Chapter 8

Interventions for Coral Reef Conservation—A Least Cost Model

Jack Ruitenbeek
H.J. Ruitenbeek Resource Consulting Limited, Gabriola, BC, Canada

Mark Ridgley
Department of Geography, University of Hawaii at Manoa, Honolulu, HI, USA

Steve Dollar
School of Ocean and Earth Science & Technology, University of Hawaii at Manoa, Honolulu, HI, USA

Richard M Huber
Environmentally and Socially Sustainable Development Sector Management Unit,
Latin American and Caribbean Region (LCSES), The World Bank, Washington, DC, USA

This chapter provides a description of the methods and results of studies undertaken using a least cost modeling framework for coral reef management and protection. The primary site investigated was the Montego Bay Marine Park (Montego Bay, Jamaica) and the surrounding area with a view to identifying the least cost interventions for coral reef management.

The Montego Bay site was chosen for a number of reasons. Foremost, recent political commitment in the region has resulted in the establishment of the Montego Bay Marine Park (the Park) as a protected area that will be managed to promote sustainable reef-based tourism while still accommodating a local fishery (Chapter 2). Impacts on the Park are varied, ranging from over-fishing to pollution impacts from sedimentation, ocean dumping from cruise-ships, and influx of nutrients through ground and surface water transport. From an ecological perspective, the area has been studied over a long period of time as there is continued interest in the precise extent and cause of reef degradation (Hughes 1994; Lapointe *et al.* 1997; O'Callaghan 1992; Sullivan and Chiappone 1994; USAID 1996).

The area is economically important, supporting a recently established free trade zone. Valuation work by Gustavson (1998; Chapter 5) places tourism and recreation values at a net present value (NPV) of US$315 million and coastal protection at US$65 million. Artisanal fisheries are valued at US$1.3 million. Contingent valuation work undertaken by Spash *et al.* (1998; Chapter 6) place the non-use benefits of the Montego Bay Marine Park area at almost US$20 million. Finally, Ruitenbeek and Cartier (1999; Chapter 7) estimate that the area's biodiversity resources have an expected NPV of US$70 million to the pharmaceutical industry through marine bioprospecting, although none of this value is currently captured under existing institutional regimes.

While this paper focuses its empirical work on Montego Bay, the models developed here are generic in nature, are transferable to other sites, and are relevant to management problems associated with optimizing the benefits achievable from coral reefs and their contiguous coastal ecosystems. These ecosystems frequently act as the backbone of local economies, and perform other useful functions such as filtering organic waste and mitigating coastal erosion. They yield medicines and tools for biomedical research, and serve as an irreplaceable source of genetic biodiversity, educational and scientific knowledge, and aesthetic pleasure. Coastal ecosystems are fragile, and are adversely affected by local sewage pollution, excessive tourism, and the accumulation of wastes generated by upland agriculture, logging, or industrial activities. Effective management of these resources requires usable analytical tools that help understand the economic and technical linkages between the ecosystems, on the one hand, and human activities that affect them, on the other. Such tools are largely lacking at present.

Some coral reef areas in the tropics are under particularly heavy pressure and are deteriorating (Chapter 1).

Reversing this progressive degradation, in both an economic and ecological sense, requires successful management. But apart from numerous practical issues, a key conceptual problem facing policy-makers is a lack of quantitative models and procedures designed to facilitate a comprehensive economic and ecological analysis, including identification, measurement and prediction of the effects of economic activity on coastal marine ecosystems. In particular, the degradation of coral reefs has not been extensively analyzed in a framework amenable to economic policy analysis. This has made it difficult to develop a priority ranking of policy and investment interventions in terms of their cost-effectiveness (i.e., there are no means by which to formulate least cost plans to control continued deterioration).

A cost-effectiveness analysis framework is therefore being developed—the focal point being to render cost-effectiveness in terms of coral reef management and protection opportunities. The potential scope of the overall general model includes all potential economic activities, interventions, and environmental impacts in the coastal zone. The models developed to date, however, are somewhat more limited as they are intended to explore selected methodological and practical issues in economic and ecological modeling of coral reefs. Specifically, three research problems are addressed simultaneously within the current framework:

- *Normalization of impacts*. First, we ask whether it is feasible to render the impacts of various economic activities in terms of a single biophysical parameter. Conventional ecological approaches to this problem such as those employed by Tomascik and Sander (1985, 1987) yield "dose-response" functions, but such functions are not typically capable of covering the full range of economic activities.
- *Separability of benefits and costs*. Second, we ask whether it is economically meaningful to separate economic benefits from costs in analyzing management choices. Conventional economic approaches to this problem rely on integrating benefits and costs (Cesar 1996; Dixon 1993) or, when benefits are not quantifiable, on ranking choices within a cost-effectiveness framework (Eskeland 1992; Ruitenbeek 1992).
- *Identification of preferred options*. Third, we ask whether one can identify any clear preferred management options for a specific site. As noted above, we have selected Montego Bay, Jamaica.

To place this research in perspective, it is useful to illustrate the management problem in terms of how it is often dealt with using conventional cost-effectiveness frameworks. Conceptually, a conventional analysis framework would provide a ranking of the cost-effectiveness of various policy or project interventions. The outcome of any modeling effort would be a cost curve of the type shown in Figure 8.1. The step-wise cost curve represents

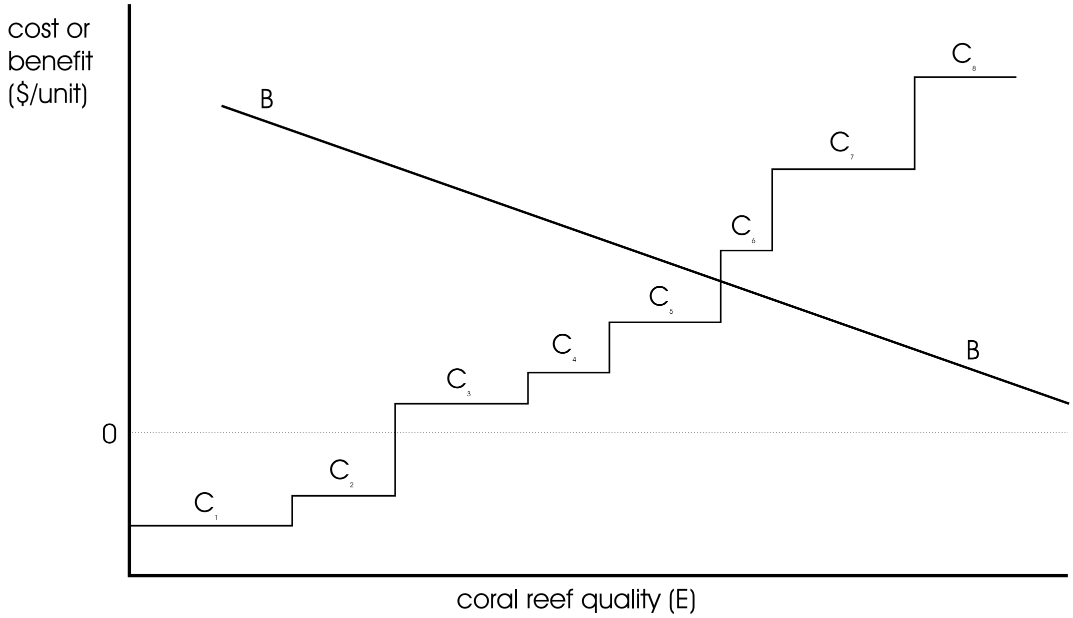


Figure 8.1. A conventional framework for optimization or cost-effectiveness analysis (C_x=measure of cost-effectiveness of intervention X in reducing effect or impact; X=policy intervention or investment; B=marginal environmental benefit curve associated with quality indicator E).

a series of interventions, each of which results in a reduction of negative environmental impacts; these interventions will, over time, cause an increase in coral abundance. The first few interventions are relatively inexpensive, and may have no net costs associated with them if, for example, they concomitantly generate economic benefits not associated with coral reef improvement. Subsequent interventions become more expensive, on a cost per unit basis. Figure 8.1 also shows a declining benefit curve, which illustrates what is typically called a "damage function." The damage function shows the marginal benefit associated with the reduced environmental damage (e.g., increased fishery productivity, higher tourism potential, or reduced shoreline erosion). Under this conventional construct, an economic optimum occurs where the benefit and cost curves intersect. The framework is often regarded as useful even if benefits are uncertain or not known. In such a case, it is often argued that the most cost-effective interventions should be undertaken first and that, from a management perspective, one need only systematically move up the cost curve.

This research, however, places in question this simplified conventional approach. The cost curve of the type contemplated in Figure 8.1 depends on the separability and independence of individual interventions. In complex systems, such independence rarely exists. Cumulative or synergistic impacts of pollutants on reef health, for example, must be reflected in management decisions. Reliance on a conventional cost-effectiveness model can, in such cases, lead to incorrect decisions. We demonstrate this empirically through developing a generic complex systems model that does not rely on the separability assumptions inherent in the conventional model, and through applying this generic model to a practical case study site in Montego Bay, Jamaica.

Early Modeling Results

The research process permitted testing of a number of methods for linking different ecological and economic models, and for experimenting with different types of fuzzy logic based predictive systems (Table 8.1). Empirical work was conducted at three sites—the Maldives, Curaçao, and Montego Bay, Jamaica. In all cases, predictive simulation models were created using fuzzy logic systems to analyze a series of potential interventions. The primary purpose of these prototype models was to explore different model forms and test the sensitivity of results to such forms. While in all cases the models generated empirical results relating to specific indicators of cost-effectiveness, the results themselves were often not regarded as reliable because of the preliminary nature of cost estimates or ecological linkages developed in each prototype.

The following outline key lessons learned from these modeling exercises:

- *Treatment of economic policy*. Model structures could readily incorporate either investments or policy interventions in their impact modeling.
- *Ecological complexity*. Early model structures were computationally limited in the number of input variables that could be managed. Also, models that incorporated feedback loops through recursiveness in the ecological parameters (i.e., treating an output variable from one period as an input variable to the next period) were often unstable and provided poor predictive capability. Final model structures were therefore selected that avoided recursiveness and introduced multiple stages to improve computation efficiency.
- *Water quality transforms*. Data deficiencies and localized complexities make this element the "weak link" in most models. For Montego Bay, the complexity of the mixing functions does not lend itself well to typical linear transport models, and continued experimentation with model structures persists through the final stages and is likely also to form an on-going research requirement.
- *Time delays*. Early models specified different functional forms for translating current impacts to future equilibrium reef quality, including the specific dynamic trajectory of changes in reef quality as it approached this equilibrium quality. Sensitivity tests undertaken at the prototype development stages showed that ranking results were relatively insensitive to assumptions regarding this trajectory, and that the major factor was simply the time delay required to reach equilibrium. Given the significant scientific uncertainty in addressing such dynamic elements, final model development focused simply on the "long-term equilibrium" reef quality taken at some fixed future time period determined by expert opinion.
- *Computation*. All of the prototype model results provide cost-effectiveness comparisons of single interventions from a common starting point using a simulation environment. Experimentation with multiple interventions showed that these interventions, at times, provided improved cost-effectiveness because of non-linearity in the ecological response function. Final modeling structures therefore concentrated on the adoption of an optimization framework that could reflect such non-linearities.
- *Interface*. The educational value of the early models was demonstrated through incorporating all of the computational routines into a user-friendly interface for the Maldives and Curaçao. The interface provides a simulation environment that permits decision-makers

Table 8.1. Basic model structure and early empirical results for three study sites.

Location	*Montego Bay, Jamaica (prototype)*	*Curaçao, south coast*	*North and South Male Atoll, Maldives*	*Montego Bay, Jamaica (final)*
Year completed	1995	1996	1996	1998
Economic Sub-Model				
Number of economic sectors	8	7	4	8
Number of investment interventions	8	4	11	7
Number of policy interventions	2	0	2	1
Non-linear (scale-dependent) cost estimating functions	●			●
Ecological Impact (Fuzzy) Model				
Number of levels	1	1	1	3
Number of inputs	7	7	6	9
Recursiveness in model		●		
Output - coral abundance	●	●	●	●
Output - coral rugosity			●	
Output - recruitment	●			
Output - reef fish			●	●
Water Quality Model				
Single part linear	●		●	
Single part non-linear		●		●
Zonal differentiation		●	●	
Fuzzy logic estimator				●
Integrated Model Structure				
Non-linear time delay	●			
Fixed delay	●	●	●	●
Time horizon (yrs)	85	10	10	25 and 55
Simulation model - single intervention	●	●	●	●
Simulation model - multiple intervention	●	●		●
Optimization				●
User-Friendly Interface		●	●	●
Empirical Findings				
Low cost intervention	outfall	protection	mining bans	
Moderate cost intervention	sewage treatment	outfall	outfall	
High cost intervention	reforestation	sewage treatment	sewage treatment	

to ask "What if?" types of questions in reef management decisions.

- *Empirical results*. Empirical results relating to prototype development (for any of the three sites) were used primarily as a pedagogical tool in explaining how economic activities and interventions interact with reef quality. The results themselves were not regarded as adequately robust to provide strong policy guidance. Empirical results for the final modeling at Montego Bay are, however, regarded as suitably robust to provide some limited policy guidance.

From the prototype development stage, two critical research issues were identified for further model development at the Montego Bay study site: (i) developing a more computationally efficient ecological predictive model; and, (ii) developing an "optimization shell" for the core model. Two other issues—water quality transform models and improvement of the "time delay" components of the ecological response to system stresses—remain important research issues, but could not be pursued in the Montego Bay site model because of data and other constraints.

Methodology

General Statement of Problem and Model Structure

The model developed in the final stages of this research consists of two distinct sub-models: (i) a biophysical or ecological reef impact model relying on fuzzy logic; and, (ii) an economic model describing current and future economic activities, policy interventions and pollution loads in Montego Bay (Figure 8.2). The sub-models are linked and run side by side either in a simulation mode or an optimizing mode to predict future reef quality, economic activity levels, and economic policies.

The objective of the model is to achieve a target coral reef quality (Q) by identifying an optimal set of interventions ($\mathbf{S}^o$) such that the cost (C) of implementing this intervention set is minimized. The nature of the analytical construct is such that this is equivalent to maximizing coral reef quality subject to a budget constraint. As noted above, conventional approaches to this type of problem have used a cost curve formulation, in which the cost of each potential intervention is analyzed along with its resultant impact on reef quality. A measure of cost-effectiveness (in terms of $/% of coral cover improvement, for example) is then derived. An optimal set of interventions then involves selecting first those interventions with a low cost-effectiveness measure ($/% improvement), and subsequently moving into higher measures. A supply curve is then derived similar to that shown in Figure 8.1.

But this conventional approach is flawed in many real life circumstances. The flaw relates to the non-linear nature of the response function, and the effects of cumulative interventions. It is readily shown, for example, that such an approach can lead to non-optimal results if the response function is unresponsive to small changes in inputs (such as sediment or pollution loads) but very responsive to large changes in inputs. In such circumstances, the first intervention will inevitably have very low cost-effectiveness (as it will generate zero response) while subsequent interventions will have higher cost-effectiveness. The appropriate analytical framework is, therefore, not to look at the problem from the point of view of individual interventions, but from the point of view of a group of interventions having a cumulative effect.

Generalized Optimization Problem

The overall optimization problem involves selecting an optimal level of coral reef quality (Q^o) such that net benefits are maximized. To derive this result, we generate a cost function $C\{Q\}$ and a benefit function $B\{Q\}$. The focus of this work is on the cost function. The benefit function is treated in Ruitenbeek and Cartier (1999; see Chapter 9).

In the generalized conceptual cost model, we consider the following:

Q = scalar indicator of coral reef quality (% coral abundance);

$\mathbf{F}$ = vector of biophysical factors that influence coral reef quality;

F_j = level of factor j such that $j = 1, 2, 3, \ldots, J$;

$\mathbf{S}$ = vector of economic interventions;

S_k = level of economic intervention type k such that $k = 1, 2, 3, \ldots, K$;

I_k = unit level of economic intervention type k;

n_k = number of units of intervention type k such that $S_k = n_k * I_k$ and $n_k = 0$;

$\mathbf{n} = \{n_1, n_2, n_3, \ldots, n_K\}$;

C_k = cost of intervention S_k; and,

r = discount rate.

The following describes the full least cost optimization problem. For a given target $\hat{Q}$, minimize C by choosing $\mathbf{n}$ subject to

$$C = C_1 + C_2 + \ldots + C_k$$

$$Q\{\mathbf{F}\} \geq \hat{Q}$$

$$F_j = F_j\{\mathbf{S}\}$$

$$C_k = C_k\{n_k, r\}$$

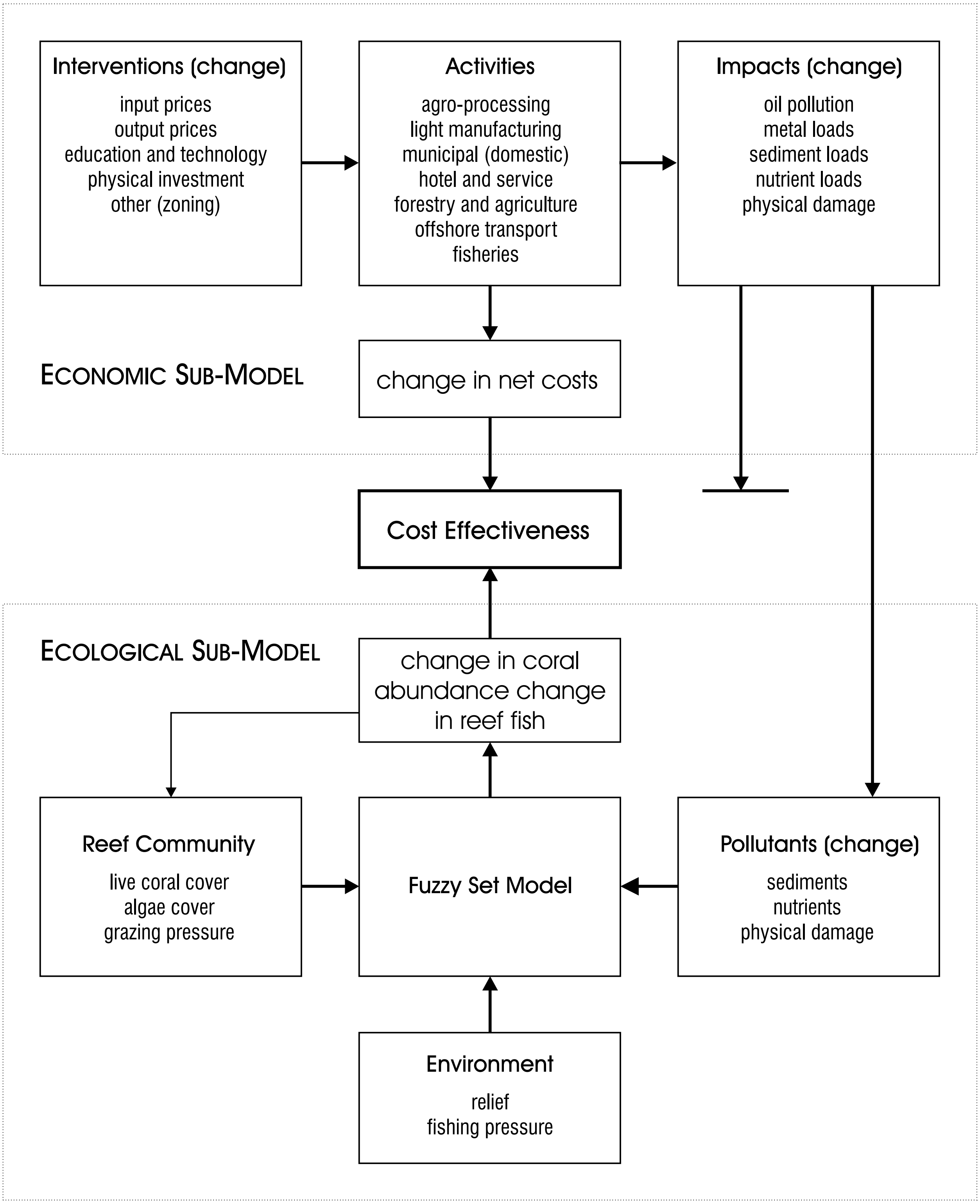


Figure 8.2. Generalized fuzzy logic based cost-effectiveness model. The model structure shows two components: an economic sub-model incorporating pollution impacts arising from economic activities, and an ecological dose-response sub-model that (potentially) incorporates recursive feedback loops. A cost-effectiveness measure is expressed in terms of a change in net costs divided by a change in reef quality.

The cost function, which can subsequently be used in an overall benefit-cost optimization, is then simply $C = C\{Q\}$ for all technically viable levels of Q. Through simulation or iteration a cost curve envelope can be derived with each point on this curve representing a vector of interventions.

Biophysical Model Structure

The purpose of the biophysical model is to describe the relationship $Q = Q\{\mathbf{F}\}$ in the above optimization problem. The general biophysical model is based on a generic coral reef system model (Figure 8.3). It relies extensively on fuzzy logic based systems in describing a complex dose-response function.

In general, a reef impact model should exhibit at least two key features. First, it should represent existing knowledge of reef ecology at a detail and within the bounds of accuracy sufficient for project evaluation. A particular requirement to achieve this aim is the model's ability to show the effects of non-linear relationships among pollutants, coral reefs, and the reefs' larger marine environment. Second, the model should be operable and provide useful results with the information available at or for any 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, considerable qualitative data are available for almost all reefs of the world. Much of these data are 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 (Johannes 1981). In some locations, it may be the only form available.

These two desiderata correspond to two defining characteristics of the model: (i) the recognition of the role played by the physico-chemical environment in influencing the interaction between inputs (such as pollutants) and reef biota and other processes; and, (ii) the use of a fuzzy logic approach to represent cause-effect relations.

How material inputs affect a reef is a function not only of the magnitude and concentration of the inputs and the condition of the reef at the time, but also of oceanographic variables such as those characterizing the hydrodynamics (e.g., mixing and residence time). These determine the concentration and ultimate exposure of the input to the reef, and the supply of chemical reactants, upon which the uptake and utilization of nutrients by biota depends.

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. With the theory first introduced in the 1960s (Zadeh 1965), fuzzy logic has proven adept at describing and helping to manage a variety of complex non-linear systems, initially those dealing primarily with electromechanical control of industrial and manufacturing processes (Kosko 1993; McNeill and Freiberger 1993), but more recently geophysical, ecological and economic systems (Ayyub and McCuen 1987; Bardossy and Duckstein 1995; Kainuma *et al*. 1991; Meesters *et al*. 1998; Munda 1995). Fuzzy methods possess a number of features that make them particularly applicable to the prediction and management of these latter 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 reef ecosystems, is approximate and imprecise at best, rendering adequate parameterization all but impossible. The ability to accommodate qualitative data concerning 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.

A brief, qualitative reprise of the bare essentials of fuzzy rule-based modeling is provided in Box 8.1. More detail is given in Ridgley *et al*. (1995) and Ridgley and Dollar (1996), as well as in standard references (Bardossy and Duckstein 1995; Kosko 1992; von Altrock 1995).

Figure 8.3 depicts the variables and structure of the fuzzy model. Variables, variable names, and fuzzy set ranges are defined in Table 8.2. The model specifies 13 variables explicitly. Three fuzzy sets are used for each input variable, while output variables are described with up to five fuzzy sets. This allows more differentiation of outputs without an increase in the number of rules. The organization into levels slows the proliferation of rules with the addition of variables. With three fuzzy sets per input, and a deterministic water quality transform function, not more than 747 rules would ever be needed to completely saturate the knowledge base. If this system were to have been modeled as a single level system, over 177,000 rules would have been required.

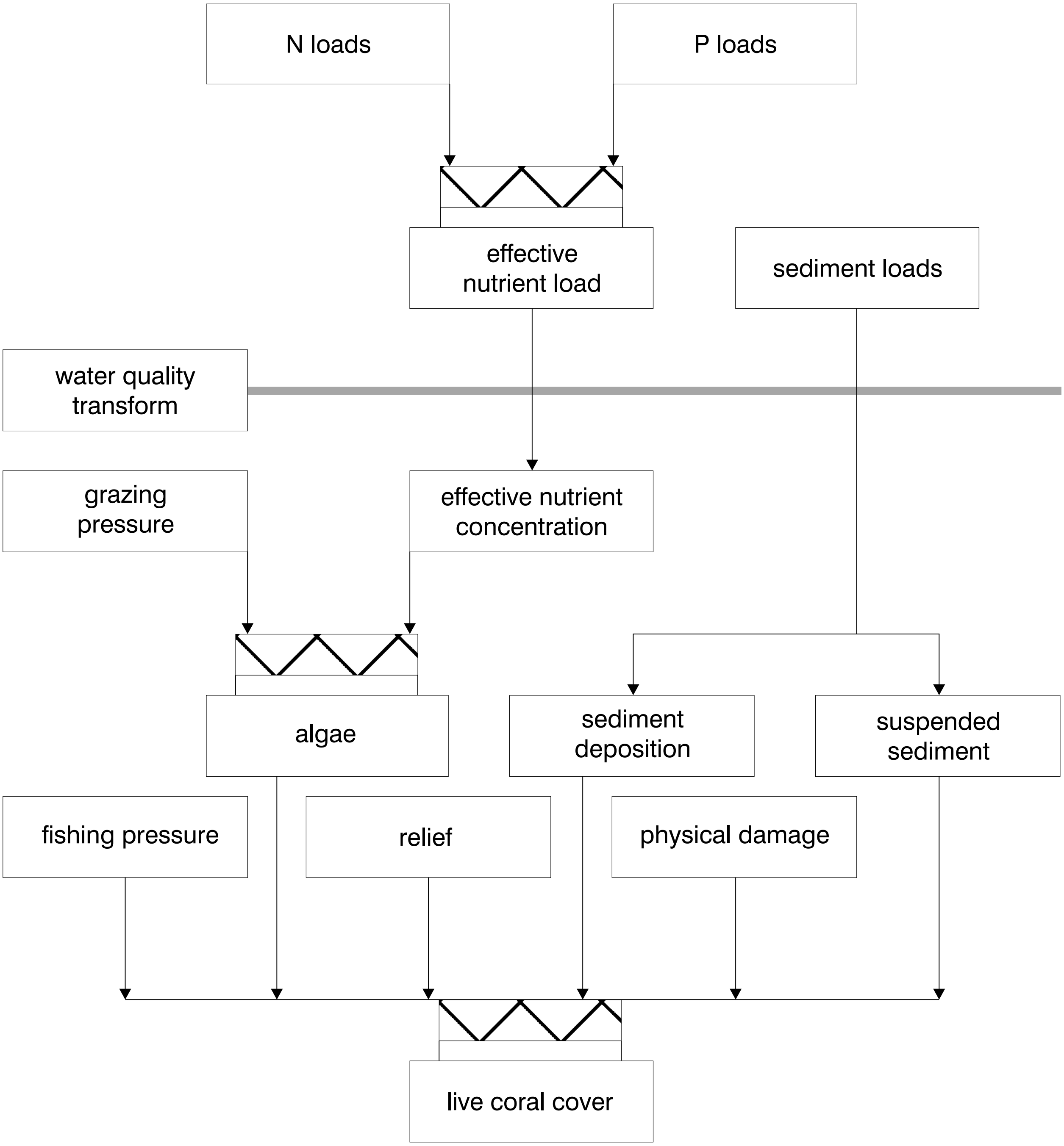


Figure 8.3. Coral reef impact model structure. The generic final ecological sub-model consists of four stages: (i) nitrogen (N) and phosphorus (P) loads are converted to effective nutrient load in a fuzzy logic transform; (ii) sediments and nutrients are converted to nutrient concentrations, sediment deposition and suspended sediment at the coral reef site using a water quality transform function that can consist either of a deterministic linear transform, a deterministic non-linear transform, or a fuzzy logic based transform; (iii) nutrient concentration and grazing pressure are converted to algae cover in a fuzzy logic transform; and, (iv) six primary determining variables are converted into live coral cover using a fuzzy logic transform. Where a deterministic water quality transform is used, and where each input takes on three potential values (low, medium, and high), the system requires a maximum rule base of 747 rules ($3^2 + 3^2 + 3^6$).

Box 8.1. An informal introduction to fuzzy modeling.

Fuzzy rule-based models relate a set of inputs to a set of outputs. The inputs in this case refer to nutrient and sediment influx, physical oceanographic characteristics (“mitigators”), and biotic state variables. Outputs also refer to biotic state variables, although not necessarily the same as the biotic inputs. Once inputs and outputs have been identified, the first step is to define the range of possible values (measurements) for each one and to divide that range into a set of overlapping intervals. Each interval defines a *fuzzy set*, referring to a relative magnitude of that input (e.g., high, medium, or low); fuzzy sets are thus sometimes referred to simply as “adjectives”. Such intervals are based on expert judgment.

Fuzzy sets are so named because of the ambiguity associated with the membership of certain values in those sets. Such ambiguity is characteristic of the linguistic terms we use to label the sets (e.g., high, medium, and low). A particular quantitative value (e.g., 25%) could be associated with more than one fuzzy set (e.g., both low and medium). How plausible it is that the value in question belongs to a particular fuzzy set is termed its degree of membership, represented by a number between 0 and 1.0, inclusive. Most quantitative values are associated with more than one fuzzy set, usually to different degrees. A value’s membership in a given fuzzy set is determined by its *membership function*. Membership functions are usually represented as geometric figures—triangles or trapezoids being the two most common—whose “tops” correspond to the full membership of 1.0, bases (the intervals defining the fuzzy sets) to a value of 0.0, and sides to intermediate values. Thus, we can conceive of each membership function as having a certain area associated with it, a view that is helpful in understanding the operation of scaling discussed below.

Given a set of inputs and outputs, their fuzzy sets, and corresponding membership functions, input-output rules are specified in terms of the fuzzy sets. The set of such rules, called the *knowledge domain*, defines a mathematical relation and constitutes a *fuzzy system*, also called a *fuzzy associated memory* (Kosko 1993). For example, a hypothetical two input, one output rule could be the following: “If nitrogen influx is high and residence time is low, then coral abundance is high.” Each input in a rule is called an *antecedent*, and each output a *consequent*.

With the knowledge base established, one now needs a way to transform a given set of quantitative inputs, with their corresponding membership degrees, into quantitative outputs. Three steps are followed to do this, often referred to as *scaling*, *combination*, and *defuzzification*:

1. *Scaling*. Scaling is the process of determining the degree to which each rule applies, called the rule’s *activation level*. If a rule has a single antecedent, the activation level is the value’s membership in that fuzzy set. If the rule has two or more antecedents with different membership degrees, fuzzy logic operators are used to determine the most appropriate activation level. If the antecedents are connected with the “and” conjunction (as in the example of nitrogen and recruitment above), then the minimum membership degree is used; if “or” is used, then it is the maximum membership. However it is obtained, the activation level is then used to scale the output fuzzy set by reducing its area and shape accordingly. The amount of reduction and the shape modification varies with the scaling method used.
2. *Combination*. In this step, all scaled consequents from active rules (i.e., whose activation levels are positive) are combined via superposition—that is, superimposing the scaled fuzzy outputs on top of each other. The composite fuzzy output is then determined through *max combination* (the point-wise maximum membership degree of the superimposed consequents) or via *sum combination* (the point-wise sum of the membership degrees of the overlapping consequents). The latter is the newer of the two approaches, equivalent to a weighted average of the active rules.
3. *Defuzzification*. The fuzzy composite consequent is transformed to a single quantitative (“crisp”) output value, either that corresponding to the centroid of the consequent set, or that having the maximum degree of membership.

Table 8.2. Input and output variables and their associated fuzzy sets, showing typical values. Square brackets indicate range. Asterisk (*) signifies an output variable. Where no values are shown for a specific fuzzy set, that set is not used. All input variables are defined by three fuzzy sets, while output variables are defined by four or five fuzzy sets.

Variable	*Low*	*Medium-low*	*Medium*	*Medium-high*	*High*
N loads (mmol m^{-2} day^{-1})	2		15		80
	[0 to 6]		[5 to 50]		[40 to 200]
P loads (mmol m^{-2} day^{-1})	0.5		4		7
	[0 to 1]		[0.8 to 6]		[5 to 10]
Effective nutrient load*	0.25	0.75	1.5	4	8
	[0 to 0.5]	[0.4 to 1]	[0.8 to 3]	[2.5 to 6]	[5 to 10]
Effective nutrient concentration (mM)	0.02		0.1		0.3
	[0 to 0.05]		[0.04 to 0.15]		[0.14 to 0.5]
Grazing pressure (kg ha^{-1} day^{-1})	10		40		110
	[0 to 30]		[25 to 100]		[80 to 150]
Algae (%)*	5		25	40	60
	[0 to 20]		[15 to 50]	[25 to 60]	[40 to 100]
Sediment loads (g m^{-2} day^{-1})	50		150		600
	[0 to 100]		[80 to 500]		[450 to 800]
Suspended sediment (g m^{-3})	0.6		2.5		5
	[0 to 2.5]		[1.5 to 5]		[4 to 10]
Sediment deposition (g m^{-2} day^{-1})	2		20		60
	[0 to 10]		[8 to 50]		[45 to 80]
Physical damage (index)	0.5		1		3
	[0 to 1]		[0.5 to 2.5]		[2 to 4]
Algae (%)	5		25		60
	[0 to 20]		[15 to 50]		[40 to 100]
Fishing pressure (kg ha^{-1} day^{-1})	2		6		20
	[0 to 5]		[4 to 15]		[12 to 25]
Relief (rugosity index)	1.2		2		4
	[1 to 1.5]		[1.25 to 3]		[2.5 to 5]
Live coral (% on available substrate)*	8	18	35	50	70
	[0 to 15]	[10 to 25]	[20 to 50]	[40 to 65]	[60 to 100]

The system of fuzzy logic rules, in effect, represents a multi-dimensional dose-response function. We can represent a "slice" of this function by generating a surface representing one output variable as a function of two input variables, with all other variables held constant (Figure 8.4).

Effective Nutrient Concentrations

It is generally considered that nutrients (primarily nitrogen and phosphorus) are one of the most important potential anthropogenic impacts to coral reefs (Chapter 1). While nutrients may or may not have a direct impact on coral growth and physiology, depending on the concentration, the major effect of increased nutrients on corals is likely a decrease in their competitive advantage over benthic algae, which can exhibit increased growth rates with increased nutrient concentrations. However, we recognize that the "effective nutrient concentration" that can affect algae abundance is not necessarily the same as nutrient loading, when loading is distinguished between N loading and P loading. The reasoning for this differentiation is based on the unifying concept in biological oceanography that plants (whether phytoplankton or benthic plants) have a definite atomic ratio of C:N:P. In phytoplankton, the ratio is commonly expressed as the "Redfield ratio" with a numerical value of 106:16:1. In benthic marine plants, the ratio is variable, but has an estimated median value of 550:30:1 (Atkinson and Smith 1983). A corollary to this standard compositional ratio of marine plants is the observation that the net uptake and release of nutrients through biochemical processes also tend towards the same ratio. Thus, the nutrient in shorter supply to make up the appropriate tissue ratio will generally be the limiting nutrient to plant growth. As a result, if only one nutrient (N or P) is elevated while the other remains at low concentrations, the effect in terms of plant growth is likely to be substantially less than if both nutrients increase correspondingly. With this concept of uptake ratios as a basis, the input of "effective nutrient loading" is determined by the ratio of N loading to P loading. The rule base states that when loading of N and P is unequal, the effective loading remains equivalent to the nutrient in shortest supply. There is, however, a caveat to this rule. Coral reefs are capable of fixing atmospheric nitrogen to form organic nitrogen. There is no equivalent biochemical process for phosphorus. Thus, if the ratio N:P of the water flowing over a reef is low relative to the uptake ratio of plants on the reef, the capability exists for nitrogen fixation to raise the potential uptake of phosphorus. On the other hand, if phosphorus is the nutrient in low relative concentration, there is no potential to increase uptake potential through atmospheric supply. As a result, we consider phosphorus the limiting nutrient in our rule base, and the input variable of "effective nutrient concentration" as being equivalent to the "effective phosphorus concentration."

Water Quality Transform Function

This model converts sediment and effective nutrient loadings at specified locations into effective nutrient

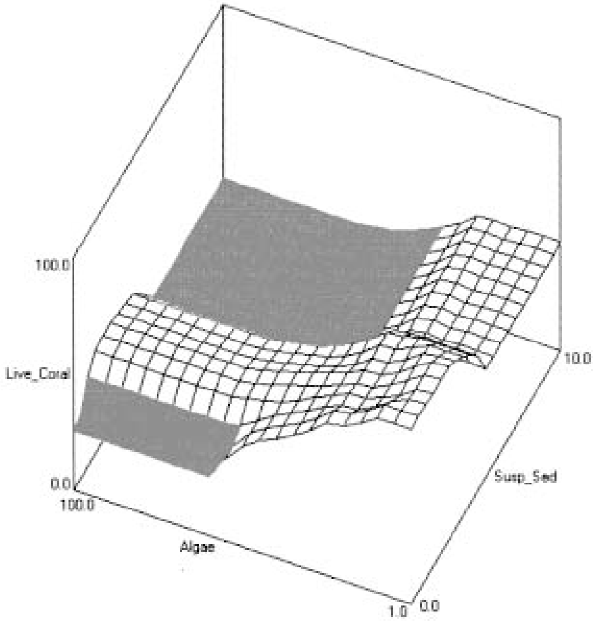


Figure 8.4. A typical fuzzy-logic generated dose response surface. This example shows live coral cover as a function of suspended sediment and algae cover, with all other variables fixed.

concentration, depth of sediment deposition, and concentration of suspended sediment over the reef. The model uses a simple fuzzy rule-based water quality transform that approximates a conventional (non-fuzzy) water quality model described in Rijsberman and Westmacott (1996; see Chapter 3).

Algae-Nutrient-Grazing Subsystem

The reasoning behind inclusion of this subsystem is, simply, that the primary effect of elevated nutrient levels on coral is the enhanced growth of algae which, *ceteris paribus*, may compete with coral for hard substratum or perhaps even smother existing live coral. However, grazing by fish, sea urchins, and other fauna will help check the proliferation of algae. Thus, a quite parsimonious function for determining algae levels is derived from nine rules describing the interplay between the effective nutrient concentration and grazing pressure.

Sediment Deposition versus Suspended Sediments

Distinction is made between the input variables sediment deposition and suspended sediments because these factors can be considered to affect coral community structure differently. While suspended sediment is often considered a detriment to coral growth and reproduction, it has been documented that many reef areas contain a high percentage cover of coral in areas where suspended sediments is also normally considered high. Species composition in such areas may be substantially different than in areas with low suspended sediment primarily as a result of the physiological capability of some species to efficiently eject sediment from living polyps. As a result, reef composition may vary dramatically between areas of differing levels of sediment suspension, but one reef assemblage cannot necessarily be considered inferior to the other. Coral cover then, in contrast to coral species mix, may not vary significantly with suspended sediment.

On the other hand, sediment deposition appears to be universally more detrimental to living coral reef structures. Coral planulae (larvae) cannot settle in areas where soft sediments continually cover the bottom, and may not survive in areas where sediment deposition is episodic but a regular occurrence. In areas of highly variable water motion, sediment deposition may occur occasionally during periods of high input and low water motion, with subsequent clearing of the deposited material when water motion increases. While adult colonies of some species may tolerate coverage by settled sediments for short periods of time (hours to days), coverage for longer periods is lethal to virtually all species. As a result, in our model, sediment deposition has a considerably stronger adverse effect upon reefs than suspended sediment. It is also important to understand that while these two input variables can co-vary (e.g., high sediment deposition in areas of high sediment suspension), it is not unusual to find reef areas where the input variables are very dissimilar, generally being a function of water motion. For example, in areas with normal high water motion from wave forces, suspended sediments can be high with virtually no deposition. On the other hand, in areas with low water motion and limited flushing as a result of physiographic structure, sediment input may be low, resulting in relatively low suspended sediment; however, because there are insufficient physical forces to remove sediment, deposition may be high. This is a typical situation in lagoonal areas, which often have soft sediment bottoms with little coral development.

Fishing Pressure

While corals themselves are sometimes the target species (mainly for curio collectors), fishing pressure is generally considered to have an important indirect impact on coral reefs. Removing a large percentage of the grazers or piscivores on any reef may cause changes in the balance between corals and algae, which can result in phase shifts in reef structure. While fishing pressure is considered an important variable, it is inherently difficult to measure and quantify for input into the model. We have chosen to employ the units of measurement presented by McClanahan (1995) in his coral reef ecosystem-fishery model, which is aimed at determining the impacts of fishing intensity and catch selection on reef structure and processes. Based on field data, McClanahan (1995) estimates that a person can catch 25kg ha^{-1} day^{-1} of fish at maximum fish biomass. This clearly depends on the techniques used and should be seen as a relative measure. We use this number as a maximum value and scale downward to create membership classes. It should be acknowledged that this variable is likely to be the most difficult to quantify in any applied situation, but it nevertheless is a necessary input for an effective model.

Economic Model Structure

Accounting for intermediate variables in the fuzzy model, the reduced form of the output and inputs to the integrated complex system function are the following. Parameters that are listed with a asterisk (*) are regarded as fixed for any given site and are not normally affected by the impacts arising from economic interventions.

$Q = Q\{F_1,\ldots, F_9\}$; coral abundance on available substrate;
F_1 = suspended sediment;
F_2 = sediment deposition;
F_3 = physical damage;

F_4 = fishing pressure;
F_5 = relief*;
F_6 = grazing pressure*;
F_7 = initial effective nutrient concentration*;
F_8 = nitrogen loads; and,
F_9 = phosphorus loads.

Various computer modeling and simulation platforms were tested to find an efficient system that could accommodate the biophysical parameters as well as the economic optimization procedures. Final modeling was conducted using MATLAB® 5.2 software relying on the specialized Fuzzy Logic Toolbox and the Optimization Toolbox (Mathworks 1998). In modeling the relationships, fuzzy rule-based systems were initially defined for each system and were subsequently modified to improve computational efficiency. The modifications included use of Sugeno transforms instead of Mamdami transforms and the specification of a fuzzy inference system for the water quality transform. All optimization routines relied on a sequential quadratic programming method, which is the most efficient algorithm for optimizing over non-linear surfaces (Floudas and Pardolos 1992; Gill *et al.* 1981; Han 1977; Powell 1978). Identification of global optima was assured through specification of different starting points to ensure convergence.

The economic model structure consists primarily of two components. One component involves the definition of a "unit intervention set," including the costs of each of the unit interventions. The second component incorporates an economic activity "baseline" that represents a base case level of activity and impact in the absence of any interventions. The baseline level of activity corresponds to $n_k = 0$ for all $k = 1$ to K. Cost information for the various interventions was based on location specific data for Montego Bay (GMRC 1996). In general, the simplified form of the cost function takes the form

$$C_k = 0 \text{ if } n_k = 0$$

$$C_k = n_k C1_k + {n_k C2_k}/{r} \text{ if } n_k > 0$$

where $C1$ is the capital cost of a unit intervention and $C2$ is the annual operating cost of a unit intervention of type k. Each of these at a "unit scale" will have some impact on economic activities and on the inputs to the biophysical model (i.e., on the vector **F**).

The economic baseline component essentially involves projecting all economic activities under the assumption of no interventions. A resultant baseline vector **F0** is generated, with a corresponding level of coral quality that can be calculated as $Q0 = Q\{F0\}$ through evaluation using the fuzzy model.

At this stage, the model can be used in two different modes: simulation or optimization. In simulation mode, the model determines the consequences of a given intervention set. An intervention set is defined by the vector **n**, and each n_k could take on a user-specified value from zero to some upper bound which is dictated by feasibility constraints (for example, it will not permit replanting more than 100% of the watershed). In optimization mode, the only input is the target reef quality (Q) and the model will generate the least cost combination given constraints on each n_k. The output is a vector **n**.

Modeling Scenarios and Interventions

The model forecasts economic activity, pollution and impact loads, and resultant coral quality over a 55 year period. The underlying forecast of economic activity is divided into the following sectors:

- *Municipal sector (domestic)*. Migration into the area is regarded as a significant element in future economic development of the region, and demands on municipal waste treatment services will escalate. Wastes from the domestic sector thus are a potentially significant contributor to overall pollutant loading.
- *Agribusiness sector*. This sector is selected because it is one of the major growth nodes in the area and has high pollution potential. Although agriculture itself is not an important contributor to regional product, value added processing may become increasingly significant in the free trade zone and elsewhere.
- *Light manufacturing sector*. This sector is highlighted because of its high pollution potential for metals, sediments, nutrients and toxic compounds. Also, growth may be expected to increase given the desire for industrial expansion in and around the free trade zone.
- *Heavy manufacturing and construction sector*. This sector also has high pollution potential, although its pollutants have traditionally been mainly sediment loads and solid wastes leading to potential physical damages on the reef.
- *Hotel and tourist service sector*. This sector is an important current component of the local economy and will continue to be a major player in the future. As such, interventions relating to this sector are likely to have a significant impact on water demands and on overall pollution loads.
- *Forestry and agriculture sectors*. These sectors are included for completeness, and because of their high potential pollution loads. In the Montego Bay area, however, their relative contributions to economic output are small.
- *Offshore transport sector*. Offshore shipping contributes to recurrent oil spills in the area. It is expected

that these recurrent impacts, as well as the risk of an oil spill, will escalate with increased processing in the free trade zone and elsewhere.

In any particular simulation or optimization, the baseline forecast is chosen as a status quo case. This describes conditions in the absence of any active interventions. We use as a reference case a rapid growth scenario developed on the basis of consultations with and documents provided by the Greater Montego Bay Redevelopment Corporation (GMRC 1996). The forecasts represent relatively rapid growth over a 20 year period, tapering off to lower levels over the remainder of the 55 year period. Specifically, population is expected to grow by about 2.5% annually for 20 years, and 1% annually in the longer term. Growth in real economic output in the manufacturing and processing sectors is expected to range between 3% and 5% in the near to medium-term, and 1% to 1.5% in the long-term. Tourism and hotel industry growth is expected to average about 3% annually for 20 years, tapering off to 1% annually afterwards. Forestry and agriculture are expected to realize only modest growth in the near-term (less than 1% annually) and no real growth over the long-term as land is converted to satisfy municipal requirements.

The model incorporates eight active intervention types for Montego Bay. The interventions, and their approximate costs, are:

1. *Sediment trap*. This involves placement of a sediment trap close to the Montego River outlet before it empties into Montego Bay. The trap is a physical barrier that slows the water flow and prevents most of the sediments from entering Montego Bay; it also removes some solid litter that might cause physical damage to the reefs. It does not reduce nutrient loads to any significant degree. Effective operation of the trap requires regular (weekly) maintenance and removal of sediments for disposal in clean fill sites. The capital cost of such a trap is estimated to be about US$6 million, with annual operational costs of about US$330,000. Smaller traps, at lower cost and efficiency, could be installed at various upstream locations.
2. *Planting of trees in the upper watershed*. This scenario reflects reforestation of the most degraded watershed areas around Montego Bay and involves planting about 150,000 acres of trees, at a one time capital cost of almost US$28 million (based on average reforestation costs for Jamaica). This intervention would lead to a substantial (almost 100%) reduction of sediment and nitrogen loads from this area.
3. *Aeration of waste*. This involves installation of a common waste treatment aeration system in the Montego Bay free trade zone, capable of treating 416 tons per day of waste. It would result in a substantial end-of-pipe reduction in sediment and nutrients from the light industry in this zone. Costs of such a facility are estimated to approach US$1 million, requiring an additional US$1 million annually for operation.
4. *Large scale centralized treatment facility*. This scenario involves installation of a common waste treatment facility capable of processing about one-quarter of the sewage and waste in the Montego Bay area. Installation of such a facility would reduce nutrient and sediment loads associated with domestic, commercial and hotel waste streams; some modest decrease in physical impacts on the reef would also be evident. In theory, up to four of these might be built over the long-term in Montego Bay; construction of additional units is, however, constrained by difficulties associated with connecting all areas, and with overcoming the common use of disposal wells. In the optimization modeling, therefore, the model limits this to only one such facility being constructed at a capital cost of about US$50 million and annual operational costs of about US$5 million. Smaller scaled down versions of this could also be constructed.
5. *Agricultural extension*. This intervention reflects the establishment of technology transfer programs along the lines of internationally accepted waste reduction programs. Such programs are aimed at reducing pollutant loads (primarily from nutrients) through providing relatively low cost (often self-financing) technologies to the agricultural and agro-processing sectors. The intervention covers up to 10% of such enterprises in the area, and will cost US$1.2 million to implement with an annual cost of about US$120,000.
6. *Outfall and pump*. This is a stand-alone intervention that would involve a sewage outfall and pump station to take the sediment beyond the reef edge (approximately 5km). The unit would cost about US$1.8 million, along with US$72,000 annually, and would mainly reduce sediment loads and physical impacts of wastes on the reef. Smaller versions at lower cost and efficiency are available.
7. *Household solid waste collection*. This scheme involves establishing a small-scale waste collection system to connect about 30,000 people in squatter settlements or low income areas to common waste handling facilities. Although the capital costs for this type of an arrangement are low (US$72,000) the operating costs are relatively high (US$36,000 annually). The effect this has on pollution loads will be to reduce sediment and nutrient loads from the household sector.
8. *Hotel tax*. This intervention simulates the impact of a 25% land tax on the existing hotel and service sector, and is meant to illustrate the impacts of a policy intervention as opposed to some of the investment interventions considered elsewhere. While this tax is not directly attacking any specific pollutant, the increase

in hotel operation costs is expected to dampen investment and decrease pollution loads. The administrative costs of such an intervention are estimated to be about US$60,000 annually.

Results

While the model provides a dynamic forecasting environment, it was found that decision-makers find it most useful if reef quality can be expressed in terms of a single index relating to a single future reference year (Werners 1998). In all modeling summaries and optimizations, therefore, a "25 year equilibrium" level of coral abundance was selected as a benchmark. Precise interpretation of this figure is somewhat complex, but it essentially describes the long-term level of coral abundance on available substrate arising from the next 25 years of activities and interventions. It therefore consolidates initial conditions (taken as 1998) with future economic development activities (and their associated negative impacts) and any mitigative interventions (and their positive impacts).

The basic technical sensitivity of the reef impact model, calibrated for Montego Bay conditions, is shown in Table 8.3. Under static conditions of no growth and no mitigative interventions, with all stresses essentially remaining at current levels, a long term equilibrium level of 43% coral abundance would be expected. Table 8.3 also demonstrates that the greatest deterioration would arise from changes in pollution loading (N, P and sediments) while reef quality is less responsive to changes in fishing pressure.

The economic impacts of single technical interventions are shown in Table 8.4. The results also show that, in the "high growth" reference forecast, a long-term equilibrium level of about 29% coral abundance would be expected. This decline, relative to the "no growth" case of 43% coral abundance, is attributable entirely to the increased impacts from economic activity in the absence of mitigating interventions. The results also indicate the potential impact of single interventions. No single intervention is capable of completely compensating for the negative impacts on coral abundance, although, if all interventions were executed, a level of about 49% coral abundance could be achieved. This, in fact, represents a 20.23% improvement on what would otherwise happen, and it would result in a present value cost in excess of US$150 million.

The results in Table 8.4 show the impact of single interventions relative to a "do nothing" scenario. Because of the non-linearity of the coral reef response, it is not possible simply to add up these interventions to arrive at a cumulative impact. The model, in optimization mode, permits setting of a target level of coral abundance (or change in coral abundance over a reference case); results for such optimizations are summarized in Table 8.5. For

Table 8.3. Changes in Montego Bay (Jamaica) coral reef quality arising from changes in key inputs. Coral abundance levels show long-term equilibrium arising from changes in physical impacts of human-induced activities on the reef ecosystem.

Scenario	*Coral cover (%)*	*Change in coral cover (%)*
Base case conditions - no economic growth	42.73	
Doubling of:		
Pollution loads (N, P and sediment)	21.83	-20.90
Physical damage	25.49	-17.24
Fishing pressure	39.80	-2.93
All inputs	6.82	-35.91
Halving of:		
Pollution loads (N, P and sediment)	56.38	+13.65
Physical damage	51.33	+8.66
Fishing pressure	44.00	+1.27
All inputs	76.18	+33.45

Table 8.4. Changes in Montego Bay (Jamaica) coral reef quality arising from single interventions. Coral abundance levels show 25 year equilibrium, and resultant total cost and average costs.

Intervention	*Coral cover (%)*	*Change in coral cover (%)*	*Total cost (million US$)*	*Average costs (million US$/%)*
Base case conditions - high economic growth	28.94	0.00		
Sediment trap	32.13	3.20	9.30	2.91
Planting of trees in upper watershed	30.57	1.63	27.90	17.12
Aeration of waste	30.57	1.63	11.84	7.25
Large scale centralized treatment facility	34.18	5.24	98.40	18.78
Agricultural extension	29.00	0.07	2.40	36.81
Outfall and pump	34.33	5.39	2.52	0.47
Household solid waste collection	30.73	1.80	0.43	0.24
Hotel tax	28.97	0.03	0.60	17.30
All of the above	49.17	20.23	153.40	7.58

any given target level, the optimization provides the least cost combination of interventions, permitting variable intensities from zero to unity. A zero indicates that the intervention is not undertaken, while any positive value shows partial or full implementation of a given intervention.

Discussion and Conclusion

Modeling results provide important insights into methodological issues as well as practical policy issues. A major methodological success of the exercise is that it was found to be feasible to model a large variety of economic and ecological parameters in a predictive system that permits comparison of policies. The fuzzy logic procedures, coupled with economic optimization tools, can take advantage of relatively sparse information sets.

The non-linearity of underlying complex systems also places in question many conventional methods of cost-effectiveness analysis that assume separability of benefits and costs, and separability of the impacts of individual interventions. Inspection of the results illustrates a number of these points.

First, the non-linearity of the coral quality response surfaces to individual interventions is shown in Table 8.4. Both the reforestation alternative and the waste aeration alternative achieve precisely the same level of coral abundance because of a localized “plateau” in the coral quality response surface. Such localized plateaus in the ecological model are relatively common and are surpassed only through more investment through additional interventions; the first intervention in such cases will always have a high cost (in terms of $/% improvement) compared to subsequent investments which move conditions beyond such a plateau.

Second, the fallacy of separating benefits from costs, and of using a continuous ranking of individual interventions, is shown in the optimization results in Table 8.5. In a conventional separable model with monotonically increasing marginal costs (such as that in Figure 8.1), an intervention that was undertaken at a low target level of coral improvement would also always be undertaken at a high target level of coral improvement. But this is clearly not the case here. Reforestation, for example, is part of the optimal intervention set at coral quality improvement targets of 14% and 20%, but it is not part of the intervention set at intermediate targets of 15% or 16%. Similarly, the intensity of the agricultural extension and hotel tax interventions do not increase monotonically. This is reflected also in the marginal cost curve inherent in Table 8.5; while generally it is increasing, there are some localized decreases (Figure 8.5). The most significant implication this has for policy-makers is that one can not simply pursue low cost interventions in the absence of some coral quality target, which will in turn be related to the economic benefits.

Table 8.5. Optimization results for Montego Bay (Jamaica), showing levels of individual interventions required to achieve target coral reef quality, and resultant total cost and marginal costs. Interventions are as follows: I1=sediment trap; I2=planting of trees in upper watershed; I3=aeration of waste; I4=large scale centralized treatment facility; I5=agricultural extension; I6=outfall and pump; I7=household solid waste collection; and, I8=hotel tax.

Change in coral cover (%)	*Intervention I1*	*I2*	*I3*	*I4*	*I5*	*I6*	*I7*	*I8*	*Total cost (million US$)*	*Marginal costs (million US$/%)*
0.25	0	0	0	0	0	0	0.13	0	0.06	0.24
0.50	0	0	0	0	0	0	0.26	0	0.11	0.20
0.75	0	0	0	0	0	0	0.39	0	0.17	0.24
1.00	0	0	0	0	0	0	0.58	0	0.25	0.32
1.25	0	0	0	0	0	0	0.71	0	0.31	0.24
1.50	0	0	0	0	0	0	0.85	0	0.37	0.24
1.75	0	0	0	0	0	0	0.98	0	0.42	0.20
2.00	0	0	0	0	0	0.04	1	0	0.53	0.44
2.25	0	0	0	0	0	0.08	1	0	0.64	0.44
2.50	0	0	0	0	0	0.13	1	0	0.76	0.48
2.75	0	0	0	0	0	0.18	1	0	0.87	0.44
3.00	0	0	0	0	0	0.22	1	0	0.99	0.48
3.25	0	0	0	0	0	0.27	1	0	1.10	0.44
3.50	0	0	0	0	0	0.31	1	0	1.22	0.48
3.75	0	0	0	0	0	0.36	1	0	1.33	0.44
4.00	0	0	0	0	0	0.40	1	0	1.45	0.48
4.25	0	0	0	0	0	0.45	1	0	1.56	0.44
4.50	0	0	0	0	0	0.49	1	0	1.68	0.48
4.75	0	0	0	0	0	0.54	1	0	1.79	0.44
5.00	0	0	0	0	0	0.58	1	0	1.90	0.44
5.25	0	0	0	0	0	0.63	1	0	2.02	0.48
5.50	0	0	0	0	0	0.67	1	0	2.13	0.44
5.75	0	0	0	0	0	0.72	1	0	2.24	0.44
6.00	0	0	0	0	0	0.76	1	0	2.34	0.40
6.25	0	0	0	0	0	0.80	1	0	2.45	0.44
6.50	0	0	0	0	0	0.84	1	0	2.56	0.44
6.75	0	0	0	0	0	0.89	1	0	2.67	0.44
7.00	0	0	0	0	0	0.93	1	0	2.78	0.44
7.25	0	0	0	0	0	0.97	1	0	2.88	0.40
7.50	0.03	0	0	0	0	1	1	0	3.19	1.24
7.75	0.10	0	0	0	0	1	1	0	3.85	2.64
8.00	0.17	0	0	0	0	1	1	0	4.52	2.68
8.25	0.24	0	0	0	0	1	1	0	5.18	2.64
8.50	0.31	0	0	0	0	1	1	0	5.83	2.60
8.75	0.38	0	0	0	0	1	1	0	6.49	2.64
9.00	0.45	0	0	0	0	1	1	0	7.15	2.64
9.25	0.52	0	0	0	0	1	1	0	7.80	2.60
9.50	0.59	0	0	0	0	1	1	0	8.45	2.60
9.75	0.66	0	0	0	0	1	1	0	9.10	2.60

Table 8.5. continued

Change in coral cover (%)	*Intervention I1*	*I2*	*I3*	*I4*	*I5*	*I6*	*I7*	*I8*	*Total cost (million US$)*	*Marginal costs (million US$/%)*
10.00	0.73	0	0	0	0	1	1	0	9.75	2.60
10.25	0.80	0	0	0	0	1	1	0	10.39	2.56
10.50	0.87	0	0	0	0	1	1	0	11.04	2.60
10.75	0.94	0	0	0	0	1	1	0	11.68	2.56
11.00	1	0	0.01	0	0	1	1	0	12.41	2.92
11.25	1	0	0.14	0	0	1	1	0	13.89	5.92
11.50	1	0	0.26	0	0	1	1	0	15.35	5.84
11.75	1	0	0.38	0	0	1	1	0	16.78	5.72
12.00	1	0	0.50	0	0	1	1	0	18.21	5.72
12.25	1	0	0.62	0	0	1	1	0	19.63	5.68
12.50	1	0	0.74	0	0	1	1	0	21.06	5.72
12.75	1	0	0.86	0	0	1	1	0	22.47	5.64
13.00	1	0	0.98	0	0	1	1	0	23.89	5.68
13.25	1	0.09	1	0	0	1	1	1	27.20	13.24
13.50	1	0.22	1	0	0	1	1	1	30.88	14.72
13.75	1	0.35	1	0	0	1	1	1	34.55	14.68
14.00	1	0.34	1	0.04	0	1	1	1	38.27	14.88
14.25	1	0.28	1	0.10	0	1	1	0.20	42.09	15.28
14.50	1	0	1	0.24	0	1	1	0.36	47.67	22.32
14.75	1	0.63	1	0.10	0	1	1	0.57	51.51	15.36
15.00	1	0	1	0.32	0	1	1	1	55.88	17.48
15.25	1	0	1	0.36	0	1	1	1	60.01	16.52
15.50	1	0	1	0.40	0	1	1	1	64.13	16.48
15.75	1	0	1	0.45	0	1	1	0.18	68.32	16.76
16.00	1	0	1	0.48	0	1	1	1	72.35	16.12
16.25	1	0	1	0.53	0	1	1	1	76.43	16.32
16.50	1	0	1	0.57	0	1	1	1	80.82	17.56
16.75	1	0	1	0.62	0	1	1	0.35	85.25	17.72
17.00	0.99	0	1	0.64	0.22	1	1	0.48	87.43	8.72
17.25	1	0.32	1	0.64	0	1	1	0.04	95.89	33.84
17.50	1	0	1	0.77	0	1	1	1	100.49	18.40
17.75	1	0	1	0.81	0	1	1	1	104.68	16.76
18.00	1	0	1	0.86	0	1	1	1	108.85	16.68
18.25	1	0	1	0.90	0	1	1	1	112.99	16.56
18.50	1	0	1	0.94	0	1	1	1	117.10	16.44
18.75	1	0	1	0.98	0	1	1	1	121.20	16.40
19.00	1	0.10	1	1	0	1	1	1	125.78	18.32
19.25	1	0.27	1	1	0	1	1	1	130.64	19.44
19.50	1	0.44	1	1	0	1	1	1	135.39	19.00
19.75	1	0.61	1	1	0	1	1	1	140.06	18.68
20.00	1	0.83	1	1	0	1	1	1	146.31	25.00
20.25	1	1	1	1	1	1	1	1	153.48	28.68

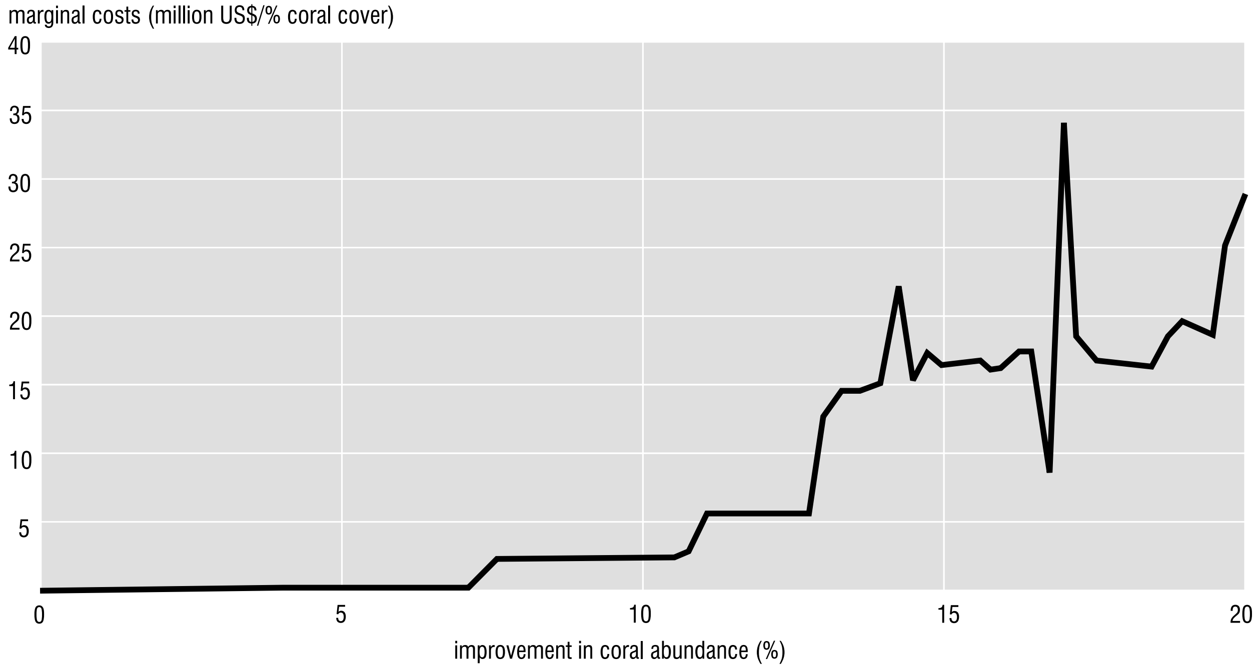


Figure 8.5. Montego Bay (Jamaica) intervention costs. Relationship shows marginal cost of the optimal intervention set for any given target improvement in coral reef quality.

The fallacy of the conventional ranking procedures is also shown by inspection of the average costs of individual interventions (Table 8.4). Such average costs are often used as a means for ranking alternatives, and are usually calculated based on "initial" conditions. Reliance on such an indicator would lead one to conclude, for example, that reforestation was more economical than a hotel tax; but the optimization results show that at higher coral quality targets (between 15% and 18% improvement), a hotel tax is the most economical option. Again, some knowledge of the economic benefits is necessary before a target can be achieved in association with the available cost intervention.

Apart from the above methodological issues, the model results do provide some practical insights to policy design decisions in Montego Bay. First, the results illustrate that some interventions are common to all optimal policy sets for intermediate levels of coral improvement. Specifically, household solid waste collection, installation of an outfall, and use of a sediment trap on the Montego River are relatively cost-effective interventions; use of these three interventions would impose present value costs of about US$12 million and achieve a coral improvement in excess of 10%. By contrast, achieving the maximum potential improvement of 20% would entail present value costs of US$153 million.

In conclusion, we note that—as with all such modeling exercises—any such prescriptions should be complemented by good judgment on the part of policy-makers. Manipulation of the models can provide insights into the generally desirability and impacts of various interventions, but such models never tell the whole story. In Montego Bay, for example, the model still treats pollutant transport and mixing with a broad brush that neglects seasonal variations and potential localized impacts on, for example, important diving sites. Such considerations are beyond the capacity of this analysis framework, although they may be of key importance to a dive industry that generates considerable local benefits through tourism.

Also, the current models do not adequately capture many of the dynamic elements of coral reef responses to human, and other, stresses. While time delays in reef response were identified as an important parameter, limitations in coral reef science and data availability prevent a thorough treatment of this subject. Consequently, it is extraordinarily difficult to reconcile or benchmark models such as this (which predict long-term equilibrium conditions) against real field data (which measure current reef conditions, often under disequilibrium conditions). Also, these models do not yet incorporate the potential impacts of non-localized stresses on reef quality that have (presumably) resulted in such massive recent die backs and “bleaching” events. Again, current measurements of reef health, which reflect such stresses in a disequilibrium state, would be difficult to reconcile against model predictions.

Consequently, this again calls for prudence in using and interpreting the results of these models. In our view, the model is most useful for providing guidance in the *changes* in reef quality induced by *localized human impacts*; the model is less robust in its predictive ability for *absolute* levels of reef quality in an environment characterized by both human-induced local stresses and other external stresses. Nonetheless, the messages of the model results are clear—pay greater attention to ecosystem responses and pay less attention to conventional constructs of cost-effectiveness that assume linear behavior. Complex systems such as coral reefs are not likely to lend themselves to simple management solutions. Modeling tools must strive to capture some of this complexity.

Chapter 9

Integration of the Models for Decision Support in Jamaica

Jack Ruitenbeek
H.J. Ruitenbeek Resource Consulting Limited, Gabriola, BC, Canada

To consolidate the findings of the research, this brief chapter provides a synthesis of the various benefit valuations for Montego Bay, Jamaica (Chapters 5, 6, and 7). In addition, we include these within the context of a key policy question for Montego Bay—how much coral reef conservation is economically optimal and how can we best achieve that level? To answer that question, we rely on selected results from the complementary cost effectiveness studies (Chapter 8) against which we juxtapose the coral reef management benefits identified through the valuation work. Specifically, this chapter:

- Identifies the relative contributions of direct use values against other values within the context of a synthesized benefit function;
- Identifies appropriate policy and institutional reforms for improving the capture of resource values associated with coral reefs in Montego Bay based on an optimizing framework; and,
- Assesses implications for future applied research.

Towards a Benefit Function

As a final step, one can aggregate the economic values into a total value and a net marginal benefit (price) function for the Montego Bay reefs (Table 9.1). The use of such values requires making a number of further assumptions regarding the sensitivity of the individual values to reef quality. As seen with the bioprospecting values, the total value of the reef was relatively high (US$70 million) but changes in reef quality within the planning range (approximately 20% to 50% coral abundance) did not have a large effect on this value.

As no specific linkage models are available for the other values estimated, we make a number of simplifying assumptions for purposes of demonstration. In general, as a reference case, we assume a linear relationship between reef quality and value for all values other than bioprospecting. In effect, this places a fixed price for these other uses and functions, and is likely to over-estimate price in some instances, while potentially under-estimating in others. For example, a degraded reef will still provide some limited erosion protection for some time; thus, an average price assuming a linear relationship will overstate this marginal benefit. For tourism, however, small changes in quality may have disproportionately larger impacts on arrivals if there is a perception that the reefs are substantially degraded (to a degree, this occurred about ten years ago in Montego Bay after some highly publicized but overstated reports of massive degradation decreased diver visits). In the case of the non-use values, the contingent valuation method (CVM) survey explicitly included a degradation scenario; hence, the end-points were well established (representing a 25% degradation) but the nature of the function between these end-points is somewhat uncertain.

Given these assumptions, it is clear that the total benefit attributable to the reefs in their current condition is approximately US$470 million and that every 1% change in abundance is likely to generate a marginal benefit of approximate US$10 million. Most of the value, and change in value, is attributable to the tourism resource. Coastal protection and non-use benefits are next in terms of planning importance. It is notable that the use benefits related to tourism are at least an order of magnitude greater than the non-use benefits that visitors express. The relative impacts of fisheries and bioprospecting on planning prices are negligible, especially if one considers only the capturable values to Jamaica.

Synthesizing Benefits and Costs for a Global Optimum

We juxtapose these marginal benefit calculations against a marginal cost function for the Montego Bay reefs, as generated by a fuzzy logic based ecological-economic

Table 9.1 Summary of valuation results for Montego Bay coral reefs

	Benefit	*Price*[a]	
	(NPV; million US$)	*(million US$/%)*	*(million US$/ha)*
Tourism/recreation	315.00	7.33	17.18
Artisanal fishery	1.31	0.03	0.07
Coastal protection	65.00	1.51	3.54
Local non-use	6.00	0.24	0.56
Visitor non-use	13.60	0.54	1.28
Subtotal	**400.91**	**9.65**	**22.63**
Pharmaceutical bioprospecting (global)	70.09	0.23	0.53
Total (Global)	**471.00**	**9.88**	**23.16**
Pharmaceutical bioprospecting (Jamaica)	7.01	0.02	0.05
Total (Jamaica)	**407.92**	**9.67**	**22.68**

[a]Marginal benefits shown at typical current reef conditions.

model (Chapter 8). This related research on cost effectiveness modeling of interventions suggested that up to a 20% increase in coral abundance may be achieved using appropriate policy measures having a present value cost of US$153 million. The cost curve envelope generated by that research showed marginal costs rising from under US$1 million/% of coral abundance to US$29 million/% of coral abundance. Global optimization using the combined cost and benefit functions suggested an "optimal" improvement of coral reef abundance of 13% requiring net expenditures of US$27 million, primarily involving installation of a sediment trap, waste aeration, installation of a sewage outfall, implementation of improved household solid waste collection, and implementation of economic incentives to improve waste management by the hotel industry. The marginal benefits and marginal cost curves for this solution are shown in Figure 9.1.

Sensitivity tests suggest that net economic benefits would need to increase by US$275 million or decrease by US$300 million for the coral quality target to vary from this by more than 2% (i.e., fall below 11% or above 15%). To justify the full expenditure (i.e., achieving a 20% coral reef improvement) would require additional benefits of US$660 million.

It is notable that the inclusion or exclusion of pharmaceutical bioprospecting values from this analysis does not have an effect on this planning outcome. Even if a strict linear relationship were applied and 100% of the bioprospecting value were capturable by Jamaica, the resultant price (US$70 million/43% coral, or US$1.6 million/%) would not be adequate to justify improvements beyond those stated above.

Implications

While any single valuation will generally be a useful policy input, it should normally be regarded as just one among many potential inputs to such a policy making exercise. It is no accident that wider reliance is being made on multi-criteria analyses, with valuation as one component of that analysis.

In terms of bioprospecting valuation, we would submit that the overall focus on valuation has perhaps distracted analysts from more pressing institutional and socio-economic concerns. Valuation results consistently demonstrate that institutional arrangements between developing countries and the rest of the world are critical components of capturing value and of mitigating risks associated with uncertain economic and ecosystem conditions. Yet local institutional capacity remains weak in Jamaica, as it does in most developing countries. Also, both the economic theory of resource utilization and the social realities arising out of extensive stakeholder participation consistently demonstrate that we must move rapidly towards decentralized and communal management of coral reef resources. Failure to do so will likely rapidly dissipate, or totally eliminate, any notional values we might attach to these resources. To address these concerns, we call for the following shift in emphasis in applied research:

- *Less emphasis on stand-alone cost effectiveness analyses*. The joint projects demonstrate that, if economic efficiency is a goal, we must pay attention to both costs and benefits when dealing with complex non-linear systems such as coral reefs.
- *Greater emphasis at the local level on socio-economic and management dimensions of direct uses*. This involves the promotion of practical local management regimes that involve affected stakeholders in the resource base.
- *Greater emphasis at the national level on institutional strengthening to participate in bioprospecting value capture opportunities*. Analytical work should focus on practical mechanisms and should directly address risk management concerns.
- *Greater emphasis on ecosystem analysis focusing on functional linkages and relationships*. The economic discipline has, in many ways, "gotten ahead of itself" in valuation. Large uncertainties in ecosystem behavior continue to undermine attempts at rational economic analysis and, in many cases, it is probably a waste of effort to conduct such analyses. To some degree, this simply requires that planners become accustomed to the uncertainty, but accelerated work in basic ecological analysis (e.g., thorough inventory work) for critical ecosystems would be money well spent.

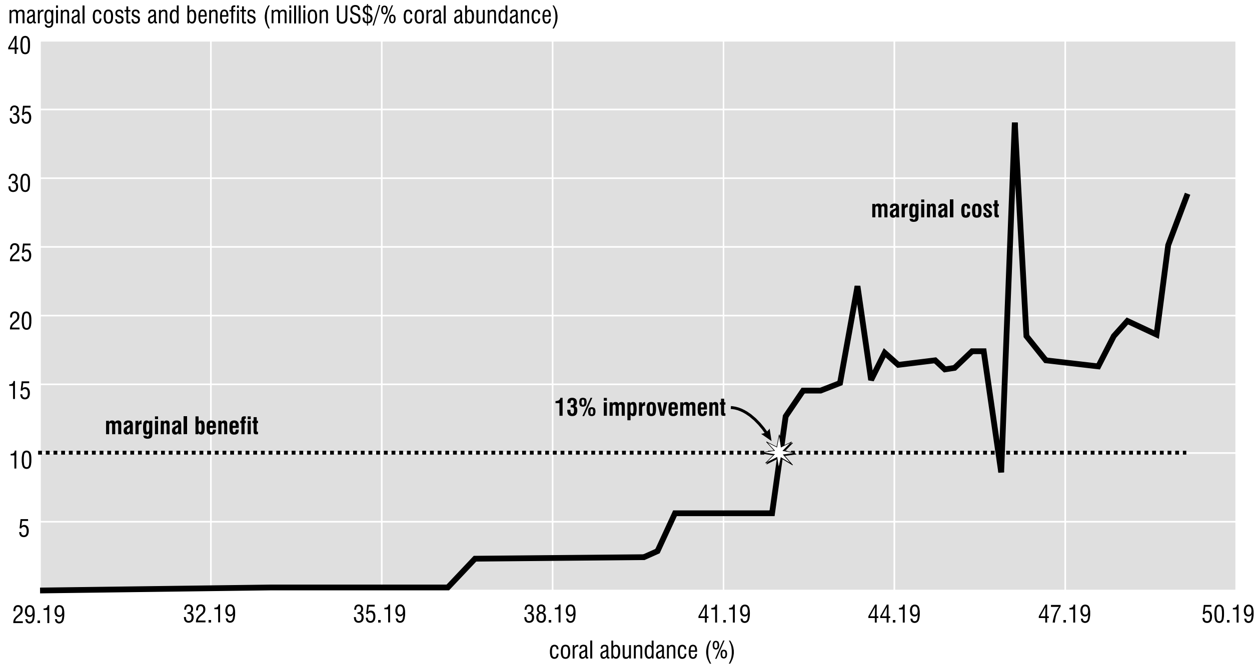


Figure 9.1 Montego Bay intervention marginal benefit and cost curves for the global optimization solution

Chapter 10

Development of the User Interface—Coral-Curaçao, Coral-Maldives, and COCOMO

Christiane Klöditz, Frank Rijsberman, Saskia Werners and Susie Westmacott
Resource Analysis, Delft, The Netherlands

As described in previous chapters, the World Bank has been involved in several projects that aim to improve the protection and management of coral reef coastal systems. Results from each of the three case study sites (Montego Bay, Jamaica; Curaçao, the Netherlands Antilles; North and South Male, the Republic of the Maldives) has led to the development of a user-friendly computer-based application that incorporates a quantitative ecological economic model designed to assist in the formulation, evaluation and ranking of various cost-effective coastal zone management practises. The three integrated coastal zone management decision support models are:

- Coral-Curaçao, a decision support system for coral reef management in Curaçao;
- Coral-Maldives, a coral reef management model for the Republic of the Maldives; and,
- COCOMO, a model for management of COral reef COasts in MOntego Bay, Jamaica.

The models were developed with local input through workshops and meetings and have been tested in further workshops. They have been used successfully as training and education aids and it is hoped that they will be developed further so as to be used later as actual planning tools.

An accompanying CD-ROM contains the three decision support models that have been developed. The CD-ROM demonstrates decision support modeling for integrated coral reef management through realistic examples rather than abstract theory. The three decision support systems aim to create awareness for the integration of different coastal issues, as well as the formulation of integrated management plans. The CD-ROM can be used by stakeholders of the three study areas, as well as to illustrate application of the methodology to other coastal zones. The models are accessible for policy-makers and specialists from various disciplines, including those with minimal or no computer experience or scientific background, as well as a large percentage of the general public. The interface of the models is based primarily on graphic information to provide users with a quick overview with minimal use of text.

Framework for Analysis

Integrated coastal management is a complex issue crossing many disciplines and involving many stakeholders. There is often no clear-cut answer to the problems faced in managing such areas. Traditional sectoral approaches have failed to tackle the interrelated issues posed by user conflicts and interests within the coastal zone. This tends to be because problems are far from structured and objectives are unknown or unclear.

Solutions for such complicated problems can be found through a decision-making and management process that implies learning from other actors. Such an approach allows various stakeholders and decision-makers to explore and understand each other, the problem area and the different perspectives and interests that exist within it. Possible actions are found by learning and developing solutions, normally working in a cyclical, iterative way. When problem solving is approached as a learning process, the thinking processes need to be formally structured. The methodology is supplied by a framework and has been developed as a step-wise approach (Figure 10.1).

One of the components of a decision support system, which the models represent, is the user interface. The design of this will be instrumental in guiding the user through the decision. A step-wise approach is used, leading the user logically from problem definition to the evaluation of alternatives. This step-wise approach is based on a generic framework for analysis that has been developed over the last 10 to 15 years (Bower *et al*. 1994; Resource Analysis and Delft Hydraulics 1993; Rijsberman and Koudstaal 1989; Westmacott 1995). Practical applications of this approach to integrated coastal management issues are given by, for instance, Baarse and Rijsberman (1986, 1987) and Ridgley and Rijsberman (1992). Following this framework, the main steps in an integrated coastal management analysis within Coral-Curacao, Coral-Maldives and COCOMO are as follows:

- Problem identification;
- Definition of objectives and criteria as yardsticks to measure fulfillment of objectives;
- Definition of scenarios for uncertain, exogenous developments;
- Definition of management strategies in terms of their component measures;
- Analysis of the impacts of the strategies in terms of the criteria; and,
- Evaluation and selection of the most desirable strategy.

Modeling for Coral Reef Management

The cost-effectiveness methodology utilized in the modeling was initially developed for Montego Bay, Jamaica, and has been tested through two case studies: i) Curaçao, the Netherlands Antilles, where the methodology has been tested and validated in a relatively data-rich environment and a coral reef system with a high level of anthropogenic influence (Chapter 3); and ii) the Republic of the Maldives, where the coral reefs are in many areas still relatively undisturbed, but where development is rapidly changing these coral reef systems (Chapter 4).

In order to cope with the difficulties of assessing the benefits of improved coastal zone management, the modeling research presented on the CD-ROM has been limited to assessing the costs of coastal zone management, using a framework that focuses on four main steps: i) the specification of economic sector interventions; ii) the modeling of the changes of these interventions on production and consumption; iii) the quantification of the physical response of these in terms of the wastes and physical damage generated; and, iv) the modeling of the impact of the wastes and physical damage on reef health. The final cost of each of the interventions is then computed, taking into account potential negative costs (e.g., from production changes). This enables interventions to be formulated in such a way as to incur the minimum costs while retaining a certain quality of reef. Further research was carried out for the Jamaica and Curaçao case studies where the cost-effectiveness analysis was expanded into a full cost-benefit analysis with quantification of the value of benefits due to changes in reef health (see also Chapter 9).

Coral-Curaçao

Coral-Curaçao (see Chapter 3 and CD-ROM) is a computerized planning tool that is able to show the impacts of coastal developments and environmental protection measures on the economy, environmental and social situation in Curaçao. Development of the model started with a preliminary visit to Curaçao in April 1995 (Rijsberman *et al*. 1995a). A subsequent visit involved collection of data and information for the development of the model (Meesters 1995; Westmacott *et al*. 1995). The first version of the model was completed at the end of 1996 and is described in Chapter 3 (see also Rijsberman and Westmacott 1996).

The initial project aimed to develop a method to evaluate the cost-effectiveness of alternative coral reef management strategies. In order to achieve this, three sub-models were developed that linked together forming a single integrated model. The sub-models were an economic activity model, a water quality model and a reef health response model. As the models were developed, additional components were added to expand the focus to

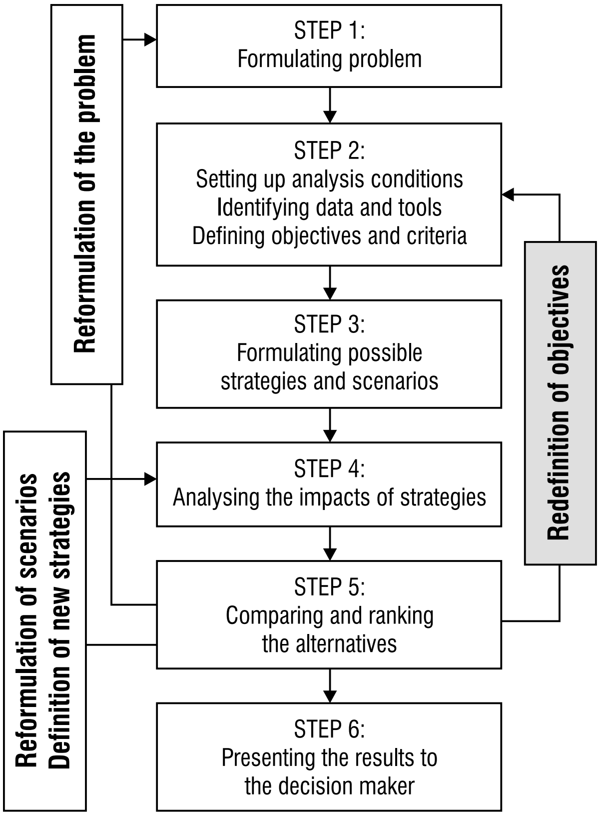


Figure 10.1. A step-wise framework describing a decision-making and coral reef management process.

cover a broad range of indicators, rather than simply cost-effectiveness. The aim was to achieve a user-friendly management model where users would input their ideas and plans for integrated coastal management for Curaçao and could analyze the impacts of the different plans in economic and environmental terms. Once developed, the Coral-Curaçao decision support model was presented to the different user groups in Curaçao, who were trained in its use.

Coral-Maldives

The Coral-Maldives decision support system (see Chapter 4 and CD-ROM) is structured in such a way that different users are able to explore a series of different coastal zone management options under varying assumptions for exogenous variables. The analysis allows the users to focus on the most cost-effective options for coral reef management and protection for the various economic development options. The impacts can be seen in terms of economic, social and environmental indicators that are selected at the outset of the analysis by the user. During the analysis, the user compares two situations: i) the reference situation; and, ii) changes in the reference situation as a result of the management options selected. In addition to the selected indicators, the user can explore more detailed information relating to the economy, reef health and coastal erosion. The final step of the analysis shows a score card of all the selected indicators. In addition, the user can use the cost-effectiveness analysis to rank the coastal zone management strategies.

The structure of the Coral-Maldives decision support system was developed and the data for the model collected during fieldwork in November 1995 (Westmacott 1996). The economic development and environmental protection options were also selected during this period through discussions with various government agencies involved in coastal zone management within the Maldives. The first version of the model was completed in 1997 and is described in Chapter 4 (see also Westmacott and Rijsberman 1997).

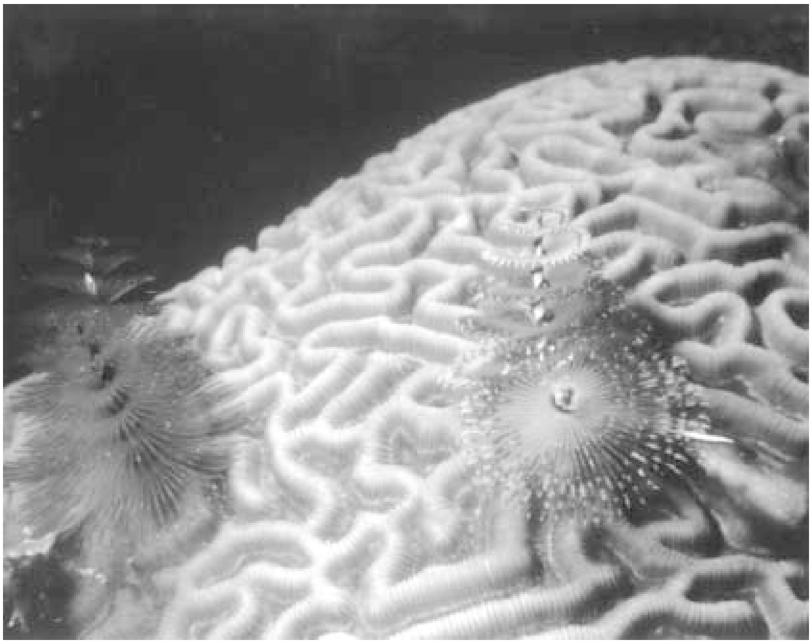
COCOMO

COCOMO (see CD-ROM) illustrates the relation between human activities and coastal problems in Montego Bay through a graphic user-friendly interface. It attempts to provide the information required to prioritize actions in order to preserve and improve the coastal environment. COCOMO is developed for policy-makers, specialists and anyone interested in coastal issues in Montego Bay. It provides information through maps, pictures, model calculations and texts. The model consists of three main parts:

- Background information on the objectives and coastal activities in Montego Bay;
- Information on the coral reef coast, including descriptions of the coral reefs and marine life, different coastal problems, and the values associated with the reefs; and,
- Calculation of the effects of different actions.

For a number of actions that will protect the reefs, the model estimates future coral reef health and the costs of the actions. The model also predicts the least expensive set of actions to realize a specified coral reef health and helps to evaluate the main causes of reef deterioration.

It is hoped that Coral-Curaçao, Coral-Maldives, and COCOMO will make significant contributions to the development of effective integrated coastal management programs and policies. The reader is encouraged to explore the use of these models through the CD-ROM included with this publication.



III: THE CONTEXT FOR POLICY APPLICATIONS AND FUTURE DIRECTIONS

Chapter 11

The Social Context for Local Management in Jamaica

Leah Bunce
International Program Office, National Ocean Service,
National Oceanic and Atmospheric Administration, Silver Spring, MD, USA

Kent Gustavson
Gustavson Ecological Resource Consulting, Gabriola, BC, Canada

Whereas previous chapters have focused on economic analyses of coral reef management, this chapter extends these analyses to consider the socio-cultural implications of reef management by demonstrating the importance, as well as means, of incorporating social and economic information into coral reef management. This chapter presents a case study analysis in which the socio-economic context of the three primary user groups in Montego Bay Marine Park, Jamaica—fishers, hoteliers and water sports operators—were addressed (see Chapter 2 for a description of the Montego Bay Marine Park). The primary tasks of the project were two-fold: first, to conduct a socio-economic assessment of these user groups; and second, to demonstrate the utility of this methodology by considering the management implications of these findings for future Park management. As such, this study serves as a site-specific test case of the socio-economic data collection methodology and the utility of the data for making management decisions.

This project was designed to assist the larger World Bank project (see other contributions in this publication) in identifying an economically efficient outcome that is also socially viable. In addition to contributing to the development of a comprehensive cost-benefit methodology for coral reefs, this study was also designed to meet the needs of the Montego Bay Marine Park (the Park) in documenting the current extent and characteristics of Park use and the socio-economic background of the users in order to determine their concerns and interests, how they would be affected by management alternatives, and opportunities for collaboration. The Park has used this information to reshape Park policies and develop and implement effective management strategies. In a more general context, this study illustrates the importance of socio-economic assessments for reef management.

This chapter: i) presents the methodology used to examine the socio-economic background of the three user groups; ii) briefly describes the socio-economic background of these groups; iii) presents the socio-economic factors that have implications for the development of Park policy and management strategies; iv) discusses guiding principles for future Park management; and, v) presents an analytical framework which can be used to examine the socio-economic implications of future management and policy scenarios.

Socio-Economics in Coral Reef Management

As government and non-government organization resources have become increasingly focused on reef management issues over the past decade, reef management practitioners and theorists have become increasingly aware that to successfully manage these fragile resources sustainably, it is not only important to consider the biophysical conditions that determine system structure and processes, but also to understand the social and economic conditions, contexts, and motivations that are associated with their use (Orbach and Johnson 1989; Renard 1991; White 1989; White *et al.* 1994). As early as 1969, the importance of socio-economic information was stressed by the US National Environmental Protection Act, which states there is a need to "...assess or estimate, in advance, the social consequences that are likely to follow from specific policy actions... and specific government actions..." (ICGPSIA 1994, p.108). The importance of socio-economic conditions was demonstrated by an examination of the socio-cultural compatibility of 68 World Bank projects (Cernea 1985, p.323). The 36 World Bank projects found to be socio-culturally compatible with the project population had an economic rate of return more than twice as high as the remaining 32 projects. As Cernea concluded,

> *Not only does a failure to consider the social and cultural context of a project invite inappropriate design at best (and user hostility at worst), but...it usually leads to projects that are ultimately ineffective, wanted neither by their supposed beneficiaries nor by the investing public agencies.* (Cernea 1985, p.323).

As a result of this growing recognition of the important role of user group demographics, perceptions, cultural values, and resource use patterns in determining effective management strategies (Renard 1991; White 1989; White *et al.* 1994), socio-economic assessments have become an increasingly important component of management decisions (Cernea 1985).

The coastal environment poses particular challenges to conducting socio-economic assessments and examining the implications of management strategies due to the diverse activities and user groups, the typically sectoralized government management regimes, and the nature of these traditionally open access resources. It is these characteristics that make understanding the user groups particularly critical. With the long history of open access evident in most coastal environments, users are inevitably thrown into conflict with competing coastal resource users as scarcity becomes an issue. Underlying the superficial issue of conflicts over the resource itself are the often conflicting social, cultural and economic backgrounds of the user groups.

Unlike biophysical assessments of coral reefs, for which established and standardized methodologies have evolved, means for assessing the socio-economic context of reef management are only beginning to be explored. The Caribbean Coastal Marine Productivity Program (CARICOMP), for example, has focused on assessing the biophysical conditions of reefs and associated habitats for over 6 years (Ogden *et al.* 1997). It is only within this year that the network has begun to consider incorporating socio-economic factors into their assessments (J. Woodley, University of the West Indies at Mona, pers. comm. 1999). At the same time, the Global Coral Reef Monitoring Network is developing a manual for conducting socio-economic assessments (C. Wilkinson, Global Coral Reef Monitoring Network, pers. comm. 1999).

The question, then, confronting many reef managers is, "What are the most appropriate, effective and efficient methodologies for conducting socio-economic assessments?" Perhaps of greater importance, "How can these assessments be utilized to receive the maximum benefit for management programs, particularly to facilitate the incorporation of users into the management process?" Due to the relative infancy of research on the socio-economic context of reef management, criteria specific to evaluating activities affecting reef resources have yet to be comprehensively developed. To date, studies have focused on issue-specific research and on the development of standard indicators for assessing the socio-cultural basis of reef uses (e.g., Pollnac 1998). Economic assessments have only recently begun to examine the extent of the benefits directly or indirectly associated with reef use (e.g., Cesar 1998; Dahuri 1996; Dixon 1992; Pendleton 1995; Tomascik 1993; Weber and Saunders 1996).

There is a lack of research concerning rapid quantitative and qualitative techniques for assessing both the social and economic bases of reef use. Yet, methodologies for conducting socio-economic assessments can be adapted from a range of established anthropological, sociological, and economic approaches, including: classical social, anthropological and economic approaches in which outside researchers use structured and often quantitative, resource- and time-intensive approaches, such as questionnaires and secondary data sources, to solicit information (Bernard 1989; Marshall and Rossman 1993; Patton 1990); rapid rural appraisal (RRA) techniques, in which outsiders elicit information from local people using rapid, semi-structured, field-based approaches, such as semi-structured interviews, focus groups, diagrams, direct observation and ranking (Chambers 1994; Pido *et al.* 1996; Schonhuth and Kievelitz 1994; Townsley 1993); and, participatory rural appraisal (PRA) techniques, in which outsiders serve as facilitators for local people to analyze their living conditions, share outcomes and plan activities using a range of community-oriented participatory programs, such as transect walks, matrix scoring, and wealth ranking (Balarin 1998; Chambers 1994; Schonhuth and Kievelitz 1994). These approaches are gradually, but increasingly, being adapted to the marine environment (Pido and Chua 1992; Pido *et al.* 1996), particularly marine fishing communities and coastal communities (e.g., Balarin 1998; Gorman 1995; Pido 1995; Pollnac *et al.* 1997; Townsley 1993). Adaptation of these methodologies to assess coral reef user groups is critical so that managers can better understand the persons who are being affected by management decisions and can best adapt management decisions for the benefit of these individuals.

Methodology

Data Topics

This study involved a comprehensive investigation of the socio-economic background of the three primary reef user groups of the Montego Bay Marine Park—fishers, water sports operators, and hoteliers. The field portion of the study was conducted during January and February, 1998, in Montego Bay, Jamaica.

The socio-economic assessment of Montego Bay Marine Park examined the current status of social and economic conditions, historic shifts in those conditions, and the extent to which they are anticipated to change. Data on the following socio-economic variables were collected with respect to each user group:

- *Characteristics of user group activities*. This included data on the types of activities (i.e., equipment used, methods employed), the nature of activities (i.e., what's involved, size and level of activity, structure of activity, type of product or output), and the location of activities, including spatial allocation among users.
- *Characteristics of the user groups*. This included demographics (i.e., nationality, age, gender, level of education, ethnicity, economic status, area of residence), cultural value of the activity to the users and to the community, employment and incomes, socio-economic links with other activities, and relations between and within user groups.
- *Users' perceptions of the reef management*. This included perceptions of reef conditions and impacts, concerns for Park management, actions proposed by the users to address concerns, current and past involvement of the user group in management, and their potential role in the future management of the Park.

Means of Data Collection

The data were collected through five principal means: document and database analysis, interviews, focus groups, telephone survey, and participant observation. Triangulation among these sources of information provided an important means to validate the findings (Buzzard 1990; Marshall and Rossman 1989; Patton 1990).

Documents and Database Analysis

An initial review of existing documents and databases established an information baseline from which the subsequent data collection could expand. The following types of documents were examined: government department records and reports, census and survey statistics, non-government organization and academic reports, Montego Bay Marine Park documents, and consultants' reports. This information was primarily used to elicit quantitative data on the user demographics, employment and incomes, and to further substantiate the perspectives revealed through the interviews.

Interviews

Interviews were the principal means of data collection and they provided the core material for developing an understanding of the different user groups. Fifty-two personal interviews were conducted with elite interviewees—persons familiar with, and knowledgeable about, one of the three user groups (Table 11.1; Dexter 1970). Interviewees were selected to provide knowledge about their user group, but to not unnecessarily duplicate information. Each of the interviewees was selected because she or he represents the interests of the group (e.g., the president of a fishers' cooperative), is an experienced par-

Table 11.1. Number of interviewees according to user group and sub-group representation.

User group	*Total number of interviewees associated with each user group*	*Sub-groups associated with each user group*
Fishers	35	River Bay landing beach White House landing beach key informants
Water sports operators	11	party cruises glass-bottom boats dive operations small watercraft all-inclusive hotel water sports
Hoteliers	6	all-inclusive hotels small hotels key informants

ticipant (e.g., a hotelier with more than thirty years experience in the Montego Bay hotel industry), or is a central member of the group (e.g., the owner of a dive and catamaran business and well-known community member). In those cases where an individual who met one of the above criteria was not readily apparent, snowball sampling was conducted in which the other interviewees were asked for recommendations of individuals who might fit the sampling requirements (Oppenheim 1992).

In order to gain in-depth information on topics relevant to the study and tailored to the knowledge and concerns of each interviewee, semi-structured interviews were conducted using flexible, open-ended interview guides (Patton 1990). A base interview guide was developed and then tailored for each interview (Table 11.2).

Most of the interviews were conducted in the interviewee's home or place of business, but some were conducted spontaneously in informal settings. All interviews were conducted in person and, with the exception of two group fisher interviews, were one on one. Before each interview began, the interviewee was given a written description of the research. Any questions regarding the study were then answered, and the importance and confidentiality of responses to interview questions explained. Detailed notes were taken during all interviews, which were transcribed as soon after the interviews as possible in order to note further details, observations and reflections.

Although interviews were the basis of the information collection, a significant amount of information came from less formal contacts. Throughout the study period, informal conversations were held with government officials, users and other individuals. These contacts were particularly useful for discovering other sources, contacts, or issues to explore further.

Table 11.2. Essential elements of the base interview guide.

Characteristics of the activity	• Current activity (range of operations; equipment used; size and frequency of activity; individuals involved; time involved); history of activity (changes in numbers and types; types of clients; locations and frequency); expectations for the future; current locations within Park waters.
Characteristics of the users	• Structure of the industry or activity; characteristics of manager, employee and/or user (including age, gender, ethnic background, education, and economic status); seasonality and duration of involvement; area of residence; basis of participation; dependency for income (including changes over time); willingness and tendency to shift to other employment; types and acceptability of alternate jobs; individuals or businesses linked to activity; type and nature of indirect ties to other activities.
Users' perceptions of Park management	• Perceptions of reef conditions; most significant impacts; perceptions of impacts from water sports, hotels, fishing, farming, cruise ships, manufacturing, littering, city sewage, others; environmental awareness and concern; group involved in marine environmental management; group resources to benefit management; top concerns for the Park; needs for better Park management.
Cultural value of activity	• Attitude and outlook towards the activity (of management, staff, and/or users); importance to the user group community; perceptions of larger Montego Bay community's attitude and outlook towards the activity; importance to the larger community and particular groups.
Community and institutional structures	• Formal and informal organizations (social and professional) and structures; decision-making processes (including addressing common problems); nature of social relations within group; relations and interactions with other groups (including fishing, water sports, hotels, farming, cruise ships, and manufacturing); other groups' effects on your use; nature of relations with government officials; trust in political institutions; relations and involvement with the Park; perceptions of the Park.
Economics	• General industry or activity economic state; profitability of industry or activity; typical cost structures (capital outlays, labor, repairs and depreciation, goods and services, taxes, other); changes over time and perceived reasons behind changes.

Focus Groups

Two focus group meetings were conducted with representatives of fishers and water sports operators to solicit further information with regard to their general concerns for management of the Park, actions they would like the Park to take to address those concerns, and the potential role their user group can play in Park management. These meetings were conducted in part because of the Park's specific interest in learning about the management concerns and interests of the primary user groups. Five water sports operators, representing four businesses, attended the water sports focus group meeting. The fisher focus group meeting was conducted with approximately thirty River Bay fishers.

Telephone Survey

Using the same target questions as the focus group meetings, a telephone survey was conducted of hoteliers to assess their concerns and interests with regard to Park management. The telephone survey was the technique of choice for this user group due to the difficulty in trying to arrange a focus group meeting. Prior to initiating the survey, a fax describing the purpose of the survey was sent to the 23 hotels who border the Park and/or who have expressed a particular interest in Park management. Eight hoteliers participated in the survey.

Participant Observation

Two means of participant observation were conducted throughout the field research period: i) participation in user group activities, and ii) participation in Park management activities. Participation in user group activities included participating in specific user activities (e.g., glass-bottom boat snorkeling) and attending user organizational activities (e.g., the Montego Bay branch meeting of the Jamaica Hotel and Tourism Association). Participation in Park management activities included observations of patrols and daily Park staff activities, and attending Park Trust meetings. These observations provided insight into the mechanics of the user group activities and also helped gain the trust of the interviewees.

Socio-Economic Background of User Groups

In order to comprehend the socio-economic values of coral reefs and the socio-economic implications of reef management decisions, it is important to understand the socio-economic framework that underlies the human behavior affecting the reefs. This section provides the socio-economic background of fishing, water sports activities, and hotel operations, which is necessary for analyzing the socio-economic factors affecting reef management in Montego Bay Marine Park. Each of these activities is associated with several user groups (Table 11.3). The profiles presented here include information on the user groups' current, past and future levels and types of usage, as well as characteristics of each user group.

Fishing

Fishing has been, and continues to be, an important socio-economic component of Montego Bay, particularly to the five landing beaches—River Bay, White House, Reading, Bogue, and Spring Gardens. Over 85% of the approximately 400 registered fishers are based out of the two largest sites, River Bay and White House, while the remainder are based out of Reading, Bogue and Spring Gardens (Figure 11.1). In addition, an estimated 150 unregistered spear fishers operate from indeterminate sites along the coastline. Excluding the number of fishers who fish outside of Park waters, there are approximately 378 fishers fishing in the Park.[1]

Table 11.3. Users associated with fishing, water sports, and hotel development.

Activity	*Primary users*
Fishing	Full-time and part-time fishers at River Bay, White House, Reading, Bogue, and Spring Gardens landing beaches
Water sports activities	Dive, snorkel, and party cruise operators (including owners, managers and staff), and visiting snorkelers and divers[a]
Hotel operations	Hoteliers (hotel owners and managers) and hotel staff

[a] Tourists, including visiting divers and snorkelers, were assessed in a contingent valuation study (Chapter 6); this report focused on the water sports operators, which includes the owners, managers, and staff.

Spear and hand line fishing are the predominant methods of fishing in Park waters, followed by net and trap fishing. Trap fishing typically occurs within a mile of shore, in depths of 30 to 60ft, on sand and near the reefs (Figure 11.1).[2] Some fishers set as deep as 80 to 90ft to avoid vandalism by spear fishers, although this approach reduces catch rates. Net fishing typically occurs in sandy areas often between the reef and the shore. The primary net fishing sites are behind Doctor's Cave reef, along River Bay landing beach, and east of Spring Gardens landing beach. Hand line (or hook and line) fishing occurs from offshore to shallow areas and, subsequently, overlaps with many of the other fishing activities, particularly those of trap fishing (Figure 11.1). Spear fishers fish as deep as 60ft and as much as half a mile offshore. Within the Park waters, the most popular spear fishing areas are the reef from the airport to off of Doctor's Cave beach, the reef along the north western side of Seawind, and the reef westward along the coast to the Great River. Although catch per unit effort (per fishing trip) has declined to approximately 10 to 20lbs per trip, the number of registered fishers has increased 68% within the past three years. As catches have declined, fishers with motorized boats are shifting to offshore trolling, which occurs outside Park boundaries. Fishers without engines continue to predominantly fish within Park waters.

Based on the interview data, a realistic average yearly individual net income before taxes for most fishers (with the exception of spear fishers) is approximately J$104,000 to J$156,000 (US$3,000 to US$4,500).[3] This results in a total net income of US$1,134,000 to US$1,701,000/yr for all fishers. Weekly individual incomes, before taxes, per

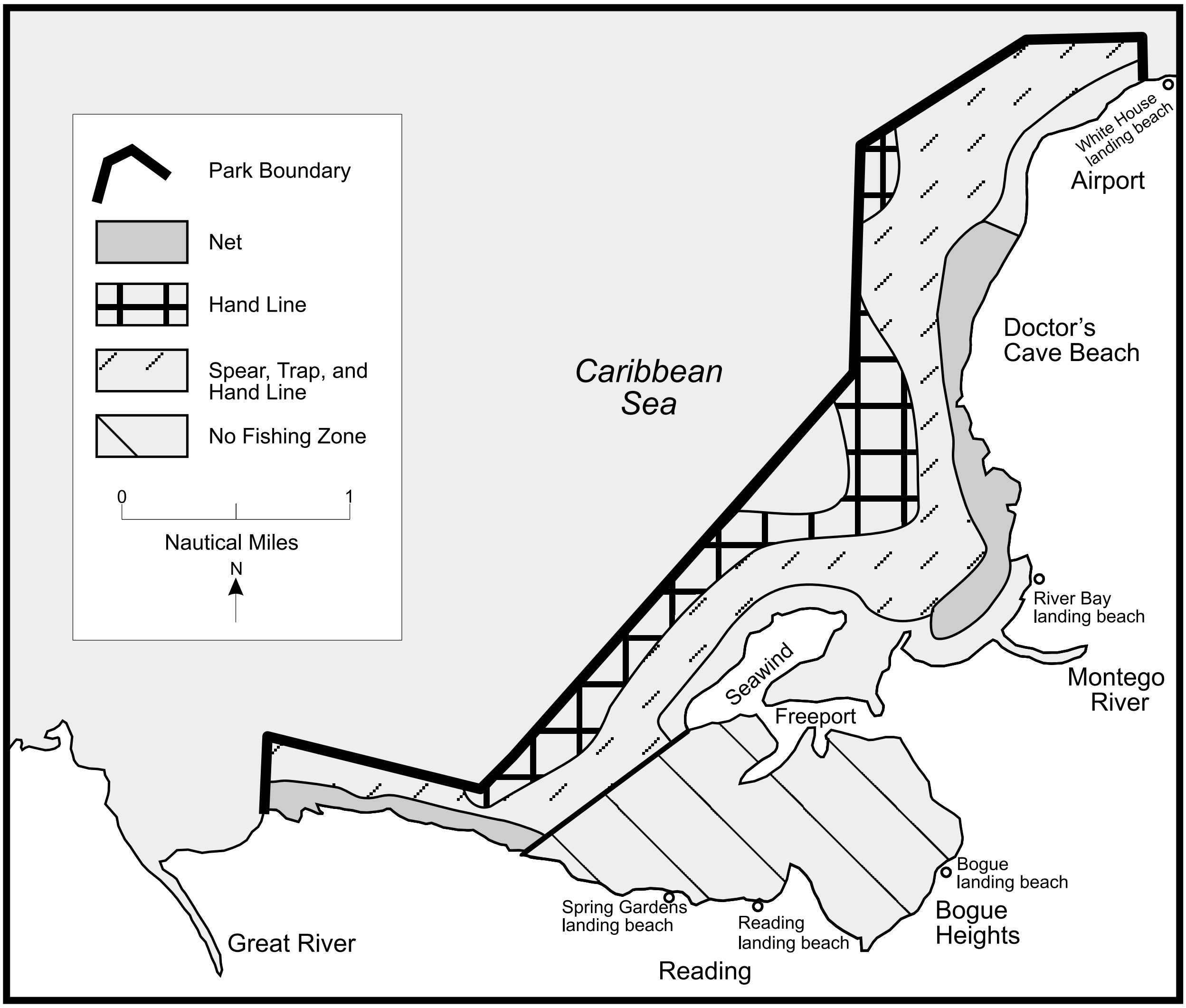


Figure 11.1. Fishing activities within Montego Bay Marine Park.

fishing activity are estimated as: J$750 to J$2,500 (US$21 to US$71) for trolling; J$250 to J$500 (US$7 to US$14) for trap fishing; J$750 to J$2,250 (US$21 to US$64) for net fishing; J$750 to J$2,500 (US$21 to US$71) for hand line fishing; and J$5,000 to J$7,000 (US$143 to US$200) for spear fishing.

According to Fisheries Division (Ministry of Agriculture, Government of Jamaica) statistics, approximately 69% of fishers depend on fishing as a full-time source of employment. Interviewees estimated that 70% to 95% depend on fishing as their sole source of income; however, fishers also noted that most fishers have a second means of income. Almost all fishers are subsistence or small-scale commercial fishermen who sell their catch directly to the public at the landing beaches.

Fishers are generally characterized as poorly educated, low income Jamaicans with reputations for being highly independent. As one fisher defined his peer group, the "poorer class of people is the fisherman." The young fishers tend to view fishing as a flexible means of making a good living while retaining their independence. Although the older fishers also value their independence, they value fishing as an important part of their lives, more so than the younger fishers. As one older fisher stated, "I love fishing more than I love girls... it's in my whole being." In addition to being important to the fishers, fishing is also an important component of the surrounding communities, particularly at White House and River Bay. As one fisher noted, "Fishing plays a major role... It's the backbone of social and economic life here."

Water Sports Activities

Water sports activities in Montego Bay include 28 dive operations, snorkel businesses, party cruisers, and small-scale water sports businesses. Based on a survey of these operations, combined they take a total of over 3,100 tourists and nearly 220 trips into Park waters each week. On an annual basis, over 163,000 tourists utilize Park waters through over 11,000 water sports trips.

Water sports operations in Montego Bay began in the 1940s when the first glass-bottom boats began operating. Following the trend of the tourism industry, water sports boomed in the 1970s and 1980s. In the last five years, the number of private water sports operations has stabilized and has started to decline, which operators anticipate will continue. Since the shift towards all-inclusive hotels began 20 years ago, water sports operations, particularly the small watercraft operations, have been increasingly owned and managed by hotels. Currently over 66% of the beachfront hotels run their own water sports. Dive businesses are independently owned and operated under contracts to the hotels, while the party cruises market their businesses through concessionaires at the hotel and water sports desks. Many of the glass-bottom boat and snorkel operations remain independently run; however, these businesses are in dramatic decline, surviving only "by the mercy of God" as noted by one operator.

With the exception of the party cruisers and the independent snorkel operators, the water sports operations are mainly located along the Park coast, particularly adjacent to the strip of hotels north of the Park and, to a lesser extent, southwest of Montego Bay (Figure 11.2). Doctor's Cave reef is the main snorkeling, diving, and cruising destination.

The water sports industry is an entrepreneurial business with strong Jamaican representation. Over 90% of the water sports operations are Jamaican owned and managed. Originally, most operators entered the business because of their love of the water—"you had to love it" and it was something that became "a way of life". However, within the past ten years, there has been a shift such that water sports operations are being increasingly viewed as a business investment. With the decline in business, owners and managers are seeking alternative additional investments.

Total direct employment in the water sports industry is estimated at 200 employees. In contrast to the owners and managers, the typical water sports staff is a young (18 to 37 years of age) Jamaican male with little education, single with two to three children, referred to by a couple of managers as "beach bums". Water sports positions are considered good jobs because they offer a relatively high income while requiring a low level of skill. The employees have the added benefit of being able to work on the water. Turnover is relatively high (one to four years) within individual shops; however, staff tend to stay within the industry as a whole.

Hotel Operations

"The cradle of Jamaica's 20th century tourist industry," Montego Bay plays a major role in Jamaican tourism (GMRC 1996). Montego Bay receives 82% of all foreign national stopovers at its airport, accommodates 38% of those visitors, receives 26% to 34% of Jamaica's cruise ship visitors, and contributes approximately 15% of Jamaica's foreign exchange earnings (GMRC 1996).

Paralleling the growth of the tourism industry in Montego Bay, the hotel industry began in the 1920s, increased in the 1940s and the 1950s, declined dramatically during the socio-political unrest of the 1970s, rejuvenated in the 1980s, and is currently viewed as stabilizing. During this time, there has been a shift in the type of hotels from elite,

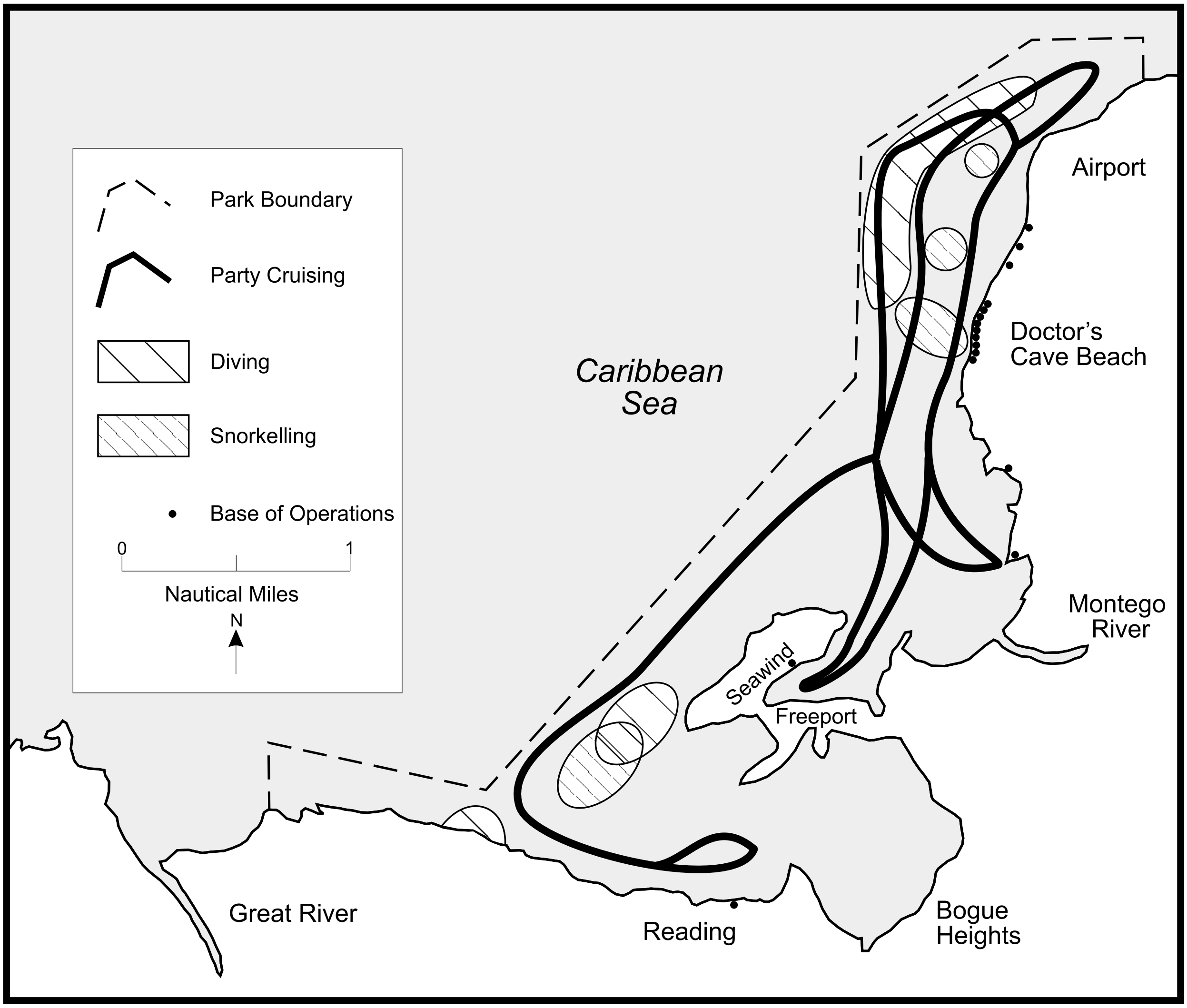


Figure 11.2. Water sports activities within Montego Bay Marine Park.

high-class, foreign-owned hotels, typical of the 1920s to 1960s, to the current mix of exclusive resorts, small European plan hotels, and large, mass-market all-inclusive hotels. Despite the continued shift towards large, all-inclusive hotels (11 of 56 hotels are currently all-inclusives), the predominate type of hotel is still small and non-all-inclusive (41 of 56 hotels have less than 100 rooms). Currently, there are 56 hotels with 5,371 rooms. Annual occupancy rates average 53.37%, with over 800,000 rooms sold per year.

In large part due to the socio-political changes of the 1970s, the hotel industry, particularly the smaller hotels, are predominantly (over 75%) Jamaican owned and managed. The hotel managers and owners view the hotel industry as both a business and as a way of life. Hotel employment is estimated at over 16,000 employees, including 6,400 direct and 9,700 indirect employees. The hotel employees, who are typically Jamaican with a high school level education, view their jobs as a means of income with few long-term expectations.

These socio-economic profiles highlight the diverse nature of these three reef user groups, all of whose activities affect the reefs and reef environment in some way. The use patterns and characteristics of the groups range from the poor communities of fishers, who have been fishing Montego Bay's waters for generations, to the water sports operators, who in conjunction with the hoteliers, serve a multi-million dollar tourism industry. These socio-economic backgrounds provide the context for assessing the management implications of the user group characteristics and usage patterns.

Socio-Economic Factors of Importance to Reef Management

Analysis of the socio-economic context of the three user groups indicates that there are several factors of particular significance for reef management programs and policies. These relate to: i) patterns of use; ii) the level of dependence on the resource; iii) the cultural value of reef activities; iv) ethnicity; v) relations within and among user groups; vi) the nature of indirect links to the Montego Bay community; vii) the level of awareness and concern for the resource; viii) relations with the Montego Bay Marine Park; and, ix) the nature and extent of resources of use to management efforts.

Patterns of Use

Comparison of usage patterns reveals a significant overlap between water sports and fishing activities (Figures 11.1 and 11.2). Doctor's Cave, located immediately offshore from the main strip of hotels, is the prime destination for party cruise, dive, snorkel, and glass-bottom boat operations. This area is also one of the most popular fishing areas for trap, hand line, and spear fishers. Since the reefs are immediately offshore from the hotels, the reefs are also at risk from sediment run-off and sewage disposal associated with hotel developments. As the intensity of use by divers and snorkelers has increased with the expanding tourism industry, rivalry has lead to conflicts over resource usage to the point that each group is accusing the other of sabotaging their ability to fish or dive the reefs. The fishers are accused of fishing out the dive and snorkel sites; the water sports operators are accused of opening the fishers' traps. These conflicts may pose the greatest challenge to managers, who are faced with having to maintain a balance of these various activities at sustainable levels, as well as having to limit or mitigate the impacts of one user group's activities on another.

Dependence on Resource Use

As discussed above, there are approximately 400 fishers and 200 water sports operators whose livelihoods directly depend on the reef resources. Approximately 70% to 95% of the fishers depend on fishing as their primary source of income with limited alternatives. The majority of water sports staff are full-time employees dependent on water sports as their primary source of income. Also, there are approximately 6,400 direct hotel employees who benefit from the reefs as a tourist attraction for hotel guests. The fact that such a large group of users is dependent on the fishing, water sports, and hotel industries for employment and earnings illustrates the importance of the reefs. Further, these findings indicate that dramatic changes in reef quality or changes in the management of reef activities could significantly and directly affect a large group of dependent users. These statistics demonstrate the political significance of continuing Park management programs to ensure the long-term sustainability of the reef resources and, subsequently, the user groups they support.

Cultural Value of Reef Activities

In addition to the benefits of reefs through direct employment and earnings and the multiplying economic effects though the larger economy, there are also cultural values associated with the reef activities. The cultural importance of fishing is demonstrated by the older fishers' love for the activity and its importance to the communities surrounding the two main landing beaches, White House and River Bay. The cultural importance of fishing confirms the need to consider the implications of management decisions not only in economic terms, but in the way management decisions may change peoples' way of life and, subsequently, impact their values.

In contrast to the older fishers, the hoteliers, water sports operators, and young fishers are increasingly viewing their activities as businesses. This shift towards a business perception of reef usage illustrates the importance of demonstrating the economic benefits of reef conservation programs in order to gain these users' compliance and support.

Ethnicity

Jamaicans dominate the fishing, hotel and water sports industries. Over 75% of the hotel owners are Jamaican, over 90% of the water sports owners are Jamaican, and all of the Park fishers are Jamaican. Furthermore, most of the hoteliers and water sports operators have been working in the tourism industry for ten to twenty years with little turnover, while most of the fishers have been fishing Montego Bay waters "since they were old enough to walk". As a consequence of their long histories in the region, these groups have direct knowledge of the resource conditions and impacts over time. This knowledge has contributed to their appreciation for the importance of conservation and sustainable use practices. In addition to taking advantage of the users' long-term knowledge to develop a better understanding of changes in resource conditions and appropriate locations for management programs (e.g., high diversity areas for reef monitoring), managers can draw on the users' pride in their natural treasures to develop concern and support for reef management programs.

Relations Within and Among User Groups

Relations between user groups are generally poor. There are limited interactions between fishers and hoteliers, in large part due to their distinct socio-economic backgrounds. Private water sports operators have feelings of resentment towards some of the hoteliers, particularly the all-inclusive managers, because they are increasingly dominating the water sports industry. Antagonistic relations have developed between fishers and water sports operators because each group feels the other is threatening their livelihood through fishing out the marine life and through opening or damaging fish traps, respectively. Regular encounters in Park waters, while using the resource, compound the problem.

With regard to the relations among users within each of these three user groups, there are strong formal and/or informal professional and social relations within each distinct user group. The two fishing communities at River Bay and White House landing beaches have established cooperatives that lobby for their mutual interests, including improved facilities and duty-free concessions. Hoteliers have both formalized interactions through the Montego Bay chapter of the Jamaica Hotel and Tourism Association, as well as informal relations through social events. Although the water sports operators do not have an organizational structure, as one operator noted, "everyone knows everyone". These formal and informal networks within each user group have provided opportunities for these users to work together towards addressing their common concerns. This framework could provide a basis for developing users' participation in, and support of, Park management programs. Further, the organizational network of each user group could be drawn upon to build ties between groups and, ultimately, develop intersectoral, comprehensive management programs that address the diversity of activities affecting the Park resources.

Indirect Links to the Montego Bay Community

There are many indirect links between these three user groups and the larger Montego Bay community that are primarily associated with the tourism and hotel industry. As the GMRC (1996) reported, the hotel industry, "has created significant inflows of foreign currency, generated widespread direct and indirect employment, triggered further rounds of economic activities, provided outlets for cultural and artistic expressions, and impacted positively on Jamaica's government revenue and to the current account of its balance of payments." With regard to water sports activities, the water sports operators are linked to each other, the hotels and the cruise operators through commissions, contracts and ownership. Forward links from fishing to other activities are relatively limited since fishing is largely subsistence with few sales; however, there are important backward links from goods and services sold to the fishers by the surrounding communities. The backward and forward linkages between various sectors indicate that management programs and changes in reef quality can have significant effects on the larger Montego Bay community.

Awareness and Concern

All three user groups recognize that marine resource conditions are deteriorating at an alarming rate. Further, these groups generally agree on the major causes—specifically, pollution from solid waste and sewage disposal. The water sports operators and hoteliers generally recognize, and are concerned about, the impacts of their own activities and their guests' activities. In contrast, the fishers do not see fishing as having a major impact on the reefs. As one fisher noted, "more fishers means catch more fish". Perhaps of greater importance, there are misunderstandings by fishers and some hoteliers regarding Park regulations, particularly boundary locations, and there is a general lack of awareness of Park activities. This lack of awareness regarding Park activities has contributed to the current lack of trust in the Park's ability to effectively manage the Park resources. Future support and assistance from these important user groups depends on better communication regarding Park activities. Further, compliance of the fishers with Park regulations necessitates an awareness program on the short-term effects of intensive fishing on marine resources *and* the long-term benefits of sustainable fishing practices.

Relations With the Montego Bay Marine Park

Water sports operators generally have strong, positive relations with the Park staff. Many water sports managers and owners have been actively involved in Park management, including lobbying for the establishment of the Park, serving on advisory commissions and the current Park Trust, and assisting in Park management programs, such as the reef mooring system and public education programs. This positive relationship is in direct contrast with the Park's relations with the fishers. The common perception of the fishers regarding management is well reflected in one fisher's comment: "Now Park is helping us into trouble... need to help us out of trouble." The fishers, who have been fishing the Montego Bay waters for generations, feel that they are being unfairly targeted in the Park's attempts to protect the reefs and the marine conditions.

Relations between the Park and hoteliers vary. Some hoteliers assist in fund-raising efforts by hosting events and sponsoring individual management programs, while other hoteliers are not even aware that the Park exists. The Park's positive relations with the water sports operators and some hoteliers indicate that these two groups can be continued sources of technical assistance and support; however, the poor relations with the fishers indicate that the Park will have to demonstrate its support of fishing activities within Park waters in order to gain the fishers' support for sustainable fishing programs and further management efforts initiated by the Park.

Resources of Use to Management Efforts

The resources of the different user groups can potentially benefit Park management. Both the water sports operators and the fishers are highly knowledgeable of the reefs and have ready access. The water sports operators snorkel and dive specific reef locations on a daily to weekly basis. Although their schedule is less predictable, reef fishers are on the water between one to five times each week and have relatively flexible working schedules. Mooring, monitoring and enforcement programs are three programs that could actively involve the operators and fishers in managing the reefs while taking advantage of their reef knowledge and access.

Hoteliers offer another important resource—funding. Hoteliers already support some community social services, such as the school bus system, as part of their public relations program; eliciting hotel support for coral reef conservation efforts would further promote community relations and contribute to their reputations as environmentally sensitive tourist accommodations. The financial resources of the relatively affluent, increasingly conservation-minded nature of many of the tourists might also be accessed through the hotels. Hosting fund-raising events, selling Park concession items in their gift shops, including a "donation to the Montego Bay Marine Park" option on guest bills, and collecting user fees are some of the ways hotels could utilize their access to the tourist community to solicit funds for the Park.

Guiding Principles for Future Reef Management

The analysis of the socio-economic factors of importance to reef management provides the basis for developing guiding principles for future reef management in Montego Bay Marine Park. The analysis highlights several major insights regarding the importance of: i) user group awareness and concern; ii) opportunities to market the Park and to provide incentives; iii) user group involvement in management; iv) management of the Park as a community resource; and, v) inter-sectoral coordination among user groups. This section discusses the importance of these principles, their current state with regard to Montego Bay Marine Park management, and how they can be developed to maximize the socio-economic benefits of reef use through effective management.

User Group Awareness and Concern

A greater awareness of the Park and its policies and programs is essential if effective management is to be achieved. High levels of user group awareness and concern regarding reef conditions, impacts and management issues serve as a basis to work towards ensuring sustainable use and conservation of the reef resources. The user groups are the individuals with potentially the greatest impacts on the reef quality, but also are potentially the greatest supporters politically, financially, and in kind. Without faith in the Park's abilities and initiatives, user support will not be forthcoming.

Currently the majority of the fishers, water sports operators and hoteliers are aware of the decline in the reef conditions and of the nature of the impacts, but many of the fishers and hoteliers are unclear or unfamiliar with Park regulations, policies and programs. The fishers, for example, perceive the Park to be trying to push them completely out of Park waters; however, Park objectives are to allow multiple, sustainable levels of activities, including fishing. As a result of these misunderstandings, many of the fishers and hoteliers, and a few of the water sports operators, lack trust, or are losing trust, in the abilities of Park authorities to manage the area. This has led to low levels of compliance with regulations and management directives and waning support for the Park. The need to increase Park awareness is at a critical stage as the demand for the marine resources and the levels of use are increasing, yet the environmental conditions are declining. This situation will only lead to an increase in the rival behavior of the users, and animosity and conflict between groups.

This lack of awareness is attributed, in part, to poor communication between the Park and the users, the lack of visible, tangible products and services from the Park, and a lack of user education regarding Park goals and programs. This analysis indicates that improved awareness requires that Park education programs be targeted specifically to the user groups, perhaps through outreach programs, and that they highlight the Park's management programs, particularly the beneficial, tangible products and services the Park provides (e.g., training for fishers, mooring system for water sports operators).

Park awareness programs also need to demonstrate the value of conservation not only in terms of biodiversity, but also in terms of the social, cultural, and economic values of reefs and their associated activities. Users' general awareness and concern regarding reef conservation may be enhanced by focusing on the benefits to their businesses and way of life, and by taking advantage of their sense of pride in their natural heritage. The owners, operators, and employees of the fishing, water sports and hotel businesses are predominately Jamaicans and long-term participants in the industry. Montego Bay Marine Park management strategies can take advantage of the resident status, nationality and history of these user groups in the area by emphasizing the direct vested interest these stakeholders have in the conservation of the reefs. Further, given that these three user groups are increasingly viewing their activities as businesses, concern for the reefs may also be increased by demonstrating the economic benefits of reef conservation in terms of the number of employees and incomes associated with reef activities. In contrast, for the older fishers, management strategies need to show the potential for maintaining the cultural values associated with fishing. Targeting the social, cultural and economic values of reefs can demonstrate the importance of sustainable use of the reefs to these diverse groups.

Opportunities to Market the Park and to Provide Incentives

In addition to developing a greater understanding of the socio-economic benefits of coral reef conservation through programs that increase awareness and concern, users must also be able to realize those benefits directly. The closer the tie between reef conditions and business earnings, the greater the users' support for reef conservation. The links between coral reef conditions within the Montego Bay Marine Park and the economic and social benefits are not immediately apparent for some user groups. For example, the tourism business in the area depends to a large extent on Montego Bay maintaining an image of a near pristine marine environment with a biologically diverse and healthy coral reef environment. However, although the economic health of the accommodations sector directly depends on tourism, the direct link between the marine environmental conditions and business activity are not necessarily perceived by owners and managers. Consequently, business and management decisions rarely consider the potential impacts of decisions on the reefs.

The Park needs to provide the link between reef conservation and the direct economic benefits to businesses. This may be accomplished by "selling" support for the Park and its reef management programs. Given the tourists' increasing demand for "environmentally friendly" products and services, tourism related industries (e.g., hotels and water sports operations) can utilize their support of the Park to attract tourists to their "eco-conscious" businesses. An example of a mechanism for soliciting support that would allow these businesses to demonstrate their environmental commitment is a "Friend of the Reef" program in which donors are presented framed certificates and given special advertising rights in tourist magazines. Given that hoteliers and water sports operators are increasingly viewing their operations as businesses, this strategy is an appropriate means to tap into these groups' financial resources to the benefit of both the Park and these user groups.

In the case of the fishers, where there are fewer direct, short-term economic benefits from reef management programs, the Park must provide socially and economically realistic alternatives if fishing activities are to be curtailed. In order for fishers to begin to cooperate with management initiatives, the Park needs to demonstrate its support of fishing activities by developing programs that benefit the fishers (e.g., low rate loans, training in alternate occupations), rather than programs that have the apparent intent to alienate their way of life (e.g., more "no fishing" zones). Such programs could be in the form of financial or educational support for an alteration in their fishing patterns or techniques. Regardless of the form, these programs need to be initiated before further restrictions on use are imposed.

User Group Involvement

Another important guiding principle for reef management is user group involvement in which there are cooperative efforts between the public and private sectors. Involvement of individuals affected by management decisions in the decision-making process helps gather political support for, increase compliance with, and reduce opposition to, policy proposals, projects, and other decisions by considering and building in users' concerns. User involvement brings into decision-making more information and a wider range of experiences, both of which contribute to the development of more realistic policies and programs. Further, user involvement ultimately maximizes limited public agency resources by drawing from user resources (e.g., fishers and dive operators' daily access to, and knowledge of, the reefs).

Many users, particularly water sports operators, already play significant roles in management of the Montego Bay Marine Park, primarily through informal and formal relations with the Park. As outlined above, water sports operators generally have strong, positive relations with the Park staff, having been actively involved in Park management. Relations between the Park and hotels and the extent of involvement by hoteliers varies. Existing, positive relations can be used to foster long-term commitments to the Park.

User involvement can be facilitated by focusing on resources that the users can provide to management such as access to, and knowledge of, the reefs and fund-raising opportunities. These resources can be tapped by working through existing organizational structures and networks. For example, the formal organizational structure provided by the Jamaica Hotel and Tourism Association has already provided a means for hoteliers to work together. This can be tapped to develop cooperative programs with the Park. Further, the strong community structure evident within the White House fishing community can provide a base for developing better communication between the fishers and the Park. This community structure can be used as a vehicle for implementing programs in which fishers are directly involved. River Bay fishers are more reticent of new approaches and, thus, will likely be more skeptical of new Park initiatives, yet there is the potential of working through the River Bay Fishermen's Cooperative to gain acceptance and direct involvement. By developing programs that utilize the users' resources and skills, these groups can be positively brought into the management process while contributing to its success.

Finally, successful development of a program of user involvement in Park management needs to demonstrate a commitment to multiple use. Fairness in user treatment needs to be instilled and perceived by users. Fishers predominantly feel that they are being unfairly targeted by management authorities in the Park's efforts to bring under control the continuing decline of the reef conditions, while other damaging activities go unchecked (e.g., party cruises, diving, snorkeling). There needs to be more balanced involvement of all the user groups.

Management of the Park as a Community Resource

The coral reefs of Montego Bay are common pool resources managed under a regime of open access. The restrictions that have been put in place with the intent of preventing or curtailing the use by some groups have been ineffectively enforced (e.g., the ban on spear fishing), while there are few restrictions on use by other groups (e.g., diving and snorkeling). The user groups are generally aware of the severe decline in the reef conditions, yet under the current management environment it is unrealistic to expect the users to curtail or alter their use patterns, with the associated loss in short-term benefits or additional incurred costs, because it will be seen as a sacrifice for the benefit of others. The open access regime needs to be replaced in favor of a management regime that provides for exclusion and the capture of economic rent from users benefiting from the use of the reef.

The issue of managing the coral reefs through the allocation of "property rights" is not only a matter of limiting and licensing users and collecting user fees (or other vehicles for rent capture). Ideally, it also involves changing the social perception of the coral reefs by developing a sense of the reefs as a community resource. This means fostering the belief that each user has an interest in effective management and that their long-term interests are protected. This strategy can strengthen their individual positions as important components of the larger community and as integral participants in Park management, whether they be fishers, water sports operators, or hoteliers.

All three previously discussed guiding principles for reef management will help develop a sense of community around the resource—a sense of community that necessarily arises out of an increase in the awareness and concern over the resource, an increase in the ability to see direct social, cultural, and economic benefits from conservation, and an active role by all users in the development and implementation of management programs.

Inter-Sectoral Coordination

Given the diversity of activities affecting the reefs (e.g., pollution, snorkeling, diving, and fishing; see Chapters 1 and 2), management must be integrated across sectors and across the land-sea boundary. Coordination within and among user groups is important for users to participate in, and contribute towards, comprehensive management efforts of these diverse activities. Building better relations, and eventually coordination, between user groups improves support for management initiatives.

The study revealed that user groups are sectoralized, with few working or social relationships forged between user groups. This sectoralization is quite evident even within particular user groups. For example, River Bay fishers have few relations with White House fishers, and all-inclusive hotel water sports operators are not on familiar terms with those working in non-hotel affiliated water sports. In many instances, the lack of either social or working relationships, and the lack of an understanding of the other users, has lead to antagonism and conflict, a lack of trust between groups, an unwillingness to comply with management initiatives, and, ultimately, further degradation of the reef.

As discussed with regard to user group involvement, the current network of users can serve as a base for developing further, positive interactions. By focusing on the similar interests of the users and ways to resolve conflicts, coordination between groups can be facilitated. By gradually building positive relations among the user groups, they will ultimately be able to work together to maximize the range of available resources, minimize duplication, and ensure complementary and cooperative programs as part of a comprehensive effort towards reef management.

Conclusions

This study compliments the other components of the larger World Bank project, which is developing and testing methodologies for estimating the benefits derived from the use of coral reefs in the developing tropics (see other contributions in this publication). The potential policy directions arising out of a cost-benefit analysis aimed at achieving an economically efficient outcome can be assessed with regard to the socio-economic implications using the analysis presented in this study. More specifically, the guiding principles, which were developed through the analysis by considering the socio-economic factors of importance for management, can be used to help focus policy and program efforts to achieve an efficient, viable, and sustainable management strategy.

As presented in the previous chapters, the coral reef valuation work focused on: i) an examination of the direct and indirect *local use* values, focusing on the estimation of the contribution of coral reef biodiversity to production values; ii) an examination of the contribution of coral reefs to the utility of individuals through a *contingent valuation* survey to reveal willingness-to-pay for both use and non-use benefits; and, iii) an examination of the potential for biodiversity values to be realized through *marine bioprospecting*, involving consideration of the size and distribution of use values through captured rent, profits, or value added. The link between the socio-economic assessment and the economic valuation studies for Montego Bay Marine Park can most clearly be seen through the identified socio-economic factors of importance for reef management. First, the extent of the dependence on resource use documented by this study outlines the nature of the direct employment and earnings for approximately 8,000 people among the three primary user groups (fishers, water sports operators, and hoteliers), as well as many socio-economic links with other components of the economy and the community at large. The direct production values associated with tourism and fisheries are the subject of the *local use* study (Chapter 5). This socio-economic assessment provides additional cultural and social context for the more detailed modeling of the associated fisheries and tourism production values. Second, the cultural value of reef activities, described here, are also addressed through the *contingent valuation* study, in which the willingness-to-pay for conservation by local residents and tourists is estimated (Chapter 6). The socio-economic assessment again provides necessary detail to assist with the successful implementation of policies and programs by providing the larger context necessary to consider the viability of alternatives. For example, potential mechanisms that can be used to capture tourist consumer surplus (the difference between the amount of money that they would be willing to pay and what they actually do have to pay), as measured through the contingent valuation, are identified through the examination of the potential user group resources.

In addition to the links with other components of the coral reef valuations, this study presents findings not addressed by the other project components. These findings relate directly to considerations necessary for effective management, including the patterns of use, the ethnicity and extent of involvement of the users, the relations within and among user groups, relations of the users with Park authorities, and the identification of user resources that may be beneficial to management. The identification of an economically efficient conservation effort based on the economic valuation and least cost intervention studies alone would not necessarily lead to a successful or efficient program in practice, without considering the implications of critical socio-economic factors such as those presented in this study.

Endnotes

[1] The approximate total of 378 fishers fishing within Park waters is based on the summation of the following: 150 unregistered spear fishers, 10% of all registered fishers in White House, and 100% of all registered net, spear, trap, hand line, and "other" fishers in the other four landing beaches.

[2] The fishing zones in Figure 11.1 are not as spatially distinct as depicted. Methods of fishing overlap with adjacent methods, particularly as one moves from offshore to inshore. However, there is an overall pattern of zonation as indicated in the figure.

[3] This calculation is based on the estimated J$2000 to J$3000 per week net income, before taxes, per fisher. A figure slightly higher than that calculated based on second-hand catch and price information was assumed based on the judgment that the higher estimate was more "realistic" (based on cross-checking of information from other sources and as provided in other components of the interviews). The net income "nets out" operating costs, maintenance and depreciation, and returns for capital investments (i.e., return to the owner of the boat). The exchange rate assumed throughout this document is J$35=US$1.