Integrated Coastal Zone Management Decision Support Modeling for Coral Reef Ecosystems

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Abstract - Decisions in coastal zone management often require the integration of numerous parameters - frequently more than the human mind can handle effectively. Many coral reef ecosystems in the tropics are deteriorating under heavy pressure from human and economic activities. This paper summarizes efforts to date by The World Bank to create multi-variate least-cost integrated coastal zone management models to assist three small island developing states: The Maldives, Curaçao and Montego Bay, Jamaica in effective coral reef management.

I. The Need For Modeling - ICZM Decision Support

Throughout the world, both in developed and developing nations, we face complex coastal zone management challenges associated with our attempt to achieve economic growth without destroying the ecological systems that support human existence. Valuable coral reef ecosystems near large human population centers are especially experiencing serious local anthropogenic related stress (e.g., overfishing, eutrophication, sedimentation, physical damage [1], [2]. Coastal zone management decisions often require the integration of numerous parameters - frequently more than the human mind can handle effectively. In managing tropical coral reef ecosystems some of these parameters include: the location of industrial and tourist facilities, water quality issues such as nutrient concentrations and sedimentation, fishing pressure, and socio-economic concerns - to name a few. To assist the three small island developing states of The Maldives, Curaçao and Jamaica (Montego Bay) in effective coral reef management, the World Bank recently created a model (*CORAL*) using multivariate statistical procedures that shows the result of ICZM decisions when a variety of parameters interact together. Costs are incorporated into the model to help decision makers choose least cost solutions - without making costly mistakes that are, in many cases, irrevocable [3].

II. Creating *CORAL* - Integrating Scientific Data And Expert Opinion

The primary question the model asks is: What is the most cost-effective means for achieving a given level of coral reef quality as expressed by percent coral cover?

The technology: *CORAL* runs on a PC laptop. The user-friendly interface is created using Microsoft Word and Excel software. The fuzzy engines are in CubiCalc, the linkage models are in MATLAB, and all the statistical work was done with SPSS software.

The science: The decision support model exhibits two key features.

First, it represents existing knowledge of reef ecology at a detail and within the bounds of accuracy sufficient for project evaluation. To achieve this aim the model has the ability to show the effects of nonlinear relationships among pollutants, coral reefs, and the reefs' larger marine environment.

Second, the model is operable and provides useful results with the information available at the location of potential application. This is a crucial requirement, since quantitative data on many oceanographic and biotic variables are frequently sparse, inaccurate, patchy, of short duration, or otherwise deficient for conventional analytical (i.e., exhibiting closed-form solutions) or numerical modeling. On the other hand, there is available for almost all reefs of the world considerable qualitative data, much of which may be in the form of expert knowledge or human judgment, derived either from formal education or from first-hand experience. In poor tropical countries, the latter may well be the dominant form of information available, in terms both of quality and abundance [4]; in some locations, it may be the only form available.

These two desiderata correspond to two defining characteristics of the model.

1. The recognition of the role played by the physiochemical environment in influencing the interaction between inputs (such as pollutants) and reef biota and other processes.

2. The use of fuzzy sets approach to represent cause-effect relations.

Modifications in the set of variables to consider, and how such elements and interactions are represented, differentiate site-specific models.

Below are just a few examples of the many ecological test-case scenarios that have been simulated with the model:

- Algae abundance as a function of the interaction of reef fish grazing pressure and effective nutrient concentration;
- The influence of algae and relief on coral cover;
- The influence of algae and suspended sediment on coral cover; and
- The influence of suspended sediment and sediment deposition on coral cover.

The logic: Coral reef data deficiencies, coupled with marked limitations on resources for reef research and management in the developing tropics, led to the adoption of a fuzzy-logic (or fuzzy-sets, fuzzy-systems) approach [5], [6], [7]. Fuzzy methods possess a number of features making them particularly applicable to the prediction and management of ecological systems.

First, they enable rigorous, quantitative system modeling even though the variables and their interrelationships are described initially (i.e., as inputs to the model) in qualitative terms. This is especially appropriate when human knowledge about the behavior of systems, such as coral reef ecosystems, is approximate and imprecise at best, rendering adequate parametrization all but impossible. The ability to accommodate qualitative data about reef systems means that more information about them, from more and different kinds of sources, is likely to be available. Since fuzzy logic allows systems to be described as sets of if-then, linguistically-specified rules relating inputs to outputs, it thus offers great potential to utilize human judgment and experiential knowledge, rather than being dependent upon mathematized theory or quantitative databases.

Finally, relative to conventional control systems, those using fuzzy methodologies have proven easier and quicker to develop and more robust in operation.

The economics: Improved methods for deriving estimates of coral reef benefits, which are used in conjunction with the model's cost function, are continually being developed [8]. This work adapts and refines existing valuation methods so they take account of the key characteristics of coral reefs, and derive more accurate estimates of coral reef benefits for selected sites [9]. To keep the analysis tractable, the model focuses on three methods for valuing the benefits:

1. Direct use valuation - estimating the lost productivity or value in the absence of proper protection or conservation [10], [11], [12], [13];

2. Contingent valuation - estimating the benefits derived from "public goods" [14], [10]; and

3. Marine system biodiversity valuation (lower level of importance to the above) - assessing marine biodiversity values using bioprospecting as the primary technical basis for valuation [15], [16].

Our modeling research applies each of these valuation methods, and then develops a synthesized benefits function based on the data collected during site-specific economic surveys.

The sociology: The socio-cultural impact assessment facet of the modeling program examines the socio-cultural framework of the reef user groups and determines the socio-cultural costs and benefits of management alternatives and changes in reef quality. The outputs are an assessment of user group activities related to coral reefs and recommendations for management alternatives based on the socio-cultural costs and benefits of alternatives. These results are then incorporated into the larger economic valuation of the costs and benefits of coral reef management and protection for the model.

III. Using *CORAL* for ICZM Decision Support - Curaçao, The Maldives, Montego Bay Jamaica

The integration: The model guides users through a generic approach to planning that structures the development, analysis and evaluation of sustainable management plans. The model is interactive, allowing user input with respect to setting of objectives and criteria, definition of scenarios, selection of measures and strategies and evaluation of impact (Fig. 1).

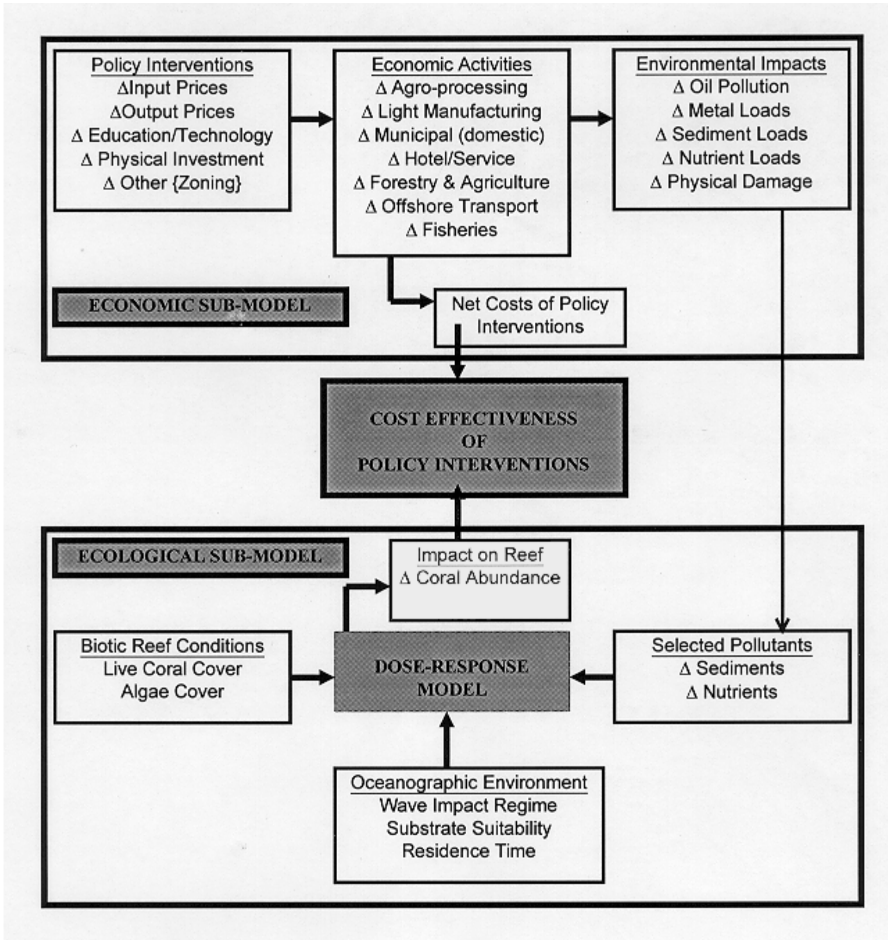
- In Curaçao, the model shows that the most cost-effective solution to maintain the current level of coral cover is a combination of deep-ocean outfalls for the residential and hotel waste water and a reduction of the discharges from the oil refinery. Such measures also have the potential to increase the average coral cover by up to 5% and in specific sections by 8-12%. In contrast, the status quo scenario shows a continuing decline in coral cover.

- In the Maldives, the model shows that the most cost-effective solution would be to prevent or limit the direct and indirect effects of land reclamation (island enlargement) inside the reef and prevent or limit the construction of harbors and access channels.

- In Montego Bay Jamaica, modeling workshops focused government officials and Montego Bay Marine Park managers on critical water quality and fisheries issues and shaped action plans in the new park management plan that include: a new park zoning plan (with mooring and demarcation buoy programs); a watershed management program, alternative income programs for fishermen; merchandise, user fee and ecotourism programs for revenue generation; education programs for school children and the community, volunteer and public relations programs, enhanced enforcement to protect fisheries resources from poaching, and research and monitoring programs to evaluate the recovery of the ecosystem and track the success of park programs.

The accuracy: The accuracy of the model is dependent on the quality of the expert opinion and best available quantitative data. While it is impossible to validate the model precisely, the accuracy of the model was assessed via peer review of the fuzzy rules and by comparison of model outputs with observed field data.

Figure 1: Economic and ecological components of the *CORAL* integrated coastal zone management decision support model.



IV. ICZM Capacity Building with *CORAL* - Helping Stakeholders

Benefits to policy makers, managers, and other stakeholders: The integrated socio-economic and ecological model, framed with a user-friendly computer interface benefits stakeholders by:

- Assisting in the communication between the various stakeholder groups;
- Facilitating the planning process required for successful ICZM;
- Providing a powerful tool to managers and stakeholders for demonstrating the need for coastal zone management - and the impacts of status quo management on valuable coral reef resources and the local economy; and by
- Identifying appropriate policy and institutional reforms for improving the capture of resource values associated with coral reefs in developing countries, and clarifying the potential operational role of The World Bank and other development assistance agencies in helping to effect these reforms.

The dissemination strategy: The dissemination strategy for this work focuses on in-country workshops and seminars for user groups and stakeholders, government agencies, and private and nongovernmental organizations involved in ICZM. It also includes activities to foster cooperation among countries on coordinated environmental policies, strategies, and action plans in the coastal zone, and provides a consultation mechanism for formulating, strengthening, harmonizing, and enforcing environmental laws and regulations.

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