopt a highly precautionary stance in the distribution and intensity of resource exploitation. The limit is people with water skills and expertise, not fancy gear…although that helps.

Conservation science is applied ecology, in an ecosystem definition inclusive of *Homo sapiens*. As such it has many of the attributes of clinical medicine. This includes the complex ethical issues raised by the need to perform experiments on systems that include people. It includes the importance of explaining scientific principles and results to folks who are unfamiliar with and mostly do not live by them. As in medicine, conservation places scientists in a peculiar position: they must be impartial observers in their research, yet also function as professionals and provide counsel through person-to-person and often emotionally charged human interactions.

B) Who does the science?

MMA science is exhausting, dirty work that is beloved of those cut out for it, whose numbers are few. Monitoring is sometimes regarded in professional circles as a dirty word, a robotic behavior devoid of originality or invention. Indeed, that is the way it is often conceived by the job market, by some NGO's, and by purveyors of international aid. Nothing could be so wrong. It is true that a part of monitoring is a simple and tedious matter of making repeated observations of the same few parameters, time after time, over and over again in the same places for years. That is the least important part, the dues, so to speak. The rest of monitoring is recognizing human perturbations as experiments, and designing clever ways to take full advantage of the windows that these perturbations open on the workings of natural and social systems. A good scientist engaged in this work can not fail to come up with original and potentially very valuable ideas. While the process of original science does sometimes take jumps or get caught in cul-de-sacs, the basic notion that one frames and tests hypotheses in sequence remains the core way of doing business. Doing so for a MMA requires an intimacy with both the natural and social history of that place that can only be born of personal experience, not book learning. This must be combined with scientific training, including basic studies, experimental design and statistics, and a solid and up to date grasp of theory in evolutionary ecology and the social sciences. Basically, this describes at the least a scientist in the mid-thirties with a doctoral degree, a post-doctoral stint, and one to two dozen scientific publications under his or her belt. Only one such person is required for biophysical sciences, and one for social sciences, if in both cases the right person is hired for the job. The Principal Investigators must design and supervise the implementation of an MMA science program, be responsible for the flow and quality of data, analyze and interpret the data, seeks frequent counsel and critical assessment from colleagues in a wide array of relevant disciplines, and finally, lead groups of colleagues involved in each study in publishing the results. Additionally, he or she must have a good touch with people, and be a leader that others will listen to and follow. Since there are very few individuals qualified to take on both natural and social science needs simultaneously, the two people who wind up as partners in hits endeavor should like and respect each other.

With a science team leader in place, what sort of people are needed to fill out an observational and data-gathering team? Who are these others? Ecological and sociological monitoring in the tropics, whether on land or sea, can only be conducted by dedicated and knowledgable individuals but academic training is not essential. A great deal is known about how to organize citizen science in the study of terrestrial plants and wildlife, meteorology, astronomy, and even social and cultural anthropology. With the ready availability of snorkeling gear, and the advent of SCUBA, this tradition extended into the sea. Participants who advance to a very high level of proficiency in species identification, natural history, and other relevant knowledge-based skills, become known as paraprofessionals. In MMAS we observed several paraprofessional and citizen science programs, mostly for coral reef monitoring. What we learned is this: it is entirely feasible to train paraprofessional marine biologists in only a few weeks or months of field and laboratory work. And, it is well worth the effort, because only people with at l ast this level of training and vetting can be relied upon to produce credible data from the field. For better or worse, the world swells with well-intentioned programs to monitor every aspect of nearshore tropical biology- coral bleaching, fish communities, rare species, commercial species abundance, spawning aggregation size, and so forth. Some of these programs- such as FLMMA- have wisely focused on empowering local citizens to monitor the conditions of their own MMAs. Unfortunately, however, we have been forced to conclude from our experience in this program, that the level of training required of these assistants to perform useful work is much higher than what is usually seen. The good ones, whose data can be believed, truly are paraprofessionals, and should expect to be compensated appropriately for their efforts, in some fashion. Ten such individuals, employed full-time, are a minimum number to carry out semi-annual monitoring of a marine reserve system such as the one boasted by Belize. This is probably not an unreasonable estimate for the counterpart team of social parascientitsts, trained to gather information from people dependent on the area management system. So, we have reached an well-equipped office with good IT capabilities, at least two senior scientists running the data show, and 20 full-time paraprofessionals who go into the field to gather the data.

This may not be a realistic goal for the four MMAS nodes or many other places, but it is a minimum goal to fulfill the most basic monitoring requirements for coastal adaptive management.

Of course, there is also need for boats, fuel, boat operators, safety gear, and so forth. Owning and operating a fleet of such vessels and moving them about as needed, is very expensive. Adapting local vessels for collaborative research is sometimes a much better way to go. Indeed in remote areas of southeast Asia, this is the only way one can operate effectively. However, collaborative research is severely impeded by the safety requirements of many academic and government institutions regarding diving and boat handling- at least for those institutions in North America, Europe, and Australia. In the MMAS Fiji node this became a crippling problem, and made it very difficult to achieve the volume of science that we had intended. This does not mean that we should not be safe. It does mean that a great deal of adaptation is required on all sides of the issue. Without serious attention to issues of safety and liability, the notion that we can concentrate the best scientific resources as needed to conduct marine ecological monitoring, is dead in the water.

C) How the science is defined and initiated

The purpose of MMA science is twofold: to determine if an MMA is performing to expectations (is it *effective*, and if not, how come); and, to understand the full *effects* of the MMA, both intended and unintended, as they ramify through both the ecological and human communities. The first purpose should be easy to define in detail, since it corresponds precisely to the stated goals of the MMA. That only works if the goals have actually been stated, and they rarely are. Consequently it is worth preceding the establishment of an MMA with a public participatory process, to ensure agreement on goals, and that the goals are realistic ones. In some governments, the goals can simply be established by decree. Whether the participants are community members or their leaders, this is the appropriate place to begin participatory modeling and scenario forecasting- that is, imagining the changes that people are hoping for by virtue of the MMA, and using computational and visual aids to explore possible ways the system might behave if a particular policy is enacted.

Something akin to this process- minus the computer wizardry- had begun to take place in each of the four major study sites prior to their adoption as MMAS nodes. However, most of the MMAS work was focused on the development of monitoring and information feedback mechanisms. There was substantial progress in a mediated modeling setting around the coding of MIDAS in Belize, and to a lesser extent, in Panama.

One critical point is that in order to obtain an accurate read on the effectiveness of an MMA, there must be control conditions to compare the exploited management regimes to. Two in particular are desirable: a regime devoid of exploitation, or at least extractive exploitation, and an open-access area. There is no problem finding open-access areas, though habitat-matched areas present a minimal challenge. However, in many political climates, the notion of a no-take or no-disturbance area is hard to support. Under such hostile circumstances, the idea of having any sort of accountability for an MMA should be abandoned, for the energies and resources are better invested in outreach to build a constituency for sustainability that could support a proper management system.

The reader knowledgeable in experimental design will have already noted the primary flaw that will plague MMA adaptive experiments: the lack or paucity of replication. Within an MMA, the only defense against this criticism is to combine random stratified and fixed station designs to secure both longitudinal (but non-independent) and latitudinal (random sampling snapshots through time representative of a sampling region) pictures of change over time. If there are several MMAS within a region, however, a replicated experiment becomes possible, with the caveat that the different management regimes are nested within site rather than being randomly distributed over the region, that a repeated-measures or other form of time-serires design is needed for the fixed sites, and that whenever the scale of the experiment is increased, this will bring with it new sources of background variance and noise.

Increasing signal-to-noise ratio is a crucial objective in MMA experimental design. The most promising approach is the one taken in MMAS to different degrees in the different nodes:

stratification of study areas across the range of environments present in a locality, and comparison among management regimes using analysis of residuals once habitat effects have been statistically factored out, to the extent that this is possible and defensible. Our best effort in this area was carried out by Burton Shank on the Belize ecological monitoring data set.

Once the goal of measuring MMA effectiveness has been addressed, it is still necessary to conduct science to reveal and explain MMA effects, particularly those that are complex, are unexpected, and offer insight into system processes. This is the kind of science at which a program like MMAS can excel, but is an unlikely luxury for a small MMA in a developing nation. Local universities that worked with MMAS have made it a priority to develop basic ecological, cultural, and socioeconomic studies relevant to long-term conservation and management needs (which encompasses nearly all studies that one might imagine). However, before launching into a wide variety of small research projects, it is wise to make the best use of monitoring data as a basis on which to frame hypotheses about process. This can be done most effectively once 5 to 10 years of comparable data have been amassed. Within MMAS this is only possible thus far only for Brazil among the nodes, and at least qualitative study is possible for the Galapagos and Phoenix Islands, our two reference sites.

D) Who pays for the science?

During MMAS, the principal focus involving costs was on the MMAS objectives and their associated investments, and the expenses of translating science for use in local policy. There is a more important issue that only becomes apparent when a large project like MMAS is over: who pays for the routine operating costs of science to support adaptive management of an MMA? The answer is almost nobody plans for this, and other than sporadic grant support from private funding agencies, few have figured it out. The logical solution is to place a cess, or maintenance tax, on all proceeds from an MMA. This implies that an MMA should have a business plan and be operated as a not-for-profit. In fact, this is essentially what is happening in those Belizean marine reserves that are operated by in-country NGO's: for example, Half Moon Caye, which is managed by Belize Audubon Society, and Gladden Spit/Laughing Bird Caye, which are managed by the Southern Environmental Association (formerly Friends of Nature). The NGO's have authority to collect user fees, and apply these in part toward monitoring, outreach, and other aspects of reserve maintenance.

An important and frequently overlooked aspect of the cost of science is the cost of analysis and dissemination of results. The greater part of this is a personnel cost. There is still need for a true-costs budget and business plan template for MMAs of various sizes and accessibilities, with ideas on how the cost of essential science, including monitoring, could be covered.

In all four MMAS Nodes, there were (and are) host scientific institutions capable of assuming a leadership role for MMA science. In Belize a new institution grew up to fill this role in the future, the Environmental Research Institute of the University of Belize. In Panama, we had STRI to partner with. In Galapagos, there was the Charles Darwin Station Marine Laboratory. In Fiji we were fortunate to engage colleagues at the University of the South Pacific, Suva. In Brazil this was the local CI office in Caravelas, affectionately referred to as "The Submarine" due to the need for highly efficient use of space, possibly combined with occasional issues with atmospheric humidity. Having The Submarine's highly skilled and respected science staff running the Brazil Node was the single major reason for this node's spectacular success.

However, MMAS leadership learned a difficult lesson when the Brazil CI-Marine office moved from Caravelas to Salvador, and it became necessary to rely upon the MMAS grant for the support needs of The Submarine, cutting deeply into funds originally considered to be available for the research itself. Of course, there is the hanging question of why the Brazilian, or Belizean, or Panamanian, or Fijian governments aren't paying for this essential function themselves. The answer is simple: among the many essential functions, accountability for marine management is not high on the list for most places in the world, including the United States of America. The US National Marine Sanctuaries Program relies just as, if not even more, heavily on private support for their management science as do its counterpart agents in other countries.

It is also logical that a part of the cost of MMA science could be paid by moneys raised through resource exploitation, such as a fisheries tax. For a major fishery this is a good idea, but what about the more common situation, where the MMA's primary beneficiaries are subsistence fishermen and their families? The values are not being appreciated through a significant commodity chain, so the opportunities for a tax and the amount that could possibly be accumulated in this way, might be negligible.

Meeting the costs of adaptive management science is a vexing and as yet unresolved problem.

How to connect science with action

As mentioned earlier, well into project implementation the MMAS program switched with strong support from the Science Advisory Committee from a sole emphasis on research, to the expectation that 15% of all investments would further the use of project results to inform decision making and the erection of new policy. This was a very successful move. MMAS results (combined with others to build a richer picture for any issue) developed conservation and management recommendations, and engaged directly with people at local to international scales to implement science-based solutions. Examples of this are illustrated on the CI Science To Action website, www.science2action.org.

Since S2A is still only putting out its first products, the relative effectiveness of different vehicles remains to be seen. Extensive review of sister projects and discussions with their project leaders suggested that outreach documents, such as full color booklets, play an important role in communicating with MMA managers and stakeholders. And so, we have produced a series of booklets, and are anxious to see if they are actually used. In addition, however, MMAS staff and scientists were actively engaged in providing assistance to and actually appearing in mass media in all the nodes, appeared at public rallies, spoke widely whenever opportunities arose, and held special meetings with government and community leaders at which MMAS results relevant to their interests were explained. One of the most amusing examples is the "Scrap the Traps" campaign, which includes T-shirts, posters, and a series of television public service spots soon to air in Belize. The TV spots tell the story of Jamaican investments in the development of a large trap fishery for reef fishes. Very few Belizeans want to see this happen, for it threatens to reverse gains made in protecting parrotfishes (in the interest of coral reef health) and commercially important fishes such as snapper, gains that promise that these same species can be sustainably fished by Belizeans. The spots feature a Jamaican actor, resident in Belize, who assumes the role of "Slippers", a slick and sketchy character who tries to push fish traps on a Belizean fishermen (played by leaders in the fishing community of Placencia). Originally, the fishermen were given a script, but they neither wanted nor did they need any script: they spoke their minds directly into the camera, and the results are likely to be persuasive. For starters, the conservation community in Jamaica has requested that the same spots be aired on Jamaican television as soon as possible!

Fiji offers one of the most promising examples of S2A, for here MMAS was able to work directly with, and essentially for, FLMMA, the Fiji Locally Managed Marine Area network. FLMMA seeks to resurrect the traditional marine tenure system in Fiji, including the liberal use of tabu areas, which are similar to no-take reserves (though traditionally these are not permanent). FLMMA already has an excellent network and regular meetings for getting messages out to all the participants, and several key MMAS messages were broadcast in this manner.

In Brazil, staff of The Submarine took to the streets and government offices themselves, participating directly in important campaigns with several important outcomes, including expansion of the buffer around the Abrolhos National Park, enforcement of the Curambau Extractive Reserve, and the creation of the Cassaruba Mangrove Reserve.

S2A in Panama, in collaboration with our partners at STRI (Smithsonian Tropical Research Institute), provided a data baseline and scientific credibility in the first zoning plan for the island of Coiba. MMAS also helped fuel a science-based change in the hook size used by local fishermen, to ensure that young commercial fishes had a chance to grow up before they were caught.

The following **Science-to-Action** publications present global research findings and lessons learned:

Marine Managed Areas: What, Why, and Where defines MMAs and discusses the challenges of implementation.

People and Oceans examines the role of people in MMAs, including the human well-being benefits and challenges of MMAs, and how socioeconomic conditions affect success.

Living with the Sea examines the role of marine managed areas in restoring and sustaining healthy oceans, particularly the importance of local management efforts.

Science-to-Action provides practical guidance for scientists and decision-makers on using science to inform ocean policy and management.

Economic Incentives for Marine Conservation provides guidance on how to select and implement incentive-based solutions: buy-outs, conservation agreements, and alternative livelihoods.

Community Health Index provides a comprehensive methodology for monitoring the condition of coral reef ecosystems.

Economic Values of Coral Reefs, Seagrasses and Mangroves: A Global Compilation provides statistics on the economic value of tropical marine resources organized by type of use and by region.

Socioeconomic Conditions Along Tropical Coasts: 2008 demonstrates people's dependence on marine resources for livelihoods, discusses people's perceptions of resource conditions, and highlights governance status worldwide organized by region.

Four-page policy briefs summarize these longer booklets and guidebooks.

These publications and information about the Science-to-Action global learning network are available at www.science2action.org.

X) Take-Home Messages

MMAS was an unusual and productive program in many respects, but its scientific design and core philosophy assume that those who would judge wait at least 10 years before reaching conclusions about what approaches worked, and which ones did not. This, of course, requires a means of maintaining a strong scaffolding of supportive science in places like the 4 nodes, for much longer than the 5-year lifetime of the MMAS grant from the GBMF. It is our hope that the ephemeral contributions brought by MMAS, plus the plan for continued collaborative work with CI at these locations, will provide the basis for an enduring partnership at each of the four original nodes, plus new nodes to be added to the network along the geographical priorities of the CI marine program as it develops further.

Several parting messages worth bearing in mind, are discussed below.

A) Regarding Social and Cultural Dimensions:

1) Virtually all MMAs, when they are established and assuming that they are well monitored and enforced, have some social, economic and cultural effects on traditional users of the resources and habitats within the MMA. These are often couched in terms of "short term costs" to achieve some long term benefits, the latter of which are often not well specified. These effects tend to be 'redistributive'; that is they shift the costs and benefits of the use of the MMA resources from one group of users to another. Examples of this are shifts of benefits from commercial fishers to recreational users and industries, and from fishers from remote locations to fishers based in local communities.

2) The involvement of all stakeholders from the very beginning of the consideration of an MMA is critical to the design, implementation, and effective enforcement of the rules of the MMA. If such involvement is present, the likelihood of cooperation and support from MMA users and their communities not guaranteed, but is significantly increased.

3) In many cases the social, economic and cultural effects of the establishment of an MMA are difficult to discern apart from the larger effects of broad socio-economic trends in which they are embedded. The most obvious example of this is the general shift from primary resource extraction to leisure-tourism industries in coastal areas, the effects of which are large-scale and significant on the biophysical, socio-economic, and often even the governance settings.

4) Even though acknowledging the short term socio-economic effects of MMAs, stakeholders most often cite long-term advantages that they recognize in terms of the benefits of resource

protection and increased benefits.

5) In order to document and include the human dimensions of the design, implementation and monitoring of MMAs, it is absolutely essential to have trained social scientists working in parallel with trained biophysical scientists and stakeholders.

B) Regarding Institutional Structure and Governance

1) In many cases, the consideration, development and implementation of MMAs, if the inclusion of stakeholders is assured, promoted community organization, cohesiveness and action.

2) The likelihood of development, implementation and success of MMAs is often dependent on appropriate legal and administrative frameworks. For example, in many of our study sites the legal authorities for local action had to be established by regional or national governments, even though the actual on-the-ground management of the MMA was done by local agents.

3) MMAs are best designed as adaptive management *frameworks*, within which specific rules and actions can be changed over time to deal with changing biophysical or socio-economic conditions and challenges.

4) The most pervasive challenge facing MMAs worldwide is often the monitoring and enforcement of the MMA rules and regulations. This is most often dependent on both the provision of adequate resources and expertise and on the support of local communities and stakeholders.

5) To be effective in overall sustainable marine resource policy and management, MMAs must be embedded in larger scale regional, national and international marine resource management regimes.

C) Regarding Natural Science

1) The effects of no-take areas on the abundance of important food fishes can appear in only a few years, even in small reserves, but these gains are subject to rapid erosion if the management regime is not strictly enforced.

2) Management effects on generally benthos take much longer to manifest than the few years' observation produced by MMAS, and those patterns that we did observe may have been due to a spatial confound during the establishment of the no-take or controlled extraction areas. Strict enforcement and a decadal time horizon are essential for MMA effects to be realized fully, or taken seriously.

3) A simple, generalized, yet powerful approach, such as CHI (Coral Health Index) should be adopted as a core program or incorporated into existing monitoring protocols. Rather than measuring a great many more biological parameters, resources that remain after basic CHI-type monitoring might better be spent on experimental studies.

4) Technology is leading toward a rapid and profound improvement of nearshore marine ecological diagnostics, and they can reduce the demand for highly skilled observers. In the course of MMAS we launched research on new diagnostics for coral health, resilience, and recruitment; and for rapid microbial assays. However, analytical costs may be high and some of

the most telling parameters are best measured via *in situ* observations by experienced underwater scientists, with manpower expansion possible through the use of experienced paraprofessionals.

5) A multi-use MMA system can provide the basis for a wonderful experiment in human-natural coupled system dynamics, and are also a sound foundation for evidence-based adaptive management. Gains in the study of community ontogeny and diversity outside the immediate management needs require a much larger investment in senior scientists willing to make a long-term commitment to field, and in particular, experimental work in a specific MMA.

6) A comprehensive, high-resolution GIS system including topographic and current features, and backed up by oceanographic and geological ground-truthing, is an essential foundation for the design of ecological monitoring programs, the conduct of experiments, the partitioning of observational variance to maximize signal-to-noise ratio, and the development of ecosystem service models (such as MIMES) and graphic user interfaces (e.g. MIDAS).

D) Synthesis of Social and Natural Sciences in Supportive Science for MMA Management

1) The current tendency for MMA management to derive insight solely from ecological data is at least an oversight, and at worst is seriously hobbling the chances for MMAs to be successful. In this respect, the development of MMA science is following in the same wrongheaded footsteps as fisheries science before it. Human and non-anthropogenic dimensions of MMA function should be studied and evaluated together, as part of a comprehensive and dynamic systems view of human-natural coupling in the coastal tropics.

2) In addition to monitoring and experiments, MMA management and marine conservation generally would benefit greatly from the synthesis of all aspects of MMA science within a common modeling platform. This platform can serve as the nexus for scenario-forecasting, a search for lawfulness in resource and values trade-offs, and visualization and thinking tools for stakeholders and decision makers.

3) Molecular and microbial diagnostics for ecological integrity in nearshore tropical marine ecosystems tap into the same basic processes and concerns as for human health. There are efficiencies to be had in consolidating these methodologies so as to address health as a systems-wide issue, that just happens to have short-term (immediate health concerns) and long-term (food, water, shelter, and cultural securities) ramifications for the people who live in coastal areas of the developing world.

4) MMAs are not a panacea for marine conservation or human welfare. However, they can serve as the focal point for a comprehensive system designed to bring coastal communities into a sustainable way of life, and to do this in a way that enriches, not diminishes, human quality of life.