PACIFIC ISLANDS FISHERIES SCIENCE CENTER

A Summary of the Guam Coral Reef Ecosystem Model Workshop and Discussions Guam, November 14–20, 2012

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INTRODUCTION

The Pacific Islands Fisheries Science Center in collaboration with the Pacific Islands Regional Office hosted the Guam Coral Reef Ecosystem Model Workshop at the historic Lujan House in Hagåtña and held additional meetings at various institutes in Guam during November 14–20, 2012. Twenty-six people from 13 organization participated in the workshop and meetings (Appendix I). The workshop and meetings were held to introduce local and federal resource managers to the use of a coral reef ecosystem model as a tool for management strategy evaluations and to develop a broad consensus on the coral reef ecosystem, including human elements, identifying the information available to simulate the system in a model, defining ecosystem services and indicators, and agreeing on goals for management. Resource managers are confronted with a range of challenges in their mission to sustain and restore coral reef services that humans desire. Restrictions of human activities needed to achieve desired ecosystem states and ecosystem services may potentially have important cultural, economic, and social implications for the residents of Guam. Hence, resource managers and users can benefit from forecasts of the ecological, economic, and social impacts of the current threats to Guam's reefs. The objective of the collaborative project is to create a model for Guam's coral reef ecosystem that can aid management decisions by making these forecasts and enabling the evaluation of ecological and socioeconomic tradeoffs of alternative management strategies.

Workshop invitations were sent out to all local and federal resource managers, the navy, coral reef scientists, the fisheries cooperative, and non-governmental organizations. A list of workshop participants is included as Appendix I. Appendix II provides the workshop agenda. The morning of the workshop consisted of presentations on the status and threats to the coral reef ecosystems (summary of Burdick et al. 2008) and on the economic and social importance of Guam's reef ecosystem to local residents and other ecosystem users (summary of Van Beukering et al 2007). The afternoon and subsequent meetings included an overview on the benefits of ecosystem models, an outline of the Atlantis Ecosystem Model framework and how it can be applied to produce a model specific to Guam's coral reefs—namely, the Guam Atlantis Coral Reef Ecosystem Model, and a discussion of the data requirements and input parameters for the model. Workshop objectives were to:

- Review and discuss the spatial model and functional groups proposed for adding into the Guam Atlantis Coral Reef Ecosystem Model.
- Identify ecosystem attributes of importance to reef users and resource managers and ecological and economic indicators related to those attributes.
- Identify alternative management scenarios for coral reef ecosystem management.
- Identify data sources.

Overview of Report

This report has three primary sections:

- A summary of the presentations on the status, threats and economic importance of Guam's coral reefs and an overview of the benefits of ecosystem models and the Atlantis Ecosystem Model framework;
- Development process and objectives; and
- A summary of the discussions that took place during the workshop (June 14) and in subsequent meetings (June 15–20).

GUAM'S CORAL REEF ECOSYSTEM AND ECOSYSTEM MODEL

Coral reefs are extremely important as habitats, natural buffers, sites for recreation and cultural practices, and as a key component of the marine economy. Coral reefs generate millions of dollars annually from marine tourism (van Beukering et al., 2007). Additionally, noncommercial and recreational fishing in Guam supports many jobs, and fishing expenditures generate millions in sales revenues and value-added benefits (J. Hospital, pers. comm.). Furthermore, Guam's fisheries serve many vital non-market functions such as building social and community networks, perpetuating fishing traditions, and providing fish to local communities. Despite the importance of reefs and nearshore habitats to Guam's economy and culture, the condition of marine resources has generally degraded over the past 20 years (Burdick et al., 2008). While some of Guam's reefs are still in fair-to-good condition, many nearshore ecosystems adjacent to urban areas and popular destinations have shown greater effects of land-based sources of pollution (Fig. 1), fishing pressure, recreational use, crown-of-thorns starfish (COTS) outbreaks, and other factors (Burdick et al., 2008; Williams et al., 2012). One additional concern is the ongoing and expected move of approximately 25,000 military personnel, their dependents and contractors to Guam as a result of a U.S. military buildup there. This increase in people will put more strain on the natural resources by way of new infrastructure, and increases in solid wastes, waste water effluent, marine recreation and fishing.

Resource managers are challenged in their mission to sustain and restore services the coral reef ecosystem supplies such as shoreline protection, tourism, food, recreation and habitat for marine life. Conservation regulations on the use of these marine resources may potentially have important cultural and socioeconomic implications for residents and visitors of Guam. Effective management must be based on sound understanding of coral reefs as ecosystems, including the human component and the complex and sometimes synergistic impacts of different stressors. As a first step in developing management plans, resource managers and users can benefit from forecasts of the ecological, economic, and social impacts of the current threats to Guam's coral reef ecosystem. Secondly, state and federal agencies have specific mandates to choose actions to mitigate negative impacts on coastal ecosystems and economies. For example, NOAA Fisheries

plays a supportive and advisory role in the management of living marine resources in coastal areas of Guam, and ecosystem-based management is an important component of NOAA's Habitat Blueprint and Next Generation Strategic Plan, as well as the National Ocean Policy 2010. To date, however, few tools have been available to help managers forecast ecological and socioeconomic effects of management regulations and compliance with federal mandates.

Figure 1--Heavy sediment runoff caused by poor, up-slope land-use practices (such as setting fires for hunting) is a main concern for reefs in the southern part of Guam. *Photos: Dave Burdick*

One model that addresses these goals and agent mandates is the Atlantis Ecosystem Model (Atlantis). Atlantis was developed by Dr. Beth Fulton at CSIRO Marine and Atmospheric Research in Hobart, Australia **(**http://atlantis.cmar.csiro.au/). This model can simulate the complex ecosystem processes that link the physical environment with the associated biological and human communities. The model includes also the main steps in an adaptive management cycle (including feedback from resource managers on performance indicators) and can be used as a decision-support tool allowing for evaluation of ecological and economical cost-benefits of alternative management strategies. A 2007 United Nations Food and Agriculture Organization report, which reviewed the world's leading 20 ecosystem-modeling platforms, rated the CSIRO Atlantis ecosystem model as the best in the world for evaluating management strategies at an ecosystem level (Plagányi et al., 2007). Atlantis is used by the Australian Government and various NMFS offices. The application of the Atlantis framework to a nearshore, coral reef-focused system will be novel.

Once developed, the Guam Atlantis Coral Reef Ecosystem Model (Guam Atlantis) will be used to evaluate and rank a set of management strategies based on socioeconomic (e.g., fishery yield and number of tourists) and biological (e.g., algal and coral cover and diversity, fish biomass and diversity) indicators. Through the Guam Atlantis Ecosystem Workshop and through spinoff meetings with local and federal resource managers and marine biologists, we seek input on the inclusion of relevant components in the model and will identify key species and processes to include and management priorities and performance indicators for evaluation.

The primary objective of the Guam Atlantis Coral Reef Ecosystem Model is to serve as a decision-support tool for Ecosystem-Based Management (EBM) of the coral reef ecosystems around Guam. The model melds diverse and dynamic ecosystem components into a single framework that allows for coordinated evaluations and projections of each component under various scenarios of climate and human activity.

DEVELOPMENT PROCESS AND OBJECTIVES

We adapted a four-step process from Integrated Ecosystem Assessments (Levin et al., 2009) to develop Guam Atlantis for the coral reef ecosystems around Guam. This process includes:

1. Scoping: Articulate the ecosystem to be assessed, identify ecosystem attributes of concern, identify stressors relevant to the ecosystem being examined, and identify management objectives (part of the workshop);
2. Indicator development: Develop and test indicators that reflect the ecosystem attributes and stressors specified in the scoping process. Specific indicators are dictated by the problem at hand and must be linked objectively to decision criteria (part of the workshop);
3. Model development: Based on the scoping and identification of the indicators, incorporate all the relevant biophysical, socioeconomic, industry-related and management-related components of the coral reef ecosystem into Guam Atlantis (to be developed in FY13 and FY14);
4. Model Evaluation: Evaluate the different potential management strategies to influence the status of ecosystem components of management concern or the drivers and pressures that affect these ecosystem components (FY15).

1. Scoping

The Ecosystem

NOAA defines an ecosystem as a "geographically specified system of organisms (including humans), the environment, and the processes that control its dynamics." NOAA further defines the environment as "the biological, chemical, physical, and social conditions that surround organisms" (Murawski and Matlock, 2006). For modeling purposes, the organisms have to be connected with each other through a food web; within this web, energy flows within an ecosystem must be greater than energy flows outside of this system.

For Guam Atlantis we identified as the core of the model structure the shallow (0-30 m) coral reef ecosystem around Guam with the reef-building hard corals that form the foundation of this ecosystem. We grouped the corals into those species that provide substantial shelter (habitat) and those that do not provide shelter, or do so to a lesser extent. Furthermore, we included micro- and macroinvertebrates which play crucial roles in the recycling of nutrients, primary producers, suspension feeders that are pivotal in incorporating otherwise transient organic matter, coral predators, and coral reef fishes. Reef fishes contribute to the maintenance of coral reef processes and were grouped based on their functional role into planktivores, invertivores, coralivores, detritivores, herbivores (separated out by their feeding mode), piscivores (separated out by their habitat, swim speed and mode of feeding), and sea turtles. Human activities included in the model are the coral reef fishery which plays a major role in supplying food to, and has a significant cultural value for, the residents of Guam, and the tourism industry which is crucial to Guam's economy (van Beukering et al., 2007).

We limited our focus to the shallow portion of the coral reef ecosystem because we have ample data from those depths from field surveys conducted by NOAA PIFSC Coral Reef Ecosystem Division, the University of Guam, and local governmental and nongovernmental research organizations on Guam. Adequate data are lacking for the deeper reef ecosystem and nearshore pelagic ecosystem. Many species of fishes cross the boundaries between these systems but we assumed that the energy flow within the shallow coral reef systems is greater than the flow between the shallow and deep or shallow and pelagic systems. For example, we included reef-associated sharks and jacks in the model, as they forage within the shallow reef structure but we did not include spinner dolphins or other marine mammals; although they spend a significant part of their time resting in sheltered bays and, therefore, contribute nutrients to the shallow reef system, they feed largely offshore on nonreef fishes. Therefore, the energy flow for marine mammals is not greater within the shallow reef system than the flow outside of this area.

Workshop objective: Review and discuss the functional groups proposed for inclusion in the Guam Atlantis model.

Ecosystem attributes

Ecosystem attributes are characteristics that define the structure, composition, and function of the ecosystem that are of scientific or management importance but insufficiently specific or logistically too challenging to be measured directly (Landres et al., 1988; Kurtz et al., 2001; Fleishman and Murphy, 2009). Examples are coral reef ecosystem trophic structure, reef fish and invertebrate composition, energy network flows within the reef system, and the overall 'health' or status of a reef.

Workshop objective: Identify ecosystem attributes of importance to reef users and resource managers.

Ecosystem stressors

Stressors or drivers are factors cause changes in the system. Natural and anthropogenic forcing factors are considered. An example of the former is climate conditions, and examples of the latter include human population size in the coastal zone and associated coastal development, the desire for recreational and cultural opportunities, etc. In principle, human driving forces can be

assessed and controlled, whereas natural environmental changes cannot be controlled but can be accounted for in management.

Workshop objective: Identify ecosystem stressors that disrupt or degrade the coral reef ecosystems around Guam and affect social, cultural, economic, and ecological services of the ecosystems.

Management objectives

The ultimate aim of the Guam Atlantis model is to understand fully the web of interactions that links drivers and stressors to coral reef ecosystem components and to forecast how changing environmental conditions, altered human use of the marine resources, and alternative management strategies affect the status of the ecosystem. The Guam Atlantis model is designed specifically to evaluate alternative management scenarios by simulating these actions in the fully developed model so that managers can make informed decisions on the predicted ecological and economic tradeoffs of those policies.

Workshop objective: Develop a set of alternative management scenarios for effective coral reef management.

2. Indicator Development

Ecosystem indicators are quantitative biological, chemical, physical, social or economic measurements that serve as proxies for the conditions of attributes of natural and socioeconomic systems (e.g., Landres et al., 1988; Kurtz et al., 2001; Fleishman and Murphy, 2009). Thus, indicators provide a practical means to judge ecosystem status and the response of ecosystem attributes to management actions. They can also be used for predicting ecosystem change and assessing risk.

Workshop objective: Identify ecological and economic indicators related to the selected ecosystem attributes (under 1).

3. Model Development

From discussions during the workshop and subsequent meetings, relevant biophysical, socioeconomic, and industry components and management components of the coral reef ecosystem were identified (see "Summary of discussion" below). These components will be incorporated in the model design and parameterization.

SUMMARY OF DISCUSSIONS

During the workshop and meetings additional data sources were identified and values for model parameters were improved with local knowledge. This included refining the habitat utilization categories for local reef fish species (juveniles and adults), and separating corals into two

functional groups: those that provide shelter and those that do not (or to a lesser degree). These meetings also revealed important datasets including coral growth rates from cores of *Porites lutea* in sediment rich areas and in a control area, sediment input in two watersheds, life history parameters of several reef fish species, and data on sea cucumbers. Additionally, the presented spatial model (Appendix III) and functional groups to simulate the ecosystem were agreed upon.

In the scoping discussions, participants identified a number of ecosystem stressors that they felt have contributed to the degradation of Guam's reefs or may do so in the future: (1) southern watersheds are highly disturbed as a result of previous coastal development, poor infrastructure, and burning of fallow land. These activities have resulted in high sedimentation rates on southern reefs; (2) current fishing practices have led to the decline or loss of ecologically important fish species, particularly large-bodied predators and herbivorous fishes; (3) cumulative impacts of the expected military buildup, including increased impervious surface area, dredging projects, increased resource use and extraction, and increases in storm water and sewage discharges; (4) inadequate sewage treatment systems and significant reliance on septic tanks (42% of households); and, (5) loss of coral as a result of crown-of-thorns starfish (COTS) predation.

In the discussion of indicators, participants identified several ecological and socioeconomic indicators, as summarized below in Table 1.

In discussions of management objectives and scenarios, participants identified as a goal having a 'sustainable' coral reef ecosystem that can achieve and maintain a more desirable state than the current state given local stressors (e.g., fishing, land-based sources of pollution, COTS predation) and climate-related threats (ocean acidification and warming). Participants would like to see a reversal of the sediment stress on the southern reefs. Present activities to achieve that include information sessions on the destructive effects of wild fires addressed to the hunters in Guam that make these fires and watershed restoration projects where the badlands or burned lands are re-vegetated. Other discussion points on achieving sustainable reefs called for reducing nutrients and bacteria loads that enter the coastal waters through septic tanks and leakages in the waste-water treatment system. Furthermore, participants would like to see a higher biomass of fishes, especially the larger, mature fishes and suggested various management scenarios to achieve this goal (see below). Although participants did not set target levels of fish biomass, coral cover, sediment load, nutrient load or other indicators, there was a general consensus that the reefs are presently degraded.

Table 1. Summary of identified ecological and socioeconomic indicators

Ecological Indicators	**Socioeconomic indicators**
Diversity index	Catch value (Noncommercial and commercial)
Benthic cover (corals, macroalgae, crustose coralline algae)	Tourism (numbers of tourists visiting)
Number of coral recruits	Invertebrate collection – octopus, sea cucumbers
Number and diversity of invertebrates associated with corals	Number of recreational divers (diver training, Scuba Bob, Sea Walker etc., operations)
Fish biomass, overall and per functional group	Trips with the Atlantis submarine
Fish size class composition	
Water quality (e.g., suspended solids, bacterial count)	
Fish habitat utilization (fishes, as generalists, will use secondary habitats if primary habitats are no longer viable while specialists will be lost if their primary habitats are lost)	

The workshop participants discussed the following management scenarios to be evaluated with the Guam Atlantis model:

1. *Increased Watershed Restoration*—Explore potential outcomes if sediment loads are reduced through watershed restoration efforts, including restoration of grasslands and forests, among others. Participants noted that USDA National Resource Conservation Service (NRCS) and researchers at Water and Environmental Research Institute (WERI) have developed a model of sediment runoff associated with rainfall (RUSLE) with case studies from National Park Service (NPS) parks and Palau which could be useful for the Guam Atlantis Coral Reef Ecosystem Model;
2. *COTS Removal*—Evaluate the costs and effects of annual, biannual or monthly COTS removal as a routine measure;
3. *Conversion from Septic to Sewer*—Assess impacts if all households are connected to the sewage system;
4. *Wastewater Treatment Upgrade*—Model ecosystem response to improved wastewater treatment from primary to secondary treatment and strict enforcement of water quality compliance for sewage outfall (e.g., bacterial counts for impaired water bodies);
5. *Fishing Regulations*—Evaluate the economic and ecological tradeoffs of (a) a ban on nighttime scuba spearfishing and surround net and lay net fishing in certain areas; (b) implementation of rotational or seasonal harvest; (c) removal of reserves and implementation of various fishery contraints (e.g., size and/or catch limits, nontransferable permits); (d) seasonal closure of spawning sites; and, (e) allow harvest of sea turtles for cultural practices.

In addition, workshop participants are interested in using the model to:

1. Explore connectivity for corals, COTS, and other species (e.g., are Guam's reefs self-seeding? What areas are source areas?);
2. Evaluate the impacts of an increased human population with a focus on resource use and extraction;
3. Model the potential impacts from increased impermeable surface areas associated with the expected military buildup (modeled as more nonpoint source pollution).

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APPENDICES

Appendix I. List of Participants of Workshop and Meetings

Names	Organization
Valerie Brown	NOAA Fisheries Pacific Islands Regional Office (PIRO) / Coral Reef Conservation Program (CRCP)
Mariska Weijerman	JIMAR - University of Hawai'i / NOAA-PIFSC – Coral Reef Ecosystem Division
Joseph Cameron	POC Coral Reef Conservation, Western Pacific Fishery Management Council, Director of Dept. of Chamorro Affairs
Gretchen Grimm	Navy
Ruben Guieb	Naval Facility Andersen Air Force Base (AAFB)
Leanne Obra	Naval Facility AAFB
Marybelle Quinata	NOAA PIRO
Adrienne Loerzel	NOAA Coral Reef Conservation Program (CRCP)
Evangeline Lujan	Administrator, Guam Coastal Management Program (GCMP)
Roxanna Miller Dave Burdick Victor Torres	Guam Coastal Management Program
Champ Quinata	Humatak Community Foundation
Jay Gutierrez	Administrator, Guam Department of Agriculture
Laurie Raymundo Brett Taylor Terry Donaldson Alexander Kerr Tom Schils	Faculty members and research associates at the University of Guam Marine Laboratory
Joe Quinata	Guam Preservation Trust and Humatak Community Foundation
Bob Gavenda	USDA Natural Resource Conservation Service
Eric Cruz	NOAA Pacific Islands Fisheries Science Center (PIFSC)
Mike Gawel	Chief of Natural and Cultural Resources at War in the Pacific National Park (NPS)
Justin Mills, Amanda Devillers	NPS
Jesse Cruz,	Division Administrator, Guam Environmental Protection Agency
Annie Leon Guerrero	Guam Environmental Protection Agency

Appendix II. Workshop Agenda

10:30 am Welcome by Valerie Brown

10:45 am A brief introduction to the NOAA Habitat Blueprint framework, the potential direct and indirect effects of the military buildup on Guam's reef areas, the reefs of Guam and the stressors that are affecting them, and the socioeconomic importance of the coral reef ecosystems (Valerie Brown)

12:30 am – 1:30 pm lunch break

1:30 pm Presentation of the benefits of ecosystem modeling, an outline of the Atlantis Ecosystem Model framework ,and its data requirements (Mariska Weijerman)

2:15 pm Discussion points / workshop objectives:

- Review and discuss the spatial model and functional groups proposed for adding into Atlantis.
- Identify ecosystem attributes of importance to reef users and resource managers and ecological and economic indicators related to those attributes.
- Identify alternative management scenarios for coral reef ecosystem management.

3:30 pm Closing remarks

Appendix III. Spatial Extent of the Guam Atlantis Coral Reef Ecosystem Model