Issues in Applied Coral Reef Biodiversity Valuation: Results for Montego Bay, Jamaica

World Bank Research Committee Project RPO# 682-22 "Marine System Valuation: An Application to Coral Reef Systems in the Developing Tropics"

Final Report
March 1999

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Abstract

The broad objective of this research is to assist policy makers in managing and protecting coral reefs by deriving improved estimates of coral reef economic benefits. While the research area of biodiversity valuation has grown significantly over the past decade, most research efforts dealing with valuation focus on terrestrial diversity; no methodical investigation has been made of marine biodiversity valuation issues.

The research includes an extensive review of existing biodiversity valuation studies, with a view to identifying appropriate methodological frameworks for marine biodiversity valuation. We generally endorse the use of a Total Economic Value approach, which includes, for example, direct use, indirect use, and non-use values; we underline, however, the need to recognize that such values are frequently non-additive. In addition, our classification framework recognizes three different methodological approaches to biodiversity valuation, which we characterize as Production Valuation, Utility Valuation and Rent Valuation methods. Each of these methods will use a different style of estimation approach, each will generally address a different type of policy problem, and each will generally result in a different empirical valuation. This research regards all of these methods as potentially useful and technically valid; while there are definite incorrect methods for valuation, there is no single correct method. Similarly, we would argue that economic value is dependent on the decision-making, institutional or policy context: there is thus no single biodiversity value that can be attached to any particular reef area. In this light, biodiversity valuation should be regarded primarily as an educational tool to assist policy-makers, and secondarily as a planning tool in formulating specific policies. Although economic theory might provide us with a basis for using benefit valuation in an optimizing framework (e.g., choosing optimal conservation levels or quality targets), we advise that this be done only with extreme caution; our results indicate that optimal policy choices are very sensitive to the chosen valuation methodology.

Empirical work for Montego Bay, Jamaica, commenced with an estimate of the net present value (NPV) of readily identified local uses using production valuation approaches; these provide a benchmark value for comparative purposes. Values estimated included tourism and recreation (NPV of US$315 million), fisheries (NPV of US$1.31 million) and coastal protection (US$65 million). The total NPV of US$381 million translates to approximately US$8.93 million per hectare net present value, or US$893,000/ha/yr on an annualized basis. This is based on an estimated coral reef area within Montego Bay of 42.65 ha.

Contingent valuation methods for the same area explored the relevance of lexicographic preferences — represented by "zero willingness to pay (WTP)" — on respondent preferences. These approaches are meant to address the consumer surplus, or individual utility, of coral reef improvement. The survey instrument was designed to capture the "non-use" benefits of marine biodiversity at Montego Bay, for both local Jamaican residents and for visitors. Expected WTP for coral reef improvement was US$3.24 per person in a sample of 1058 respondents (a similar study for Curaçao placed this at US$2.08 per person). But this value was heavily dependent on whether respondents believed that marine systems possessed inherent rights, or that humans had inherent duties to protect marine systems; such preferences would increase WTP by up to a factor of three. For typical population characteristics, and using typical visitor profiles, it is estimated that the Montego Bay biodiversity has a net present value of US$13.6 million to tourists and US$6.0 million to Jamaica residents. The total NPV of US$19.6 million translates to approximately $460,000/ha, or $46,000/ha/yr on an annualized basis.

The above values imply a net present value of approximately $400 million for the Montego Bay reefs. At present, no institutional arrangements exist for capturing any values for biological prospecting, so this value may be taken as a lower bound estimate. While it is difficult to translate this into a marginal benefit function, best estimates for coral abundance and available substrate suggest that this is equivalent to a marginal benefit of US$10 million per % of coral abundance improvement. Related research on least-cost modeling of interventions suggested that up to a 20% increase in coral abundance may be achievable through 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 $1 million per % of coral abundance to $29 million per % 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 in the areas of: 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. 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 (achieving a 20% coral reef improvement), would require additional benefits of some $660 million.

The impact of pharmaceutical bioprospecting values on this optimal value depends on a number of factors. Using typical cost estimates for Jamaica, and typical hit rates and end-use values, scenario analyses were conducted using a parametric model. These scenarios place marine bioprospecting values at about $7775 per species. This value is somewhat higher than typical estimates for terrestrial species, primarily because of somewhat higher success rates. Using base case estimates of ecosystem yields for the Montego Bay area, coupled with a hypothetical sampling program that would be consistent with National Cancer Institute standards for marine sampling, a base case value of $70 million is ascribed to the Montego Bay reefs; approximately $7 million would be realistically capturable by Jamaica under typical royalty regimes or sample rental arrangements. None of this value is captured under existing institutional arrangements.

The first differential of the bioprospecting benefit function is calculated to arrive at an ecosystem marginal "global price" of $530,000/ha or $225,000/% coral abundance. For Jamaica’s share, the relevant "local planning price" computes to approximately $22,500/% coral abundance. Including this additional price within the optimization calculation does not affect the outcome: "optimal" improvement of coral reef abundance remains at 13%. The model demonstrates primarily the sensitivity of total and marginal values to ecosystem yield and institutional arrangements for capturing genetic prospecting value. For example, sensitivity analyses within a plausible range of species-area relationships generated global benefits for the Montego Bay reef of $54 to $85 million; reef prices ranged from $698,000/ha to $72,500/ha.

In conclusion, biodiversity valuation is best implemented within a specific policy context; choice of any given technique should be driven by specific policy questions or analytical issues. Most techniques still fail to adequately come to grips with issues of system complexity; these include issues such as non-linear ecological-economic linkages, interdependencies and redundancy in the species discovery process, cost interdependencies in the R&D process of bringing new products to market, and ecosystem yield in terms of species-area relationships for coral reef systems. Empirical studies demonstrate that optimal policy choices are frequently very sensitive to assumptions made regarding such issues. Substantial work also remains to be done in the area of risk analysis and industry structure.

Environmental valuation has often been described as an art rather than a science; if this is true, then coral reef biodiversity valuation may well best be described as magic.

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Summary

WHY Value Marine Biodiversity?

Marine ecosystems are among the most diverse systems in the world. Their proper management will deliver a wide range of economic benefits to the local and the global economy. Coral reefs, in particular, generate a large number of direct local uses – such as fisheries and tourism – while also harboring biological products and information that are of increasing interest to the pharmaceutical and other industries. Some coral reef areas in the tropics are under particularly heavy pressure and are deteriorating; a recent World Bank report on coral reefs identified such ecosystems as the highest priority areas for conservation (Hatziolos *et al*. 1998). As such, marine biodiversity is potentially the most significant sustainable use of marine products, and valuing this biodiversity is of substantial research interest. While the research area of biodiversity valuation has grown significantly over the past decade, most research efforts dealing with valuation have focused on terrestrial diversity; no methodical investigation has been made of marine biodiversity valuation issues.

The broad objective of this research is to assist policy makers in managing and protecting coral reefs by deriving improved estimates of coral reef economic benefits. The key problem in this research is to adapt and refine available valuation methodologies so that they account for key coral reef characteristics. The research also identifies the not insignificant limitations to many of these methods.

This report summarizes the results of this research work, highlighting key methodological findings and lessons, as well as providing empirical results using various techniques of local use valuation, non-use valuation, and biological prospecting valuation. The lessons and results are cast in the context of policy choices that would face typical developing country management authorities.

WHAT is Biodiversity Valuation?

As a point of departure, this research basically asks, “What is a coral reef worth?” It is tempting to look for a single number – in terms of dollars or Euros or some local currency – that we can attach to a hectare of coral reef substrate, the same way we might attach a price to a barrel of apples. When the Cunard liner Royal Viking Sun hit a reef in the Gulf of Aqaba some years ago, Egyptian authorities sought US$23 million in damages for the loss of about 2000 square meters of coral reef (Sheppard 1996). The implied price of US$10,000 a square meter seemed remarkably high at the time – it would make reefs among the most valuable real estate in the world – but the case served to focus more attention on the "art" of economic valuation, rather than on the value itself.

In general, the quest for determining a single coral reef price would be fraught with frustration. Serious well-researched attempts to value biodiversity have typically resulted in huge ranges of values. Policy makers might rightfully ask why scientists can not agree on a single number; they often interpret this lack of precision as bad science, bad analysis, bad data or – in less harsh terms – as scientific uncertainty. Unfortunately, the outcome is typically that little action is taken, that status quo policies remain in place, and that reefs further deteriorate.

But the reality is that it is not likely that we shall ever find a single "biodiversity value," and that analysts and policy makers must come to grips with that reality. It is somewhat like trying to nail a cream pie to a wall: it seems obvious what we want to accomplish, yet all attempts fail to consider every aspect needed to achieve the task. This reality arises from two simple observations: "biodiversity" means different things in different contexts; and, "value" means different things to different people. Before presenting our own empirical results, we shall expand on each of these notions.

What is Biodiversity?

Many complex and different meanings can be, and have been, ascribed to the term "biodiversity." Its scope of meaning seems to expand daily. In the Global Overlay Program of the World Bank, for example, many recent forest biodiversity valuation exercises include values associated with carbon sequestration to abate global climate change, even though biodiversity and climate change are the subjects of two quite distinct international conventions. One might rightfully ask, then, "If biodiversity valuation can include values for climate change, where does one draw the line in valuation?" The only way to answer this fully is to review the different meanings that one might attach to biodiversity. Again, we see that the different meanings can have different implications for valuation. Also, there are important similarities – and differences – among marine, terrestrial and coral reef biodiversity (Box S.1).

Box S.1
Marine, terrestrial, and coral reef biodiversity

Both marine and terrestrial systems are open. Organisms transport themselves across boundaries either under their own steam, or more often transport is provided by physical processes (e.g., wind, land bridges, or ocean currents.) But marine systems are relatively more open than terrestrial systems because water provides the dispersal medium. The majority of marine species distribute their larvae among the plankton via ocean currents. As a result, the recruitment line could cover hundreds of kilometers. In terrestrial systems, conversely, self-powered dispersal is limited; even species which rely on air for dispersal are only air-borne for a limited time. Given the differing patterns of dispersal in marine and terrestrial ecosystems, species endemism is a more common phenomenon on land than in the sea.

Marine ecosystems include coral reefs, intertidal zones, lakes, estuaries, and pelagic and deep ocean systems. The relative degree of species and ecosystem biodiversity in these systems depends on the physical characteristics of the particular system. In general, marine organisms exhibit more genetic diversity than terrestrial organisms; and terrestrial ecosystems exhibit more species diversity than marine systems. Marine systems have more higher-level taxonomic diversity than terrestrial environments: among all macroscopic organisms, there are 43 marine phyla and 38 terrestrial phyla; of the 33 animal phyla, 32 live in the sea and only 12 inhabit terrestrial environments (Reaka-Kudla 1995). However, in a coral reef, which is dominated by substrate, species and ecosystem biodiversity is relatively high; in the open pelagic ocean, where there is no substrate, diversity is relatively low.

Because of the existence of substrate, coral reef ecosystems and terrestrial ecosystems share similar structuring processes. Terrestrial ecosystems are dominated by substrate, biotic interactions, and the properties of air. Coral reef systems are similarly dominated by substrate and biotic interactions; but instead of air, they have to deal with the physical properties of water. By contrast, open ocean ecosystems, having no substrate, are dominated primarily by the properties of water. In coral reefs and terrestrial ecosystems – particularly rainforests – physical complexity, high species diversity, high functional diversity, and co-evolved species associations are biologically generated. To differing degrees, the biota control the structures of these systems. In open ocean pelagic ecosystems, with the absence of substrate, ecosystem structure is more the result of abiotic forces than biotic interactions.

Based on recorded species, fewer than 15 percent of currently named species are found in the ocean (Gaston 1996). However, coral reefs rank among the most diverse of all natural ecosystems, comparable to rainforests. The coral reef contains thousands of species interacting among themselves and abiotic conditions in a crowded marine environment. The result is many fine subdivisions of food and space resulting in high productivity, and efficient use of space. For example, symbiotic algae with coral polyps process the polyps' wastes thus improving recycling and nutrient retention. Also, diurnal and nocturnal fish species share their specific shelter sites.

The crowded and competitive conditions on coral reefs result in many types of interactions between species. One interaction well developed in the reef is antibiosis: the production by one organism of substances repulsive or fatal to another. These are the highly bioactive compounds investigated for various pharmaceutical properties: such as antiviral, antimicrobial, antitumor, and anticoagulant. These are used in the production of pharmaceuticals to treat viral and bacterial infections, cancers, and heart disease. Corals have also developed strategies to protect themselves from abiotic forces; for example, pigments protect the coral organism from harmful ultra-violet rays. These can be used for the production of sunscreens for humans.

The term biodiversity indicates a broad range of biotic phenomena ranging from the smallest unit studied – genetic diversity – to the earliest studied – species diversity – to the recently studied – ecosystem diversity. Within ecosystem diversity, both biotic and abiotic processes are studied as elements of functional, community and landscape diversity. When discussing the value of biodiversity, one should be clear about what the term connotes.

Genetic diversity refers to diversity *within* species – its total variety of genes. Different populations of the same species are not genetically identical; nor are individuals within the same population. Therefore, whereas the genetic diversity of a collection of species obviously declines with the extinction of a member species, it also declines with the extinction of a population of that species – a process known as genetic impoverishment. In the marine environment while some species extinction events have been documented, the loss of marine biodiversity comes primarily from genetic impoverishment.

Genetic diversity is important for adaptation: those species with high genetic diversity are better equipped to adapt to environmental changes. In agriculture, for example, genetic *uniformity* in a cultivated species renders that species vulnerable to climatic variations and disease. *Genetic resources*, a category of genetic diversity, refers to the actually or potentially useful characteristics and information contained in the genes and chemical substances of microbes, insects, plants, animals, and other organisms. Extracted from these organisms, genetic resources take the form of biomolecules, germplasm, enzymes and chemical compounds to be used for innovation in agriculture, horticulture, pharmaceuticals, and other types of chemical industries producing products ranging from skin care to industrial microbes for waste degradation.

Species diversity refers to diversity *among* species; it is the variety of different species within a collection of species. In the hierarchical system used to classify living things, species represents the lowest of the main taxa after kingdom (the highest), phylum, class, order, family, and genus. Estimates of the total number of species on earth range between 5 and 120 million; only about 1.8 million species have so far been described (Reaka-Kudla 1997).

Species diversity is important for ecosystem health. Ecosystem resilience is affected by the loss of its functional diversity (discussed below), which occurs with the extinction of functionally important species. Some species are functionally redundant meaning that should they be removed, there exist other species within the ecosystem that can assume their function. However, species which provide a critical structuring service in the ecosystem may not be replaceable, and their removal will change the structure of the system. For example, if a key predator is removed from an ecosystem, the dominant prey can then exclude its competitors thereby simplifying the ecosystem structure to a monoculture.

In terms of economic value, species diversity provides a breadth of consumptive opportunities in terms of current and future sources of food, nutrients, medicine, and construction materials. It also provides non-consumptive option and existence values. However, consumptive opportunities afforded by species diversity can become limited or less desirable, as a result of over-exploitation of certain species. For example, the over-harvest of top marine predators for human consumption is resulting in marine catches from lower trophic levels. Due to the over-harvesting of these top predators, humans are consuming different species that are further down the food chain; but as we move down the food chain, there are fewer potential species fit for human consumption.

Ecosystem diversity refers to the constituent biotic and abiotic elements and processes of an ecosystem, defined over a particular spatial and temporal scale from days and centimeters to millennia and thousand kilometers. The term includes the concepts of community, landscape, and functional diversity. Community diversity refers to species combinations and interaction, habitat pattern, relative abundance, distribution, population age structures, and trophic structure. Landscape diversity refers to the variety of spatial scales and patterns of species combinations across the landscape: the patchiness of the landscape. Functional diversity refers to the degree of niche subdivision, and the number and abundance of functionally distinct species filling the niches.

The maintenance of ecosystem diversity is important for the protection of genetic and species diversity contained within the system, and for the overall resilience of the system. Ecosystem resilience refers, in general, to its ability to absorb disturbances and renew itself. A disturbance can be defined as any phenomenon that causes organism mortality. Functional diversity is particularly important in maintaining ecosystem resilience. Research has shown that the more functionally diverse an ecosystem, the better equipped it is to recover from shocks.

The economic value of ecosystem diversity stems from its direct use values (recreation, research and education); its indirect values (biological support, physical protection); and its existence and option values. Direct use values are the most obvious because they enter the economy in some way; indirect values are generally less so because their economic value is not priced, or is hidden in production of some other good or service. The biological support provided by a coral reef, for example, can be considerable. The pelagic juvenile (larval) stages of reef organisms provide a food source to other ecosystems, as larvae drift on ocean currents, or as fish species migrate between their particular ecosystem and the reef. The reef is thereby supporting commercial fisheries both offshore and in nearby seagrass beds, lagoons, and mangroves. Seabirds also use the reef as a food source; and turtles feed and breed on the reef. On a global scale, coral reefs play a role in the global calcium and carbon balances. Coral reefs also provide physical protection to shorelines. The calcium carbonate skeletons of coral reef organisms form an effective barrier that dissipates wave energy. As a result, reefs protect coastlines from storms and currents thereby reducing coastal erosion.

What is "Value"?

Value, like beauty, is in the eye of the beholder. And differences in the perception of economic value are rife throughout the biodiversity valuation literature. Many different methodologies exist for attaching values, and these generally focus on some of the direct, indirect, and non-use values alluded to above. These are all different components of what economists often call the Total Economic Value (TEV). But even among these methods, there are differences of focus. Some methods may focus on the value to an end user, such as the ultimate value of a drug to a cancer patient. Other methods may focus on the share of income that is received by the licenser of a process or owner of a resource, such as a patent holder or a developing country institution. Still other methods focus on how biodiversity contributes to a given income generating process, such as through an artisanal fishery. In this research, we distinguish between these three types of methodologies, classifying them as production valuation, utility valuation, and rent valuation approaches (Table S.1). Many of the differences in values can be ascribed simply to the application of such different approaches. In our view, there is no correct or incorrect approach, as each of these methods will generally address a different policy or decision-making problem. A key lesson, however, is that the distribution of value, and the incidence of costs and benefits of resource use, often play a critical role in such decision making. As is often the case, it is not so much the size of the pie that is of interest, as how it is divided.

WHERE was the Research Done?

The main empirical focus of this study is in the Montego Bay Marine Park area on the north coast of Jamaica. Earlier related work also conducted cost-effectiveness analyses in the Maldives and in Curaçao; work in the area of contingent valuation was also conducted in Curaçao (Brown *et al*. 1996, Meesters 1995, Meesters *et al*. 1995, 1996, Rijsberman and Westmacott 1996, Westmacott and Rijsberman 1996).

The Montego Bay site (Figure S.1) was chosen for a number of reasons. Jamaica is itself committed to sustainable management of its biodiversity, having signed the Convention on

Table S.1
A system for classifying marine biodiversity valuation methodologies

	Biodiversity Production Valuation Methods	**Biodiversity Utility Valuation Methods**	**Biodiversity Rent Capture Valuation Methods**
Economic Basis	"Supply-Oriented"	"Demand-Oriented"	"Profit-Oriented"
Description	Values biodiversity within an economic production function.	Values biodiversity within an economic utility function.	Values biodiversity as a distribution of profits or value-added.
Valuation Target	Measures the contribution of biodiversity to the value of output in a produced good or service. Can estimate and isolate direct or indirect Use Values, including ecological functions or embedded information.	Measures the contribution of biodiversity to the utility of an individual or society. Can estimate aggregated Use and Non-use Values, including consumer's surplus.	Measures one or more components of the distribution of Use Values, focusing on captured rents, profits or value added. Can isolate value of embedded information.
Examples of Methods	Cobb-Douglas Production Function Linear Transforms Non-linear Transforms	Contingent Valuation Hedonic (quality-adjusted) Pricing 'Value of life' measures	Royalty evaluations Patent system evaluations Joint-venture evaluations
Examples of a Model	Q = Q{L,K,M,R,Ib} Q=drug production; L=labor; K=capital; M=materials; R=R&D effort; Ib=Biodiversity information content Value of biodiversity is marginal change in Q as Ib changes.	U=U{Y, C, Cb} U=individual or society's utility; Y=income level; C=consumption level; Cb=consumption or availability of biodiversity Value of biodiversity is marginal change in U as Cb changes.	Π=s{$\sum$PX} Π= profit or rent vector (n participants) s=revenue sharing transform P=price vector (m inputs/outputs) X=input/output vector Value of biodiversity is Π.
Examples of 'Terrestrial Biodiversity' Values	Estimates have been made of the expected value of rainforest species in the production of drugs or agricultural products. Typical values fall in the range of $1,000 to $10,000 per untested rainforest species.	Measures of the value of lives saved and avoided disease from single rainforest species (e.g., rosy periwinkle in cancer treatment) often far exceed $100 million.	Evaluations of revenue sharing through typical patent and joint-venture arrangements show low capture rates of biodiversity values in developing countries. Cameroon collects about $20 per untested rainforest species.

Biological Diversity on 6 January 1995. But foremost, recent political commitment in the region has resulted in the establishment of the Montego Bay Marine Park as a protected area that will be managed to promote sustainable reef-based tourism while still accommodating a local fishery. Originally under public jurisdiction, a bold experiment was undertaken when the park was transferred to private management in 1996. A group of concerned citizens, which formed the Montego Bay Marine Park Trust in 1992, obtained responsibility from the Government of Jamaica to manage the park under the authority of the Natural Resources Conservation Authority.

Moreover, 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. The area is economically important, as it also supports a recently established free trade zone. 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 (O'Callaghan 1992, Hughes 1994, Sullivan and Chiappone 1994, Louis Berger 1995, Lapointe *et al*. 1997).

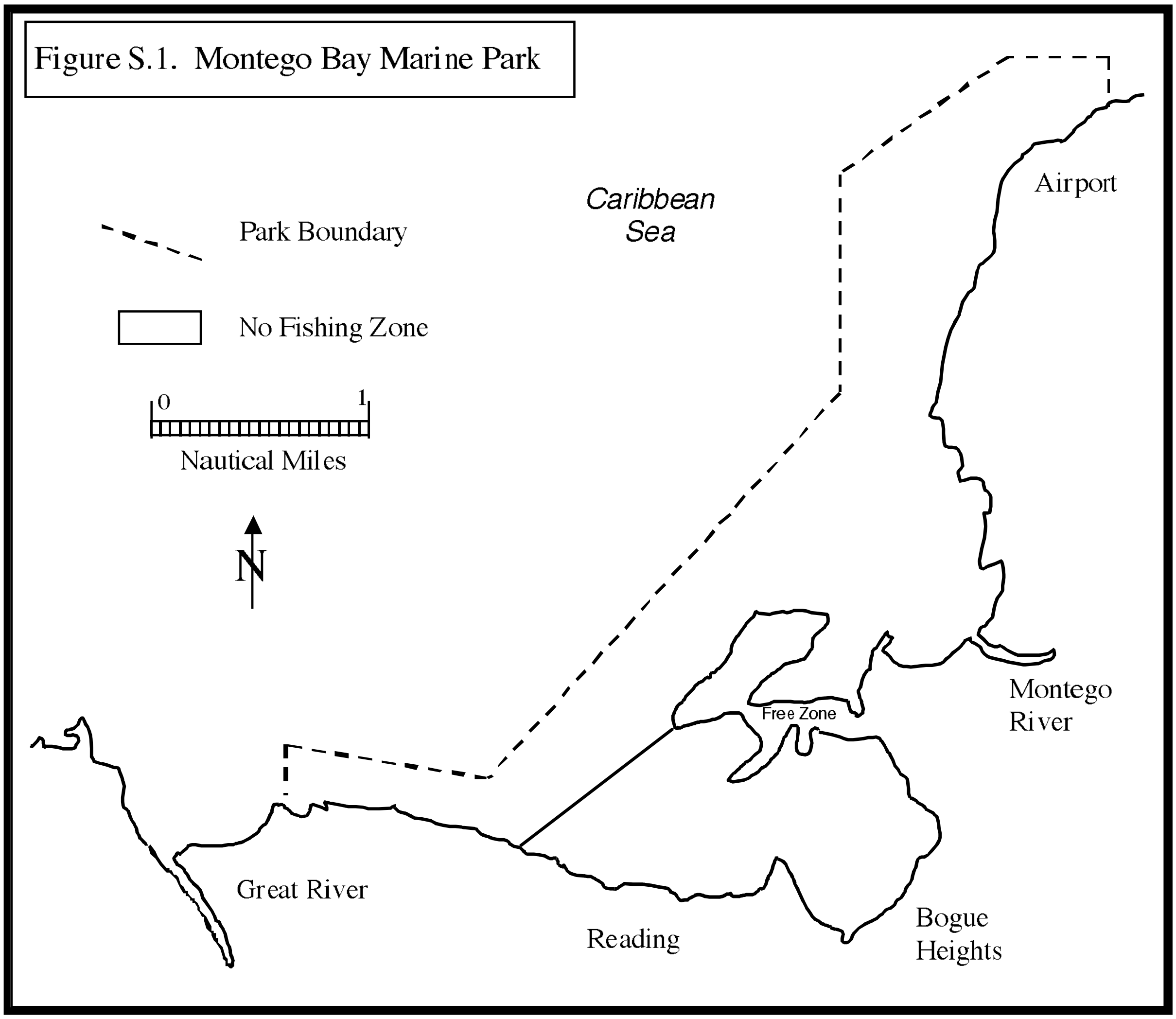

Figure S.1. Montego Bay Marine Park

HOW was the Research Done?

In addition to extensive literature reviews and careful implementation of conventional research methods, there has been extensive participation throughout the research process in a number of areas to gather information, get stakeholder input, and check output. Workshops and meetings have been held at the study site to receive feedback on the research methodology, analytical issues, and interim output. A six step consultative approach was used that has better enabled the team to check information with the academic, private, public, NGO, and consultant community. First, the team elicits participant views and reactions through interviews and roundtable discussions. Second, participants and affected groups take part in work sessions, generally limited in the number of participants. The third and fourth steps are workshops so that the views and reactions of participants can be taken into account in the final report; one workshop occurs before a draft final report is prepared, and a second workshop occurs before the final report is completed. The fifth step involves questionnaires as a way of eliciting participant views. The sixth and final step provides for the distribution of documents or reports.

Phase I empirical work benefited greatly from participation of local stakeholders and participants. Contingent valuation survey pretests were conducted with the cooperation of the Montego Bay Marine Park Trust, which was active both in the design and implementation of the pretest. Indeed, Park T-shirts were given as gifts to all respondents in the pretest. In addition, preliminary study results have been presented and reviewed locally in Montego Bay during a workshop and seminar in February 1997. Similar seminars were held in February 1998 and February 1999.

The research has also had ongoing interactive feedback in the policy making environment. While there is an existing management plan for the area, it is under constant review. Modeling workshops associated with this research have focused government officials and Montego Bay Marine Park managers on critical water quality and fisheries issues and shaped action plans in the new park management plan. These include: (i) a new park zoning plan (with mooring and demarcation buoy programs); (ii) a watershed management program; (iii) alternative income programs for fishermen; (iv) merchandise, user fee and ecotourism programs for revenue generation; (v) education programs for school children and the community; (vi) volunteer and public relations programs; (vii) enhanced enforcement to protect fisheries resources from poaching; and, (viii) research and monitoring programs to evaluate the recovery of the ecosystem and track the success of park programs.

Socioeconomic Lessons

In valuation, the distribution and incidence of physical and social impacts is important. Rapid ecological assessments have provided a cost-effective means to gain necessary biological information to assist with management strategies. Similarly, rapid socioeconomic assessments offer a means of quickly and efficiently evaluating the social and economic basis of the various user groups whose activities are affecting or affected by coral reef management efforts. But because of the relative infancy of research considering the socioeconomic context of reef management, there is a lack of research on developing rapid quantitative and qualitative techniques for assessing both the social and economic bases of reef uses.

To complement the economic analysis work, a methodology was developed for conducting rapid socioeconomic assessments of coral reef user groups (Bunce and Gustavson 1998). This methodology was applied to the three primary user groups of Montego Bay Marine Park – fishers, watersports operators, and hoteliers – during a six-week field period in January and February 1998. The utility of this methodology was demonstrated by considering the management implications of these findings for Montego Bay Marine Park.

Through document and database analysis, interviews with individuals representative of their user group, and participation in and observation of user activities, data on the following socioeconomic variables were collected: (i) characteristics of the user groups' activities; (ii) characteristics of the user groups themselves; and, (iii) users' perceptions of reef management. Scoping meetings and telephone surveys were also conducted with representative individuals from each user group to discuss major concerns regarding future management of the Montego Bay Marine Park, specific actions proposed by the users to address these concerns, and the role of each user group in the future management of the Park.

Analysis of the socioeconomic background of the user groups highlighted several socioeconomic factors with management implications, specifically: (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

Box S.2
Recommended guiding principles for Montego Bay reef management arising from rapid socioeconomic assessment

A rapid socioeconomic assessment methodology was developed and implemented in 1998, resulting in several guiding principles for reef management in Montego Bay Marine Park:

1. *Greater awareness* of the Park and *concern* over the deterioration of the reefs are critical building blocks for long-term compliance and support. To build trust in the Park's abilities, the Park needs to increase the visibility of its goals, and particularly its programs and services that are beneficial to the users (e.g., the mooring system, retraining programs for fishermen).
2. *Marketing the Park and providing incentives* will promote the perception of the Park as an asset to the users. The Park needs to provide direct links between reef conservation and business revenues by marketing support of the Park as an environmentally friendly means of attracting tourists.
3. *User group involvement* in the Park must be changed in nature to actively include the full range of users in the planning process, in the development of programs (e.g., representation on advisory boards) and in the implementation of programs (e.g., assistance with monitoring programs).
4. *Community resource management* of the Park should evolve as a target in which all user groups can participate. Currently, the reefs are managed under an almost entirely open access regime. There needs to be a shift in the users' perception of the reefs such that each user group feels it has an interest in effective management, and that their long-term interests are protected.
5. *Intersectoral coordination* needs to be recognized as an important component of developing an effective, comprehensive reef management program. By building relations between user groups through the existing networks, the users can begin to work together and with the Park to maximize the range of available resources, minimize duplication, and ensure complementary and cooperative programs as part of a comprehensive effort toward reef management.

Source: Bunce and Gustavson (1998).

Montego Bay Marine Park; and, (ix) the nature and extent of resources of use to management efforts. The management implications of these socioeconomic factors provided several guiding principles for reef management in Montego Bay Marine Park (Box S.2).

Institutional Lessons

Institutional arrangements – through revenue-sharing agreements, royalties or public policies – refer to the mechanisms through which developing countries might share in the benefits of commercial development of their marine resources. While such arrangements are common for hydrocarbon, mining or fisheries resources, they are novel in the realm of biodiversity. The notion that countries such as Jamaica can integrate use of marine genetic resources into coastal zone planning, through using such arrangements, is a relatively new one. Certain international treaties empower government under international law to enact such regulations. But such arrangements form a critical, and necessary, link in transferring genetic resource values to developing countries. The nature of the arrangements, and their enforceability, will more often than not be a determining factor in whether biodiversity values are captured locally.[1]

To explore this distributional dimension of economic value, an institutional study was undertaken in Jamaica by Putterman (1998). The study provides an assessment of Jamaican institutions with expertise relevant to the management of marine genetic resources, and makes policy recommendations intended to enable Jamaica to capture the maximum value created by commercial research and development of marine genetic resources.

Currently there are no Jamaican policies to regulate access to genetic resources, or even to recognize these as valuable material. The NRCA Act of 1991 does give authority to the Natural Resources Conservation Authority to regulate the use of natural resources, as well as the authority to require permits for various kinds of prescribed uses; but genetic resources uses are not specified. Overall, there is some anxiety in Jamaica over the absence of mechanisms to ensure that Jamaica shares in the benefits of genetic resources utilization (especially when foreign private companies are involved). But there is also a good appreciation for the value of private investment in genetic resources development as a tool for economic development and biodiversity conservation. Policy development should include mechanisms for regulating access to genetic resources, establishing novel rights to property and traditional knowledge, developing prior informed consent procedures, and creating a national benefit-sharing formula.

In addition, the study explored some specific mechanisms for capturing economic values. Optimally, the government of Jamaica would require all research contracts and Material Transfer Agreements to incorporate up-front or guaranteed compensation in exchange for the transfer of genetic resources samples. Also, some contingent compensation would be forthcoming through royalties or profit sharing. It is not recommended that the government of Jamaica impose an access fee on private companies seeking genetic resources research material. Because of the highly competitive nature of natural products sourcing, arbitrary access fees would increase the cost of Jamaican genetic resources and would likely price these resources out of the market.

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[1] The Convention on Biological Diversity highlights the "sovereign rights" of Parties over genetic resources (Articles 3 and 15.1), stating that governments have the right to regulate access to these resources on "mutually-agreed terms" (Article 15.4) and with "prior informed consent" (Article 15.5). Other relevant provisions include access to technology, including proprietary technology and biotechnology (Articles 16 and 19), and knowledge pertaining to traditional uses of genetic resources (Article 8j). The UN Convention on the Law of the Sea highlights the rights of member States to grant or withhold consent for marine scientific research, stating that consent can be withheld if the research is of direct significance for the exploration and exploitation of natural resources, whether living or non-living (Articles 246.3 and 246.5a). Finally, the Trade-Related Intellectual Property subagreement (TRIPs) to the World Trade Organization (WTO) Agreement calls for Parties to adopt a wide range of intellectual property rights regimes, including patents, plant breeders rights, and trade secrets.

Box S.3
Recommendations for Jamaican genetic resources policy

Policy recommendations intended to incorporate the management of marine genetic resources into integrated coastal zone management planning in Jamaica are developed by Putterman (1998). The recommendations are intended to allow Jamaica to fulfill obligations under the Biodiversity Convention and the Convention on the Law of the Sea, guaranteeing benefit-sharing while avoiding large disincentives to private sector investment. Key components of genetic resources policy include the following:

1 *Regulate Access Up-Front with Permits and Contracts.* Because there are no internationally recognized protocols on rights to genetic resources and traditional knowledge, it is necessary to define rights to these resources by contract before samples are collected. The NRCA, or possibly the Ministry of Commerce and Technology, would be appropriate regulatory agencies. It is highly recommended that private parties be allowed to negotiate draft research contracts independently. These draft contracts would be submitted to the regulatory agency for review along with the collecting permit application. A multi-disciplinary Genetic Resources Advisory Authority, with expertise in scientific matters, contract law, community rights and business development, would convene to review draft contracts.

2 *Establish Sui Generis (Novel) Rights to Tangible Property and Traditional Knowledge.* To define who has the right to negotiate genetic resources research contracts, it will be necessary to create rights to both the tangible and intangible (intellectual property) manifestations of these. Tangible property includes the physical embodiment of genetic resources and value-added research material. Intellectual property here refers mainly to traditional knowledge. A modification of industrial trade secrets laws, which Jamaica is required to develop under the WTO Agreement, is recommended for creating rights to this knowledge. *It is strongly recommended that the government of Jamaica refrain from nationalizing genetic resources rights*. This creates the possibility of establishing community rights; local resource tenure systems have been successful in creating local incentives for sustainable resource management.

3 *Develop Prior Informed Consent Procedures.* To give the legal owners of rights to genetic resources and traditional knowledge a means to control use of these resources, it will be necessary to devise a Prior Informed Consent mechanism to be used in the negotiation of "mutually-agreed terms." At the national level, establishing a Genetic Resources Advisory Authority would be sufficient to ensure Prior Informed Consent of the government of Jamaica. There is a critical role for NGOs in facilitating Prior Informed Consent decisions by local communities. Requiring foreign researchers to obtain Prior Informed Consent directly from each and every local stakeholder may act to strongly discourage foreign direct investment. A more user-friendly method would be to require a local research partner organization to obtain a Certificate of Prior Informed Consent from the government, certifying that research material has been obtained with adequate Prior Informed Consent from local stakeholders. Foreign researchers would then merely have to ensure that domestic partners present an approved Certificate of Prior Informed Consent.

4 *Create a National Benefit-Sharing Formula.* To ensure fair and equitable distribution of income from genetic resources utilization, a national formula to convert a portion of this income into public goods is necessary. An existing formula would simplify genetic resources negotiations. An ideal revenue-sharing arrangement would allow domestic research partners such as private companies, NGOs (including those managing National Parks), and local communities to keep a portion of their income to maintain incentives for private investment and innovation. The remainder of genetic resources income would be set aside for broader uses (e.g., protected area management across Jamaica.) Developing a set of guidelines or fixed percentages, through defining these national set-asides on genetic resources income, would streamline the permit approval process; set-aside percentages could be recorded directly on the genetic resources permit.

Source: Putterman (1998).

Also, it is recommended that the government of Jamaica encourage the development of local value-added research services. These could provide inventoried biodiversity samples – or advanced research material derived from these samples – directly to private industry for a fee. Sample rental fees can be in the form of monetary compensation, which would be designed to recover the full costs of collection and processing. Note that value-added genetic resources research material is difficult to obtain. Marine genetic resources in particular are prized for the complex structures and novel biological activities of chemicals and enzymes derived from them. Jamaican organizations offering these types of material would give Jamaica a clear competitive advantage over other countries.

Valuing the Obvious – Local Uses

Empirical work for Montego Bay, Jamaica, commenced with an estimate of the net present value (NPV) of readily identified local uses using production valuation approaches; these can be regarded as a benchmark value for comparative purposes. Initial priority-setting and valuation estimates done by Huber and Ruitenbeek (1997) in association with local stakeholders was subsequently refined and updated by Gustavson (1998) through identifying specific direct and indirect uses during a site visit in January and February 1998. Direct local use values were estimated on an annual basis for two broad categories of uses: nearshore fisheries and tourism. Indirect use values associated with coastal protection were also estimated. These local uses of the Park waters were identified as the most significant during the final study site application, as well as being of the highest policy priority. Other uses considered were aquarium trade, mariculture, coral crafts, non-coral crafts, and coral sand extraction; all of these were of negligible value.

Tourism services include accommodations, food and beverage service, entertainment (including independent watersports and attractions), transportation, shopping, and other miscellaneous services. NPV estimates associated with tourism in Montego Bay range from US$210 million (using a 15% discount rate) to US$630 million (using a 5% discount rate); at a 10% discount rate the value is US$315 million. In contrast to some other recreational valuation studies on larger coral reef areas (Driml 1999), we here attribute this entire value to the availability and maintenance of the intact coral reef. This is therefore the value at risk, to the extent that it would all be lost if the coral reef resource were totally degraded.

Fishing in the waters of the Montego Bay Marine Park is artisanal, and largely subsistence in nature. Trap, net and hand line fishing occur off of canoe-type vessels, launching from any one of five landing beaches in the area; in addition, there are numerous spear fishers using Park waters. The NPV estimate associated with fishing is US$1.31 million at a 10% discount rate. This assumed a shadow value of labor of 75% of the market wage; the fishery value is in fact negative if one assumes full market rates.

The value of coastal protection is estimated from the value of land that is vulnerable to erosion; this represents approximately 100 hectares (250 acres). Assuming this area to be vulnerable to erosion along the approximately 34 kilometers (21 miles) of shoreline within the Montego Bay Marine Park boundaries means that approximately the first 30 meters (100 feet) of shoreline property are at risk of erosion should the protective function of the coral reefs be compromised. The NPV of the total amount of land at risk of erosion, based on this area, is estimated to be US$65 million.

The total NPV of US$381 million translates to approximately US$8.93 million per hectare, or US$893,000/ha/yr on an annualized basis. Allocation to reef area corresponds to an estimated available coral substrate area within the Montego Bay Marine Park of 42.65 hectares.

The value for the direct uses represents what would typically be considered to be producer surplus or rent. In other words, it is the difference between the total revenues taken in through the use of the coral reefs, and the total economic costs associated with operating the activity. Of great interest to the management authorities of the Montego Bay Marine Park, as well as to managers of any coastal marine system, is to capture at least a portion of this rent to pay for the necessary management, and potential enhancement, of the resource. The current efforts of the Montego Bay Marine Park to implement user fees should be encouraged. An independent administration of a program of rent capture that ultimately varies at least according to the level of use and the type of business (assuming that there is a certain level of per use rent capture associated with a particular activity) will help ensure that the funds are accessible by management authorities.

Valuing the Less than Obvious – Biodiversity Non-use

Contingent valuation methods (CVM) are meant to address the consumer surplus, or individual utility, associated with coral reef improvement. Such methods explore the willingness to pay

(WTP) by respondents, for given changes in reef quality. Specifically, a survey instrument was designed to capture the non-use benefits of marine biodiversity at Montego Bay, for both local Jamaican residents and for visitors. Coral reef conservation benefits were valued in monetary terms to identify various economic and demographic characteristics of this valuation and its determinants.

Table S.2
Predicted willingness to pay – Montego Bay coral reef conservation*

	P(>0)	E(WTP)
Sample Means – All	65.77%	3.24
Sample Means – Typical Local	68.49%	3.75
Sample Means – Typical Tourist	62.51%	2.73
Locals with Moral Duties/Rights	70.72%	4.26
Locals with No Moral Duties/Rights	52.37%	1.66
Tourists with Moral Duties/Rights	64.22%	2.98
Tourists with No Moral Duties/Rights	45.17%	1.17

* P(>0) is probability of non-zero bid; E(WTP) is expected WTP in US$.

Source: Spash, van der Werff ten Bosch, Westmacott and Ruitenbeek (1998).

Although CVM is well-developed and routinely used in assessing environmental benefits, the current study involved several areas of innovation. Coral reef quality had previously been neglected by valuation work with most developing country CVM studies focusing on other issues (such as water quality) or on specific urban locations. More significantly from a research perspective, the study undertaken for this research by Spash *et al*. (1998) addressed the existence of lexicographic preferences as one of a number of outstanding methodological questions associated with biodiversity valuation requiring further attention. The methodological problems associated with lexicographic preferences – which occur when a respondent refuses to assign a value to conservation – occur both at the survey stage and at the data reduction and interpretation stage. At the survey stage, responses typically show up as zeros, and surveys must be designed to probe further into such responses and attempt to link them to some form of preference structure associated, for example, with perceptions of rights or duties of marine animals. At the interpretation stage, data analysis is confounded by a large number of excluded data (with the high number of zeros), which still may provide useful information; usual methods of bid curve analysis relying on averages or bid distributions are inadequate in such circumstances. These methodological challenges were overcome by careful design of a questionnaire that permitted probing of respondents and through the adoption of econometric maximum likelihood estimation techniques for analysing the bid functions.

Expected WTP for coral reef improvement was US$3.24 per person in a sample of 1058 respondents (Table S.2); a similar study for Curaçao placed this at US$2.08 per person. But this value was heavily dependent on whether respondents believed that marine systems possessed inherent rights, or that humans had inherent duties to protect marine systems; such preferences would increase WTP by a factor of two to three in Jamaica. Based on these values, for typical population characteristics, and using typical visitor profiles, it is estimated that the Montego Bay biodiversity has a net present value of US$13.6 million to tourists and US$6.0 million to Jamaica residents. The total NPV of US$19.6 million translates to approximately $460,000/ha, or $46,000/ha/yr on an annualized basis.

Valuing the Subtle – Biological Prospecting

A comprehensive review was undertaken of methods and models relevant to bioprospecting benefit valuation (Cartier and Ruitenbeek 1999). The goal of the review was to identify issues and potential models that have been considered in the valuation of terrestrial bioprospecting, and adapt these to a situation of marine bioprospecting. Particular attention was paid to *pharmaceutical* bioprospecting issues. The resultant model is used in an exploratory fashion to derive benefit values for pharmaceutical bioprospecting at Montego Bay.

The literature review highlighted a number of factors that have tended to be crucial in the derivation of values in terrestrial bioprospecting valuation models (Table S.3). These issues include: (i) estimation of gross vs. net economic values; (ii) estimation of private vs. social returns; (iii) capture of rent shares by local governments; (iv) estimation of average vs. marginal returns, and the role of redundancy and substitutability in each of these; and, (v) treatment of complexity through interdependence of discoveries and ecosystem yields.

The estimating model for Montego Bay bioprospecting focuses on a model of average social net returns, using localized cost information for Jamaica, and benefit values and success rates based on proprietary information for marine-based pharmaceutical products in the Caribbean. As with the other models reviewed (Table S.3), the approach essentially reflects an estimate of social value based on private behavior; similarly, the model excludes explicit calculation of option values. The institutional costs associated with rent capture are estimated for Montego Bay but are found to be small in relation to overall costs and benefits; they are at most US$230,000 in present value terms.

Table S.3. Comparative summary of pharmaceutical bioprospecting models

	Farnsworth & Soejarto (1985), Principe (1989ab), Pearce & Puroshothaman (1992ab)	Aylward (1993)	Mendelsohn & Balick (1995,1997)	Simpson, Sedjo & Reid (1996), Simpson & Sedjo (1996ab), Simpson & Craft (1996)	Artuso (1997)	Solow et al. (1993), Polasky & Solow (1995)	Ruitenbeek & Cartier (1999)
Model Attributes							
Analytical Specification Only						✔	
Terrestrial System Application	✔	✔	✔	✔	✔		
Marine System Application							✔
Policy Applications							
Education & Awareness	✔						
National Level Policies	✔	✔	✔		✔		✔
Private Profitability Analysis		✔		✔	✔		
Site Specific Planning				✔		✔	✔
General Economic Attributes							
Gross Economic Value	✔						
Net Economic Value		✔	✔	✔	✔	✔	✔
Private Costs	✔	✔	✔	✔	✔	✔	✔
Social Costs (including Institutional)		✔			✔	✔	✔
Time Delays		✔	✔	✔	✔	✔	✔
Average Species Value	✔	✔	✔		✔	✔	✔
Marginal Species Value				✔		✔	
Average Habitat Value		✔	✔		✔	✔	✔
Marginal Habitat Value				✔	✔	✔	✔
Specific Model Parameters							
Discovery Process Stages (Hit Rates)	**1**	**1**	**1**	**1**	**9**	**1**	**3**
Discovery Process Stages (Costs)	**1**	**1**	**1**	**1**	**9**	**1**	**1**
Revenue Sharing Treatment	■	■		✔	■	✔	✔
Redundancy/Interdependency				✔	■	✔	
Ecosystem Yield (Species-Area Relationship)				✔	✔	✔	✔
"Price Function" (Once Differentiable Value)				✔	✔	✔	✔
Industry Structure/Behavior						■	
Risk Preference/Aversion Behavior					■		■

✔ Explicitly Relevant or Incorporated

■ Treated Qualitatively or Partially

20-Mar-99

The adopted model uses some of the concepts incorporated in the terrestrial bioprospecting valuation models and builds on these for the marine environment by explicitly introducing parameters relating to *rent distribution* and complexity, as reflected by *ecosystem yield*. Sensitivity analyses demonstrated that these two parameters are likely to have the most significant impact on captured values, and on planning problems. Rent distribution is introduced as a policy variable, while ecosystem yield is a composite measure of species and sample yield potentially available from the Montego Bay reef. We derive likely estimate ranges for ecosystem yield based on typical species-area relationships postulated in the island biogeography literature (Simberloff and Abele 1976, Quammen 1996, Reaka-Kudla 1997). Finally, the results are once differentiated to derive a marginal benefit function, which relates value to coral reef abundance or area, and can be interpreted as our estimate of coral reef "price" that would be applied within a planning framework.

Using typical cost estimates for Jamaica, and using typical hit rates and end-use values, scenario analyses were conducted using a parametric model. These scenarios typically place marine bioprospecting values in the neighborhood of $2600 per sample, or $7775 per species. The per species values are somewhat higher than typical estimates for terrestrial species; primarily because of higher demonstrated success rates in terms of product development. Success rates are generally somewhat better than those for terrestrial sampling programs; the implied rates within our model are of the order of 1:30,000.

Translating these values to a system such as Montego Bay will depend on the specific bioprospecting program and the ecosystem yield of samples and species. The bioprospecting program is designed as one that might typically follow National Cancer Institute (NCI) protocols (Colin 1998), which would realize comprehensive sampling over a period of approximately 16 years. Estimates for ecosystem yield generate a result that there are about 18,000 target species available for sampling at the Montego Bay area of 42 hectares; this is based on a derived result that incorporates known reef area, expert assessments of reef quality, and a standard species-area relationship for marine organisms of the form $S=cA^z$. In the reference case we take z=0.265, but a plausible range for this parameter of z=0.2 to z=0.3 yields confidence limits for the target range of species of 10,600 to 47,400. Consistent with other findings, we assume each species yields on average three testable samples, each of which may in turn be assayed for multiple targets.

Using base case estimates of ecosystem yields for the Montego Bay area, coupled with a hypothetical sampling program that would be consistent with NCI standards for marine sampling, a base case value of $70 million is ascribed to the Montego Bay reefs; approximately $7 million would be realistically capturable by Jamaica under typical royalty regimes or sample rental arrangements. None of this value is captured under existing institutional arrangements.

The base case value of $70 million corresponds to equilibrium coral abundance levels of 43% on available substrate; ecosystem model predictions set this as a long-term equilibrium in the event of no additional stresses on the reef. Where current economic growth places new stresses on the reef, a predicted "degradation" to approximately 25% is set as a comparative case. Under this case, the global value of the reef would be $66 million: a loss of about $4 million.

Also, the first differential of the benefit function is calculated to arrive at an ecosystem marginal "global price" of $530,000/ha or $225,000/% coral abundance. For Jamaica's share, the relevant "local planning price" computes to approximately $22,500/% coral abundance. The model demonstrates the sensitivity of total and marginal values to ecosystem yield and institutional arrangements for capturing genetic prospecting value. For example, sensitivity analyses within the plausible range of species-area relationships generated global benefits for the Montego Bay reef of $54 to $85 million; reef prices ranged from $698,000/ha to $72,500/ha.

The relatively low "price", and the apparently small drop in benefits from significant coral reef degradation, underlines the importance of the ecosystem yield. In effect, two factors contribute to this result. First, because of the non-linear relationship between species and area, a decrease in coral abundance does not translate one to one into a decrease in species or available samples. Second, the loss in available samples is not experienced immediately; annual sampling constraints under a sustainable program under NCI standards at Montego Bay would yield approximately 3300 samples annually. The economic effect of these "lost samples" is therefore discounted substantially, and would consequently have less of an impact on current management decisions.

Detailed sensitivity results are shown in Table S.4. In particular, we note:

- ecosystem values, in terms of prices that would enter a planning function for land allocation and investment decisions, are most sensitive to assumptions regarding ecosystem yield.
- an appropriate risk mitigation strategy for Jamaica would likely involve some combination of a net profit share ($\alpha > 0$) and modest sample fee. Such a strategy would guaranty captured

Table S.4. Model results for marine pharmaceutical bioprospecting valuation – Montego Bay. Parametric assumptions relate to z-factor within species(S)-area(A) relationship $S=cA^z$, a contingent net profit share (α) and a fixed sampling feel level f ($/sample). Model solves for total samples (N) available at Montego Bay and the typical length (T) of sampling program that would be required to harvest these. Economic calculations relate to the expected net present value of the program to the world (NPV_G) and to Jamaica (NPV_J). A first differential of the function yields a global "price" (P_G) and Jamaican "price"(P_J) for coral reefs that could be applied within a planning framework equating marginal benefits to marginal costs.

Case	z	α	f ($)	N	T (yr)	PV_G (MM$)	PV_J (MM$)	P_G ($/%)	P_J ($/%)
Base Case Scenario at 43% Coral Abundance									
Reference*	0.265	10%	0	53,660	16.3	$70.09	$7.01	225,614	22,561
High z	0.3	10%	0	31,763	9.6	$54.46	$5.45	297,516	29,752
Low z	0.2	10%	0	142,099	43.1	$84.61	$8.46	30,901	3,090
Fee Only	0.265	0%	250	53,660	16.3	$70.09	$6.76	225,614	21,763
High z	0.3	0%	250	31,763	9.6	$54.46	$5.25	297,516	28,699
Low z	0.2	0%	250	142,099	43.1	$84.61	$8.16	30,901	2,981
Blended Revenue Shares	0.265	8%	50	53,660	16.3	$70.09	$6.96	225,614	22,402
High z	0.3	8%	50	31,763	9.6	$54.46	$5.41	297,516	29,541
Low z	0.2	8%	50	142,099	43.1	$84.61	$8.40	30,901	3,068
High R&D Cost	0.265	10%	0	53,660	16.3	$17.64	$1.76	56,783	5,678
[R/C Ratio=1.1:1]	0.265	0%	250	53,660	16.3	$17.64	$6.76	56,783	21,763
	0.265	8%	50	53,660	16.3	$17.64	$2.76	56,783	8,895
Low Hit Rate	0.265	10%	0	53,660	16.3	$25.02	$2.50	80,525	8,052
[1:80,000]	0.265	0%	250	53,660	16.3	$25.02	$6.76	80,525	21,763
	0.265	8%	50	53,660	16.3	$25.02	$3.35	80,525	10,795
Unconstrained**	0.265	10%	0	53,660	1.0	$139.07	$13.91	1,054,202	105,420
High z	0.3	10%	0	31,763	1.0	$82.32	$8.23	699,475	69,948
Low z	0.2	10%	0	142,099	1.0	$368.27	$36.83	2,145,937	214,594
Institutional***	0.265	10%	0	53,660	16.3	$70.09	$6.96	225,614	22,561
Degradation Scenario at 25% Coral Abundance									
Reference z	0.265	10%	0	46,477	14.1	$66.12	$6.61		
High z	0.3	10%	0	26,994	8.2	$49.37	$4.94		
Low z	0.2	10%	0	127,492	38.6	$84.06	$8.41		

*Uses study result hit rates of 1:30,000 and Sales:R&D Cost Ratio of 1.5:1. Prices P_G and P_J may be converted to $/ha basis by dividing by 0.4265.
** Assumes all samples are collected and subjected to preliminary screening immediately (in 1 year).
*** Includes institutional overheads of central government agencies.

values of the same order as those expected in the reference case, but would reduce exposure to hit rate uncertainties, product marketing uncertainties, and ecosystem dynamics.

- results are sensitive to sampling constraints. If it were realistic to assume that all relevant sampling and screening could be done immediately, the present value would double in the reference case.
- the impacts of the incremental institutional costs – for operating a national program consistent with the recommendations in Box S.3 – are minimal.

Table S.5
Summary of valuation results – Montego Bay coral reef

	Benefit	Price*	
	NPV (MM$)	MM$/%	MM$/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

* Marginal benefits shown at typical current reef conditions.

Summing Up the Values – 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 reef (Table S.5). The use of such values requires making a number of further assumptions about the sensitivity of the individual values to reef quality. As seen with the bioprospecting values, the total value of the reef was relatively high ($70 million) but changes in reef quality within the planning range (of 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 demonstration purposes. 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 underestimating in others. For erosion, for example, a degraded reef will still provide some limited erosion benefit for some time; an average price assuming a linear relationship will thus overstate the marginal benefit. For tourism, however, small changes in quality may have disproportionately larger impacts on arrivals if there is a perception that the reef is 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 there). In the case of the non-use values, the contingent valuation survey explicitly included a degradation scenario, hence the end-points were well established (they represented 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 reef in its current condition is approximately $470 million, and that every 1% change in abundance is likely to generate a marginal benefit of approximate $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. The relative impacts of fisheries and bioprospecting on planning prices are negligible, especially if one considers only the capturable values to Jamaica.

We juxtapose these marginal benefit calculations against a marginal cost function for the Montego Bay reef, as generated by a fuzzy logic based ecological-economic model (Ruitenbeek *et al*. 1998, Annex A). This related research on cost effectiveness modeling of interventions suggested that up to a 20% increase in coral abundance may be achievable through 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 $1 million per % of coral abundance to $29 million per % 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 in the areas of: 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. 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 (achieving a 20% coral reef improvement), would require additional benefits of some $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 ($70 million per 43% coral = $1.6 million/%) would not be adequate to justify improvements beyond those stated above.

Summary and Conclusions

This project has looked at biodiversity valuation in general, with a view to considering the different methods that may be relevant to applied marine biodiversity valuation. Methods relating to direct and indirect uses and functions are among the best developed, and techniques are readily transferred to coral reef systems. Methods relating to non-use values are also available, although they are complicated by methodological issues such as lexicographic preferences.

Of greatest research interest, however, is the field of biological prospecting valuation. Models for terrestrial systems have evolved considerably over the past decade, although none have yet been applied to marine systems. Also, bioprospecting model development in the literature has tended to be isolated in two distinct areas: agriculture and pharmaceuticals. While both have similar foundations in the modeling of the value of applied research (Evenson and Kislev 1976), distinct literatures have developed in agricultural and pharmaceutical modeling development. This has arisen because of different technical aspects of bioprospecting in these fields, as well as different policy concerns.

From a technical perspective, bioprospecting values are derived somewhat differently in agriculture and pharmaceuticals. In both cases, the actual *value* associated with biodiversity is closely tied to the type of information provided, as opposed to any particular material good (Swanson 1996). In the case of pharmaceuticals, this information provides a stock of ideas that can be used to synthesize key compounds, often establishing new products and markets (WCMC 1994a). In the field of plant genetic resources, however, the information itself provides direct genetic information that can be introduced into other economic species or crops which already have a market (WCMC 1994b).

Efforts in agricultural valuation have been driven by policy questions that address issues such as food security, farm incomes, and efficient research methods in a market where end products (such as food crops) are dominated by open competition (Evenson *et al*. 1998). Much of the research work in agricultural prospecting is funded through public institutions and international agencies. In agriculture, modeling has addressed distributional concerns related to the improvement of farm level incomes, and the social benefits arising from incorporating traits in improved crop varieties (see Smale 1995, 1998, Smale *et al*. 1995). Also, it has often focused on the valuation of genetic traits and optimization of the search paths for finding economically useful traits within large samples (often maintained in *ex situ* collections) (e.g., Gollin and Smale 1998).

By contrast, the pharmaceutical bioprospecting literature was, initially, dominated by policy concerns relating to the *in situ* conservation of wild genetic resources (e.g., "drugs from the rainforest"). The intensely private – and often seemingly monopolistic – nature of new drug patenting and development, coupled with long testing periods, has meant that institutional questions frequently dominate discussions relating to valuation. Most models remain relatively deterministic; only more recently have concerns such as optimal research paths entered the pharmaceutical bioprospecting literature (Artuso 1998). Moreover, the role of ecosystem and habitat conservation and their potential yields of "new" species adds a dimension that is often absent from discussions in the agricultural bioprospecting literature.

In the case of marine systems, the issues are further complicated by ownership concerns and the perceived system yield of useful information. Management and ownership of marine and near-offshore resources is a problematic topic in most jurisdictions, and the entire discipline of Integrated Coastal Zone Management (ICZM) is targeting such problems through what are by and large institutional reforms and interventions. Also, on balance, marine systems are receiving greater scrutiny for new sources of drugs while bioprospecting for useful maricultural traits is limited (Henkel 1998). For example, in early 1999, more than 30 drugs derived from marine species were under preclinical investigations by private and public research organizations, and by the National Cancer Institute (Mestel 1999).

The marine bioprospecting valuation approach we take in this study falls primarily into the realm of deterministic models relating to pharmaceutical development. These attempt to infer social values from intensely private behavior. The model we develop, like its counterparts, makes no explicit calculation of option value. It does, however, provide insights into issues of value related to marine environments, focusing on issues such as marine product success rates, institutional revenue sharing issues, and ecosystem yield. We encourage further research that looks into such issues in greater depth, and extends models to bioprospecting for other marine products, such as mariculture. In that respect, future modeling efforts are likely to borrow more extensively from both the agricultural and the pharmaceutical literature.

We maintain, however, that no single terrestrial bioprospecting valuation model should be preferred over the others; each has a different policy application. In pharmaceutical bioprospecting, the early models of gross economic value had an important role to play for education and awareness policies, although they may be less useful for management and specific planning. The next generation of models, those relating to net economic values, taught us that we need to pay greater attention to the allocation and calculation of costs within the biological prospecting process. This has distributive implications, such as through the incidence of benefits and costs to the private sector vs. society at large, as well as efficiency considerations, such as whether it in fact makes economic sense to undertake biological prospecting. In particular, the average cost models showed us how sensitive economic values can be to technical parameters (such as success rates) and to economic variables, such as royalty rates or R&D costs.

But even these models fail to tell the whole picture, or answer all of the relevant economic policy questions. From a system planning perspective, we are constantly reminded that we must pay attention to the complexity inherent in biological and ecological systems, as well as within the discovery process itself (Brown and Goldstein 1984, Solow *et al*. 1993, Polasky and Solow 1995). One manifestation of this is the potential for interdependence of probabilities within the discovery process; an example of this was illustrated by Simpson *et al*. (1996) in their treatment of "redundancy" to show that the value of the marginal species is in fact quite low when such complexities are considered. Another manifestation of this complexity arises at the policy planning stage when trying to transfer "$/species" values to some tract of ecosystem such as rainforest. In such cases, the yield of species by the ecosystem is typically non-linear, and the first differential of this relationship must be estimated before allocative decisions about optimal levels of conservation can be made. Again, this issue was touched upon by Simpson *et al*. (1996), as well as by Artuso (1997), and their findings illustrate the sensitivity of valuation results to assumptions relating to ecosystem yields.

As another example of the complexity and interdependence issue, none of the models have adequately grappled with differentiating among the *intended reasons* for bioprospecting. It is normally assumed that we are looking for new products and new discoveries that will somehow cure all of our worst maladies. In fact, however, some of the bioprospecting is oriented to looking for new – but cheaper – sources of existing materials. In that respect, bioprospecting is akin to mineral or oil exploration … we know what we are looking for and are simply looking for a cheaper source. In this case, redundancy is not an issue; indeed, redundancy may be a positive rather than a negative factor in valuation.

To date, no single model has provided all of the answers. At best, they provide some indication of value, and what that value is sensitive to within a given policy context. There remain substantial limitations to valuation techniques. When designing a new model, or choosing among the existing ones, one must therefore pay attention to the particular policy issues or analytical issues one wishes to address. For marine products, these issues can be quite different than those related to terrestrial products. 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 also being made on multi-criteria analyses, with valuation as one component of that analysis. Adger *et al*. (1999) demonstrate how such MCA techniques can be of particular use in marine park planning applications where there are often a large number of stakeholders, having a wide variety of interests and objectives.

Further, we would submit that the overall focus on valuation has perhaps distracted analysts from more pressing institutional and socioeconomic concerns. Valuation results consistently show 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. But this decentralization is often fettered by a bureaucratic malaise that resists such change, as well as other vested interests in maintaining the status quo. It is incumbent on analysts to assist opinion leaders in overcoming such constraints.

In closing, we might be reminded of two principles in particular, developed as a result of extensive interdisciplinary consultations initiated in 1992 by the Marine Mammal Commission:[2]

> Principles for the conservation of wild living resources. …
>
> Principle II. The goal of conservation should be to secure present and future options by maintaining biological diversity at genetic, species, population and ecosystem levels; as a general rule neither the resource nor other components of the ecosystem should be perturbed beyond natural boundaries of variation. …
>
> Principle V. The full range of knowledge and skills from the natural and social sciences must be brought to bear on conservation problems.
>
> (Mangel *et al*. 1996).

When dealing with ecosystems, these principles essentially mean "exercise precaution; work together." The same principles, it seems to us, should apply to biodiversity valuation.

[2] The full set of Principles and its discussion appears in Mangel *et al.* (1996) and in Perrings (1997).

Issues in Applied Coral Reef Biodiversity Valuation:
Results for Montego Bay, Jamaica

World Bank Research Committee Project RPO# 682-22
"Marine System Valuation: An Application to Coral Reef Systems in the Developing Tropics"

Final Report
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Chapter 1

Introduction

Background

Marine ecosystems are among the most diverse systems in the world. Their proper management will deliver a wide range of economic benefits to the local and the global economy. Coral reefs, in particular, generate a large number of direct local uses – such as fisheries and tourism – while also harboring biological products and information that are of increasing interest to the pharmaceutical and other industries (Henkel 1998, Mestel 1999). As such, marine biodiversity is potentially the most significant sustainable use of marine products, and valuing this biodiversity is of substantial research interest. While the research area of biodiversity valuation has grown significantly over the past decade, most research efforts dealing with valuation have focused on terrestrial diversity (e.g., McNeely 1988, Pearce and Moran 1994, Evenson *et al*. 1998, Smale 1998); no methodical investigation has been made of marine biodiversity valuation issues.

The broad objective of this research is to assist policy makers in managing and protecting coral reefs by deriving improved estimates of coral reef economic benefits. The key problem in this research is to adapt and refine available valuation methodologies so that they account for key coral reef characteristics. The research project was completed in two phases under World Bank Research Committee funding. Phase I supported preliminary work to review methods relating to local use valuation and to contingent valuation. Phase II focused on empirical implementation of the methods.

To provide a policy context for the work, and to test some of the valuation methods, field work focuses on Caribbean marine systems with specific site studies being conducted in Montego Bay, Jamaica (Box 1.1), and on the south coast of Curaçao. The work complements other World Bank-assisted efforts being undertaken in Jamaica; these

Box 1.1
Montego Bay Marine Park, Jamaica

Established	1974
Park Area	15.30 km^2
Coral Reef Area (est.)	42.65 ha
Montego Bay Population (1996)	110,000
Average per capita Income (1996)	US$2300

Box 1.2
Relationship between Biodiversity Valuation (RPO#682-22) and Least-Cost Model (RPO#680-08) projects

With support from the World Bank Research Committee (RPO#680-08), a study was conducted to develop a least-cost model for coral reef conservation and management in the developing tropics (Annex A). A key aspect of this model is that it integrates economic marine- and land-use issues in the coastal zone, with ecological conditions that affect coral reef quality. Impacts of management interventions, which influence pollution loads and resource extraction, are cast in terms of a standardized impact on coral reef mortality and biodiversity abundance. The central output of the model, which is developed for sites in Jamaica, Curaçao and the Maldives, is a cost function that identifies the lowest cost interventions for achieving any desired level of coral reef quality.

The least-cost model in effect provides information about the supply of coral reef quality. This is useful from an operational perspective as it identifies which particular low-cost interventions should be pursued before higher cost interventions are promoted. Some of the low cost interventions have, in fact, a negative cost because there may be other local benefits associated with them, such as improved energy or material efficiency. While the least-cost model shows which interventions should be pursued first, it does not identify an economically optimal level of coral reef conservation and is therefore not capable by itself of saying how much total investment should take place. To identify this level of investment, some knowledge is also required of the demand for coral reef quality, which establishes the marginal benefit for improvements in reef quality. Estimation of the benefits for maintaining coral reef quality is thus the focus of the Biodiversity Valuation research exercise (RPO#682-22).

include the development of a least-cost model for coral reef protection (Box 1.2) and ongoing support to the Montego Bay Marine Park for development and planning.

Although this project focuses its empirical work on Montego Bay, many of the methods 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. As noted earlier, 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 which 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; a recent World Bank report on coral reefs identified such ecosystems as the highest priority areas for conservation (Hatziolos *et al*. 1998). For example, coral reef ecosystems around the small island states of the Caribbean, notably Jamaica and Trinidad, have deteriorated, as have the inland bays in Southeast Asia, notably around Singapore, Indonesia and the Philippines. About 10% of the world's reefs have already been degraded beyond recognition, while another 60% are likely to disappear in the next 10-40 years; the 30% of reefs that do not appear to be undergoing negative effects are those in remote areas. The range of impact thus extends from none to severe, with the severe stress often highly localized.

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 monetary benefits from various coral reefs products and services have not been extensively analyzed. This has made it difficult to develop a priority ranking of policy and investment interventions in terms of their cost-effectiveness and overall scale. This is the central problem being addressed by the current World Bank research projects on least cost modeling and biodiversity valuation.

Summary Statement of the Problem

While the issue of the valuation of biodiversity benefits from ecosystems has received considerable recent attention, only limited efforts have been devoted to marine systems in general, and to coral reefs in particular. One consequence of this relative neglect is that the available valuation methodologies do not take full account of several key characteristics of coral reefs. The central problem addressed in this research effort is to refine the valuation methodologies applicable to coral reefs, and derive more accurate estimates of coral reef benefits for selected sites.

Summary Objectives and Goals

The general goal of this work is to assign a monetary value to the benefits from coral reefs. A procedure is developed which can be applied to any specific reef. One of the most challenging aspects of this valuation is to assign a value to biodiversity itself. Work in this field has concentrated, to date, on valuing terrestrial biodiversity. This study attempts to translate some of the techniques and values from the terrestrial side to the more complex marine side. It also investigates a range of methodological issues that pertain to marine biodiversity valuation.

Relevance to World Bank Operations

The research is relevant to ongoing and, particularly, future World Bank operations. To date, in Latin America, there has been no Bank lending specifically for coral reef management, and experience in other regions has been limited. But the Bank's role in coral reef management projects is expected to increase in the future; the Bank is currently assisting a number of countries in designing coastal zone related projects. Also, the Global Environment Facility (GEF), for which the Bank is an implementing agency, is interested in developing projects to manage and protect biodiversity, such as of the type found in coral reefs.

Lessons from similar studies of terrestrial systems have revealed that the most significant operational benefits of this type of research are related to the identification of appropriate institutional interventions. Many successful efforts in rainforest conservation, for example, as well as the Biodiversity Protocol of the Earth Summit, have been linked to a growing understanding among decision-makers of the *magnitude and distribution* of various benefits associated with sustainable management of biodiversity resources. This research will, therefore, assist in identifying appropriate institutional interventions.

Study Process

The work including a multidisciplinary team consisting of economists, a conservation biologist, a socioeconomist, a bioprospecting specialist, and specialists in community development and marine park management in tropical countries. For operational reasons, the research was separated into the following major components to facilitate information gathering and presentation:

- Methodology Refinement. A number of preliminary literature surveys were conducted for distinct research fields. Annexes provide detail relating to contingent valuation, conservation biology, protected areas, bioprospecting and R&D issues. These are summarized in the Phase I Interim Report (Huber and Ruitenbeek 1997), with key findings summarized in this chapter. Subsequent literature reviews in Phase II concentrated on biodiversity valuation and bioprospecting.
- Empirical Studies. Three sets of empirical studies are undertaken to explore the issues related to: (i) a local use study to estimate key direct and indirect uses; (ii) a contingent valuation study to isolate non-use values and address, in particular, some of the problems associated

with lexicographic preferences; and, (iii) a marine biodiversity valuation study to isolate specific biodiversity prospecting use values associated with pharmaceutical product development.

- Dissemination. This includes activities oriented to training of researchers, dissemination of results, and interaction with government policy makers and stakeholders in the project study areas.

Study Scope

The study and research attempts to perform both a synthesis function, by summarizing the state of the art knowledge of work conducted to date in the field of marine biodiversity valuation, and an extension function, by applying lessons learned within this context to a new site in a new policy context. While the synthesis and review function is intended to be comprehensive, it is recognized that the work on extending this is at best exploratory. The field of empirical biodiversity valuation is still very much in its infancy, and we therefore attempt to focus on some key issues in undertaking the empirical work.

The scope is, however, intended to be multidisciplinary. The need for a greater integration of disciplines was a key aspect of Agenda 21 during the 1992 United Nations Conference on Environment and Development, and has since been reiterated on numerous occasions in planning and policy making contexts (Mangel *et al*. 1996). But the results of this multidisciplinary work remain novel to policy makers and decision makers; typically no single unequivocal result is forthcoming from the work. The work arising from this research is similar: it can provide policy guidance in the decision making process, but it does not point to a single best decision. This is consistent with Kenchington's (1992) observations that proper marine management decisions must rely on an extensive amount of specific empirical work within a broader strategic framework. The contributions of economic valuation provide some input into this empirical work.

As such, the scope is also not without limits. There are specific questions that we attempt to address. These include questions such as: What are the highest priority and most economically valuable direct uses? How do individual economic and demographic characteristics influence an individual's willingness to pay to conserve coral reefs? If people believe that marine systems have rights, does this make it impossible to attach an economic value to these systems? What is the potential value from pharmaceutical bioprospecting in coral reef areas, and how is this value influenced by institutional arrangements and ecosystem complexity? Can economic benefit valuation of marine biodiversity provide any policy guidance as to the optimal levels of coral reef conservation, or the best ways to achieve such levels?

In asking such questions, we also by necessity exclude a wide range of other potential topics or issues, which may be equally or more important in the decision making process. In the case of Montego Bay, for example, certain types of harvesting opportunities associated with craft marketing were excluded because of limited current levels and the illegality of the activities; this made it impossible to obtain reliable information, even though it may be an economically important activity to some groups. Similarly, we have not extended the analysis into all areas of policy relevance, such as optimal fee structures for the Marine Park. Such an analysis is of policy interest, and could be informed by some of the results of this research, but it would also require an analysis of the entire park system in the country, which is beyond the scope of this work. In the ecological realm, we acknowledge that we focus primarily on two hitherto unestimated functions or products: erosion control and bioprospecting for pharmaceutical products. Recent environmental work suggests that coral reefs are in fact generators of carbon dioxide, and would thus contribute negatively to climate change (Kawahata *et al*. 1997); this result would, by economists, be construed as a negative benefit of conserving coral reefs but we have not entered into the methodological aspects or the empirical calculus of this issue. In brief, by asking specific questions we inherently ignore other potentially relevant and related questions. While most scientists are well aware of this aspect of such research, policy makers often need to be reminded of it.

Report Outline

This report provides a consolidated summary of the research findings relating to the biodiversity valuation project.

Chapter 2 provides the economic framework, highlighting the basic optimization framework that requires assessment of benefit and costs in a planning context. It also provides results of the preliminary literature review that provided an overall benefit classification framework that relied on a Total Economic Value approach, and a new methodological classification framework that shows the role of production valuation, utility valuation, and rent valuation. Chapter 3 provides a comprehensive review of the economic valuation literature that is relevant to marine biodiversity valuation. The review provides a complete listing of studies associated with marine valuation, and provides a sub-sample of studies from the broader valuation literature to illustrate some key methodological points. The chapter also touches upon the agricultural bioprospecting literature, while providing a detailed review of five sets of pharmaceutical bioprospecting valuation models to illustrate the progression of methodologies that has occurred for terrestrial pharmaceutical bioprospecting. These models form the basis for developing a model of marine pharmaceutical bioprospecting valuation that is later applied to Montego Bay. Chapter 4 – complemented by case studies in Annex B – presents a number of specific distributional issues in biodiversity valuation, summarizing socioeconomic and institutional studies that were conducted in Jamaica during the course of this research.

Empirical investigations commence with the results of a benchmark local use analysis presented in Chapter 5; the analysis discusses a wide range of potential direct and indirect uses, and provides explicit values for fisheries, tourism, and erosion control in Montego Bay. It also discusses a number of policy issues associated with such values, including fee structures for the direct local uses. Chapter 6 provides the results of contingent valuation survey work conducted in Montego Bay and in Curaçao; it highlights the role of lexicographic preferences and how the survey was implemented and analyzed to reduce the problems sometimes associated with such preferences. Chapter 7 develops a marine bioprospecting model that takes attributes from some of the models reviewed in Chapter 3, and complements these models by focusing on issues relating to institutional revenue-sharing and to ecosystem yield. The analysis provides estimates of pharmaceutical prospecting value for Montego Bay as a function of selected economic, institutional, and ecosystem characteristics.

Results of the empirical work are summarized and consolidated in Chapter 8 through synthesizing a consolidated benefit function of the local use, non-use and bioprospecting values. A key component of this synthesis involves generating a planning curve – the marginal benefit function – through analyzing the first differential of the economic benefits; problems associated with generating such a function are discussed in the context of juxtaposing the marginal benefit curve so generated with the marginal cost curve generated by the complementary cost effectiveness studies. Chapter 8 also provides some summary comments and suggestions for further research steps, while Annex C outlines the dissemination strategy and activities associated with this project.

Chapter 2

Economic Framework

Chapter Acknowledgments

This chapter was prepared by Jack Ruitenbeek, Cynthia Cartier and Richard Huber. It extends work and concepts relating to methodology classification summarized in Huber and Ruitenbeek (1997). The authors are grateful to Steve Dollar and Mark Ridgley, who contributed to the insights relating to cost-effectiveness modeling; these are summarized here and are reported separately in Ruitenbeek, Ridgley, Dollar and Huber (1999). Tim Swanson provided helpful review comments relating to the discussion on option values contained in this chapter.

Introduction

In a recent address to a coral reef symposium, Nancy Knowlton of the Smithsonian Tropical Research Institute called on improved interdisciplinary studies between biology and economics to help solve some of the hard decisions that need to be made in coral reef management. She stated the economic challenge succinctly:

> In order to defend reefs economically, the marginal costs of reducing stress on reefs must be less than the marginal benefits associated with so doing. Calculating the economic costs of treating sewage, not fishing, or not building are fairly straightforward, and have been used for years to support policies that are detrimental to reefs. More recently, economic analyses of the benefits associated with maintaining or improving the health of reefs have made important strides. To use such analyses, however, we need to make biological as well as economic assumptions. … While it is tempting to assume simple biological relationships, such assumptions are rarely if ever justified.
>
> (Knowlton 1998, p. 183)

The economic challenge is thus to address both the costs and benefits of reef management, within a context of ecological complexity. A key theme in the closing chapters of this research work is that assumptions relating to complexity can have a greater bearing on management choices than many of the economic assumptions. Unfortunately, most economic modeling efforts fail to address complexity issues, and many therefore risk providing incorrect advice. At this stage, no single approach is likely to address the complexity issues adequately, and a variety of methods has therefore been developed to assist decision makers in an environment of uncertain information.

Within the discipline of economics, and in particular neoclassical economics, standard analyses focusing on system costs or benefits remain the focus of empirical research. In some instances these are cast in formal benefit cost analyses (BCAs), while in others they are cast in terms of cost-effectiveness analyses. In either case, such frameworks attempt to shed light on optimal investment levels, optimal conservation levels, or optimal policy structures.

In this chapter we revisit briefly the conventional problem of optimality that leads us to equate marginal benefits and marginal costs. We also, at this stage, introduce some of the key results from the World Bank Research Committee companion studies that were undertaken in least-cost modeling and cost-effectiveness analysis (Ruitenbeek, Ridgley, Dollar and Huber 1998, 1999 [RRDH]). We then take a closer look at the benefit side of the problem, reviewing briefly lessons from the literature and how they can contribute to our understanding of benefit classification, as well as methodology classification.

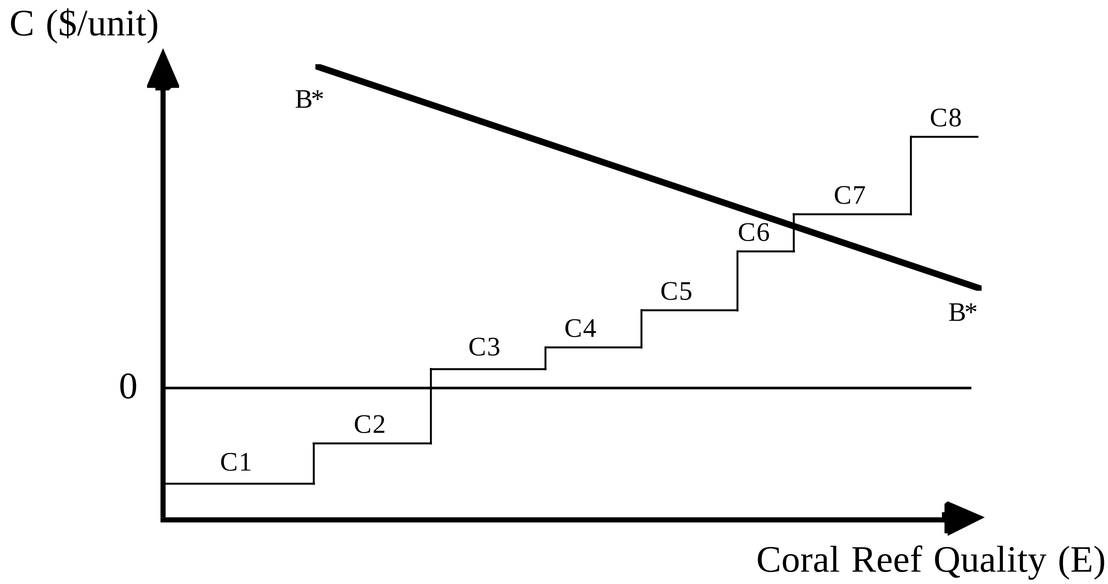
Optimal Coral Reef Quality

To elaborate on Knowlton's above reference to marginal costs and benefits, it is useful to illustrate the management problem in terms of how it is often dealt with using conventional economic optimization frameworks.

Conceptually, a conventional analysis framework would provide a ranking of the cost-effectiveness of various policy or project interventions. The outcome of any analytical efforts would be marginal cost and marginal benefit curves of the type shown in Figure 2.1. This figure shows costs and benefits on the vertical axis, and some indicator of coral reef quality on the horizontal axis. The step-wise cost curve represents 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. In Montego Bay, for example, changing the fishery from open access to a common property regime will improve environmental quality and increase net benefits from the fishery (Gustavson 1998.) Subsequent interventions become more expensive, on a cost per unit basis. Figure 2.1 also shows a declining marginal 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

Figure 2.1
A conventional framework for economic optimization analysis

Cs= Measure of cost-effectiveness in reducing effect/impact indicator "E" by intervention 's'
E= Quality indicator
s= policy intervention or investment
B*-B* = Marginal environmental benefits associated with reducing quality indicator E



productivity, higher tourism potential, or reduced shoreline erosion). Under this conventional construct, an economic optimum occurs where the marginal benefit and marginal 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.

Research related to cost-effectiveness analyses by RRDH, however, places in question some components of this simplified conventional approach. The cost curve of the type contemplated in Figure 2.1 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. RRDH demonstrate this empirically through developing a generic complex systems model that relied on modeling four ecological subsystems in a fuzzy logic framework, and linking these to an eight intervention economic model. The model was applied to Montego Bay, Jamaica, and used to generate an optimized cost envelope that is similar to the cost curve in Figure 2.1, but where each intervention in fact represents a set or bundle of policy choices (see Annex A). As one moves from lower to higher reef quality, interventions enter and exit the optimal intervention set. The nature of this set is such that some of the interventions at higher reef qualities are absent at lower reef qualities; RRDH show that this apparent anomaly arises from non-linearities within the ecosystem response function. Such non-linearities, as Knowlton acknowledged, are likely to be the rule rather than the exception.

The implication that this has for optimal reef management planning is quite profound. First, it is not sufficient to look only at economic costs within a cost-effectiveness analysis framework; such an approach risks providing wrong policy prescriptions. Second, it underpins the importance of addressing the benefit side of the equation; such an estimation of benefits must be undertaken to provide an accurate analysis. Third, the slope of the benefit function, as expressed through the marginal benefit curve, is of greater importance; it is no longer adequate to say that benefits exceed costs; optimal reef quality becomes a management target. But estimating such a benefit function requires that analysts pay closer attention to the relationships between benefits and some measure of reef quality. In later chapters, we address this issue through discussing, for example, ecosystem yield in the context of how many discoveries or species a given reef area may generate. Results of bioprospecting valuation can, as will be shown, be sensitive to such assumptions. Fourth, within this context, it simply underlines the need for economists and coral reef scientists to work together in identifying the relevant ecological and economic relationships.

Classification of Benefits and Methodologies

Given the importance of estimating benefits within any planning context, it is useful to make sure that all parties have similar understandings of the terms in use. To this end, the literature provides some useful insights in how we classify benefits. Unfortunately, the literature also provides some confusing directions on how we classify benefit methodologies: usually it distinguishes between direct methods and indirect methods, which have little, if anything, to do with direct or indirect use benefits. We therefore here provide a first glance at the literature, and set down some common ground definitions both for benefit classification and for methodology classification.

Box 2.1
Local use values – a general framework

Total Economic Value = Use Values & Non-Use Values

<u>Use Values</u>	Example
=	
Direct Use Values	[fish, recreation, building supply]
&	
Indirect Use Values (Functional Values)	[storm protection, nursery ground]
&	
Option Value	[preserve options for future use]
<u>Non-Use Values</u>	
=	
Bequest Value	[passing on natural assets 'intact']
&	
Existence Value	[knowledge that system exists]

Benefit Classification

Any cursory look at the literature on economic benefit valuation makes it obvious that there is a need to adopt a consistent classification framework for economic benefits. The one adopted for this research is consistent with a broad literature of environmental economics and terrestrial biodiversity valuation, summarized by Pearce and Moran (1994), among others, and is shown in Box 2.1. Total Economic Value (TEV) is taken as a function of "use" and "non-use" values. The literature review explicitly identified approximately 20 potential functions and uses of coral reefs, as shown in Table 2.1. Use Values comprise: (i) Direct Uses such as fisheries, recreation, and building supplies; (ii) Indirect Uses or Functions such as storm protection; and, (iii) Option Values that preserve options for future use. Non-use Values include Bequest Values (the value associated with passing on natural assets intact) and Existence Values associated with simply knowing that the resource exists.

It should be noted that, although this framework often shows that the different values are additive (with "+" signs), the actual methods that are used to estimate separate values may not always be additive. We therefore prefer to show the framework using "&" signs, implying a functional though not necessarily additive relationship. Contingent valuation surveys, for example, may capture a combination of direct use and non-use benefits, depending on the

Table 2.1
Local uses and functions of coral reefs

Functions	Sustainable Uses	Non-sustainable Uses
• Global biogeochemical cycles • Breeding, spawning, nursery, feeding and foraging habitats for marine organisms • Coastal protection (self-repairing breakwaters that provide coastal protection) • Source of sand for beaches and dunes that support complex ecosystems • Source of information for medical, agricultural or industrial uses • Natural recorders of past climate and environmental variation • Educational opportunities	• Offshore fisheries • Reef fisheries (fin-fish, invertebrates, marine reptiles, marine algae) • Marine tourism • Mariculture • Biotechnology and bioprospecting (source of bioactive substances for medical and pharmaceutical uses) • Aquarium trade • Coral sand mining (limited) • Small-scale souvenir manufacture	• Coral and sand extraction for lime production, building blocks, other construction materials • Destructive fisheries • Large scale collection of reef organisms • Large scale Aquarium trade • Development on reefs for landfill expansion or other construction

wording of questions. Analysts must therefore be familiar with the valuation methods being employed to ensure that double counting does not arise.

Methodology Classification

Introduction

Marine biodiversity is potentially the most significant sustainable use of marine products, and applying a method to value this biodiversity is of substantial research interest. The research area of biodiversity valuation has grown substantially over the past decade as generalized arguments for exceedingly large values of biodiversity have been put forward by many (McNeely 1988, Prescott-Allen and Prescott-Allen 1988, Principe 1989b, Norse 1993b, Barbier *et al*. 1994, Flam 1994, Beattie 1995). Marine biodiversity, in particular, is recognized for its importance in developing countries in marine biotechnology applications such as aquaculture, marine natural products chemistry, bioremediation, biofilm and bioadhesion, cell culture, biosensors and terrestrial agriculture (Zilinskas and Lundin 1993). Applying a method to value this biodiversity is of key policy interest; economic values of previously untraded goods can draw attention to the economic importance of marine products to a country's development prospects, and can provide guidance for implementing appropriate conservation mechanisms.

The economic literature can be characterized by two schools of thought. The first school of thought demonstrates that either on a theoretical or empirical basis, global biodiversity valuation should not or can not be conducted in any meaningful manner. Perrings *et al.* (1995), for example, explore the idea that many philosophical arguments exist for treating biodiversity conservation as a constraint to economic development, and that valuation of such biodiversity simply implies that trade-offs are possible and potentially desirable. Spash and Hanley (1995) draw attention to the methodological difficulty of valuation where lexicographic preferences exist; and Ruitenbeek (1990) argues that all neoclassical approaches of estimating global biodiversity values relying on partial equilibrium techniques are incapable of providing a valid estimate because of scale considerations. Tacconi and Bennett (1995) argue that, from an intergenerational perspective, biodiversity values are effectively infinitely large and that any practical analysis should therefore focus entirely on finding cost-effective mechanisms for conservation.

A second school of thought either explicitly or implicitly accepts that some form of valuation is desirable or possible, and many methodologies have been developed to attempt to isolate these values (see Aylward *et al*. 1993, for an earlier review). To date, all methodical attempts at estimating biodiversity value have focused on terrestrial biodiversity (e.g., Beese 1996, Gaston 1996, Pearce and Moran 1994, Loomis and White 1996, Kohn 1997, Evenson *et al*. 1998, Smale 1998), and valuations have generally covered a very large range of estimates.

Related to both of these schools of thought is the concept of option value, which is also often linked to concerns of valuing information under conditions of uncertainty. While empirical work in the area of option values has been limited, it is now more commonly accepted that there is some expected value in retaining an option to have access to future information (Hanneman 1989). Some argue that this option value is so large, in the case of biodiversity, that valuation is unnecessary. Such arguments often cause analysts to ignore explicit valuation and resort to cost-effectiveness analysis within an optimizing framework to determine what an optimal strategy might be (e.g., Pardey *et al*. 1998). In more rigorous theoretical constructs, Swanson (1995b) demonstrates that such an option value is unconditionally positive in the case of biodiversity information.

Classification Framework

Most methodology classifications focus on *how* benefits are measured, and thus distinguish between “direct vs. indirect” methods. These categories are not related to direct or indirect use benefits, but relate instead to the way information is collected. Direct methods attempt to elicit

Table 2.2
A system for classifying marine biodiversity valuation methodologies

	Biodiversity Production Valuation Methods	Biodiversity Utility Valuation Methods	Biodiversity Rent Capture Valuation Methods
Economic Basis	"Supply-Oriented"	"Demand-Oriented"	"Profit-Oriented"
Description	Values biodiversity within an economic production function.	Values biodiversity within an economic utility function.	Values biodiversity as a distribution of profits or value-added.
Valuation Target	Measures the contribution of biodiversity to the value of output in a produced good or service. Can estimate and isolate direct or indirect Use Values, including ecological functions or embedded information.	Measures the contribution of biodiversity to the utility of an individual or society. Can estimate aggregated Use and Non-use Values, including consumer's surplus.	Measures one or more components of the distribution of Use Values, focusing on captured rents, profits or value added. Can isolate value of embedded information.
Examples of Methods	Cobb-Douglas Production Function Linear Transforms Non-linear Transforms	Contingent Valuation Hedonic (quality-adjusted) Pricing 'Value of life' measures	Royalty evaluations Patent system evaluations Joint-venture evaluations
Examples of a Model	Q = Q{L,K,M,R,Ib) Q=drug production; L=labor; K=capital; M=materials; R=R&D effort; Ib=Biodiversity information content Value of biodiversity is marginal change in Q as Ib changes.	U=U{Y, C, Cb} U=individual or society's utility; Y=income level; C=consumption level; Cb=consumption or availability of biodiversity Value of biodiversity is marginal change in U as Cb changes.	Π=s{∑PX} Π= profit or rent vector (n participants) s=revenue sharing transform P=price vector (m inputs/outputs) X=input/output vector Value of biodiversity is Π.
Examples of 'Terrestrial Biodiversity' Values	Estimates have been made of the expected value of rainforest species in the production of drugs or agricultural products. Typical values fall in the range of $1,000 to $10,000 per untested rainforest species.	Measures of the value of lives saved and avoided disease from single rainforest species (e.g., rosy periwinkle in cancer treatment) often far exceed $100 million.	Evaluations of revenue sharing through typical patent and joint-venture arrangements show low capture rates of biodiversity values in developing countries. Cameroon collects about $20 per untested rainforest species.

preferences directly through questionnaire or survey; indirect approaches try to value preferences by looking at consumer or market behavior.

In the case of biodiversity valuations, however, the "direct vs. indirect" classification taxonomy is *not* regarded as particularly useful because it does not provide any insights into *what*, in fact, is being measured by any given technique. A review of the different approaches that have been used for terrestrial biodiversity valuation suggested an alternative classification system. Consequently, this research has resulted in the adoption of a new method of classification of marine biodiversity valuation techniques.

In this framework, three quite different classes of biodiversity value are usually estimated; the following classification scheme has been adopted (see also Table 2.2):

- *Biodiversity production values*. These are measures of the value of biodiversity within an economic production function, and may therefore also be considered as focusing on a supply-oriented approach to valuation. They are frequently used to estimate direct use values for fishery output, for example, but the approach can also be used to estimate indirect uses such as ecological functions. In the terrestrial biodiversity literature, they often attempt to estimate the value of inputs to specific drugs or agricultural uses.
- *Biodiversity utility values*. These are measures of the value of biodiversity within an economic utility function, thereby attempting to capture total consumer surplus or demand-

oriented value. Contingent valuation techniques are often used to capture non-use values, or other techniques are used to value the final end-use benefits of biodiversity.

- *Biodiversity rent capture values*. These are measures of how much value is retained or captured within a country or region, or by a particular interest group. The methods usually concentrate on one part of a profit function, and are more interested in identifying a specific profit share than in identifying total economic value. The estimates derived by such approaches may be quite small if there are local institutional weaknesses or failures that prevent benefits from being captured.

Lessons from Production Function Approaches

The basic methods used for valuing local uses involve estimating the lost productivity or value in the absence of proper protection or conservation. Dixon and Sherman (1990) provide a review of these techniques, which can readily be applied to any type of ecosystem and are usually associated with some form of shadow-pricing of goods and services. Examples of empirical applications to various marine systems in an impact-sensitive framework, including mangroves, coral reefs, estuaries, beaches, seagrass beds and other coastal systems, are provided in Alder (1995) and in Ruitenbeek and Smith (1995). Specific studies of Caribbean coral reef systems are provided in Dixon (1992) and Pendleton (1995); Sawyer (1992), Tomascik (1993), Cesar (1996), Dahuri (1996) and Weber and Saunders (1996) show similar analyses for coral reefs in the Pacific. Typical direct uses of coral reefs include tourism, fishery, building materials, and craft materials (e.g., black coral). From a practical research perspective, a key lesson from all of these empirical studies is that analyses should focus initially on a small number (usually fewer than five) of locally important goods and services. Proper identification and careful evaluation of these uses under different impact or conservation scenarios will provide important insights into the nature and relative scale of the benefits of conservation.

Another lesson from these empirical analyses is that the direct use values provide an important benchmark for other, less easily quantified, uses. While most of these other uses are still associated with some particular current or future use (such as bioprospecting or amenity), the uncertainty associated with valuing these goods and services is often orders of magnitude greater than the uncertainty associated with the simple direct (but often untraded) uses. Valuation of the direct uses provides an initial comparative basis for subsequent valuations of other goods and services. The availability of such baseline information is necessary, for example, to estimate option values for future uses. Also, the baseline information allows setting of management and research priorities after all of the valuations are conducted.

Lessons from Utility Function Approaches

Analysts often focus on final end-use utility or value because of the public good nature of biodiversity. Public goods are those for which complete exclusion is not possible: many people can enjoy the benefits from a specific service without affecting the level of enjoyment of others. Biodiversity benefits are often thought to fall into this category, and many production function approaches can not deal adequately with the public good aspect of biodiversity.

Braden and Kolstad (1991) provide an excellent survey of techniques that might be regarded as utility-based approaches (e.g., travel cost methods [TCM], hedonic pricing, willingness-to-pay [WTP] surveys). Contingent valuation methods (CVM) constitute one group of techniques used to estimate benefits; such methods are well-developed in the realm of environmental cost benefit analysis. A key lesson from this work is that the design of the survey questions and the sample frame of the survey can have a significant influence on the values derived through CVM, but applications to tropical ecosystem conservation are becoming relatively common (Dixon and Sherman 1990, Ruitenbeek 1992). But few comprehensive studies have addressed marine systems in tropical developing countries; most CVM analyses in developing countries focus on WTP surveys for energy or water use (World Bank 1992).

One difficulty of using CVM in this context relates to lexicographic preferences. Stated simply, lexicographic preferences exist where decision makers are unwilling to accept any trade-offs for the loss of a good or service. The literature demonstrates that, where such preferences are prevalent, CVM techniques require methodological adjustments; the first step of a proper CVM should therefore be to determine the potential extent of such preferences. Work by Spash and Hanley (1995) suggests that lexicographic preferences for biodiversity may be widespread in developed countries (their survey was conducted in the UK) and that, moreover, the actual definition or understanding of biodiversity differs sufficiently among respondents. CVM techniques under such conditions are highly suspect unless they have been modified to take account of such preference structures. An important research question for the application of CVM techniques is whether contingent valuation of coral reef biodiversity in developing countries is similarly constrained.

Lessons from Biodiversity Rent Capture Approaches

Much of the variation in biodiversity values in the literature can be attributed to various attempts to measure biodiversity rents or profits. Different analysts use different definitions for rent or profit, and in some cases the profit includes a portion of the consumer surplus that final end-users would presumably be willing to pay for a given product. In all cases, however, the methods have invariably attempted to isolate the expected value of a single species of plant or animal through tracing impacts through production functions, demand functions, and distribution functions. In the agricultural bioprospecting literature (e.g., Smale 1995), values often focus on individual traits or characteristics of such plants or animals. In effect, these rent capture approaches can be thought of as a composite of the production and utility function approaches, with a particular view to isolating the rent or profit share that is captured by a specific interest group.

A number of examples for terrestrial biodiversity valuation have focused specifically on capturing the consumer surplus component, and these often generate very high values. For example, based on the impact on human lives saved, Pearce and Puroshothaman (1992ab) estimate a US biodiversity value of US$7 billion annually arising from 40 plant species. By contrast, other analysts have focused on rents or profits captured by the original owners of a product or technique. These techniques are based on actual values capturable through existing patent or royalty schemes and typically generate values of well under $1,000 per species (Ruitenbeek 1989, Harvard Business School 1992ab, Pearce and Puroshothaman 1992ab, Aylward 1993, Reid *et al.* 1993a).

A number of lessons can be drawn from the experience derived from valuing and trying to capture terrestrial biodiversity. First, the actual *value* associated with biodiversity may be closely tied to the type of information that it provides, as opposed to any particular material good (Swanson 1996). In some cases this information provides a stock of ideas that can be used to synthesize key compounds; this occurs largely in the pharmaceutical industry (WCMC 1994a). In other cases the information itself provides direct genetic information that can be introduced into other economic species; this occurs largely in the field of plant genetic resources (WCMC 1994b). The second lesson is that a large array of values can be estimated, depending upon the type of technique used; it is therefore important to understand the limitations and applications of any given technique. Finally, and perhaps most important, proper interpretation of the different values can provide important policy implications. For example, the simple comparisons listed above generally demonstrated that techniques based on human life generated the highest valuations whereas those relying on capturable benefits through royalties or patents generated the lowest values. The low value of transfers is a chronic problem with inventions and information, and has been dealt with at length in the literature of R&D economics (Nordhaus 1969, Rosenberg 1969, 1974, Griliches 1984, Pakes and Schankerman 1984, Schankerman and Pakes 1986.) Such observations have subsequently fostered a search for mechanisms that improve developing countries' access to a greater share of the biodiversity value (Stähler 1994, Swanson *et al*. 1994, Norton-Griffiths and Southey 1995, Swanson 1995ab, 1996, Watson 1995, Southgate 1996). The GEF, for example, explicitly transfers resources to developing countries.

Summary

Although this research works within a conventional optimizing economic framework that relies on quantification of economic costs and benefits, the role of ecosystem complexity can not be understated. Work by RRDH showed that cost-effectiveness analysis within the context of non-linear complex reef ecosystems can lead to incorrect policy choices unless information relating to economic benefits is also available.

To address benefit valuation, we adopt a relatively conventional framework for benefit classification. The one chosen is consistent with a broad literature of environmental economics and terrestrial biodiversity valuation, summarized by Pearce and Moran (1994), among many others. Total Economic Value (TEV) is taken as a function of use and non-use values. The literature explicitly identifies approximately 20 potential functions and uses of coral reefs. Use values comprise: (i) Direct Uses such as fisheries, recreation, and building supplies; (ii) Indirect Uses or Functions such as storm protection; and, (iii) Option Values that preserve options for future use. Non-use Values include Bequest Values (the value associated with passing on natural assets intact) and Existence Values associated with simply knowing that the resource exists.

In addition, we develop some categories for methodology classification, primarily to help – in the first instance – describe the often wide differences in values that are generated by different methodological approaches. We also use these to categorize the different individual studies that are reviewed in a subsequent detailed literature review (Chapter 3). In general, however, three quite different classes of biodiversity value are usually estimated, based on *production* functions, *utility* functions or *rent* capture. Some important implications for empirical research include:

- production function approaches to valuation of a small number of local direct and indirect uses can provide a useful benchmark for other valuations;

- utility function approaches, and contingent valuation in particular, can provide useful insights into non-use and other values that are associated with the public goods nature of products, services or information derived from marine biodiversity. Care must be taken in designing surveys to accommodate lexicographic preferences; and,
- rent capture approaches can be used to isolate the expected biodiversity value of an individual species or trait. In doing this, care must be taken in identifying the institutional context (or revenue sharing context) and in recognizing that much of the value may in fact be associated with *information* rather than physical products.

Chapter 3

Review of the Empirical Biodiversity Valuation Literature

Chapter Acknowledgments

This chapter was prepared by Cynthia Cartier and Jack Ruitenbeek. For comparative purposes, the summary Table 3.1 also incorporates results contained in Chapters 5, 6, and 7 of this final report, although the results are not discussed in detail here. The authors are grateful to Anthony Artuso and Tim Swanson for helpful review comments received on an earlier version of this chapter.

Introduction and Summary of Findings

The primary objective of this literature review is to illustrate the techniques that have been used and the results that have been achieved in empirical studies relevant to marine and coral reef biodiversity valuation. Very little has, in fact, been done that relates only to marine biodiversity, while an extensive amount has been done that covers related areas, such as coastal resource valuation, or terrestrial biodiversity valuation. The purpose of this chapter is not to provide an exhaustive review of all of the valuation literature that may be relevant; such a review would encompass literally thousands of articles. Recent work to promote benefit transfer techniques in Australia and Canada, for example, has resulted in two searchable internet-based bibliographies that permit users to transfer benefits from one study site to a new study site.[3] Also, up-to-date on-line searchable databases relating to biodiversity issues are available from researchers active in the field.[4]

A secondary objective has been to audit and expand on some of the early secondary literature (e.g., Aylward 1993, Pearce and Moran 1994) with a view to updating those reviews. These studies have been frequently cited in what is now becoming a third round, or tertiary

[3] The Canadian effort is available by subscription and is maintained by Environment Canada and is entitled "EVRI: Environmental Valuation Reference Inventory." At the end of 1998 it contained about 850 references, primarily relating to the valuation of water-related issues. It is located at: http://www.evri.ec.gc.ca/EVRI/. The Australian effort is free of charge to use and is spearheaded by the New South Wales Government, and is entitled ENVALUE. It relies on an extensive data base developed by experts in the field of valuation, and addresses a wide range of pollution and environmental management issues. It is located at: http://www.epa.nsw.gov.au/envalue/StudyCnt.asp.

[4] One such site is maintained at Oregon State University by Professor Stephen Polasky, who has done personal research work in genetic valuation and coauthored a bibliography on biodiversity conservation (Polasky *et al*. 1997). The site is located at: http://www.orst.edu/dept/ag_resrc_econ/biodiv/biblio.html.

literature, on the subject and we have referred to the primary articles to ensure consistent and accurate comparable representations of methods and results.

Third, we pay particular attention to pharmaceutical development, and this chapter presents a rigorous comparison of five sets of models that have been used for terrestrial biodiversity prospecting valuation relevant in this area. These range from early models of gross benefits to more recent models that attempt to reflect some of the complexities found in terrestrial ecosystems. This review forms the basis for developing a similar model for marine biodiversity (Chapter 7).

As a preamble to the discussion on pharmaceutical bioprospecting models, we also explore some of the more general findings from the agricultural bioprospecting literature. The agricultural bioprospecting models have developed along a somewhat different path than the pharmaceutical models; while aspects of the agricultural models are relevant to marine bioprospecting, our empirical focus in this study is on the pharmaceutical aspects. This focus is driven by the current policy interest in many developing countries in capturing values from drug research. On balance, marine systems are receiving greater scrutiny for new sources of drugs while bioprospecting for useful maricultural traits is limited (Henkel 1998). For example, in early 1999, more than 30 drugs derived from marine species were under preclinical investigations by private and public research organizations, and by the National Cancer Institute (Mestel 1999).

All existing economic valuation studies pertaining to coral reef habitats were reviewed to determine what types of use and non-use values are typically estimated, and what types of valuation approaches are employed. The studies were generally categorized as falling into either “production value”, “utility value” and “rent value” estimates, as described in Chapter 2 and reiterated in summary form in Box 3.1. Value categories include: recreation, harvested products, education and research, ecological functions, and existence/option values. In some categories, valuation studies of other habitats are included because either the study approach is interesting, or because few coral reef valuation studies exist for the particular use or non-use value. Such is the case for coral reef studies on existence and option values, and for ecological function valuations.

Box 3.1. Biodiversity production, utility and rent valuation measures.

1. *Biodiversity production values*. These are measures of the value of biodiversity within an economic production function, and may therefore also be considered as focusing on a supply-oriented approach to valuation. They are frequently used to estimate direct use values for fishery output, for example, but the approach can also be used to estimate indirect uses such as ecological functions. In the terrestrial biodiversity literature, they often attempt to estimate the value of inputs to specific drugs or agricultural uses.
2. *Biodiversity utility values*. These are measures of the value of biodiversity within an economic utility function, thereby attempting to capture total consumer surplus or demand-oriented value. Contingent valuation techniques are often used to capture non-use values, or other techniques are used to value the final end-use benefits of biodiversity.
3. *Biodiversity rent capture values*. These are measures of how much value is retained or captured within a country or region, or by a particular interest group. The methods usually concentrate on one part of a profit function, and are more interested in identifying a specific profit share than in identifying total economic value. The estimates derived by such approaches may be quite small if there are local institutional weaknesses or failures that prevent benefits from being captured.

From the studies reviewed, the value estimates for uses and non-uses of coral reefs are categorized in Table 3.1a (for habitats) and Table 3.1b (for pharmaceutical genetic resources), and the approach taken for the valuation is summarized. A study by de Groot (1992) – an ambitious valuation of the Galapagos National Park – appears in many of the valuation categories. It is included in this review because of its breadth of treatment of a marine area which, although a minor attribute, does include coral reef habitat. It is also included because of its various valuation approaches.

After examining the valuation studies that focused on coral reefs, we find that:

- existence and option valuations are rare; only one study estimated the existence value of a coral reef site (the Great Barrier Reef);
- most valuation studies involving coral reefs are concerned with their recreational and tourism use value;
- no studies estimate the genetic resource use value of coral reefs, although all acknowledge it;
- the most commonly valued harvested product of coral reefs is fisheries; but the natural systems underlying the harvest (e.g. reef/fish relationships) are simplified, if not ignored;
- the education and research values are based on expenditure estimates, or on budget allocations from funding institutions; and,
- coastal protection afforded by the coral reef habitat is the only ecological function valued.

Table 3.1a. Habitat valuation studies relevant to coral reef management

Ecosystem and Original Study	Approach: Utility	Approach: Production	Approach: Rent	Valuation Results	Miscellaneous Notes including Secondary Sources
Option & Existence Values (for Habitats)					
Existence and Option Value, Great Barrier Reef (Hundloe *et al.* 1987)	★			CVM: A$45 million/yr consumer surplus or A$4/visit WTP to ensure that the Great Barrier Reef is maintained in its current state; based on a 1986 mail survey of Australian citizens 15+ yrs old; estimate excludes respondents who had visited the Reef.	As reported in Hundloe (1990).
Inspiration and Spiritual Values, Galapagos National Park (de Groot 1992)	★			Expenditures: $0.20/ha/yr for cultural/artistic inspirational use, based on sales of books and films; $0.52/hr/yr for spiritual use, based on donations.	Inspiration value is classified as productive use value; spiritual value as conservation value. Both are included here as they are both arguably vicarious use values.
Option Value, Galapagos National Park (de Groot 1992)		★		US$120/ha/yr which is equal to the total value of all the Park's conservation and productive use values combined.	Conservation values include inter alia habitat/refugia value, recreation; productive uses include food, construction materials, etc.
Existence Value, Brazilian Amazon (Gutierrez & Pearce 1992)	★			CVM Studies: $30 billion total based on arbitrary WTP estimates from various CV studies; aggregated across the OECD adult population.	As reported in Pearce & Moran (1994).
Conservation Value, Blanket Peat Bog Scotland (Hanley & Craig 1991)	★			CVM: $580/ha NPV of conserving the area; based on a mail survey; WTP of non-users was $21.60, WTP of users was $43.70; average WTP ($30/household) was applied to the regional population, put on a per ha basis, and discounted at 6%.	Study was a CBA of two options: (i) conservation of the area; and (ii) conversion to block plantations. Option (ii) yielded a NPV of minus $1590/ha. As reported in Barbier *et al.* (1997).
Minimum Option Value, Massachusetts Wetlands (Danielson & Leitch 1986)	★			$343/acre; based on average annual amount paid by US Fish and Wildlife Service in 1980 to owners of unaltered wetlands for preservation easements.	As reported in Pearce & Moran (1994).
Conservation Value, Kakadu Conservation Zone, Australia (Imber *et al.* 1991)	★			CVM: A$124/yr for 10 yrs average WTP to avoid a major mining development impact scenario; and A$52.80/yr for 10 yrs to avoid a minor impact scenario; based on a nationwide in-person survey.	A major criticism of the study was the "embedding effect." As reported in Munasinghe and McNeely (1994).
Existence Value, Nadgee Nature Reserve, Australia (Bennett 1984)	★			CVM: At least A$20, or A$2/yr in perpetuity WTP of Canberra residents for the continued existence of the Reserve; based on an in-person survey of 544 residents, bid curve analysis, and a 10% real interest rate.	Coastal area with high diversity of habitats; managed with emphasis on non-participatory benefits.

Table 3.1a. Habitat valuation studies relevant to coral reef management

Ecosystem and Original Study	Approach: Utility	Approach: Production	Approach: Rent	Valuation Results	Miscellaneous Notes including Secondary Sources
Existence Value Prince William Sound, Alaska (Carson *et al.* 1992)	★			CVM: Median $31/household one-time tax for measures to prevent future oil spills like that of the Exxon Valdez; based on in-person survey of 1043 US citizens; WTP aggregated over affected households yielded $2.8 billion in total lost non-use value.	Natural resource damage assessment done for the State of Alaska. As reported in Pearce & Moran (1994), and Carson *et al.* (1996).
Direct Use Values for Marine Areas – Harvested Products					
Fisheries Valuation Great Barrier Reef (Driml 1999)		★		Productivity Change: Gross Revenue A$143 million (1996); based on 1995/96 catch data for major commercial species, and a survey of current fish prices.	Study updates Driml (1994) estimates presented in Driml (1997) and Driml *et al.* (1997).
Fisheries Valuation Bacuit Bay, Philippines (Hodgson & Dixon 1988)		★		Productivity Change: PV Gross Revenue $9108 with logging vs $17,248 with logging ban; based on assumed constant returns to scale of natural systems; and on regression analyses of sediment loading, coral cover and species, and fish biomass relationships.	CBA study evaluates management options: (i) continuation of logging as usual; (ii) logging ban in Bacuit Bay drainage basin.
Fisheries Valuation, Taka Bone Rate Coral Reef Atoll, Indonesia (Sawyer 1992)		★		Productivity Change: PV Gross Revenues (billion Rp): -2 to 103 without management vs 47 to 777 with management; based on fishing activity surveys; and sensitivity analyses wherein fish catch declines range 0-15% and discount rates vary 5-15%.	CBA study evaluates management options: (i) no management; (ii) establishment of marine park with regulated fishing.
Fisheries Valuation, Indonesia Coral Reefs (Cesar 1996)		★		Productivity Change: NPV of fisheries loss/sq km of reef: $40,000 (poison fishing); $86,000 (blast fishing); $94,000 (coral mining); $81 (sedimentation); $109 (overfishing); based on assumptions about the reef and fishery impacts of these practices.	Study uses CBA to compare the private and social net benefits of a sustainably managed reef fishery, with those of a fishery subjected to detrimental fishing practices, coral mining, or sedimentation.
Fisheries Valuation, Philippines (McAllister 1988)		★		Productivity Change: $80 million/yr in lost fish production caused by dynamiting, muro-ami, and poisoning of coral reefs; based on estimates of current and potential production.	Production levels are calculated for varying levels of reef damage.
Aquarium Trade, Philippines (McAllister 1988)	★			Productivity Change: Global aquarium trade attributable to the Philippine Coral Reefs: $10 million in 1988 could be increased by 50% with sustainable production practices.	The price of Philippine aquarium species is discounted internationally due to method of capture.
Productive Use Values, Galapagos National Park (de Groot 1992)	★	★		Productivity Change: $0.40/ha/yr (permitted) ornamental product sales; $0.70/ha/yr local fish and crustacean harvest; $5.20/ha/yr construction materials value (terrestrial and coastal areas).	de Groot classifies ornamental resources, food, and construction materials as having productive use value within the "production function" category of environmental functions.

Table 3.1a. Habitat valuation studies relevant to coral reef management

Ecosystem and Original Study	Approach: Utility	Approach: Production	Approach: Rent	Valuation Results	Miscellaneous Notes including Secondary Sources
Wetland Valuation, Florida (Bell 1989)		★		Productivity Change: Marginal productivity of commercial marine species: $88/ha/yr; based on a wetland production function describing wetland/fisheries productivity linkage; and market prices of commercial species.	As reported in Barton (1994).
Direct Use Values for Marine Areas - Recreation & Tourism					
Recreation Value Great Barrier Reef (Driml 1999)		★		Productivity Change: Gross Recreation Value A$769 (1996), includes A$647 for commercial tourism and A$123 for recreational fishing & boating; based on volume & price data for hotel stays & reef trips, and survey data for private recreational boat use.	Study updates Driml (1994) estimates presented in Driml (1997) and Driml *et al.* (1997).
Visits to Great Barrier Reef "Region" (Hundloe *et al.* 1987)	★			TCM: A$144 million/yr consumer surplus for domestic tourists and international tourists; based on travel cost expenditure by visitors to the "Reef Region."	As reported in Hundloe (1990).
Visits to Coral Sites and the "Reef Region" of the Great Barrier Reef (Hundloe *et al.* 1987)	★			TCM: A$106 million/yr consumer surplus; based on travel costs to coral sites by both domestic and international tourists, and includes all attributes of the "Reef Region."	As reported in Hundloe (1990).
Visits to Coral Sites within the Great Barrier Reef (Hundloe *et al.* 1987)	★			CVM: A$6 million/yr consumer surplus or over A$8/adult visitor WTP to see coral sites in their present (1986-87) condition; based on a survey of visitors to reef sites only, thereby excluding all other attributes of the Great Barrier Reef "Reef Region."	As reported in Hundloe (1990) and Driml *et al.* (1997).
Coral Reef Value and Its Impact on Tourist Volume Negril, Jamaica (Wright1995)	★			CVM: $31/person/yr WTP, for a consumer surplus of $5 million/yr by visitors to maintain coral reef in current condition; and $49/person/yr for a surplus of $8 million/yr to restore reefs to "excellent" condition; based on CVM survey data and 162,000 visitors/yr.	Also, TCM was used to estimate a demand curve for vacations; the coral reef consumer surplus was netted out of vacation consumer surplus to examine the resultant shift in demand and reduction in tourist volume if reef quality should decline.
Dive Value, Bonaire Marine Park (Dixon *et al.* 1993)	★	★		CVM: $27.40 average WTP for a consumer surplus of $325,000; based on 18,700 divers in 1992 paying a $10/diver/yr fee. Productivity Change: Gross tourist revenue of $23.2 million (1991).	The study also estimated the revenues and costs of dive tourism, and the carrying capacity of dive sites (4000-6000/site/yr, for a total of 190,000-200,000).

Table 3.1a. Habitat valuation studies relevant to coral reef management

Ecosystem and Original Study	Approach: Utility	Approach: Production	Approach: Rent	Valuation Results	Miscellaneous Notes including Secondary Sources
Dive Value Bonaire Marine Park (Pendleton 1995)	★	★		Productivity Change: Net Tourism Revenue $7.9 to $8.8 million (1991); based on ownership & profit data. TCM: $19.2 million consumer surplus. Park NPV: $74.21 million local benefits; $179.7 million consumer surplus; based on 20 yr period, 10% discount rate.	The study compares its net value estimate to the gross value estimate of Dixon *et al.* (1993). It argues for a "project appraisal approach" to protection valuation.
John Pennekamp/Key Largo, Florida (Leeworthy 1991)	★			TCM: $285 to $426/person/day consumer surplus; based on a survey of some 350 park users in 1990; nine models were estimated; final estimate range taken from the two models which best fit the data.	The inclusion of an "opportunity cost of time" variable was found to increase significantly consumer surplus estimates.
Tourism Palawan Coral Reef, Philippines (Hodgson & Dixon 1988)	★			Productivity Change: PV gross revenue $6,280 with logging vs $13,334 with logging ban; based on mean hotel capacity, occupancy, and daily rates; and an assumed 10% annual decline in tourism revenue due to degradation of seawater quality from sedimentation.	CBA study evaluates management options: (i) continuation of logging as usual; (ii) logging ban in Bacuit Bay drainage basin.
Tourism Valuation, Indonesia Coral Reefs (Cesar 1996)		★		Productivity Change: NPV of tourism loss/sq km of reef $3000-436,000 (from poison fishing); $3000-482,000 (blast fishing or coral mining); $192,000 (sedimentation); based on assumptions regarding the rate of reef degradation associated with each practice.	CBAs for each reef-destroying activity estimate the value of tourism loss. For each activity, reef degradation causes a decrease in potential tourism revenue. All rates of change are based on assumptions.
Recreation, Galapagos National Park (de Groot 1992)	★			Productivity Change: $45/ha/yr for the total protected area; based on maximum carrying capacity of 40,000 visitors/yr, and average expenditures per visit of $1300.	Classified as a productive use value within the "carrier function" category of environmental functions.
Vacation Value, Galapagos National Park, Ecuador (Edwards 1991)	★			Hedonic Demand Analysis: $312/day/person in 1986; based on a nonlinear regression using cost, duration, and itinerary data from travel brochures; as well as cost and duration survey data.	Value of a Galapagos vacation is regressed on duration, accommodation, and itinerary data; model is differentiated with respect to duration to get the implicit price of a vacation day.
Education & Research - Marine Areas					
Belize Coral Reefs (Spurgeon 1992)	★			$150,000/yr; based on annual expenditures by UK Coral Cay Conservation to maintain 25 researchers on reefs in Belize.	
Panama Coral Reefs (Spurgeon 1992)	★			$2.5 million in 1991; based on a percentage of the Smithsonian Research Institute's budget for work in Panama.	One-sixth of the 1991 $15 million budget is considered attributable to coral reefs in Panama.
Galapagos National Park (de Groot 1992)	★			$2.73/ha/yr; based on research expenditures, and expenditures on field courses, fellowships, training courses, education facilities and materials.	Classified as a productive use value within the "information function" category of environmental functions.

Table 3.1a. Habitat valuation studies relevant to coral reef management

Ecosystem and Original Study	Approach: Utility	Approach: Production	Approach: Rent	Valuation Results	Miscellaneous Notes including Secondary Sources
Indirect Uses - Ecological Functions					
Coastal Protection, Philippine Coral Reefs (McAllister 1991b)		★		Replacement Costs: US$22 billion; based on construction costs of concrete tetrapod breakwaters to replace 22,000 sq km of reef protection.	As reported in Spurgeon (1992).
Coastal Protection, Indonesia Coral Reefs (Cesar 1996)		★		Productivity Change: NPV of coastal protection/sq km of reef: $9000-193,000 (blast fishing); $12,000-260,000 (coral mining); based on replacement costs, the rate of reef destruction from each activity, and the rate of decline in reef's ability to protect.	CBAs for each reef-destroying activity include the cost of protective function losses. For each activity, reef destruction reduces the protective capability of the reef. The reef's loss of protective capability is linked linearly to its protective value.
Organic Waste Treatment, Galapagos National Park (de Groot 1992)		★		Replacement Costs: $58/ha/yr based on the costs of artificial purification technology; applies to marine area only.	Classified as a conservation value of the Park, in the category of "regulation functions."
Biodiversity Maintenance, Galapagos National Park (de Groot 1992)		★		Shadow Price: $4.9/ha/yr which equals 10% of the market value of any activity reliant on biodiversity maintenance.	Classified as a conservation value of the Park, in the category of "regulation functions."
Nature Protection, Galapagos National Park (de Groot 1992)	★			$0.55/ha/yr nature protection; based on the park budget and the idea that money invested in conservation management should be seen as productive capital because of the environmental functions and socio-economic benefits provided by conservation.	Classified as a conservation value of the Park, in the category of "carrier functions."
Habitat/Refugia Galapagos National Park (de Groot 1992)		★		Benefit Transfer: $7/ha/yr; based on the similarities of the Dutch Wadden Sea and Galapagos estuarine areas, it was assumed that 10% of fishery in Galapagos depends on the nursery function provided by inlets and mangrove lagoons.	Classified as a conservation value of the Park, in the category of "regulation functions."
Nitrogen Retention & Recycling, Gotland, Sweden (Gren 1995)	★	★		$34/kg NPV for nitrogen abatement from wetland restoration; based on (i) $100/person/yr WTP for improved water quality; (ii) a surface/ground water hydrological model; and (iii) the nitrogen absorptive capacity of wetlands.	As reported in Barbier *et al.* (1997).
Natural Predator, Greater and Lesser Antilles (Narain & Fisher 1994)		★		Productivity Change: $670,000/1% decline in Anolis Lizard population; based on value of lost output when the lizard is not there to feed on crop destroying insects.	As reported in Barbier *et al.* (1994).

Table 3.1a. Habitat valuation studies relevant to coral reef management

Ecosystem and Original Study	Approach			Valuation Results	Miscellaneous Notes including Secondary Sources
	Utility	Production	Rent		
Watershed Protection, Cameroon (Ruitenbeek 1992)		★		Productivity Change NPV: $12/ha/yr watershed protection value of fisheries; $2/ha/yr, flood control; $1/ha/yr, soil fertility maintenance; based on production losses resulting from Park deforestation, discount rate of 8%, and 513,800 "hectare-years".	Watershed protection benefits were part of a social cost benefit analysis of protecting the Korup National Park. Values expressed in 1989 constant terms.
Valuation Studies Associated with World Bank Research Committee Project					
Option & Existence Values (for Habitats)					
Non-use Value Montego Bay Coral Reefs (Spash *et al.* 1998)	★			CVM: Survey design specifically targeted to dealing with lexicographic preferences through probing of zero bids and analysis of zero bids using tobit estimation. Expected WTP for tourists ranged from $1.17 to $2.98 for 25% coral reef improvement; for locals range was $1.66 to $4.26 Upper values were for respondents perceiving strong moral duties and rights; lower were for no such duties/rights. Based on population characteristics, non-use NPV of Montego Bay reefs estimated to be US$19.6 million.	Summary available at: http://www.island.net/~hjr
Non-use Value Curaçao Coral Reefs (Spash *et al.* 1998)	★			CVM: Similar survey design as Montego Bay study, above. Expected WTP for tourists ranged from $0.26 to $5.82; for locals range was $0.19 to $4.05. Based on population characteristics, non-use NPV of Curaçao reefs estimated to be US$4.5 million.	Summary available at: http://www.island.net/~hjr
Direct Use Values for Marine Areas – Harvested Products					
Artisanal Fisheries Valuation Montego Bay Coral Reefs (Gustavson 1998)		★	★	Productivity Change: Net Present Value US$1.31 million (1996); includes trap, net, hand line and spear-fishing by local fishers. Cost of inputs is deducted from gross values to arrive at net values. Base case assumes shadow price of labor of 75% market rate; 100% market valuation leads to negative NPVs for fishing.	Full text available at: http://www.island.net/~hjr
Direct Use Values for Marine Areas - Recreation & Tourism					
Recreation Value Montego Bay Coral Reefs (Gustavson 1998)		★	★	Productivity Change: Recreation NPV US$315 million (1996); includes tourist related accommodation, food & beverage, entertainment, transportation, retail and miscellaneous services. Cost of service provision is deducted from gross values to arrive at net values.	Full text available at: http://www.island.net/~hjr

Table 3.1a. Habitat valuation studies relevant to coral reef management

Ecosystem and Original Study	Approach: Utility	Approach: Production	Approach: Rent	Valuation Results	Miscellaneous Notes including Secondary Sources
Indirect Uses - Ecological Functions					
Coastal Protection, Montego Bay Coral Reefs (Gustavson 1998)		★		Productivity Change: Net Present Value US$65 million (1996); based on land values at risk or vulnerable to coastal erosion along foreshore. Author notes this is upper value and is dependent on erosion incidence assumptions in absence of reef, which are highly speculative.	Full text available at: http://www.island.net/~hjr
Other - Cost Effectiveness Analysis					
CEA of Interventions, Montego Bay (Ruitenbeek *et al.* 1999)		★		Estimates of cost-effectiveness of 8 specific interventions, with impacts normalized to coral reef abundance using fuzzy logic model incorporating non-linear ecological and economic linkages. CEA approach uses continuous optimization of "intervention sets" and demonstrates non-transitivity of individual interventions. Indicates up to 20% coral reef abundance improvement possible at PV cost of US$153 million. Marginal costs rose from under $1 million/% to $29 million/% over a 42 hectare reef area.	Full text available at: http://www.island.net/~hjr

Table 3.1b. Pharmaceutical genetic resource valuation studies relevant to coral reef management

Ecosystem and Original Study	Approach: Utility	Approach: Production	Approach: Rent	Valuation Results	Miscellaneous Notes including Secondary Sources
Genetic Resources - Terrestrial Systems					
Value of Plants Used in Pharmaceutical Industry (Farnsworth & Soejarto 1985)		★		$203 million/successful species/yr; based on 1980 US gross drug sales; survey data showing that 25% of all prescriptions contain one or more active plant-based agents; and 40 plants account for those active agents.	Extended by Aylward (1993): $1.6 million/untested species/yr based original study's stated success rate of 1:125.
Value of Plants Used in Pharmaceutical Industry (Principe 1989ab)	★	★		$1.5 trillion/yr total value of plant-based drugs (US & OECD); based on value of a statistical life ($8 million, 1983$); percentage of lives saved by anticancer drugs(15%); and percentage of drug-based anticancer drugs (40%).	Extended by Aylward (1993): $37.5 billion/successful species/yr given 40 plants responsible for all plant-based drugs; $18.8 million/untested species/yr based on original study's stated success rate of 1:2000.
Value of Research Discovery in Korup Park, Cameroon (Ruitenbeek 1989)			★	$7500 annual expected value of genetic discoveries to Cameroon; based on average patent values;10 patentable discoveries/yr; and host country's ability to capture 10% of the rent from the discoveries.	Extended by Aylward (1993): $150/untested species/yr assuming 500 species inhabit the Korup forest area and a success rate of 10:500.
Value of Tree Species Used in Pharmaceutical Industry (McAllister 1991a)		★		$250,000/yr gross value of a tree-derived pharmaceutical; based on global sales of plant-based drugs; and percentage of tree species likely to contain marketable pharmaceuticals (3%).	Extended by Aylward (1993): $7500/untested species/yr (1990$) based on original study's stated success rate of 3:100.
Value of Research Discovery in Costa Rica (Harvard Business School 1992)		★	★	$253,000 expected NPV/research discovery; based on net drug sales, and a 5% royalty on revenue to host country (Costa Rica).	Extended by Aylward (1993): Annual Value $253/untested species based on original study's stated success rate of 1:10,000. [sic.] {The correct calculation would show NPV $25.30 /untested species.}
Value of Plants and Land to the Pharmaceutical Industry, Rainforest Flora (Pearce & Puroshothaman 1992ab)	★	★	★	$390 million/successful plant species/yr based on 1990 US gross drug sales; $7 billion/yr based on the value of lives saved ($4 million/life). Rainforest values: $0.01-$21/ha for success rates 1:1000 and 1:10,000; a 5% royalty; and 10% rent capture by host country.	Extended by Aylward (1993): Annual global value per untested species: $819 using drug sales; $1.5 million using value of lives saved. Based on original study's 5% royalty & 10% rent capture rates; success rates 1:10,000 and 1:1000; and, a 4.2 multipler to convert US estimate to global estimate.

Table 3.1b. Pharmaceutical genetic resource valuation studies relevant to coral reef management

Ecosystem and Original Study	Approach			Valuation Results	Miscellaneous Notes including Secondary Sources
	Utility	Production	Rent		
Value of Biotic Samples (Reid *et al.* 1993)			★	$52,500 NPV of agreement to supply 1000 biotic samples; based on 3% royalty, 5% discount rate, $10 million annual net sales after 10 yrs development, 15 yrs patent protection, and cumulative success rate of 1:40,000.	Extended by Aylward (1993): NPV $52.50/untested species. Based on "sample to lead" success rate of 1:10,000. [sic.] {The correct calculation would show NPV $5.25 /untested species.}
Net Private and Social Returns to Biotic Samples and Biodiversity Protection in Costa Rica (Aylward 1993)		★		Net return per biotic sample: $21.23 (private) to $33.91 (social); based on NPV of a new drug source. Social cost model includes costs of biodiversity protection and publicly provided taxonomic information. Success rate is 1:10,000.	Estimates PV of net returns generated by a protected area containing 10,000 species; all species are submitted to a single screening program and there is one success in the first year.
Net Private and Social Returns to Biotic Samples Costa Rica (Aylward 1993)			★	Total Net return on 10,000 biotic samples: -$.98 million (social) to $4.91 million (private); based on net revenue to a new drug source; 2% royalty, private & social costs as in above model. Success rate is 1:10,000.	Above model is modified to calculated the PV of net royalty returns on a collection of 10,000 species.
Net Private and Social Returns to Biotic Samples under Various Distributional Arrangements (Aylward 1993; Barbier & Aylward 1996)			★	Net Returns: $5 million (private); -$240 million (social); based on throughput of 2000 samples/yr, protection for 500,000 species over 600,000 ha, $233/sample royalty, $213/sample in collection & classification fees, 40 prospecting years, and 10% discount rate.	Models the investment choices faced by a developing country. Choices pertain to investment in pharmaceutical prospecting: (i) biodiversity protection; or, (ii) capacity expansion to produce species information.
Value of Plants and Land to Pharmaceutical Industry (Mendelsohn & Balick 1995, 1997)		★		IF all potential drugs are discovered: $449 million NPV/successful species for a total $147 billion NPV or $48/ha tropical forest; based NPV of a new drug source, and 328 plant-based drugs yet to be discovered and developed.	Extended by Artuso (1997): $1.2 million/tropical forest plant species given 125,000 plant species.
Value of the Marginal Plant Species to the Pharmaceutical Industry (Simpson et al. 1996)		★		Value of marginal species: $9,000 based on 250,000 species to test, success rate of 1:83,333 and revenue to cost ratio of 1.5. Sensitivity analysis: A success rate less than 1:12,500 reduces value to zero; revenue/cost ratio of 1.10 reduces value to $2.20.	Models the private pharmaceutical value of the in situ "marginal species", which is valued on the basis of its incremental contribution to the probability of making a commercial discovery.
Value of Marginal Threatened Habitat to the Pharmaceutical Industry (Simpson *et al.* 1996)		★		Maximum private value for endangered habitat: Estimates range from a low of $0.20/ha (California Floristic province) to high of $20.63/ha in Western Ecuador (where there is high concentration of endemic plants).	Uses theory of island biogeography, marginal species value results (above), and data from Myer's (1988, 1990) 18 biodiversity "hot spots".

Table 3.1b. Pharmaceutical genetic resource valuation studies relevant to coral reef management

Ecosystem and Original Study	Approach: Utility	Approach: Production	Approach: Rent	Valuation Results	Miscellaneous Notes including Secondary Sources
Social Value of Marginal Species (Simpson & Craft 1996)		★		Value of marginal species to consumers: $33,000; value of loss of 25% of all world's species: $111 billion; based on the existence of 10 million species available for screening, and global pharmaceutical sales and cost estimates.	Uses a model of product differentiation which accounts for consumer surplus.
Social Value of Marginal Threatened Habitat to the Pharmaceutical Industry (Simpson & Craft 1996)		★		Value of marginal ha: Estimates range from a low of $29/ha (California Floristic province) to high of $2,888/ha in Western Ecuador.	Uses theory of island biogeography, marginal species value results (above), and data from Myer's (1988, 1990) 18 biodiversity "hot spots".
Value of Marginal Species when Research Intensity is Optimal (Simpson & Sedjo 1996b)			★	Value of marginal species when there exist 250,000 species: $2600; when there exist 1 million species: $0.0. Calculations based on 500 therapeutic objectives, $125 million/new product; 5 yr testing period; and a 4% discount rate.	For each period the model maximizes the value of the collection by choosing the optimal collection size, given the number of species remaining to be tested and the variable costs of testing.
Net Private and Social Value of Biotic Extracts (Artuso 1997)		★	★	NPV per biotic extract before taxes: $487 (private) to $7671 (social); based on NPV of new drug sources, and success rates which vary with different stages the of R&D process. The cumulative success rate of the process is 1:111,111.	Model treats R&D as a series of phases, each with specific revenues, costs, and success rates.
Valuation Studies Associated with World Bank Research Committee Project					
Genetic Resources - Marine Systems					
Value of Pharmaceuticals from Coral Reefs (Ruitenbeek & Cartier 1999)			★	Value of Montego Bay coral reef based on model incorporating drug values, local bioprospecting costs, institutional costs, discovery success rates for marine extracts, and a hypothetical bioprospecting program for the area using National Cancer Institute sampling protocols. Model highlights role of revenue sharing arrangements and ecosystem yield in deriving total benefits and marginal benefits. Average Net Social Value of species in base case is estimated to be $7775. Based on base case sampling program, total social NPV of Montego Bay reef area is US$70.09 million. First differential of the benefit function yields US$225,000/% or US$530,000/ha coral abundance.	Authors note sensitivity of results to assumptions in ecosystem yield and species-area (SA) relationships, which relied on SA estimates by Reaka-Kudla (1995) for global coral ecosystems. In base case $S=cA^z$, z=0.265. Within potential range of z=0.2 to z=0.3, NPV shifts from $85 million to $54 million and marginal benefit shifts from $72,500/ha to $698,000/ha. Summary available at: http://www.island.net/~hjr

Literature Relating to Existence and Option Values

Only one study estimated a combined option and existence value for a coral reef habitat. Hundloe *et al*. (1987) uses contingent valuation methods (CVM) to estimate the value of coral sites within the Great Barrier Reef to "vicarious" users. From adult Australian citizens, willingness-to-pay (WTP) bids to ensure that the reef is maintained in its (then) current state are used to calculate a consumer surplus of A$45 million a year. Bids from survey respondents who had visited the reef are excluded, but the motives behind bids from non-users were not distinguished. Therefore, although the estimate represents non-use value, it does not separate option and existence values. In any case, the authors stress that the valuation is an underestimate because it excludes the vicarious value of the reef to overseas residents.

For the Galapagos National Park, de Groot (1992) estimates option value. He also estimates "inspirational" and "spiritual" values which are included here because these could be considered vicarious non-use values. The option value is estimated to be at least equal to the combined value of all the so-called productive and conservation (ecological) uses of the park. The value of cultural and artistic inspirational use is based on the value of book and film sales. The value of spiritual use is based on financial donations because, the author argues, at least part of donated money indicates an ethical or intrinsic value attached to the park.

As existence and option valuations involving coral reef habitats are scarce, studies involving other types of habitats were reviewed for their methodological approaches to valuing non-use benefits. The six non-coral reef studies documented in Table 3.1 are frequently cited as examples of non-use benefit valuation; all but one employ CVM to estimate non-use value.

Literature Relating to Harvested Product Valuations

Table 3.1a summarizes the results of seven studies involving harvested products from coral reef habitats; all of the valuations use a change in productivity approach with varying degrees of linkage complexity. Two of the studies (Driml 1999, de Groot 1992) do not incorporate ecological economic linkages: the valuations simply represent the gross financial value of harvested products. Four other studies try to link reef quality to fishery productivity: reef quality is viewed as a factor of production, a change in which leads to a change in reef productivity; the productivity change is measured in terms of output levels. These approaches rely on ecological quantitative analysis and ecological economic linkages.

The harvested products category includes a valuation of coral reef aquarium fish production. The estimate represents the gross financial value of the trade, and includes an estimate of the potential change in value with improved production practices. For its methodological interest, we also include a study of harvested products in a *wetland* habitat. It uses a relatively complex ecological economic linkage model which treats habitat area as a variable input to fisheries production.

Three types of weakness are often evident in these types of valuations. First, and most serious, is that fisheries value is usually assumed to be its gross revenue, thus ignoring the opportunity cost of capital and labor in fishing effort. Such gross value estimates for fisheries over-state the net benefits from such activities and often make it politically difficult to find other economically benign and sustainable uses of a reef area. Second, the dynamics of the coral reef and surrounding natural systems are often simplified, if not ignored. Perrings and Walker (1995) argue that the dynamics of natural systems are characteristically highly nonlinear, discontinuous, and sometimes irreversible around a range of critical thresholds. Third, a less obvious weakness of many of these approaches is that they usually base harvest rates on some level of extraction effort which is implicitly assumed to be value-maximizing. In the simplest cases, current (observed) extraction rates are assumed to occur in perpetuity, even though these may be either above the socially optimal rate (from the usual types of over-fishing practices) or, more rarely, below the optimal rate (e.g., where there are barriers to entry). Some analysts are more careful about this aspect of extraction, and base their assessments on maximum sustainable yield (MSY) to introduce some form of sustainability constraint (Cesar 1996). Even in such cases, however, it is important to note that MSY does not necessarily coincide with an economic optimum; standard fishery and bioeconomics texts (Clark 1976) teach us that it may be economically optimal to extract at rates either below or above the MSY depending on the attributes of the specific fishery. In cases where current harvest rates are used, it is likely that the methods over-estimate value; while estimates based on MSY will likely underestimate economic value.

A recent study by Driml (1999) estimates the gross financial value for the commercial fishery of the Great Barrier Reef. Effort and catch data on selected major commercial fish species were obtained from the Queensland Fisheries Management Authority. Price data were obtained by a brief survey of the fish and prawn markets. Volume and price data yield an estimated gross financial value of A$143 million (1996$).

The Hodgson and Dixon (1988) CBA study estimates the gross revenue value of fisheries in Bacuit Bay, Palawan with and without a logging scenario. It is the most complex of the coral reef valuations examined, in that it first undertakes a quantitative analysis of the natural systems affecting fisheries. Using environmental data, linkage coefficients are estimated to determine: (i) the relationships between sedimentation, coral cover and coral diversity; and (ii) the relationships between fish biomass, coral cover and coral diversity. The coefficients were obtained using linear regression analysis; this implicitly assumes constant returns to scale of the natural systems, a considerable simplification of the functioning of natural systems.

A CBA study by Sawyer (1992) estimates the gross revenue value of fish catch on Taka Bone Rate, an Indonesian coral reef. In the absence of empirical natural system linkage models for the area, sensitivity analyses are conducted on the base year value of the fish catch. By simply assuming different rates for fish catch productivity change, NPV estimates are calculated.

For Indonesia, Cesar (1996) uses CBA to compare the potential productive value of coral reef fisheries, to the value of those same fisheries in the presence of different threats to reef quality and productivity. Threats include poison fishing, blast fishing, over-fishing, coral mining, and sedimentation. Each threat is analyzed in isolation from the others, and in terms of its net benefits on a per square kilometer basis. Therefore, a hypothetical reef area faces only one threat which provides a net private benefit to the individuals responsible for it, as well as societal losses due to the detrimental treatment of the reef.

Potential productivity of reef fisheries is that associated with an intact reef area, and a level of effort which achieves the MSY of that area. Additional assumptions about fish prices, labor, and other input costs provide a *net* benefit valuation. The private net benefit of destructive fishing practices is based on threat-specific assumptions regarding prices, effort, yield, input costs, the rate of coral death, the rate of yield decline, and the rate of coral recovery, if any. Coral death and fishery yield are assumed to be linearly related. The societal loss to fisheries is the difference between the net private benefit of the destructive fishing practice, and the net benefit associated with the MSY level of effort.

In the cases of coral mining and sedimentation there are only net losses to fisheries. Private benefits accrue in other sectors: construction and logging. Losses to reef fisheries from coral mining is the difference between the MSY of an intact reef, and the yield of a gradually destroyed reef. It is therefore based on assumptions regarding the rate of coral destruction from mining, and the associated yield decline. For the threat of sedimentation, the calculation of reef fisheries yield decline is based on the ecological linkage coefficient estimates of Hodgson and Dixon (1988).

In an often cited study of the value of Philippines coral reefs, McAllister (1988) calculates the change in fisheries productivity as a result of reef damage from dynamiting, poisoning, and muro-ami fishing. The valuation methodology is simply a comparison of current yields with potential yields. The productive area of the reef (some 33,000 km^2 out of a total 44,000 km^2) is disaggregated according to its condition: poor, fair, good, or excellent. The yield associated with each condition is calculated and the total yield for the productive area is compared with the potential yield were the entire reef in good condition.

McAllister (1988) also estimates foregone earnings in the production of marine aquarium fish. Sodium cyanide is typically used for gathering marine fish, which damages the reef and reduces the price of the final product (net-caught tropical fish command a higher price). Based on the reported value of the Philippines trade in aquarium fish, the author estimates that a 50 percent increase in value could be realized if the aquarium fish were produced on a sustainable basis.

For the Galapagos National Park, de Groot (1992) estimates the gross financial value of legally traded ornamental goods, local fish and crustacean harvest, and the value of construction materials. Associated capital and labor costs are excluded from the calculations, as are any consideration of the functioning of the underlying natural systems providing these products.

For methodological interest, a wetland valuation study of marine harvested products is included in Table 3.1a. Bell (1989) takes a marginal valuation approach to fisheries in a Florida wetland. The incremental value of a hectare of wetlands habitat is assumed to be equal to the marginal productivity of the wetlands-dependent fisheries. The study estimates a non-linear bioeconomic production function for fisheries. The approach is similar to those describe above for coral reef fisheries, although the specification of the production function is more complex. The area of the (wetland) habitat input is variable, whereas in the coral reef studies, the area of the coral reef habitat input is fixed. In the coral reef studies, the valuations therefore pertain to the total reef area as the input, not increments thereof.

Literature Relating to Recreation and Tourism Valuation

The recreation and tourism direct use value attributable to a coral reef is usually estimated by accounting for the tourism revenue generated by a particular coral reef holiday destination. From a utility perspective, these values ignore the consumer surplus generated by the recreation experience and as a result underestimate the value of the recreation experience. From a production perspective, gross tourism revenue – the figure most often calculated – ignores the labor and capital costs of supplying the services, as well as the costs associated with the environmental impacts of tourism.

Another problem with using tourism revenue relates to the bundling of a vacation destination's attributes. When a coral reef is just one attribute of the bundle, tourism revenue cannot be solely attributable to the reef. The more important the reef attribute in the vacation experience bundle, the higher the proportion or tourist revenue that can be attributable to the reef. In any case, the basic problems of using gross revenue and ignoring associated costs persist.

In Table 3.1a, most of the studies focusing on coral reef recreation/tourism estimate consumer surplus using a travel cost method (TCM) or a CVM; however, three – Driml (1999) for the Great Barrier Reef, Cesar (1996) for Indonesia, and Hodgson and Dixon (1988) for Bacuit Bay – take the gross revenue approach. The study of Negril, Jamaica by Wright (1995) combines the CVM and the TCM. Two studies valuing recreation in the Galapagos are included for comparison with each other: one uses a gross revenue approach; the other employs hedonic demand analysis.

Australia's Great Barrier Reef (GBR) is probably the most studied reef in the world. Since 1975 several economic studies of the GBR have been conducted, most commissioned by the Great Barrier Reef Marine Park Authority (Driml *et al*. 1997). Table 3.1a includes the most recent estimate of the Reef's gross financial value (Driml 1999), as well as consumer surplus estimates for recreational fishing, visits to the "Reef Region", and visits to coral sites within this region (Hundloe *et al*. 1987).

Driml (1999) estimates the gross financial value of tourism to the GBR for the 1995/96 period. It is an update of an earlier estimate by the same author. The calculation focuses on commercial tourism (reef trips, accommodation, resort packages); and recreational fishing and boating. Data pertaining to the volume and price of reef visits, total visitor nights at island resorts and elsewhere, and an estimate of average daily tourist expenditure yields a value of

A$647 million (1996$) for commercial tourism. The value of recreational fishing and boating was estimated using earlier survey work by Blamey and Hundloe (1993), and current records of registered private boats adjacent to the park. Survey data showed that 63% of registered private boats are used for recreational fishing; the data also provided an estimate of average yearly expenditure on recreational fishing and boating. With these data Driml (1999) calculates recreational fishing and boating in the GBR to be worth A$123 million (1996$).

Hundloe *et al*. (1987) first uses the TCM to estimate the consumer surplus for both domestic and international tourists to the Reef Region. The Reef Region comprises all the islands and reefs within the outer boundaries of the Great Barrier Reef Region. The study then isolates the consumer surplus associated with visits to coral sites. Coral sites are areas within the Region where coral can be viewed. For this, travel cost data was collected from visitors who had visited or planned to visit coral sites, as part of their visit to the Region.

The consumer surplus associated with visits to the Region is calculated to be A$144 million per year; the surplus associated with visits to coral sites within the region is A$106 million per year. However, the researchers felt that the latter estimate still included all the attributes of the Reef Region, valued by those who had come to view coral as part of their vacation package. To calculate the consumer surplus of only the coral sites, with all other attributes of the Region removed, a CVM study was conducted that focused only on tourists visiting the reef sites. The resultant consumer surplus was estimated to be A$6 million per year; this might be regarded as a lower bound of the direct recreational value of the reef.

In another example of isolating the coral reef attribute of a vacation site, a study of Negril, Jamaica, estimates the consumer surplus of Negril as a vacation destination, as well as that part of the surplus attributable solely to the coral reef attribute of the vacation experience. Wright (1995) begins by conducting a CVM survey to determine the value of coral reef quality to vacationers. The study then uses the TCM to estimate a demand curve and the associated consumer surplus for a Negril vacation experience. Assuming a parallel shift (downward) of the demand curve, the study then nets out the consumer surplus associated with maintaining coral reef quality in its current condition. From the shift, and further assuming a fixed average cost of supply, the decrease in tourism volume as a result of coral degradation is calculated. The value of the change in tourism revenue is then used as input into a CBA.

Various ecological and economic analyses have been conducted for Bonaire, Netherlands Antilles. Dixon *et al*. (1993) calculates gross revenues from tourism, the carrying capacity of coral sites, and the consumer surplus associated with diving in the Marine Park. Arguing that quality diving is the primary attribute of Bonaire, the researchers calculate gross revenues from dive-based tourism of $23.2 million. Capital and labor costs associated with providing tourism services are not included in the estimate. Dixon *et al*. (1993) also conduct a CVM survey of divers and calculate a consumer surplus of $325,000 for divers in 1992.

Also for dive-based tourism in the Bonaire Marine Park, Pendleton (1995) estimates *net* revenue and consumer surplus for 1991. Net revenue is calculated using net revenue and local ownership data (obtained from Bonaire's Department of Revenue and its Tourism Corporation). Consumer surplus is calculated using the TCM. The travel demand function uses marine park permit data (which provides tourist origin data), and surveys of vacationers. Net revenue ranges from $7.9 to $8.8 million per year; estimated consumer surplus is $19 million annually.

Arguing for a project appraisal approach for the valuation of resource protection, Pendleton also estimates the net present value of the Bonaire Marine Park to the local economy, and to tourists. For the NPV calculation, it is assumed that the Park is just being established. Capital and operating cost estimates are taken from Dixon *et al*. (1993); net benefits (revenue and consumer surplus) are the Pendleton (1995) estimates. Over a 20 year period, at a 10 percent discount rate, the net present value of the Park to the local economy is $74.21 million; and the NPV of consumer surplus enjoyed by tourists is $179.66 million.

Using the TCM, Leeworthy (1991) estimates consumer surplus for the John Pennekamp Coral Reef State Park. Survey data obtained from over 300 people includes number of trips taken to the park in the past year, round trip mileage, travel time, activities undertaken at the Park, and various socioeconomic data. Nine model specifications using linear and semi-log functional forms are estimated. Consumer surplus estimates derived from the semi-log forms are rejected on the basis that the magnitudes were out of range of previous studies. The results of two linear models are accepted based on data fit and respective consumer surplus estimates. The two models differ only in that one included the opportunity cost of time; it is found that inclusion of this variable significantly increased consumer surplus estimates in all the model specifications.

The Dixon and Hodgson (1988) CBA of logging in Bacuit Bay, Palawan includes a benefit calculation for tourism. The productivity change/gross revenue approach uses hotel capacity, occupancy, and rate data, to calculate base year tourism revenue. In the logging scenario – which involves coral reef degradation – dive-based tourism revenue is reduced by 10% per year to a level of zero about half way through the forecast period. The PV of tourism revenue is assumed as solely attributable to the condition of the coral reef and is then calculated for inclusion in the CBA.

For Indonesia, Cesar (1996) uses CBA to compare the potential productive value of reef-based tourism to its value in the presence of poison fishing, blast fishing, and coral mining. CBAs are conducted for each threat, in isolation from the other threats. The potential tourism value of a hypothetical reef area is estimated as a range, the bottom of which represents a low potential tourism scenario, while the top of the range represents a high potential tourism scenario. The low potential value is an average of the net revenue generated in an area of no tourism, and that generated in an area of moderate tourism. The high potential value is an average of the net revenue generated in an area of moderate tourism, and that generated in an area of major tourism. A case study of tourism in Lombok provides an estimate of net revenue in an area of major tourism potential; data gathered in Ambon provide an estimate of net revenue in an area of moderate tourism potential. The net benefit estimates are on a per square kilometer of reef basis, and represent a 25-year period discounted at 10 percent.

The societal losses in tourism productivity are based on threat-specific assumptions regarding the percentage and type (low or high tourism potential) of reef area affected. The valuation also incorporates assumptions of rates of tourism declines – from its potential level – in response to reef degradation. In general, tourism declines sharply after poisoning, blasting, or mining begins. The cost to tourism of sedimentation/pollution is based on cost estimates of the abatement measures which would be required to address the problem.

Two recreation valuation studies of the Galapagos National Park are interesting in terms of their different approaches, the impacts of their assumptions, and the resultant valuations. de Groot (1992) calculates gross revenues to estimate the value of tourism; Edwards (1991) also calculates gross tourism revenues but does so via a hedonic demand analysis. Both estimates were done around the same time period: 1987.

The de Groot study estimates the price of a Galapagos vacation by adding up average transportation, park and non-park expenses. Doing so, he arrives at $1300/visitor for a Galapagos vacation experience. The analysis then assumes 40,000 tourists per year to arrive at gross tourist revenue of $52 million/year. For comparison with other Park values, recreation value is then put on a per hectare basis, using both the marine and terrestrial area of the park.

Edwards (1991) takes a far more complicated approach to the estimation primarily because, for tax policy analysis, a vacation demand curve is needed. Edwards decided that the heterogeneity of the packages (in terms of cost and travel itineraries) precluded the use of the standard regression analysis using time series or travel cost data. Therefore, a two-stage modeling exercise is used to estimate both implicit prices and a demand curve.[5] The average implicit price of a Galapagos vacation *day* turns out to be $312 which means, according to the estimated demand curve, that 7.3 vacation days will be demanded. Given these two figures, the average price of a vacation in the Galapagos is $2278/visitor; including a minor tax, brings the total price to $2318/visit.

Although the price/visitor in the Edwards study is almost twice that used by de Groot, gross tourist revenue calculated by Edwards is only $39 million/year compared to de Groot's $52 million/year. The difference stems from the level of tourist volume used in each calculation. de Groot assumes that the maximum carrying capacity of the islands is 40,000 visitors/year which also equals tourist volume. However, in the Edwards study, tourist volume is determined by the estimated demand curve – which provides the number of vacation days demanded at any given price – and the 1986 Park limit of 125,000 visitor days/year. At the average (implicit) price of $312, 7.3 days are demanded and the 125,000 visitor days/year limit therefore implies 17,123 tourists.

Literature Relating to Education and Research Values

Gross financial expenditures are typically used to estimate the education and research value of coral reef habitats. The expenditures include food, lodging, and fees for researchers and educators; boats and diving gear; research/education facilities and equipment. Multiplier effects associated with these initiatives are not estimated. The valuation of economic benefits associated with information generated by the research has not yet been attempted.

[5] The implicit price model is obtained by first estimating a market value model. The total cost of vacation packages is regressed on the attributes of those packages (type of accommodations, destinations, and duration). The estimated market value model is then differentiated with respect to days in the Galapagos, to arrive at another relationship wherein price is a function of the days in the Galapagos, and of total vacation expenditure. Survey data on days in Galapagos and vacation cost was entered into the implicit price equation to obtain implicit price data, which would then be used in the estimation of a demand curve for a Galapagos vacation experience. From the demand curve so estimated, at the average per day implicit price ($312), vacation days demanded would be 7.3 implying a total vacation cost of $2278.

An inherent weakness of all of these studies, which base their methodologies on expenditures estimates, is that they simply provide a measure of direct economic impact and say little about the efficiency of such expenditures or of the optimal level of such expenditures. Their connection to economic benefits is somewhat specious, although they may to some degree be construed as some revealed willingness to pay for having access to a particular reef area of research interest.

Spurgeon (1992) places values on the education and research value of coral reefs in Panama and Belize. The estimates are based on coral reef budget allocations of research-funding institutions in the US and UK. Costs associated with the research are excluded but, because the payment is coming from off-shore, capital and labor are not being reallocated within Panama or Belize and the expenditure therefore represents a pure benefit to those countries. Environmental costs associated with using a reef as a research focus are usually considered to be minimal, unless the research involves significant extraction levels of reef organisms.

For the Galapagos, de Groot (1992) estimates separately expenditures on research and expenditures on education. In the calculation, it is not clear who finances these activities. To the extent that the Ecuadorian government provides money, the costs of supply should be deducted from gross expenditures. de Groot goes on to estimate the potential value of education and research by assuming that only half of the maximum sustainable use level of the islands is currently being utilized. The final value of education and research to the Galapagos is therefore double the level of current expenditures.

Literature Relating to Ecological Function Valuations

Ecological functions provided by coral reefs include: (i) biological support to other ecosystems and organisms; (ii) physical protection to terrestrial, and other marine habitats; and, (iii) global life support through calcium – and, potentially, carbon – storage. For Indonesia (Cesar 1996) and the Philippines (McAllister 1991b), values for coastal protection have been estimated. For the Galapagos, de Groot (1992) estimates the value of biological functions. The economic value of coral reefs for their carbon and calcium storage functions has not been attempted, although there exist volume estimates of their carbon and calcium storage capacities. Table 3.1a includes valuation studies of ecological functions associated with other habitats: nutrient recycling function in wetlands; biological support for agriculture; and, watershed protection by a rainforest.

McAllister (1991b) estimates the protection function value of coral reefs in the Philippines by calculating the costs of replacing the reefs with artificial devices to protect the coast. This type of calculation is considered to be minimum estimate of the protection value afforded by reef because: (i) delayed response time could mean that terrestrial productivity is lost in the interim; and, (ii) artificial devices will forever need maintenance. The estimate obtained by McAllister is based on the per unit area cost of installing a certain type of barrier (concrete tetrapod devices) and multiplying that unit cost by the length of coastline fringed by coral reefs. The estimate does not allow for variations in the protective requirements along the coastline, given varying rates of coastal erosion and levels of economic activity.

For Indonesia Cesar (1996) uses CBA to compare the potential value of the coastal protection function of a coral reef, to its value as it succumbs to the impacts of blast fishing and coral mining. Replacement costs are used to estimate the potential value of the function. Calculated on a per square kilometer basis and discounted over a 25-year period, a range of value is estimated with low and high scenarios. The low scenario is an average of land value and replacement costs in, respectively, remote and moderately built-up areas. The high scenario is an average of replacement costs in moderately built-up areas, and those in areas with major infrastructure. The CBAs treat blast fishing and coral mining separately; the hypothetical reef faces only one threat at a time. In each analysis, the value of the societal loss of the reef's protective function is the decline in the potential value of the protective function as the reef is destroyed. The yearly losses in protective function value are based on threat-specific assumptions regarding the rate of reef destruction, the point at which the level of destruction starts to impair the ability of the reef to provide coastline protection, and the ability of the reef to recover.

In the Galapagos, de Groot (1992) estimates values for a number of ecological functions. A fishery nursery function value of the Galapagos refugia is estimated using a benefit transfer approach. Based on similarities of the Dutch Wadden Sea and Galapagos estuarine areas, de Groot assumes that 10 percent of the Galapagos fisheries is dependent on the inlets and lagoons of the Park. He also estimates the waste recycling function of the Galapagos marine area by calculating the cost of artificial purification technology. The valuation is based on an estimate of the total recycling capacity of the Galapagos sea shelf, and the unit cost of recycling organic waste. Finally, de Groot (1992) estimates values of two biological support functions: "biodiversity maintenance" and "nature protection". Arguing that biodiversity maintenance is a necessary precondition to other functions and human activities, de Groot assumes a shadow price of 10% of the value of any activity directly or indirectly dependent upon this function. Activities included all the productive uses ranging from recreation, to education and research. According to de Groot, the nature protection function relates to the value to society associated with preserving natural areas of particular naturalness, diversity, and uniqueness. The budget of the Galapagos National Park Service is used to estimate the value of this particular function.

The remaining three studies illustrate the valuation of ecological functions in other habitats. Gren (1995) estimates the nitrogen retention and recycling function of wetlands in Gotland Sweden. The approach is quite complex in comparison to those described above. It involved: (i) a natural systems hydrological model; (ii) an estimate of the absorptive capacity of wetlands; and (iii) a CVM analysis to determine the WTP for improved water quality by area residents. Narain and Fisher (1994) estimate the value of the biological support function of a lizard in the Caribbean's Greater and Lesser Antilles. The Anolis lizard feeds on insects that are detrimental to various export crops. Using a production change approach, the study estimates the change in agricultural output associated with a decline in the lizard population. In the final study surveyed, the value of the watershed protection function of the Korup, Cameroon tropical rainforest is estimated by Ruitenbeek (1992). This function provides flood control and maintains soil fertility. Assuming a logging scenario, the study uses a change in productivity approach to value lost agricultural output associated with flooding and loss of soil fertility.

Genetic Resource Valuation Models in Agriculture – Some Lessons

Genetic resources are important for providing the scientific information necessary for the production of new and improved food sources, new pharmaceuticals, new chemicals, and new environmental protection strategies (microorganisms to aid the degradation of toxic waste; microorganisms to reduce agricultural chemical dependence). The economic value of genetic resources has been most studied in the agricultural sector where they enter the production process directly. Valuations attribute actual production changes in particular crops to the improvements brought about by the introduced genetic material. We review a number of these here for completeness, but note that – while valuable lessons can be learned from such models – many of the specific empirical valuation techniques are of less applicability at this time to coral reef valuation. Most marine genetic product potential is associated with information contained in the resources, rather than with the genetic material itself. This makes the pharmaceutical potential of marine products a more obvious bioprospecting target than the agricultural (or maricultural) potential.

Bioprospecting model development in the literature has tended to be isolated in two distinct areas: agriculture and pharmaceuticals. Both have similar foundations, consistent with the constructs and models of Evenson and Kislev (1976) who described a general model for valuing applied research. But distinct literatures have developed in agricultural and pharmaceutical modeling development. This has arisen because of different technical aspects of bioprospecting in these fields, as well as different policy concerns.

Technical Issues

The manner in which new genetic material enters the production process differs among industries. In agriculture, genetic material is used directly by transferring desirable genes identified in donor species to recipient species. The transfer is done using either traditional *hybridization* methods involving the sexual crossing of closely related species, or it is done using *biotechnology* techniques of modern genetic manipulation. These methods enable the development of crop varieties with improved yield, in-built microbial pesticides, particular environmental adaptation traits, nitrogen-fixing capabilities, disease resistance, and retarded spoilage rates.

By contrast, in the pharmaceutical industry, new genetic material is most often used indirectly; the biological material is not transferred from one species to another as in agriculture. Instead, the genetic information provided by the material is used to develop new products unrelated to the original source. Pharmaceutical companies screen life forms, or samples of life forms, in search of chemical compounds with particular biological activities: antiviral, antifungal, antileukemic, anticoagulant, etc. Once identified and if considered to have pharmaceutical potential, such a compound is usually then synthesized from its basic chemical constituents. Should it proceed successfully through the R&D process, it then enters production for human use.

Bioprospecting values are thus also derived somewhat differently in agriculture and pharmaceuticals. In both cases, the actual value associated with biodiversity is closely tied to the type of information provided, as opposed to any particular material good (Swanson 1996). In the case of pharmaceuticals, this information provides a stock of ideas that can be used to synthesize key compounds, often establishing new products and markets (WCMC 1994a). In the field of plant genetic resources, however, the information itself provides direct genetic information that can be introduced into other economic species or crops which already have a market (WCMC 1994b).

Policy Issues

Efforts in agricultural valuation have been driven by policy questions that address issues such as food security, farm incomes, and efficient research methods in a market where end products (such as food crops) are dominated by open competition (Evenson *et al*. 1998). Much of the research work in agricultural prospecting is funded through public institutions and international agencies. In agriculture, modeling has addressed distributional concerns related to the improvement of farm level incomes, and the social benefits arising from incorporating traits in improved crop varieties (see Smale 1995, 1998, Smale *et al*. 1995). Also, it has often focused on the valuation of genetic traits and optimization of the search paths for finding economically useful traits within large samples (often maintained in *ex situ* collections) (e.g., Gollin and Smale 1998). More recently, policy concerns have focused on genetically modified (GM) crops using transfers of genetic materials.[6] Impacts of GM crops and biotechnology in developing countries pose a wide range of policy issues that extend from food security to property rights to institutional capacity (Zilberman *et al*. 1998).

By contrast, the pharmaceutical bioprospecting literature was, initially, dominated by policy concerns relating to the *in situ* conservation of wild genetic resources (e.g., "drugs from the rainforest"). The intensely private – and often seemingly monopolistic – nature of new drug patenting and development, coupled with long testing periods, has meant that institutional

[6] GM products have been in the public eye more recently and have raised a number of policy issues which are likely to become interesting topics for valuation. Direct economic improvements from GM crops are becoming better documented. For example, it is estimated by the John Innes Center in the UK (M Gale, Director, press release, 8 March 1999) that Roundup Ready soya, which was genetically engineered to resist Roundup herbicide, saved farmers some $30 a hectare because of a 40 per cent reduction in herbicide. But while the higher net incomes and the lower (as yet unmeasured) externalities of reduced pesticide use may be regarded as "benefits" from such modifications within any policy context, uncertainties associated with health concerns

questions frequently dominate discussions relating to valuation. Most models remain relatively deterministic; only more recently have concerns such as optimal research paths entered the pharmaceutical bioprospecting literature (Artuso 1998). Moreover, the role of ecosystem and habitat conservation and their potential yields of "new" species adds a dimension that is often absent from discussions in the agricultural bioprospecting literature.

In the case of marine systems, the issues are further complicated by ownership concerns and the perceived system yield of useful information. Management and ownership of marine and near-offshore resources is a problematic topic in most jurisdictions, and the entire discipline of Integrated Coastal Zone Management (ICZM) is targeting such problems through what are by and large institutional reforms and interventions.

Lessons

Numerous studies estimate the economic value of new genetic material to various agricultural crops (Prescott-Allen and Prescott-Allen 1988, WCMC 1992, 1994b). Table 3.2 contains a selection of the earlier studies based on a review conducted by the World Conservation Monitoring Centre. Basically, these valuations involve examining the total change in yield, and attributing the cause of the change between a technology component (fertilizer and pesticide use, tillage, machinery, etc), and a genetic component. Most valuations are general in that value is attributed to the "genetic component." However, some valuations are more focused, attributing value to the specific trait transferred in the genetic material. All generally attribute substantial values to the crop improvements and, implicitly or explicitly, to the research and development activities that resulted in such improvements.

More recent work has further affirmed many of these values. Extensive investigations conducted through the International Maize and Wheat Improvement Center (CIMMYT) in Mexico have paid particular attention to economic issues associated with crop genetic resources; these are reported in a comprehensive edited volume by Melinda Smale (1998).[7] Interestingly, in

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over GM crops (as asserted by anti-GM campaigners) would presumably constitute some disbenefit in any calculus of economic valuation. To date, however, such valuations have not been conducted.

[7] An extensive series of CIMMYT discussion papers and related publications is documented on the CIMMYT web site located at: http://www.cimmyt.cgiar.org/. Many of these relate to farm level studies and the role of institutional changes and policy interventions in improving incentives for farm level conservation of genetic resources. Saade (1996) describes impacts on farmer's incomes of high yield wheat varieties in Tunisia; a major conclusion was that large farmers and state farms were the primary beneficiaries of such introductions. Hartell *et al.* (1997) use econometric studies to investigate the relative contributions of various inputs to improved farm income in Pakistan; they conclude that in some areas the genetic improvement has made

Table 3.2
Early Survey of the Value of Genetic Contributions in Agriculture

Crop	Location*	Production Effect of Genetic Resources	Study
Value to Cultivated Varieties			
Maize	USA 1985-89	$2.3 million/yr to North Dakota	Frohberg 1991
Rice	Asia Green Revolution	$1.5 billion/yr	Walgate 1990
Wheat	Asia Green Revolution	$2.0 billion/yr	Walgate 1990
Barley	USA 1930-80	50% of doubled yield gain	OTA** 1987
Sorghum	USA 1950-80	1-2% yield gain	Miller & Kebede 1984
Pearl Millet	India 1992	$200 million/yr	ICRISAT 1990
Potato	USA 1930-80	50% of a four-fold yield increase	OTA 1987
Soybeans	USA 1902-77	79% of 23.7 kg/ha/yr yield gain	Specht & Williams 1984
Tomato	USA 1930-80	50% of a three-fold yield gain	OTA 1987
Value of Specific Genetic Traits Transferred to Cultivated Varieties			
Wheat	Turkey	Disease resistance: $50 million/yr	Witt 1985
Barley	Ethiopia	Protection from Yellow Dwarf Virus: $160 million/yr to California	Witt 1985
Hops		Reduced bitterness in beer: $15 million/yr to British brewing industry	Witt 1985
Beans	Mexico	Protection from bean weevil: 25% of stored beans in Africa; 15% in S. America	Rhoades 1991
Grapes	Texas	New root stock: Revitalized European wine industry after its decimation by a louse infection.	Rhoades 1991

* In case of transfer of genetic traits, location refers to that of donor species.
** OTA = Office of Technology Assessment.
Source: World Conservation Monitoring Centre (1992).

the Preface to that volume (p. xv), Timothy Reeves and Prabhu Pingali, as Directors of CIMMYT, emphasize the importance both of *ex situ* conservation of genetic resources – which they construe as gene banks – and of *in situ* conservation of genetic resources, which they define as "farmer's fields." This is a key attribute of cultivated agricultural resource: *in situ* resource conservation and stewardship is at a managed farm level, and often deals with known traits. By contrast, pharmaceutical genetic resource conservation issues typically deal with wild resources, having unknown traits or characteristics. Agricultural models focusing on known traits have thus found limited applicability in the pharmaceutical valuation literature.

farmers better off while in other areas (those with production constraints) the contributions of the genetic improvement are minimal and that farm policy would be better targeted to production management.

Nonetheless, there are a number of general lessons that can be gleaned from the agricultural bioprospecting modeling. Among the more important lessons are:

- Search methods can influence values. Optimal search models consistently show that economic values can change significantly depending on search methods (e.g., stages of search). Agricultural models typically try to introduce some methods relating to optimal search; such methods are typically lacking from pharmaceutical bioprospecting models.
- Value is a function of complex interactions. Work on cost-effectiveness analysis within agricultural genetic prospecting (Pardey *et al*. 1998) illustrates that optimal search strategies influence concurrently both the costs and benefits of prospecting. It is thus not usually adequate to model costs or benefits in isolation of each other.
- Distribution of values is an important policy concern. Much of the agricultural literature is concerned with "who gains" from genetic resource development, and what sorts of institutional structures might be most effective and fair. Models that reflect such distributional elements will receive greater policy attention.
- Geography is important. In contrast to the early work of Evenson and Kislev (1976) which focused on single trait optimal search models, more recent work by Evenson and Lemarié (1998) has modeled optimal search within a context of multiple traits and multiple potential target geographic locations, where individual site characteristics may have different distributions of traits available for search, and may have different cost structures involved with the search. They observe that some sites may be particularly good targets for bioprospecting activities. Specifically, they note (p. 91): "When alternative (substitute) resources exist, collection costs can lead to shifts in sources by regions. If a small region is a relatively rich source for a particular trait, collection costs may be low, and marginal values may be high. It will always pay to collect from such a region when profits are maximized independently and will almost always pay to do so even when they are maximized jointly." From a modeling perspective, this implies one should pay attention to site specific characteristics and, ideally, how these might relate to global conditions. For systems such as coral reefs, this insight is particularly applicable.

Genetic Resource Valuation Models in Pharmaceuticals – A Review

Most modeling efforts to value genetic resources for pharmaceutical use have taken a change in production approach. The value of preserving a species for pharmaceutical use is based on the potential value of an unknown or untested species in the production of a new drug. What is clear from the wide range of models is that: (i) they often attempt to address somewhat different policy problems; and, (ii) they attempt in various ways to demonstrate how selected issues or exogenous factors can influence "values".

The early models use *gross* revenues of all plant-based drugs to impute a value for individual plant species responsible for those drugs. More recent models estimate the *net* revenues from hypothetical new drugs; these make an assumption regarding the number of species or biotic samples required to find a new drug source, and thereby calculate an average value for those species. Another modeling approach is to calculate the marginal value of a species. In this case, net revenues are used to calculate the change in the value of a collection of species when one more species is added.

Some modeling efforts have used a royalty approach to value genetic resources. In one model, an assumed royalty is applied to the average patent value of a new drug (Ruitenbeek 1989). In two other models, an assumed royalty is applied to an estimate of net new plant-based drug revenues (Harvard Business School 1992, Reid *et al*. 1993).

Table 3.1b summarizes the approaches and results of genetic resource valuation studies. Below, the frequently cited early and recent studies are discussed in greater detail. Most of the studies take a change in production approach or explicitly attempt to value rents; Aylward (1993) also estimates a royalty-based model.

It should come as little surprise that many of the model results are exceedingly sensitive to key economic or biophysical assumptions; many models that generate positive values in a base case scenario return negative (or significantly smaller) values when tested under different (yet still plausible) sets of assumptions. For example, a great deal of attention is often paid to what are loosely called “hit rates”, or the basic probability of success in developing a commercial drug from some randomly sampled species, natural product, or extract. While it is often assumed that such hit rates are exogenously determined, akin to rolling a many-sided die, they are in fact themselves an endogenously determined variable within pharmaceutical screening processes (Box 3.2). Such complexities further complicate numerical analyses in an area often complicated by secrecy agreements or other data gathering constraints.

Box 3.2
Success rate determinants in pharmaceutical bioprospecting

For a prospecting program as a whole, a high success rate is desirable. However, given that R&D costs per extract increase with each phase, low success rates in the individual screening phases may be desirable to reduce the costs associated with ultimately unsuccessful leads. To some degree, prospecting firms can manipulate the success rates of the early R&D phases by specifying the composition of the collection, and by adjusting the technical parameters of the screens. In general, success rates can be manipulated by:

- Using prior information (ethnobiological, ecological, biomedical) to collect extracts for testing against specific therapeutic targets.
- Reducing the chemical similarity of extracts within a collection by increasing the taxonomical diversity of that collection.
- Adjusting screening parameters to affect the number of extracts that proceed through to the isolation and dereplication phase of the program.
- Using new sources of biological material for those therapeutic targets that have been the subject of many prospecting programs.

The prospecting strategy for the collection may be *random* selection, using little or no prior species information; or it can be *rational* selection, using prior ethnobiological, ecological, or biomedical information. There may be numerous therapeutic targets against which the extracts are tested; or there may be as few as one target. There is some empirical evidence that programs utilizing prior information to find leads for a small number of therapeutic targets have higher success rates in the exploratory stage, than programs using no prior information. Success rates can also be increased by using a taxonomically diverse collection for investigation. Generally, a diverse collection is more likely to be chemically dissimilar, and will consequently yield a greater number of novel compounds; hence the discovery of one will not severely reduce the probability of discovering another within the same collection.

Through the treatment of the extracts, the phase-specific success rates are manipulated. Screening sensitivities can be adjusted to obtain relatively low or high hit rates from a given collection. Since R&D costs per extract increase with each phase, reducing the cost of a screening program means identifying and dropping ultimately unsuccessful leads (false positives) as soon as possible. Low success rates in the screening phases would achieve that end. For example, adjusting the screens to identify common compounds early would permit only extracts with relatively rare compounds to proceed to a subsequent isolation and dereplication phase, thereby increasing the success rate of this more costly phase of R&D. However, setting the screens to achieve low success rates will also mean foregoing potentially promising leads (false negatives).

A factor beyond the control of the individual prospecting firm is the amount of existing research that has been conducted involving the particular therapeutic targets. The more existing research there is, the more likely that relatively rare compounds, reactive with the targets, have already been discovered and investigated. However, a different bioassay of the same extract may prompt bioactivity revealing previously missed compounds. Furthermore, a collection consisting of biological material drawn from under-investigated sources (such as marine ecosystems) is more likely to yield a novel compounds than material drawn from more studied sources (such as tropical forests).

The Artuso (1997) model allows for phase-specific success rates which could reflect the prospecting strategy and the screening parameters of an individual prospecting program. A complication to the basic model also allows for a declining rate of success in the isolation and dereplication phase to account for the probability of increasing chemical similarity between the extracts of a given collection. Chemical “similarity” or “redundancy” is the focus of Simpson *et al.* (1996). Related to chemical similarity is the issue of “medicinal” or “therapeutic” redundancy, discussed by Simpson *et al.* (1996), and Artuso (1997). This type of redundancy refers to the situation wherein different chemical compounds from different species produce similar therapeutic effects.

Early Models of Gross Economic Benefits

Farnsworth & Soejarto (1985); Principe (1989ab); Pearce & Puroshothaman (1992ab)

The first group of studies to estimate the economic value of genetic resources to the pharmaceutical industry employed three types of data: total drug sales, an estimate of the number of plant-based drug sales as a percentage of total drug sales, and the number of plant species responsible for the plant-based drugs. (Farnsworth and Soejarto 1985, Principe 1989ab). Modifications to these valuations involved the addition of estimates of the value of lives saved through the use of plant-based drugs. (Principe 1989ab, Pearce and Puroshothaman 1992ab). These studies produced gross values attributable to the 40 ‘successful’ plants that were responsible for all the plant-based drugs in the pharmaceutical industry.[8] A typical calculation is as follows:

$$VPD = (rp * S * P_{avg})/40$$

where,

VPD equals the total value of plant-based drugs;
rp is percent of prescriptions containing one or more ingredients derived from plants;
S equals the total value of prescription drugs; and,
P_{avg} equals the average price of a prescription.

Using this approach, Farnsworth and Soejarto (1985) estimate that each of the 40 plant species used to derive the plant-based drugs is worth \$203 million to the US. Principe (1989ab) extends the calculation to include drug sales in the OECD, and the value of lives saved from plant-based cancer drugs. From Principe’s work, the 40 plant species are potentially worth \$37.5 billion each.

Pearce and Puroshothaman (1992ab) modify and update the Principe (1989ab) data to calculate the average value of the 40 plant species responsible for the bulk of plant based drugs to be \$390 million per plant, and possibly as high as \$7 billion per plant. The authors extend the model to calculate the average value of a hectare of rainforest:

$$VRL = (NR * p * r * a*VP) / H$$

where

VRL equals the per hectare value of rainforest land;
NR equals the number of plant species at risk (60,000);

[8] Farnsworth and Soejarto (1985) list 40 flowering plants responsible for all plant-derived drugs sold in 1980.

p equals the success rate of finding a new plant-based drug source (1:10,000 to 1:1000);
r equals the royalty rate on a new drug source (5%);
a equals the amount of value that a host country can capture from a new drug source (10% to 100%);
VP equals the value of a plant-based drug source ($0.39 to $7.00 billion); and,
H equals the number of hectares of rainforest (1 billion).

Based on the above model and data assumptions, Pearce and Puroshothaman find values per hectare of tropical rainforest ranging between $0.01 and $21/ha.

As shown in the last column of Table 3.1b, Aylward (1993) extended the valuation estimates of the above studies by using the success probabilities stated in the original articles to arrive at implied values for an untested species. For example, Farnsworth and Soejarto (1985) found the value of a single (successful) plant species to be $203 million. At the time the article was written, the authors believed the probability of a plant becoming an drug source was 1 in 125 plants tested. Aylward used this probability to calculate the study's implied valuation of an untested species to be $1.6 million.[9]

These early models had a number of common limitations. Their main limitation is that they do not account for the costs of new drug development. Such costs include: (i) obtaining biotic samples; (ii) R&D of screening samples; and, (iii) production and marketing of a new drug. The exclusion of cost and investment information undermines some of the specific policy usefulness of the study results, but the results did serve – and continue to serve – an important educational purpose in raising awareness about the value of critical ecosystems to drugs and human well-being.

Another limitation of these models is that they do not consider how the use of alternatives to natural product research might affect the valuations. Also, the studies are concerned with estimating the value of known pharmaceutically beneficial plants. There is an implicit assumption that species are not substitutes: benefits from different species are assumed additive whether or not they are providing the same type of benefit. Subsequent studies and models attempted to address some or all of these limitations.

[9] If a successful plant species is worth $203 million and it takes 125 untested plants to find a new drug source, then each of the 125 untested plants is worth $1.6 million ($203/125).

Recent Models of Net Economic Benefits

Since 1993, most approaches to estimating the pharmaceutical value of species preservation try to calculate the *net* value of biological material in the R&D process. In contrast to earlier efforts, these models account for the costs associated with new drug development, from sample acquisition to administration and marketing. Recent models also incorporate the effects of generic drug competition on the expected sales revenue profile of a new drug. Net revenues are discounted to the start of the R&D process to determine the net present value (NPV) of biological material to the pharmaceutical prospecting firm.

Essentially, the models by Aylward (1993), Mendelsohn and Balick (1995), and Artuso (1997) estimate the *average* value of the genetic material by dividing the NPV of a new drug by the number of species (or biotic samples) that need to be screened before the new drug source(s) is(are) found. Simpson *et al*. (1996) estimate the *marginal* value of genetic material by calculating change in the value of a collection of species when one more species is added to the collection.

The models described below vary in terms of their data requirements. For comparison, the fixed parameters and data sources are summarized in a table for each model. The tables reveal that the models use one or more common sources of empirical data: specifically, the studies by Grabowski and Vernon (1990), and DiMasi *et al*. (1991). These frequently cited studies represent the most recent from a body of economic literature which focuses on empirical estimation of the R&D cost to the pharmaceutical industry of an approved "new chemical entity" (NCE). Grabowski and Vernon (1990) estimate the rates of return to R&D for 100 new drugs (or NCEs) introduced into the US during the 1970s. The net present value of each NCE is calculated using sales data; estimates of promotion and production costs; R&D cost estimates based on Hansen (1979, 1980)[10]; and opportunity cost of capital estimates based on a capital asset pricing model. The major finding of the study is that the rate of return on the average new drug is approximately 9 percent.

R&D estimation work by DiMasi *et al*. (1991) is based on a survey of 12 US pharmaceutical firms.[11] The firms provided R&D cost and timing data for 93 NCEs which entered the "clinical" R&D phase during the 1970-82 period. The R&D process is divided into 1

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[10] The R&D cost studies by Hansen (1979, 1980) and DiMasi *et al*. (1991) are similar in their approaches in that both studies use NCE-specific survey data for a multi-phase R&D process.

[11] DiMasi JA, Hansen RW, and Grabowski HG are in the process of updating their 1991 work (Pers. comm., 08/98).

preclinical phase, 3 clinical phases, and 2 animal testing phases. The clinical and animal R&D costs associated with each NCE were obtained from the survey. However, the preclinical costs – those associated with collection, screening, isolation, synthesis, and modification – could not be disaggregated by NCE. To arrive at a preclinical cost of a NCE, the authors used aggregate cost data to derive a ratio of preclinical to total cost. This ratio was then applied to the individual NCE estimates of clinical costs to derive estimates of the respective preclinical costs. In the study's base case, the R&D cost per approved NCE was found to be $114 million (1987$). This estimate was capitalized at 9% (the Grabowski and Vernon finding) to the point of new drug approval thereby increasing the average R&D cost to $231 million per new drug.

Aylward (1993)

Aylward (1993) estimates the net returns to "pharmaceutical prospecting." Up to a point, the approach is essentially the same as that used in the Grabowski and Vernon (1990) study which analyzed empirical data to find the rate of return to pharmaceutical R&D. In the Aylward study, the net present value of a hypothetical new drug is calculated using a potential sales profile, estimates of promotion and production costs, and R&D cost estimates based on DiMasi *et al.* (1991). At this stage the approaches start to diverge. From the revenue stream, Aylward also deducts the cost of biotic samples to arrive at the net returns to pharmaceutical prospecting.[12]

Aylward's main contribution to the analysis of returns to pharmaceutical prospecting is in the apportionment of net returns across the factor inputs in the pharmaceutical prospecting process. These include: (i) biodiversity protection; (ii) biotic sample acquisition, including taxonomic identification; and, (iii) research and development which includes the activities from chemical extraction to application for regulatory approval.

Two slightly different models are developed to estimate expected net *private* returns, and the expected net *social* returns to the factor inputs. To calculate net private returns, the analysis excludes factor costs typically subsidized by the state (e.g., biodiversity protection and taxonomic identification.) To calculate net social returns, all factor costs are included.

Calculation of the value of the individual species subjected to screening by a pharmaceutical firm proceeds essentially the same as in the above models; net returns are divided by the number of species required to find one successful new drug source: the success rate. The

Aylward model is slightly different because pharmaceutical prospecting is separated into different activities. Specifically, net returns to an untested species are calculated by applying the success rate to the "net returns to biotic sample acquisition." Applying the success rate to the "net returns to biodiversity protection" yields the net returns attributable to the biodiversity protection of a given species.

Modeling Returns to Factors of Pharmaceutical Prospecting

Aylward presents a situation wherein genetic prospectors have access to a fully protected wildland area containing at least 10,000 different species of plants. Over the course of one year, 10,000 species are screened against one therapeutic target for pharmaceutical potential. Assuming a species success rate of 1 per 10,000, one new drug source is eventually identified.

The gross return of the resultant new drug (GR) is calculated as a revenue stream incorporating four phases of the product life: (i) pre-patent; (ii) on-patent before regulatory approval; (iii) on-patent after approval; and, (iv) post-patent when sales decay due to generic drug competition.

The gross return to pharmaceutical prospecting (GR^{PP}) is calculated by removing production and marketing costs from the projected revenue stream of the new drug. The net return to pharmaceutical prospecting (NR^{PP}) is calculated by removing the cost of pharmaceutical prospecting C^{PP} from GR^{PP}:

$$NR^{PP} = GR^{PP} - C^{PP}$$

In the "private cost" version of the model, C^{PP} is defined as the private cost of pharmaceutical prospecting (PC^{PP}) which equals the sum of the private cost of R&D ($PC^{R\&D}$) and the private cost of biotic samples (PC^{BS}). The net private return to pharmaceutical prospecting (NPR^{PP}) is:

$$NPR^{PP} = GR^{PP} - [PC^{R\&D} + PC^{BS}]$$

In the "social cost" version of the model, the cost of pharmaceutical prospecting (C^{PP}) additionally includes the social cost of taxonomic information, and the social cost of biodiversity protection.[13] Hence the C^{PP} becomes the *social* cost of pharmaceutical prospecting (SC^{PP}) which

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[12] Grabowski and Vernon may have implicitly deducted the cost of biotic samples because they used R&D cost estimates from Hansen (1979, 1980) which, according to DiMasi *et al*. (1991), included "discovery costs".

[13] The social cost of taxonomic information reflects the costs to collect, curate and identify a specimen not already held in a local reference collection. The social cost of biodiversity protection is area specific, and should include the direct, indirect, and opportunity costs of preservation. Aylward estimates the direct and opportunity costs of preserving 600,000 hectares of Costa Rican parkland. Direct cost is based on park budget projections; opportunity cost is based on local land prices and an estimate of

equals the sum of the social cost of biodiversity protection (SC^{BP}); the social cost of R&D ($SC^{R\&D}$), and the social cost of biotic samples (SC^{BS}) – which includes the social cost of taxonomic information (SC^{TI}). The net social return to pharmaceutical prospecting (NSR^{PP}) is:

$$NSR^{PP} = GR^{PP} - [SC^{BP} + (SC^{BS} + SC^{TI}) + SC^{R\&D}]$$

To apportion the net return across the different factors of prospecting, in each model, the expected net return to each factor is assumed to be equal to its proportional share in the total cost of the prospecting process. Therefore, in the private cost model, the net private return to R&D ($NPR^{R\&D}$), and to biotic samples (NPR^{BS}) are apportioned as follows:

$$NPR^{R\&D} = (PC^{R\&D} / PC^{PP}) * NPR^{PP}$$
$$NPR^{BS} = (PC^{BS} / PC^{PP}) * NPR^{PP}$$

In the social cost model, the net social returns to R&D ($NSR^{R\&D}$), to biotic samples (NSR^{BS}), and to biodiversity protection (NSR^{BP}) are calculated similarly.

Expected Net Returns Per Species or Per Biotic Sample

In the social cost model, the expected net return attributable to a species in the protected area is equal to the success rate multiplied by the net social return to biodiversity protection. Aylward assumes that there are 10,000 species in the protected area; all will be screened and one will provide a new drug source. Hence the success rate is 1:10,000.

In the private cost model, the expected net return attributable to a biotic sample subjected to the screening program is equal to the species success rate (1:10,000) multiplied by the net private return to biotic samples (NPR^{BS}), adjusted for the number of samples per species that are screened. Aylward assumes that two samples from each species enter the program. The success rate for biotic samples (as opposed to species) is therefore 1:20,000.

The results of the models are shown below (data and sources are provided in Table 3.3).

Private Cost Model	
Total net return to pharmaceutical prospecting (NPR^{PP})	\$39.13 million
Total net return to R&D ($NPR^{R\&D}$)	\$38.71 million
Total net return to biotic samples (NPR^{BS})	\$0.42 million
Net return per biotic sample	\$21.23

the net present value of neighboring agricultural land. Assuming a certain number of species residing in the parkland, a per species protection cost is then calculated.

Social Cost Model

Total net return to pharmaceutical prospecting (NSR^{PP})	\$33.24 million
Total net return to R&D ($NSR^{R\&D}$)	\$30.91 million
Total net return to biotic samples (NSR^{BS})	\$0.68 million
Net return per biotic sample	\$33.91
Total net return to biodiversity protection (NSR^{BP})	\$1.66 million
Net return per tested species	\$165.79

Net Returns from Prospecting Royalties

In addition to the cost-based models described above, Aylward (1993) also estimates a royalty-based model. For comparison with the cost-based models, both the net private, and net social, expected royalty on biotic samples are calculated.

In the royalty model, gross revenue consists of only sales up to patent expiration. Distribution costs, expressed as a percentage, are removed from gross sales to arrive at net sales (NS), on which royalties are calculated. Royalties received by the producer of biotic samples then depend on the expected rate of royalty (r). Adjusting for the species success rate (P) and the number of samples provided per species (n), the expected gross royalty on biotic samples (RY^{BS}) is:

$$RY^{BS} = P * r * NS / n$$

The private net royalty on biotic samples (NPR^{BS}) is calculated by adding to RY^{BS} the initial fees received by the collector (F) and netting out the private cost of biotic sample acquisition. The social net royalty (NSR^{BS}) is calculated by also netting-out the social costs of taxonomic information and biodiversity protection. The results from this model are:

Royalty per Biotic Sample (RY^{BS})	\$233.12
Total net return to biotic samples (NPR^{BS})	\$4.91 million
Total net return to biotic samples (NSR^{BS})	–\$0.98 million

Table 3.3
Model parameters in Aylward (1993)

Sales - Patent period mean sales for an average drug	$69 million (model calculation)	Based on Grabowski & Vernon (1990) sales data adjusted to 1990$ using nominal growth rate for drug prices.
Real price trends of pharmaceuticals	5%	Deflated nominal US pharmaceutical price trends in for the period 1980-91.
Decay rate of post-patent sales	11%/yr	Grabowski & Vernon (1990)
Patent life	18	Based on Ballance, Pogany and Forstner (1992) findings of 15-20 yrs in OECD countries.
Rate of return for on-patent drugs	40-50%	Ballance, Pogany and Forstner (1992)
Time to Patenting	2 years	assumption
Production & Marketing costs	60% of sales	The Economist 1992, Merck & Co. 1992
Pre-tax ROR on P&M	5-10%	Ballance, Pogany and Forstner (1992)
Private costs of R&D	$91 million (model calculation)	Based on DiMasi *et al.* (1991).
Length of R&D Period	12 years	DiMasi *et al*. (1991); US Pharmaceutical Manufacturers Association (1991)
Cost of capital in pharmaceutical industry	10%	Based on Grabowski & Vernon (1990) estimate of 9%; and others.
Per biotic sample collection fee in developing countries	$50	Based on interviews with collectors working in developing countries.
Biotic Samples per Species	2 samples/species	assumption
Species hit rate	1:10,000	Based on various studies ranging from 1:125 to 1:40,000.
Social costs of taxonomic information	$100	Based on case study of Costa Rica's National Biodiversity Institute, Aylward *et al*. (1993).
Cost of Biodiversity Protection	$50/species/year	Derived from estimates of direct and opportunity costs of protection in Costa Rica.
Royalty rate on biotic samples	2%	Industry sources suggest 1-3% range.

Mendelsohn and Balick 1995 and 1997[14]: World Value of New Drug Sources

Mendelsohn and Balick (1995) estimate the net present value of a new drug. They also estimate the number of new drug sources remaining to be discovered in tropical forests around the world. Given these two estimates – the NPV of a typical new drug, and the number of new drugs yet to be discovered and developed – they arrive at a total worth of yet to be discovered drugs from tropical forests.

The model calculates the net revenue stream associated with the development, production and marketing of a new drug. The revenue profile reflects the pre-patent, on-patent, and post-patent periods. It covers a 29 year period: the first 10 years are devoted to R&D; sales of the new drug begin in year 11 and reach a peak in year 19. For the industry as a whole, sales level off after the peak year; for the firm holding the patent, in the post-period revenue is quickly eroded due to generic drug competition. The authors argue that if sales (of the new drug) are aggregated across all firms, the peak net revenue level would likely be maintained indefinitely. Using the data summarized in Table 3.4, the authors arrive at a NPV of $449 million per new drug.

To arrive at the number of drugs remaining to be discovered in the rainforests of the world, the authors rely on the following assumptions:

- One-half of the 250,000 known species of higher plants are found in rainforest ecosystems.
- Each plant has six chemically distinct extracts that can be tested.
- At any one time, the pharmaceutical industry as a whole tests sample extracts against 500 statistically independent screens (an individual company screens for about 50-75 different therapeutic uses).
- Probability of success is one per one million tests which implies that on average one new drug would be developed from every 333 plant species.[15]

From the above, there are approximately 375 plant-based drugs in the tropical forests.[16] About 47 plant-based drugs have already been discovered, leaving 328 yet to be discovered.

Given the NPV estimate of $449 million per new drug, and the estimate of 328 new drugs yet to be discovered in the rainforest, the authors conclude that there is approximately $147 billion (NPV) worth of new drugs in the rainforests around the world. Allocating this amount over the area of rainforest in the world provides a genetic resource value of $48/ha. Allocating $147 billion over the 125,000 rainforest plant species implies that any one species is worth $1.2 million.

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[14] The 1997 reference concerns a short note which corrected a calculation error in the earlier 1995 article. The correction made it unprofitable for an individual firm to bioprospect. However, for the industry as a whole (the results reported here), the value of bioprospecting for new drugs remained positive.

[15] Given that each plant has 6 distinct extracts, 333 plants would provide about 2000 extracts. If each of these is subjected to 500 screens then these 333 plants would provide 1 million tests, which would yield one success.

[16] Assuming there are 125,000 plant species in the rainforest all yielding 6 extracts, there are then approximately 750,000 potential extracts which can each be subjected to 500 screens. At a success rate of 1 in 1 million, there would then be 375 potential drugs (125,000 x 6 x 500 x .000001)

Table 3.4
Model parameters in Mendelsohn and Balick (1995)

Patent period average sales for an average drug	$29 million	OTA (1993)
Decay rate of post-patent sales	20% +	OTA (1993)
Patent life	20 years	not indicated
Production & Marketing Costs	60.6% of sales	OTA (1993)
Length of R&D period	10 years	Grabowski & Vernon (1990)
Private costs of R&D (Present Value)	$125 million	OTA (1993)
Cost of capital in pharmaceutical industry	5%	OTA (1993)
Species hit rate	1:333	see above
Per biotic sample collection fee in developing countries	$100	

Artuso (1997)

All of the above models to determine the average pharmaceutical value of an untested species use R&D cost estimates based on empirical research by others. The emphasis is on determining the expected net revenue associated with a new drug, rather than on the details of the R&D process itself. The empirical modeling efforts by DiMasi *et al*. (1991) or Grabowski and Vernon (1990), on the other hand, examine the R&D process in greater detail.

As discussed above, the empirical work on pharmaceutical R&D uses survey data at the individual firm level to develop costs for distinct phases of the R&D process. However, these studies do not provide valuations for genetic material inputs to the R&D process. Preclinical costs – which would include the input cost of genetic material – are estimated using aggregate data because firms are unable to allocate preclinical costs to specific new chemical entities (NCEs).

To value genetic material, Artuso (1997) borrows from the empirical models in that the approach breaks R&D into phases and estimates phase-specific (expected) costs. In the Artuso model, R&D is divided into nine phases from '"initial screening" of samples to "new drug approval." The model differs from the empirical ones because its ultimate goal is to arrive at a (maximum) value that a single prospecting firm would pay for genetic material at a single point in time; the firm is assumed to be a small player in a large industry. Phase-specific expected revenue is also estimated to arrive at the expected net present value of a prospecting program, which equals the total value of a collection of genetic extracts subjected to that program. In the base case there are 15,000 extracts in the program; therefore, average value of an extract is simply the NPV of the program divided by 15,000.

The model estimates the pharmaceutical value of genetic inputs by incorporating a specific "rate of success" into each phase of the process. The expected cost of each phase is dependent upon the number of genetic samples under investigation *in that phase*. The number of samples under investigation in any particular phase will equal the number of samples that tested positively in the *preceding* phase. Therefore, the success rate of the preceding phase is the relevant rate for calculating costs in the current phase.

Model to Value a Set of N Biological Extracts

We first summarize the calculation of expected R&D costs. The expected revenue, and net present value calculations follow thereafter.

The expected total cost of pharmaceutical R&D is the summation of the expected costs associated with each phase of the process. The expected cost of each phase i (EC_i) equals the sum of its fixed costs (FC_i), and its variable costs. Variable costs depend on the cost per test of an extract (c_i), the number of extracts tested, and the number of therapeutic targets (M) against which the extracts are screened. The number of extracts tested in any phase depends upon the number of extracts originally entered into the screening process (N), and the success rates of all preceding phases (s_j). Hence, the expected cost of phase i is:

$$EC_i = FC_i + NM\, c_i \prod_{j=0}^{i-1} s_j$$

To arrive at the present value expected cost of phase i (PVECi), for the duration of the phase (d_i) the average annual cost of the phase (EC_i/ d_i) is discounted to the present. The period over which discounting occurs must account for D_i – the total duration in years of all phases up to and including phase i.

$$PVEC_i = \frac{EC_i}{d_i} \sum_{t=0}^{d_i - 1} (1 + \text{discount rate})^{-(t + D_{i-1})}$$

The present value of the expected total cost (PVETC) of the R&D process is the summation of the present value of the expected cost of each phase of the process ($PVEC_i$). If there are n phases in the pharmaceutical R&D process, then:

$$PVETC = \sum_{i=1}^{n} PVEC_i$$

Table 3.5
R&D phase data used by Artuso (1997) for baseline analysis ($'000)

No. of Extracts Tested	15,000					
No. of Therapeutic Targets	10					
Real Discount Rate	8.5%					
Phase	Phase Duration	Success Rate	Mean No. of Successes	Cost per Trial	Expected Phase Cost	PV Expected Phase Cost
Initial screening	0.75	0.005	750	0.10	15,000	14,548
Secondary screening	0.10	0.400	300	1	750	732
Isolation & Dereplication	0.50	0.100	30	20	6,000	5,712
Synthesis & Modification	1.50	0.500	15	250	7,500	6,585
Preclinical Trials	1.00	0.400	6	771	11,570	9,170
Clinical Phase I	1.35	0.750	4.5	3137	18,822	13,557
Clinical Phase II	1.88	0.475	2.14	9933	44,698	28,239
Clinical Phase III	2.49	0.700	1.50	18817	40,222	21,282
NDA	3.00	0.900	1.35	1,000	1,496	633
Cumulative	12.57	$9\text{x}10^{-6}$	1.35	33,930	146,058	100,457

First four phases: data based on various natural product screening programs. Preclinical and clinical phases: data based on Burger (1990), Hansen (1979), and DiMasi *et al*. (1991).

Table 3.5 shows the phase data used to calculate PVETC.

For the calculation of revenue, the expected number of approved drugs (A) following from an R&D process is a function of the number of extracts screened (N), the number of screening targets (M), and the probability of any given compound advancing through all phases of the R&D process – the multiplicative product of the success rates of all the phases:

$$A = NM\prod_{i=1}^{n} s_i$$

The number of new drugs receiving regulatory approval (A) multiplied by the discounted value of expected new drug revenue (R_t) yields the before-tax present value of expected *gross* revenue. Netting-out all non-R&D costs – production, equipment, marketing, administration – yields the present value of expected *net* revenue ($PVENR_t$). The discounting period includes all n phases of the R&D process, plus T – the average commercial life (in years) of a new drug. Therefore:

$$PVENR = qA * \sum_{t=1}^{Dn+T}(R_t - Z_t)(1+r)^{-t}$$

Table 3.6
Model Parameters in Artuso (1997)

Sales revenues for new drug	Series	Based on Grabowski & Vernon (1990) and adjusted to 1994 prices.
Sales decay	7.5 %/year in yrs 12 -20	
Product life	20 years	Vagelos (1991)
Global to US sales ratio	1.9	Grabowski & Vernon (1990); Joglekar & Patterson (1986)
Plant & Equipment	50% of gross revenues in yr 10; 2/3 occur in yr 1; balance equally spread over yrs 2 through 10	Based on Grabowski & Vernon (1990).
Administration & operating costs	40% of revenue	
Marketing	100%; 50%; 25% of sales in yrs 1,2,3 respectively	
Tax rate	35%	
Discount Rate	8.5%	Based on Capital Asset Pricing Model.

where,

q = average proportion of annual revenues after deducting all production and marketing costs; and,

Z_t = cost in year t of any initial capital and marketing costs not captured by q.

Table 3.6 shows the data and sources used in the PVENR calculation.

Accounting for the tax liability of a private firm (r percent), the difference between the present values of expected net revenue, and expected total cost of R&D, yields the expected net present value of N biological extracts to the private firm ($ENPV_{priv}$). That is to say:

$$ENPV_{priv} = (1-r)(PVENR - PVETC)$$

The expected net present value of N biological extracts to society ($ENPV_{soc}$) is estimated by ignoring the tax liability, and accounting for consumer surplus and additional societal benefits such as reduced contagion and increased productivity. A scalar (m) is used to increase PVENR to capture consumer surplus and any additional benefits:

$$ENPV_{soc} = m(PVENR) - PVETC$$

The results of the expected private NPV calculations are shown below.

	Before Tax	After Tax
Total (15,000 extracts)		
Expected Net Revenue	$108.8 million	$70 million
Expected R&D Costs	$100.5 million	$65 million
Expected Net Value	$7.3 million	$5 million
Per Extract		
Expected Net Revenue	$7,184	$4,669
Expected R&D Costs	$6,697	$4,353
Expected Net Value	$487	$316

Sensitivity analyses were conducted by changing the assumptions regarding the discount rate, drug revenues, and the success rates of different phases of the R&D process. For example, decreasing the discount rate from 8.5% to 8%, the expected NPV of N extracts increased from $7.3 million to $18 million. Reducing the primary screening rate by 20% from 0.005 to 0.004 reduced the expected NPV of N extracts from $7.3 million to $2.9 million. If the preclinical success rate is reduced by 20% from 0.400 to 0.320, the expected NPV of the prospecting program becomes negative.

A Model addressing Marginal Economic Value

Simpson, Sedjo, and Reid (1996)

Simpson and colleagues (including Simpson and Sedjo 1996ab, Simpson and Craft 1996) note that most of the existing valuations of biodiversity for genetic prospecting have estimated the *average* value of a species. Those reviewed above, for example, calculate the value of a new, plant-based commercial drug, net of all production, marketing, and R&D. That net value represents the maximum amount a prospecting firm would pay for a collection of species to screen for new drug sources. The value of an individual species within the collection is estimated by multiplying the value of the collection (the net value of a new drug) by a probability that an untested species will yield a commercially viable new drug source (the success rate). The result is an average value for the individual species subjected to the screening program. From a policy planning perspective, however, some of the economic efficiency decisions made for a given site (e.g., a conservation area), would also require information relating to *marginal* values of species. Such valuations generally take on a different analytical form. The Simpson *et al*. (1996) model estimates the value of a species by deriving its *incremental contribution* to the total value of the collection of species. For example, if a prospecting firm has a collection of 249,999 species of plants, the model calculates the additional value of screening a 250,000th species.

The rationale for a marginal valuation approach is based on the existence of "redundancy" among natural chemicals. Genetic resources may be relatively redundant for the following reasons:

- If all individuals of a species produce the same compound, a viable population of the species is all that is needed to guarantee supply; individuals in excess of the number required to maintain the population are redundant.
- In many cases, the same chemical compounds can be found in different species, hence there will be redundant species for those particular compounds.
- The discovery of a novel compound occurring in particular species may in fact only duplicate the therapeutic mechanisms already produced by an existing compound.

The possibility of redundancy is built into Simpson *et al*. (1996) model so that the expected value associated with screening an additional species declines, due to the increasing probability of having hit upon a novel compound from samples already screened.

The authors derive a demand function for genetic resources in pharmaceutical research. In doing so they demonstrate that if the collection of genetic resources to be screened is large, then the expected value of the marginal species will be low because the probability of redundancy is positively related to the size of the collection. Furthermore, the higher the probability of success in finding a novel compound within the collection, the higher will be the probability of redundancy, and the expected value of the marginal species will be even lower.

Model to Value the Marginal Species

Each sampling is treated as an independent Bernoulli trial with equal probability of success. When a positive hit occurs, the sampling process is halted because further positive hits would be redundant. The value (V) of a collection of n samples to be screened is then:

$$V(n) = (pR - c) / p * [1 - (1 - p)^n]$$

where,

p is the probability with which any species sampled at random yields a success;
R is the revenue generated by the new drug, net of production/marketing costs;
c represents R&D costs only; and,
n is the size of the collection.

Table 3.7
Model parameters and results in Simpson *et al.* (1996)

Number of species	250,000	Myers 1988, Wilson 1992
Expected number of new products	10	US FDA average
Cost of single new product development	$300 million	DiMasi *et al*. 1991, OTA 1993.
Revenue to cost ratio	1.50	assumption
Discount rate	10 percent	assumption
Revenue	$450 million	
Cost per sample (c)	$3,600	
Maximizing probability (p*)	0.000012	
Probability of a hit in entire collection	0.9502	
Value of the marginal species	$9,431.16	

The value of the marginal species denoted as v(n) is the difference between V evaluated at n and V evaluated at n+1:

$$V(n+1) - V(n) = v(n) = (pR-c)(1-p)^n$$

Equation v(n) is differentiated with respect to p to find p* – the probability which maximizes the value of the marginal species. v(n) is then evaluated at p* to determine v* – the maximum value of the marginal species, given the size of the collection, sales revenue, and R&D costs. Hence:

$$p^* = (R + nc) / (n+1)^*R$$
$$v^* = v(n,p^*) = [(R - c) / (n+1)] * [(R-c)/R * (n/(n + 1))]^n$$

The model is adjusted to allow for the expected number of new drug approvals per year (A). The marginal value of a species is discounted at the rate r. Discounting takes places over an infinite time horizon, hence the marginal value equation is simply:

$$v(n) = (A/r)(pR-c)(1-p)^n$$

and the maximum expected present value of the marginal species (EPV v*) is:

$$EPVv^* = (A/r)^*[[(R - c) / (n+1)] * [(R-c)/R * (n/(n + 1))]]^n$$

Results

The model estimates a maximum potential value for the marginal species; data inputs and key results of a valuation exercise using the model are shown in Table 3.7. Given the cost and revenue data, for a collection of 250,000 species, the probability which maximizes the value of the marginal species (p*) is 0.000012 (or 1:83,333). Success probabilities greater or lower than p* reduce the value of the marginal species. Evaluated at the maximizing probability p*, the maximum expected value of the marginal species is just under $10,000.

Tests are run on the model to demonstrate the extreme sensitivity of the expected value to the probability of success and to the relative magnitudes of the revenue and cost variables. With costs and revenues constant, if the probability of success drops below 0.000008 (1:125,000), the value of the marginal species is negative. The lower success rate results in a loss in marginal value because the incremental revenue from testing the last available species has decreased. On the other hand, if the success rate increases to 0.00004 (1:25,000) the value of the marginal species declines to $67. The loss in marginal value is because of the increased likelihood that the novel compound has already been found in another species.

Valuation of Tropical Forests

Using the output of the model, the authors calculate the prices pharmaceutical companies would be willing to pay to preserve biodiversity-rich sites. Given the estimate of the marginal value of a higher plant species of approximately $10,000, the authors estimate the value of the marginal hectare of endangered habitat. Using the theory of island biogeography, for 18 biodiversity "hot spots", a species-area curve is differentiated to determine the change the number of species from a given change in the size of a particular forest area. Combining the results of these calculations with the marginal species value estimate, the authors derive land values ranging from $0.74/ha in Central Chile, to $20.63/ha in Western Ecuador.

Summary – A Look at the Frontiers of Valuation and Modeling

This chapter has looked at the biodiversity valuation literature, with a view to considering the different methods that may be applicable to marine biodiversity valuation. Methods relating to direct and indirect uses and functions are among the best developed, and techniques are readily transferred to coral reef systems. Methods relating to non-use values are also available, although they are complicated by methodological issues such as lexicographic preferences.

Of greatest research interest, however, is the field of biological prospecting valuation. Models for terrestrial systems have evolved considerably over the past decade, although none have yet been applied to marine systems. Also, bioprospecting model development in the literature has tended to be isolated in two distinct areas: agriculture and pharmaceuticals. While both have similar foundations in the modeling of the value of applied research (Evenson and Kislev 1976), distinct literatures have developed in agricultural and pharmaceutical modeling development. This has arisen because of different technical aspects of bioprospecting in these fields, as well as different policy concerns.

The bioprospecting valuation approaches we build on fall primarily into the realm of deterministic models relating to pharmaceutical development. These attempt to infer social values from intensely private behavior. The model developed later in this research (Chapter 7), like its counterparts, provides no explicit empirical calculation of option values. It does, however, provide insights into issues of value related to marine environments, focusing on issues such as marine product success rates, institutional revenue sharing issues, and ecosystem yield. We encourage further research that looks into such issues in greater depth, and extends models to bioprospecting for other marine products, such as mariculture. In that respect, future modeling efforts are likely to borrow more extensively from both the agricultural and the pharmaceutical literature.

We maintain, however, that no single terrestrial bioprospecting valuation model should be preferred over the others; each has a different policy application. In pharmaceutical bioprospecting, the early models of gross economic value had an important role to play for education and awareness policies, although they may be less useful for management and specific planning. The next generation of models, those relating to net economic values, taught us that we need to pay greater attention to the allocation and calculation of costs within the biological prospecting process. This has distributive implications, such as through the incidence of benefits and costs to the private sector vs. society at large, as well as efficiency considerations, such as whether it in fact makes economic sense to undertake biological prospecting. In particular, the average cost models showed us how sensitive economic values can be to technical parameters (such as success rates) and to economic variables, such as royalty rates or R&D costs.

But even these models fail to tell the whole picture, or answer all of the relevant economic policy questions. From a system planning perspective, we are constantly reminded that we must pay attention to the complexity inherent in biological and ecological systems, as well as within the discovery process itself (Brown and Goldstein 1984, Solow *et al.* 1993, Polasky and Solow 1995). One manifestation of this is the potential for interdependence of probabilities within the discovery process; an example of this was illustrated by Simpson *et al*. (1996) in their treatment of “redundancy” to show that the value of the marginal species is in fact quite low when such complexities are considered. Another manifestation of this complexity arises at the policy planning stage when trying to transfer “$/species” values to some tract of ecosystem such as rainforest. In such cases, the yield of species by the ecosystem is typically non-linear, and the first differential of this relationship must be estimated before allocative decisions about optimal levels of conservation can be made. Again, this issue was touched upon by Simpson *et al*. (1996), as well as by Artuso (1997), and their results illustrate the sensitivity of valuation results to assumptions relating to ecosystem yields.

As another example of the complexity and interdependence issue, none of the models have adequately grappled with differentiating among the *intended reasons* for bioprospecting. It is normally assumed that we are looking for new products and new discoveries that will somehow cure all of our worst maladies. In fact, however, some of the bioprospecting is oriented to looking for new – but cheaper – sources of existing materials. In that respect, bioprospecting is akin to mineral or oil exploration … we know what we are looking for and are simply looking for a cheaper source. This result is underlined by theoretical modeling work done by Evenson and Lemarié (1998). They show that, within an optimal search framework which distinguishes between different geographical regions, bioprospecting may shift towards species-rich (or trait-rich) regions where lower cost searches are available. In this case, redundancy is not an issue; indeed, redundancy may be a positive rather than a negative factor in valuation.

To date, no single model has provided all of the answers. At best, they provide some indication of value, and what that value is sensitive to within a given policy context. There remain substantial limitations to valuation techniques. When designing a new model, or choosing among the existing ones, one must therefore pay attention to the particular policy issues or analytical issues one wishes to address. For marine products, these issues can be quite different than those related to terrestrial products. 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 also being made on multi-criteria analyses, with valuation as one component of that analysis. Adger *et al*. (1999) demonstrate how such MCA techniques can be of particular use in marine park planning applications where there are often a large number of stakeholders, having a wide variety of interests and objectives.

Chapter 4

Valuation and the Socioeconomic and Institutional Context

Chapter Acknowledgments

This chapter relies on material extracted from Bunce and Gustavson (1998) relating to socioeconomic issues, and from Putterman (1998) relating to institutional issues. Full copies of both of these background papers are available at: http://www.island.net/~hjr.

Introduction

Anthropologists have for some time reminded us of the importance of local institutions, cultures, and decision making structures in the everyday life of small and large societies alike. Inter-disciplinary work has started to shed light on the importance of such concerns in valuation. It is no longer adequate just to conduct a cost benefit analysis; we must also concern ourselves with the distribution of such costs and benefits. We can no longer assume that some invisible hand will distribute compensation or earnings in a just manner; we must look at the institutional structures available for implementing compensation mechanisms and, if necessary, recommend the adoption of new structures or the reform of existing ones. Finally, we can no longer take for granted that cultural values will somehow persist through the maelstrom of development – or even of conservation – initiatives; explicit efforts must often be made to recognize and protect such values[17], perhaps to the detriment of the goals sought by those pursuing development or conservation.

It is in that spirit that this project initiated two empirical studies relating specifically to distributional concerns. The first of these (Bunce and Gustavson 1998) addressed socioeconomic issues in the Montego Bay Marine Park area. The second (Putterman 1998) addressed institutional issues in Jamaica as a whole, with a focus on mechanisms and structures relating to biological prospecting for terrestrial or marine products.

[17] The valuation of "cultures" is a relatively new area within the economics discipline, with a range of associated methodological and empirical challenges; such explicit valuations have been excluded from analyses undertaken in this project. Dixon *et al*. (1998) provide case studies demonstrating such techniques.

Socioeconomic Issues

Section Acknowledgments

This section is extracted from a background paper prepared by Leah Bunce and Kent Gustavson, published as: *Bunce LL, Gustavson KR (1998) Coral reef valuation: a rapid socioeconomic assessment of fishing, watersports, and hotel operations in the Montego Bay Marine Park, Jamaica and an analysis of reef management implications. World Bank, Washington.* A full copy of this background paper is available at: http://www.island.net/~hjr.

Coral reef management involves a range of strategies to ensure sustainable use and conservation of reef resources, including limits on the number of users, spatial and temporal restrictions on usage, education programs, and research and monitoring programs. Increasingly, theorists and practitioners are finding that management plans based on sound biological data are not sufficient for developing effective reef conservation efforts. Rather, the success of management programs has been found to be strongly affected by social, economic and political processes (Orbach and Johnson 1989). Given that natural resource management ultimately involves changing human behavior, the greater the understanding of that behavior, the greater the likelihood of success of management efforts.

As early as 1969 the importance of socioeconomic 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..." (Interorganizational Committee on Guidelines and Principles for Social Impact Assessment [ICGPSIA] 1994, p. 108). The importance of socioeconomic conditions was demonstrated by Cernea (1985) in an examination of the socio-cultural compatibility of 68 World Bank projects. The 36 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, socioeconomic assessments have become an increasingly important component of management decisions (White 1989, Renard 1991, White *et al*. 1994).

The coastal environment poses particular challenges to conducting socioeconomic assessments and examining the implications of management strategies because of the diverse activities and user groups, the typically sectoralized government management regimes, and the nature of these traditionally open access resources. These characteristics 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. The often conflicting social, cultural and economic backgrounds of the user groups typically underlie the superficial issue of conflicts over the resource itself.

Realizing the unique nature and complexity of the coastal environment, methodologies have been developed to assess the socioeconomic backgrounds of coastal user groups. In 1994 the National Oceanic and Atmospheric Administration (NOAA) established ICGPSIA, which defined widely referenced guidelines for conducting social assessments (ICGPSIA 1994). Their guidelines were adapted from the key elements of standard social assessments, which include historical and current levels of participation in the activity, demographics of the participants, dependency of participants on the activity for employment and income, and traditional, cultural and social issues associated with the activity (Finsterbusch and Partridge 1990, Ingersoll 1990). With the added recognition of the importance of underlying economic conditions, and the difficulty of meaningfully isolating social from economic behaviors and motivations, social assessments have been further expanded to incorporate economic data.

In the past ten years there has been an increasing emphasis on conducting socioeconomic assessments as a participatory process (Taylor *et al*. 1995). One increasingly popular approach is participatory rural appraisals, in which local people share, enhance and analyze their knowledge (Chambers 1994). In conjunction with this shift toward promoting user participation, there has been a move to focus socioeconomic assessments around issues of concern defined by the community rather than collecting data on set indicators (Taylor *et al*. 1995).

The Socioeconomic Study

This study developed a mix of standard indicators and user issues by questioning users regarding their primary concerns with regard to reef management and by collecting baseline socioeconomic data through interviews, document analysis, participation observation and focus groups. The study examines the socioeconomic basis of the three primary user groups in Montego Bay Marine Park: fishers, watersports operators, and hoteliers. The socioeconomic (social, cultural, and economic) background of these groups is assessed and the socioeconomic factors that have implications for the development of policy and management alternatives are discussed. The analysis concludes with a discussion of guiding principles for future reef management in Montego Bay Marine Park.

More generally, the socioeconomic assessment presents a methodology and an analytical framework that can be used to examine the socioeconomic implications of future management and policy scenarios. As such, the study serves as a site-specific test case of the socioeconomic data collection methodology and the utility of the socioeconomic data for making management decisions. Consequently, this case study analysis can be adapted for use in the examination of other coastal management case studies.

In addition to contributing to the development of a comprehensive investigative methodology for coral reefs, this study was also designed to meet the needs of the Montego Bay Marine Park. The Park is used by multiple groups, including fishers, divers, snorkelers, swimmers, and other recreationalists. It is impacted by a wide range of external activities, including sewage disposal, solid waste disposal and land-clearing, as well as activities associated with its direct use, such as watersports activities and fishing. The mission of the Park is "To conserve and restore the marine coastal resources in the Montego Bay Marine Park for the maximum sustainable benefit to traditional users, the community and the nation, by providing effective programs for public education, technical support, monitoring and interpretive enforcement" (Montego Bay Marine Park 1997). The government authority with the legislated responsibility for the management of parks and protected areas, the Natural Resources Conservation Authority, delegated management of the Park to a volunteer board of trustees, the Montego Bay Marine Park Trust (the Trust).

The Trust is currently drafting a management plan and, in the process, is re-examining the Park's institutional structure and management programs. There is strong interest in, and emphasis on, promoting stakeholder involvement in Park management. This is, therefore, an important time to document the current extent and characteristics of Park use, and to examine users' concerns and interests. Consequently, the study provides opportune information that will prove valuable to the Trust in its endeavors to develop and implement an effective management strategy.

Findings and Recommendations

The analysis of the socioeconomic 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) intersectoral coordination among user groups. We here discuss the importance of these principles, their current state with regard to the Montego Bay Marine Park management, and how they can be developed to maximize the socioeconomic 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, watersports 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; but 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 watersports operators, lack trust, or are losing trust, in the abilities of Park authorities to manage the area. This has lead 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 of 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 systems for watersports operators).

Park awareness programs also need to demonstrate the value of conservation both in terms of biodiversity, and 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, watersports 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 net 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 socioeconomic 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 watersports 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 watersports 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 themselves.

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. 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., financial or educational support), rather than programs that have the apparent intent to alienate their way of life (e.g., more “no fishing” zones). Regardless of the form, these programs need to be initiated before further restrictions on use are imposed.

User group involvement

Another important guiding principle from 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 watersports operators, already play significant roles in management of the Montego Bay Marine Park. As outlined above, watersports 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 resource management, such as access to, and knowledge of, the reefs and fund-raising opportunities. These resources can be tapped by working through the existing organizational structures and networks. For example, the formal organizational structure provided by the Hotel and Tourism Association has already provided a means for hoteliers to work together, which can be tapped to develop cooperative programs with the Park. Further, the strong community structure evident within the Whitehouse fishers 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 their efforts to bring under control the continuing decline of the reef conditions, while other damaging activities go unchecked (e.g., party cruises, diving, and 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 a common pool of 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 no 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 are fishers, watersports 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.

Intersectoral coordination

Given the diversity of activities affecting the reefs (e.g., pollution, snorkeling, diving, and fishing), 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 Whitehouse fishers, and all-inclusive hotel watersports operators are not on familiar terms with those working in non-hotel affiliated watersports. 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 amongst 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 toward reef management.

Institutional Issues in Biodiversity Prospecting

Section Acknowledgments

This section is extracted from a background paper prepared by Dan Putterman, published as *Putterman DM (1998) Access to marine genetic resources in Jamaica: incorporating genetic resources utilization into integrated coastal zone management. A Study of Policies and Institutions. Study prepared for the World Bank. World Bank, Washington*. The paper also discusses three Jamaican case studies involving the use of genetic resources in light of the effects that proposed genetic resources policies would have on these projects; these are summarized in Annex B. The case studies include: marine bioprospecting in Jamaican coastal waters; international private sector collaborations in anticancer research; and biotechnology-based improvement of Jamaican papaya germplasm. A full copy of this background paper is available at: http://www.island.net/~hjr.

Coral reefs generate a large number of direct local uses – such as fisheries and tourism – while also harboring biological products and information that are of increasing interest to pharmaceutical and other industries. Biodiversity that is of interest to industry for its potential to provide diverse chemicals, enzymes and genes is known as genetic resources. Genetic resources yielding potentially valuable products include terrestrial and marine microbes, plants, insects, venomous animals and marine organisms (Table 4.1).

Institutional Study Objectives

The notion that countries such as Jamaica can integrate the use of marine genetic resources into coastal zone planning, so as to share in the benefits of commercial development, is a new one. Certain international treaties empower the government of Jamaica under international law to enact such regulations. As such, the specific objectives of this study are: (i) to provide an assessment of Jamaican institutions with expertise relevant to the management of marine genetic resources, and; (ii) to provide a concise set of policy recommendations intended to enable Jamaica to capture the maximum value created by commercial research and development with marine genetic resources. Because regulating development of marine and terrestrial genetic resources utilizes common policy mechanisms, this study presents policy recommendations applicable to both. In addition, three case studies are presented to illustrate the impacts of these recommendations in existing bioprospecting efforts in Jamaica (Annex B).

Table 4.1
Large global markets exist for products derived from genetic resources

Market sector	Estimated global sales (US$)*
Pharmaceuticals [1]	$256 billion
Pesticides [2]	$47 billion
Agricultural Seeds (commercial sales) [3]	$13 billion
Nutraceuticals (herbal products, phytomedicines) [4]	$12.4 billion
Cosmetics: skin care products [5]	$6 billion
Industrial Enzymes [6]	$1.6 billion
Industrial Microbes [7]	$0.68 billion
Biotechnology Enzymes [8]	$0.6 billion

* Market sectors highlighted use variable percentages of genetic resources as starting material. For pharmaceuticals, this is about 40%. For agricultural seeds, nutraceuticals, enzymes and microbes, this is 100%. Values have been normalized by Putterman (1997, 1998) and are based on the following primary sources: [1] Scrip 1996; [2] Burrill & Lee 1993, Moffat 1993, World Bank 1991; [3] Van Gaasbeek *et al* 1994; [4] Brevoort 1996, Yuan & Hsu 1996; [5] Niebling 1996; [6] Stroh 1998; [7] Perez 1995; [8] New York Times 1993.

A Brief Revisit of Bioprospecting Issues

Commerce involving genetic resources can be divided into R&D and production. Examples of production include using plants or microbes for manufacturing of pharmaceuticals, agrochemicals or herbal products. Examples of R&D include research to identify new industrial enzymes or new pharmaceutical drugs from genetic resources, also called “bioprospecting”.

Valuable marine genetic resources include marine microorganisms, plants, invertebrates and cartilaginous fish. Marine genetic resources often contain unusual or highly complex molecular diversity not found in terrestrial organisms, although the potential molecular diversity among marine microbes may be higher still. The list of potentially useful products derived from marine genetic resources includes anticancer compounds, antivirals, antibiotics, antifungals, anti-inflammatory agents and hormonal modulators, as well as industrial enzymes, agrochemicals, marine biomaterials, and extremely potent toxins.

Genetic resources R&D can be divided into a series of value-adding processes, beginning with a biological inventory requiring accurate taxonomic identification of specimens. Following inventory, the chemicals or genes are extracted from the genetic resource, and the extracts are screened with laboratory tests known as bioassays to detect and purify the desired biological activity. Further commercial R&D may involve expensive animal or human testing. Increasingly, developing country organizations are finding opportunities to collaborate with natural products industries of developed countries, to add value locally to genetic resources and hence to increase the financial return on their utilization.

It is customary to define all the obligations of research partners through prior negotiation utilizing legally-binding contracts or Material Transfer Agreements. Numerous mechanisms for compensation exist, including *rental fees* for the loan of research material to private firms, *rural employment* through participatory biodiversity inventories, *licensing fees* for the use of patented research material, and *technology transfer* enabling local value-adding R&D. Technology transfer is especially relevant for augmenting *tropical disease research. Deferred or contingent compensation* includes milestone payments and royalties, as well as sourcing agreements to allow rural populations to cultivate high-value raw material for processing into phytomedicines, cosmetics, pharmaceuticals, agrochemicals and so on.

Introduction to Genetic Resources Policy

The Convention on Biological Diversity highlights the "sovereign rights" of Parties over genetic resources (Articles 3 and 15.1), stating that governments have the right to regulate access to these resources on "mutually-agreed terms" (Article 15.4) and with "prior informed consent" (Article 15.5). Other relevant provisions include access to technology, including proprietary technology and biotechnology (Articles 16 and 19), and knowledge pertaining to traditional uses of genetic resources (Article 8j). The UN Convention on the Law of the Sea highlights the rights of member States to grant or withhold consent for marine scientific research, stating that consent can be withheld if the research is of direct significance for the exploration and exploitation of natural resources, whether living or non-living (Articles 246.3 and 246.5a). Finally, the Trade-Related Intellectual Property subagreement (TRIPs) to the World Trade Organization (WTO) Agreement calls for Parties to adopt a wide range of intellectual property rights regimes, including patents, plant breeders rights, and trade secrets.

Currently there are no Jamaican policies to regulate access to genetic resources, or even to recognize these as valuable material. The NRCA Act of 1991 does give authority to the Natural Resources Conservation Authority to regulate the use of natural resources, as well as the authority to require permits for various kinds of prescribed uses, but genetic resources uses are not specified. Overall, while there is some anxiety in Jamaica over the absence of mechanisms to ensure that Jamaica shares in the benefits of genetic resources utilization (especially when foreign private companies are involved), there is also a good appreciation of the value of private investment in genetic resources development, as a tool for economic development and biodiversity conservation.

Summary of Jamaican Institutions

The particular institutional strengths useful for designing and implementing genetic resources policy are summarized below.

Government of Jamaica

Those ministries of greatest relevance to developing and implementing genetic resources policy include the Ministry of Foreign Affairs, with jurisdiction over Jamaica's Exclusive Economic Zone (EEZ), the Ministry of Commerce and Technology, which oversees the National Commission on Science and Technology (chaired by the Office of the Prime Minister), and the Ministry of Environment and Housing. The Industry Section of the Ministry of Industry, Investment and Commerce processes patent applications in Jamaica. The Natural Resources Conservation Authority already has a biodiversity permit system in place that may be adaptable to cover genetic resources collecting. This permit system regulates the import or export of species listed under the Convention on the International Trade in Endangered Species (CITES). To advise on scientific issues relevant to this duty, the NRCA has created the CITES Scientific Authority, an interdisciplinary advisory body comprised of scientists and conservationists. Use of an interdisciplinary advisory body is also recommended for regulating access to genetic resources.

Although the Fisheries Division of the Ministry of Agriculture has jurisdiction over management of marine natural resources in the water column, it does not manage submerged lands. Submerged land in Jamaica's Exclusive Economic Zone is administered by the NRCA. The Forest Department has jurisdiction over natural resources management on public lands, including Forest Reserves. To avoid duplication, it is not recommended that either the Fisheries Division or the Forest Department develop a separate capacity to manage genetic resources. Finally, the Commissioner of Lands, a quasi-private corporation, owns land rights to all Crown (public) lands, including Forest Reserves. Although private property rights are well-defined in Jamaica, community land and community resource tenure do not exist.

Academia

Scientific expertise necessary for evaluating proposed genetic resources projects and for developing research collaborations is found mainly within academia, although a handful of private companies possess expertise relevant to herbal products development. Relevant academic departments at the University of the West Indies, Mona Campus include the Centre for Marine Sciences and the Department of Life Sciences, both of which possess expertise in marine taxonomy. The Institute of Jamaica also contains a large number of taxonomic collections, and it currently serves as the scientific focal point for Jamaica to the Convention on Biological Diversity. Both the Port Royal Marine Laboratory and the much larger Discovery Bay Marine Laboratory possess mariculture research facilities.

The Department of Chemistry employs natural products chemists, and is equipped with most laboratory equipment necessary for purification and structural determination of biologically active secondary metabolites. A Biotechnology Center also exists within the School of Medicine, with expertise in microbiology and tissue culture. Finally, technology transfer expertise also exists within the university through the Office of Planning of the Vice Chancellor’s Office. An attorney is available there to provide advice on contracts and material transfer agreements.

Non-Government Organizations

Numerous local NGOs in Jamaica are developing expertise in community management of natural resources, and some of these have been delegated responsibilities by the NRCA to manage Protected Areas. Among these are the Jamaica Conservation and Development Trust (JCDT), which manages the National Parks Trust and the Blue and John Crow Mountains National Park. JCDT identified major threats to the Blue and John Crow Mountains area as subsistence agriculture on marginal lands, primarily steep and easily eroded slopes, as well as the related problem of squatters’ settlements on park land.

The Montego Bay Marine Park Trust manages the Montego Bay Marine Park. As is the case with JCDT, this NGO’s management rights and responsibilities have not been well-defined by the NRCA, such that, for example, the right of the Trust to experiment with community resource tenure is uncertain. The MBMP Trust identified major threats to Montego Bay biodiversity as overfishing by artisanal fishers as well as land-based sources of marine pollution. Finally, the National Environmental Societies Trust is a coalition of 26 active local NGOs in Jamaica, comprised of three focus groups concerned with sustainable community development, ecosystems management, and public education. Several NGOs are collaborating in the development of new protected areas, and expressed great interest in possible applications of genetic resources for community enterprise development, especially high-value herbal products such as essential oils and botanical extracts, as well as potentially valuable marine products.

Private Sector

Existing private sector expertise in law and herbal products development may have useful applications in both policy development and project implementation. One private law firm interviewed, Myers, Fletcher and Gordon, employs several attorneys, including at least one partner, with a strong interest in environmental matters and relevant expertise in intellectual property and contract law. Federated Pharmaceuticals, Ltd. is setting up a production line for herbal products under its Natural Products Division. Finally, the Jamaica Promotions Corporation (JamPro), is a quasi-private corporation whose mission it is to promote economic development in Jamaica. JamPro has access to business development expertise, including information on business plans, sources of capital, marketing and contracts.

Recommendations for Jamaican Genetic Resources Policy

Appropriate policy reforms will permit Jamaica to incorporate the management of marine genetic resources into integrated coastal zone management planning. The policy recommendations are intended to allow Jamaica to fulfill obligations under the Biodiversity Convention and the Convention on the Law of the Sea, guaranteeing benefit-sharing while avoiding large disincentives to private sector investment. Four components of genetic resources policy should be addressed.

Regulate Access Up-Front with Permits and Contracts

Because there are no internationally-recognized protocols on rights to genetic resources and traditional knowledge, it is necessary to define rights to these resources by contract before samples are collected. The NRCA, or possibly the Ministry of Commerce and Technology, would be an appropriate regulatory agency. It is highly recommended that the government of Jamaica allow private parties to negotiate draft research contracts independently. These draft contracts would be submitted to the regulatory agency for review along with the collecting permit application. A multi-disciplinary Genetic Resources Advisory Authority, with expertise in scientific matters, contract law, community rights and business development, would convene to review draft contracts.

Establish *Sui Generis* (Novel) Rights to Tangible Property and Traditional Knowledge

To define who has the right to negotiate genetic resources research contracts, it will be necessary to create rights to both the tangible and intangible (intellectual property) manifestations of these. Tangible property includes the physical embodiment of genetic resources and value-added research material. Intellectual property here refers mainly to traditional knowledge. A modification of industrial trade secrets laws, which Jamaica is required to develop under the WTO Agreement, is recommended for creating rights to this knowledge. *It is strongly recommended that the government of Jamaica refrain from nationalizing genetic resources rights*. This leaves open the possibility of establishing community rights; local resource tenure systems have been successful in creating local incentives for sustainable resource management. Nationalizing resources tends to undermine the ability of local communities to have a say over resource management, especially because such nationalization typically involves channeling resource revenues directly to central coffers or to a centralized agency.

Develop Prior Informed Consent Procedures

To give the legal owners of rights to genetic resources and traditional knowledge a means to control use of these resources, it will be necessary to devise a Prior Informed Consent mechanism to be used in the negotiation of "mutually-agreed terms." At the national level, establishing a Genetic Resources Advisory Authority would be sufficient to ensure Prior Informed Consent of the government of Jamaica. There is a critical role for NGOs in facilitating Prior Informed Consent decisions by local communities. Requiring foreign researchers to obtain Prior Informed Consent directly from each and every local stakeholder may discourage foreign direct investment. A more "user-friendly" method would be to require a local research partner organization to obtain a Certificate of Prior Informed Consent from the government, certifying that research material has been obtained with adequate Prior Informed Consent from local stakeholders. Foreign researchers would then merely have to ensure that domestic partners present an approved Certificate of Prior Informed Consent in order to be in compliance.

Create a National Benefit-Sharing Formula

To ensure fair and equitable distribution of income from genetic resources utilization, a national formula to convert a portion of this income into public goods is necessary. An existing formula would simplify genetic resources negotiations. An ideal revenue-sharing arrangement would allow domestic research partners such as private companies, NGOs (including those managing National Parks), and local communities to keep a portion of their income in order to maintain incentives for private investment and innovation. The remainder of genetic resources income would be set aside for broader uses (e.g., protected area management across Jamaica.) Developing a set of guidelines or fixed percentages, by defining these national set-asides on genetic resources income, would streamline the process of permit approval. The set-aside percentage could be recorded directly on the genetic resources permit.

For example, national regulations might require that 25% of royalty income were due the stakeholders that gave their Prior Informed Consent for biodiversity collections to proceed, another 50% were due a biodiversity trust fund earmarked to pay for conservation activities in *all* Protected Areas, and the final 25% were divided among other trust funds for community economic development and education. Such a formula would simplify genetic resources negotiations, as it would remove from consideration any discussion of how to divide up this income.

Establishing Compensation Protocols

Valuation literature dealing with biological prospecting frequently cites the institutional arrangement for rent capture as a key element for realizing economic benefits locally (Ruitenbeek 1989, Pearce and Moran 1994, Swanson 1995b). If rent capture is zero, there is no incentive for developing country governments or local populations to conserve the resources for bioprospecting. If the rent capture approaches or exceeds 100%, however, there is no incentive for foreign firms to prospect in that country; in effect, the country will have priced itself out of the international market. Striking a balance between these extremes is therefore a necessary function of the compensation protocols, reflected in a combination of agreements and formulas. A number of potential mechanisms were identified with a view to considering their potential impacts. Specifically, four scenarios are analyzed in detail (Putterman 1998) for the manner in which the value of marine genetic resources varies according to different rights claims by Jamaica.

Zero compensation

This scenario represents the status quo in Jamaica. Access to genetic resources, where granted, does not result in compensation to either the people or the government of Jamaica.

Minimal contingent compensation (royalties)

In this scenario, the government of Jamaica would require all applicants for access to genetic resources to sign a research contract or Material Transfer Agreement guaranteeing a royalty payment (contingent compensation) upon commercialization of any inventions derived from the transferred resources. The royalty provision means that private companies seeking access to genetic resources would incur an additional cost, but this added financial risk would be deferred. Royalty claims are a risk-limiting mechanism to share some of the benefits of genetic resources utilization, as payments are contingent upon commercial success. However, royalty payments allow biodiversity-rich source countries to capture only a relatively small portion of the total value of genetic resources. In addition, given the usually unfavorable odds that genetic resources research will yield commercial products, a royalty-only benefit-sharing scheme is unlikely to yield *any* benefits to Jamaica at all.

Contingent compensation with production (royalties & sourcing rights)

In this scenario, the government of Jamaica would again require all applicants for access to genetic resources to sign a research contract or Material Transfer Agreement. In this case, the agreement would also require the recipient to consider Jamaica as the first source of supply of raw or processed material for commercial production. These "sourcing rights" create opportunities for the development of new high-value agricultural exports as well as local processing industries. Marine sourcing might entail collecting from wild populations, or use of mariculture techniques if possible. Note that this strategy also relies solely upon contingent benefits. As such, given the usually unfavorable odds that genetic resources research will yield commercial products, this benefit-sharing scheme is unlikely to yield *any* benefits to Jamaica at all.

Guaranteed compensation for value-added products (rental fees plus royalties & sourcing rights)

In this scenario, the government of Jamaica would require all research contracts and Material Transfer Agreements to incorporate up-front or guaranteed compensation in exchange for the transfer of genetic resources samples. This would be in addition to the contingent compensation described above. *It is not recommended that the government of Jamaica impose an "access fee" on private companies seeking genetic resources research material.* Due to the highly competitive nature of natural products sourcing, arbitrary access fees merely serve to increase the cost of Jamaican genetic resources and are likely to price these resources out of the market.

Rather, it is recommended that the government of Jamaica encourage the development of local value-adding research services, which could provide inventoried biodiversity samples – or advanced research material derived from these samples – directly to private industry for a fee. Sample rental fees can be in the form of monetary compensation, which would ideally encompass the full costs of collection and processing *plus* a margin over and above this. Note that value-added genetic resources research material *is* difficult to come by, *especially* marine genetic resources which are prized for the complex structures and novel biological activities of chemicals and enzymes derived from them. Jamaican organizations offering these types of material would give Jamaica a clear competitive advantage over other countries.

Regulating genetic resources utilization under this scenario would require significant investment to develop the technical ability of private parties to undertake advanced contractual negotiations in Jamaica, and to develop the corresponding technical ability within the government of Jamaica to review these negotiations. It might also require a significant investment in training, equipment, and supplies by the local research partner. In this sense there is some risk involved in implementing this policy scenario. Funding for project development may be available from the private sector, augmented by public sector funding including grants and soft loans.

Chapter 5

Local Use Valuation

Chapter Acknowledgments

This chapter is extracted from a background paper prepared by Kent Gustavson, published as: *Gustavson K (1998) Values associated with the local use of the Montego Bay Marine Park. Study prepared for the World Bank. World Bank, Washington*. A full copy of this background paper is available at: http://www.island.net/~hjr.

Introduction

Empirical work for Montego Bay, Jamaica, commenced with an estimate of the net present value (NPV) of readily identified local uses using production valuation approaches; these can be regarded as a benchmark value for comparative purposes. Initial priority-setting and valuation estimates done by Huber and Ruitenbeek (1997) in association with local stakeholders was subsequently refined and updated by Gustavson (1998) through identifying specific direct and indirect uses during a site visit in January and February 1998. Based on reviews of secondary materials and discussions with stakeholders in the Montego Bay area, eleven local uses were identified that might be of interest in a valuation framework (Table 5.1). Of these, tourism and fisheries were consistently cited as high priority, and recent experience with onshore damage by hurricanes suggested that the coastal protection function of coral reefs should also be highlighted.

A number of other uses and functions were not valued explicitly. While some small scale local uses (aquarium trade, mariculture, crafts, and coral sand extraction) might be of importance in the future, their level of activity was intermittent and small and, in some cases, illegal. Bioprospecting use was of considerable interest, but that specific use would be investigated as a separate exercise. In the area of “indirect uses”, there was no basis for drawing linkages between the local coral reef habitat and offshore fishery productivity and, in any event, offshore fishery data were not in a suitable format for determining such linkages. Also, while the “value of coral reefs as a record of natural historical events” was an interesting information function, this value was of low policy priority. Consequently, the study specifically values the high policy priority areas of recreation, nearshore (artisanal) fishery, and coastal protection. Also, policy issues relating to economic rent capture in direct uses are addressed.

Table 5.1
Local use screening and summary of valuations results – Montego Bay Jamaica

Category/Use	Estimating Basis and Comments		Net Present Value* (millions 1996 US$)		
			r=5%	r=10%	r=15%
Direct Uses					
Recreation & Tourism	Based on net values from accommodations, food and beverage service, entertainment (including independent watersports and attractions), transportation, shopping, and other miscellaneous services.		$630	$315	$210
Nearshore Fishery	Based on net values from trap, net and hand line fishing occurring off of canoe-type vessels, launching from any one of five landing beaches in the area; also, catch from spear fishers using Park waters is included.		$2.92	$1.31	$0.815
Biological Prospecting	n.e.	Estimates of this component are undertaken as a separate study.			
Aquarium Trade	negl.	Low policy priority. Information from SIJ, JPC and GMBRC showed negligible trade.			
Mariculture	negl.	Low policy priority. Information from SIJ, JPC and GMBRC showed negligible trade.			
Crafts - Coral	negl.	Low policy priority. Illegal activity. Information from GMBRC showed negligible trade.			
Crafts - Other	negl.	Low policy priority. Information from GMBRC showed negligible trade.			
Coral Sand Extraction	negl.	Low policy priority. Illegal activity. Information from GMBRC showed negligible trade.			
Indirect Uses (Functions)					
Coastal Protection	Based on approximately 250 acres that are vulnerable to erosion. Land rental values are used as a proxy for economic value and are in turn based on a weighted average of hotel, industrial and domestic land use.		$130.0	$65.0	$43.3
Offshore Fishery	n.d.	SIJ fishery data could not reliably permit isolation of offshore values. Values were associated by species or landing site for Jamaica as a whole and “catch” in any given region could not be isolated. Also, no ‘linkage’ studies could confirm linkage between offshore fisheries and coral reef cover.			
Natural Records	n.e.	Low policy priority with no apparent basis for estimating value (i.e., there were no records that such data had ever been used for any planning purposes.)			

*Notes: r= annual real discount rate; n.d. = no data; n.e. = not estimated; negl.= currently negligible;
SIJ = Statistical Institute of Jamaica; GMBRC = Greater Montego Bay Redevelopment Corporation;
JPC = Jamaica Promotions Corporation.

Valuation Methods

Production Function Model

Before the local use values are derived, it is important to place this exercise within the context of a theoretical model. In this case, the marine resources themselves are envisioned as contributing to an economic productive process as traditionally described with a production function.

This study considers local uses ultimately to be supply-oriented *production function contributions* of marine systems to economic value. In other words, we are concerned with measuring the contributions of marine ecosystems to the value of output in a produced good or service. The contribution of marine systems to economic value through a production function is most readily envisioned through a Cobb-Douglas model:

$$Q = Q\{L, K, R\}$$

where,

Q = output;
L = labor;
K = capital; and,
R = resource base (or biodiversity).

In such a model, the value of marine systems or biodiversity is the marginal change in Q as R changes. The economic value of a reef resource equals the value of its marginal product: the increase in the value of output associated with a unit change in the reef resource input holding all other inputs constant. This benefit model, along with separately modeled costs, facilitates the examination of economic efficiencies associated with reef management decisions that change reef quality. For example, if Park management authorities implement a program that results in a 5% increase in the live coverage of coral reef (one possible measure of R), a derived production function can be used to examine the resulting increase in local economic benefits that may be realized. This study does not explicitly derive the specific production function, but makes the first step by describing the inputs and the values attributed to the use of the resource.

Information Sources

The primary means of data collection was document analysis and database search. The types of documents and databases analyzed included government department records and reports, census

Box 6.1. Nature and sources of information used for deriving local use values associated with the Montego Bay Marine Park

Tourism	
Tourist Arrivals, Expenditures, & Accommodation Use	Annual Travel Statistics, Jamaica Tourist Board
Tourist Expenditure Survey 1992	OAS (1994)
Accommodation Costs	Jamaica Promotions Corporation capital cost models
Nearshore Fisheries	
Number and Type of Fishers & Boats	Registration of Fishermen Database, Fisheries Division, Jamaican Ministry of Agriculture
Types of Fishing Activities	Bunce and Gustavson (1998)
Fishing Revenues & Costs	Nicholson (1994); Bunce and Gustavson (1998)
Coastal Protection	
Shoreline Land Values	Jamaica Promotions Corporation; Urban Development Corporation; various local real estate agencies; local land developers

and survey statistics, non-government organization and academic reports, Montego Bay Marine Park documents, and consultants' reports. This study also benefited from the information made available through a concurrent project – a rapid socioeconomic assessment of fishers, watersports and hotel operations – the results of which are reported elsewhere (Bunce and Gustavson 1998).

Direct local use values which can be attributed to the benefits that are achieved through the use of the Park were estimated on an annual basis for two broad categories of uses: *the nearshore fisheries and tourism*. Indirect use values associated with *coastal protection* were also estimated. Box 6.1 shows the primary sources of the data used and describes the nature of the information.

The focus of this study is on the three primary categories of uses; this avoids detailed examination of other minor local uses, and is in keeping with the experience of other investigations into the local use benefits of coral reefs (see Chapter 3) which illustrate that analyses should focus on a small number of benefits that are of immediate policy relevance. Recognizing limitations and constraints on research resources, it is through the detailed documentation and modeling of a small number of local uses that more valuable information can be gained regarding the changes in benefits realized through changes in the quality of the resource. Furthermore, more detailed modeling of a few direct use values will provide a benchmark from which to examine other, less significant local use values for which less detailed information is available.

Net Present Values of Direct and Indirect Local Uses

To arrive at the annual value of the contribution of the coral reefs of Montego Bay Marine Park to direct and indirect economic activities, the *net value* of those activities was calculated. The net value is the remainder of the total monetary value of the benefits once all existing economic claims to the production have been deducted. This remainder is the economic production claim that can be attributed to the marine system. To calculate the net value associated with coral reef use, all variable costs that represent a claim on economic production were first deducted from the gross receipts of the economic activity. This included the costs of utilities, operating services sold to the businesses, repairs and maintenance, goods and materials, government license and registration fees, insurance, and the opportunity costs of labor. It does not include such items as government taxes and subsidies (transfer payments) as these are not payments for activities that involve economic production *per se*. Similarly, any internal financial transactions, such as depreciation, or external financial transactions, such as bank interest payments, are not included; returns on capital assets are treated separately and inclusion of such internal financial transactions at this stage would thus constitute double counting.

The net operating values were then translated to true net values where possible by converting the value of capital investments or stocks to annual flow values to be deducted from the annual net operating values. The equivalent annual capital cost can be estimated through the use of an annuity factor:

$$E = \frac{C}{AF}$$

where,

E = equivalent annual capital cost;
C = value of capital at cost; and,
AF = annuity factor.

An infinite time horizon is assumed, such that AF = 1/*i*, where *i* is the discount rate used in the specific NPV calculation. Total values of capital investments considered available values at cost of buildings, equipment, and land. Information regarding the value of capital at cost was not always forthcoming or possible to reasonably estimate. In those instances, a full-cycle analysis was not possible, and the net operating values are reported. These cases are explicitly noted in the results.

For the next step in the calculation, we assume that a continuing, sustainable use is possible at the level of use for the given year and that the total value that we are interested in takes into account an infinite stream of net annual benefits. Thus, the *net present value* (NPV) for each direct and indirect benefit is calculated. The NPV can be simply thought of as the current equivalent net value associated with the use of the Park waters, or the contribution of marine biodiversity to productive economic output summed annually over an infinite time stream. Future values are discounted in order to reflect the social time preference rate. To illustrate the sensitivity of the analysis to the chosen discount rate, three rates are separately assumed in the calculations - 5%, 10% and 15% per annum. The NPV is thus represented as:

$$\mathrm{NPV} = \frac{(\mathrm{R} - \mathrm{C})}{\mathrm{i}} = \frac{\mathrm{NV}}{\mathrm{i}}$$

where,

R = revenue;
C = costs;
i = discount rate (5%, 10%, and 15%); and,
NV = annual net value.

It must be emphasized that the derivation of NPVs in this project is not a cost-benefit analysis *per se*. In a cost-benefit analysis, one would compare the economic value of the resource after an intervention (e.g., a management strategy which would improve reef conditions) with the economic value before an intervention. This report does not consider the effect of possible management interventions on the economic value derived from the reefs of Montego Bay Marine Park, or the changes in derived value with changes in reef quality. The NPVs reported here represent the 'value at risk'; in other words, it is the direct and indirect local use values which would be lost if the resource was completely degraded.

Interpreting Sustainable Level of Use

As noted above, the calculation of NPVs assumes that the level of use in the base year is sustainable – the benefits will continue to be received in perpetuity. The validity of this assumption must be checked against biophysical information regarding the conditions of the reefs in Montego Bay as they have changed over time. Moreover, any future or continuing changes in reef ecological conditions will necessarily have an effect on the current levels of local use. There are two documented ecological surveys (Hitchman 1997, Sullivan and Chiappone 1994) which examine reef conditions in the Montego Bay Marine Park. As well, there is additional information available on the reef conditions as perceived by the primary user groups; this latter information is outlined in Bunce and Gustavson (1998).

This study will not attempt to make assumptions regarding the sustainable level of local use. The coral reefs of Montego Bay are part of a highly complex system, involving interactions between ecological components, user groups, and land-based activities. Although there are certainly negative ecological impacts associated with increases in the levels of local use, the relationship is not simple, nor can the ecological impacts be isolated from other coastal and land-based activities. The high degree of system uncertainty, as well as system links, synergies and feedbacks, make assumptions regarding the sustainable level of use difficult.

Valuation Results

Direct Local Use: Tourism

Tourism services include accommodations, food and beverage service, entertainment (including independent watersports and attractions), transportation, shopping, and other miscellaneous services. For the year 1996, accommodations accounted for 57.9% of the total annual net value, food and beverage service 2.9%, entertainment 21.5%, transportation 5.2%, shopping 4.5%, and miscellaneous services 8.0%.

Net present value estimates associated with tourism in Montego Bay range from US$210 million (using a 15% discount rate) to US$630 million (using a 5% discount rate); at a 10% discount rate the value is US$315 million. In contrast to some other recreational valuation studies on large coral reef areas such as the Great Barrier Reef (Hundloe *et al*. 1987, Driml 1999) – which attribute portions of the estimated value to the reef resource – we here attribute the entire value to the availability and maintenance of the intact coral reef. For smaller near-shore reef systems that are tied integrally into the local economy, full attribution is likely to be a reasonable assumption (see also, Dixon *et al*. 1993 who in effect attributed the total value to the Bonaire reefs, which are similarly integrally tied into the local tourism economy). The base value

Table 5.2. Net annual values and net present values for the fisheries of Montego Bay Marine Park, 1998 (midpoints of ranges shown in square brackets)

	i = 0.05	i = 0.10	i = 0.15
Net Annual Value			
millions of current 1998 J$	-4.83 to 21.8 [8.5]	-5.92 to 21.2 [7.6]	-6.47 to 20.7 [7.1]
Net Present Value			
millions of current 1998 J$	-96.6 to 436 [170]	-59.2 to 212 [76]	-43.1 to 138 [47]
millions of constant 1996 J$	-59.0 to 266 [104]	-36.1 to 129 [46.5]	-26.3 to 84.2 [29.0]
millions of constant 1996 US$	-1.66 to 7.49 [2.92]	-1.02 to 3.63 [1.31]	-0.741 to 2.37 [0.815]

of US$315 million is therefore the value at risk, to the extent that it would all be lost if the coral reef resource were totally degraded.

Direct Local Use: Nearshore Fishery

Fishing in the waters of the Montego Bay Marine Park is artisanal, largely subsistence in nature (Bunce and Gustavson 1998). Trap, net and hand line fishing occur off of canoe-type vessels, launching from any one of five landing beaches in the area; in addition, there are numerous spear fishers using Park waters. The current total number of fishers is approximately 378 (Bunce and Gustavson 1998).

The net present value estimate associated with fishing is US$1.31 million at a 10% discount rate. Sensitivities (as shown in Table 5.2) were conducted to different levels of shadow wage rates assumed for fisher labor; extremes were set from 50% of market wage to 100% of market wage, with 75% the reference level for analytical purposes. It is notable that the fishery value is in fact negative if one assumes full market rates.

Coastal Protection

Local indirect uses, or ecosystem functional contributions to economic production value, are also potentially significant. This study considers the coastal protection that coral reefs afford as the sole indirect use value that can be quantified. Support of the offshore fisheries through ecological interactions may also be significant, but there are as yet no theoretical tools available to quantify the role of the coral reefs in offshore fisheries production. The literature that examines the biological contribution of coral reefs and the interactions with offshore fishes and pelagic production does not allow translation to quantifiable economic contributions. There are also indirect values associated with coral reefs theoretically linked as a component of natural historical event records; however, the investigation of this information function, while a potentially interesting academic exercise, is of low policy priority and thus not explored. Assimilation of wastes, pollution and discharge from anthropogenic sources is yet another potential indirect benefit, yet coral reefs are highly sensitive to nutrient and sediment inputs and as such these latter benefits are not considered to be *viable* or *sustainable* indirect uses to be considered in the local use model.

The average shoreline NPV of land vulnerable to erosion within Montego Bay Marine Park was estimated to be J$350 (US$9.86) per sq. ft. or J$15.2 million (US$0.428 million) per acre in early 1998. The NPV of the total amount of land at risk, based on approximately 250 acres being vulnerable to erosion, is thus currently US$107 million (1998 dollars) or US$65 million in constant 1996 dollars. Using 250 acres as being vulnerable to erosion along the approximately 21 miles of shoreline within the Montego Bay Marine Park assumes that approximately the first 100 feet of shoreline property are "at risk" of erosion should the protective function of the coral reefs be compromised.

At first glance, we note that this value would translate to a marginal benefit of US$1.5 million per hectare of coral substrate, based on the approximately 42.65 hectares of available substrate. But interpretation of this value within a production function normally would require a detailed description of linkages between coral reef quality and the shoreline protection function. At present, such information is not available, hence we can only make a number of general observations. Primarily, we note that even dead coral on substrate can provide some limited erosion protection for a short period of time; the length of this period depends on oceanographic factors, such as current, wave heights, and periodicity of extreme events such as storms. Experience in Jamaica with such events is limited, but most anecdotal evidence suggests that storms (including hurricanes) are frequent enough that erosion is regarded as a critical policy problem. Recent hurricanes destroyed beaches and buildings, and some locals still attribute a drop in tourist revenue (and hence land values) to damage done through the 1980s and 1990s. Thus, even though the periodicity of extreme events is not annual, their relative frequency would suggest that the values "at risk" could in fact be lost quite quickly in the event of reef disappearance. Unlike other areas of the world (where erosion is a long-term effect associated with reef degradation), the protection afforded by the Montego Bay reefs may be more immediate. Nonetheless, the values for coastal erosion should be regarded as “upper bounds” to the benefit function. If these benefits are deferred (e.g., through an expectation that the next extreme event is in fact not going to occur immediately) or mitigated (e.g., through an expectation that even dead and destroyed reefs will provide some protection), then the marginal benefit (i.e., the first differential of the value to reef abundance) is more likely to be less than the US$1.5 million cited above.

Policy Issues Relating to Capturing Economic Values

The values reported for direct uses in this study represent what would typically be considered to be producer surplus or rent. In other words, it is the difference between the total business revenues taken in through the use of the coral reefs, and the total costs associated with operating the business or activity. Of great interest to the management authorities of the Montego Bay Marine Park, as well as to managers of any coastal marine system, is to capture at least a portion of this rent to pay for the necessary management, and potential enhancement, of the resource. In other words, there are social costs associated with the conservation of the resource that should be paid by the users.

As a component of the study, current existing government charges that may capture a portion of the rent were explored. Currently, it is not the policy of the Montego Bay Marine Park to charge user fees – a recognized, explicit mechanism for rent capture – to the direct users of the reefs, although the Park is in the early stages of beginning such a program. Other government charges which are specifically linked to either tourism or fisheries related activities may capture a portion of either producer or consumer surplus, but are not necessarily designed explicitly to do so. This includes business license fees, fisheries license fees, beach fees and tourist departures taxes. These are discussed below. No other government or management agency fees or charges are specifically linked to either tourism or fisheries related activities. Corporate profit taxes, or personal income tax in the case of the fishers or of individually distributed profits from tourism-related businesses, may also capture a portion of the rent. However, taxes are paid to general revenues and thus are not explicitly available for use in Park management. The extent to which taxes may capture tourism or fisheries rent is not explored further here.

License Fees

Tourism Related Business License Fees

The Jamaica Tourist Board receives business license fees from tourism related businesses, with the exception of accommodations. As of February 1998 this includes the following:

- J$3000 (US$84.51) per operator per year for watersports, attractions, tour operators, and car rental companies;
- J$100 (US$2.82) per operator per year for craft vendors; and,
- J$4000 (US$112.68) per machine per year for gaming operations.

The accommodations license fee, or "hotel license tax", is charged by the Inland Revenue Department and goes into general revenues. The fee schedule is based on the 'category' of the accommodation: A, B, C, or D. This system is being phased out, but the premise on which it is based is being maintained: a schedule of fees that varies roughly in relation to the size of the accommodation's revenues. The more deluxe or expensive hotels are currently classified as A or B and are charged an annual fee of J$600 (US$16.90) per room per year. Less expensive forms of accommodation and villas are assessed a fee of J$300 (US$8.45) per room per year, while the least expensive accommodations pay J$150 (US$4.23) per room per year.

Fisheries License Fee

The current annual fishing license fee is J$150 (US$4.23). The fee is collected by the Fisheries Division of the Ministry of Agriculture. As there are no other fishery-related businesses directly tied to the activity in Montego Bay (e.g., processors, packers, transport companies) and all fish sales are directly to the consumer (Bunce and Gustavson 1998), there are no other relevant government license fees or charges which may be considered to capture any rent from fishing.

In principle, license fees are collected to pay for the government costs of regulating and administering the business or activity. Ideally, they are set to recover all costs, yet if set high enough they will also effectively capture a portion of the rent. Tourism related business and fisheries license fees are relatively small. No information is available with regard to the actual costs associated with regulating the reef-related activities, yet it is likely that in all cases these costs are not recovered. Thus, tourism business and fisheries license fees are not believed to currently capture any resource rent.

Table 5.3. Schedule of fees as stated in the amended Beach Control Authority Regulations (licensing) 1993 of Jamaica

category	fee per operator per year
hotels (100 rooms and over)	J$5,000 (US$140.85)
hotels (under 100 rooms)	J$3,000 (US$84.51)
guest houses (30 rooms and over)	J$2,000 (US$56.34)
guest houses (under 30 rooms)	J$1,000 (US$28.17)
commercial recreational beaches, public recreational beaches, proprietary and member clubs	J$3,000 (US$84.51)
beach used exclusively in connection with a dwelling, house or building rented for recreational purposes	J$2,000 (US$56.34)
commercial or industrial beaches (other than commercial recreational)	J$5,000 (US$140.85)
fishing beach (10 or more boats or with a fish depot)	J$100 (US$2.82)
fishing beach (less than 10 boats)	J$50 (US$1.41)
beach reserved exclusively for the use of owner's of lots in a subdivision	J$2,500 (US$70.42)
beach reserved exclusively for the use of schools, churches, or other bodies or persons for charitable or educational purposes	J$100 (US$2.82)

Beach Fees

The NRCA currently charges a "beach fee" which is a license fee charged under the Beach Control Act for use of the foreshore and the seafloor (usually to a point 25m seaward of the high water mark) for either commercial or private purposes[18]. The law requires that a license be obtained "...for the use of the foreshore in connection with any commercial enterprise along the coast which involves the use of or encroachment on the foreshore and/or the floor of the sea and the overlying water." (NRCA 1997, p 5). Licenses are renewable on an annual basis and can grant either exclusive or non-exclusive use of the foreshore (the granting of exclusive licenses is no longer practiced, although existing exclusive licenses are renewable).

Relevant sections of the fee schedule as stated in the amended Beach Control Authority Regulations (licensing), 1993, are shown in Table 5.3. Those not listed include various fees that are charged for encroachments on the foreshore or floor of the sea (e.g., breakwaters, pipelines, pools, buildings, fences, steps, platforms) and those associated with moorings.

The policy direction of the NRCA is for the use of these fees primarily for the "...rehabilitation of public bathing beaches and the monitoring of beaches generally." (NRCA

1997, p.24). It is also the position of the NRCA that current license fees are "trivial" relative to the profits generated by the use of the public resource. The Authority is very conscious of finding ways in which to raise more revenue, particularly that associated with use of a public resource. The beach fee is a direct mechanism for rent capture; however, none of these funds are explicitly directed to pay for the management of the Montego Bay Marine Park.

Departure Tax

All individuals departing Jamaica from either the airport or a cruise ship terminal are charged a departure tax of J$500 or US$15 (depending on visitor preferred currency of payment). As it relates to the use of the waters of the Montego Bay Marine Park, the departure tax as a charge to tourists does not effectively capture rent, but captures at least a portion of the consumer surplus. In other words, the collected funds represents a portion of the amount that visitors would be willing to pay for their visit to Montego Bay (and for some, other regions of Jamaica) above the amount that they actually had to pay. Resource rent captured by the tourism industry through the provision of reef-related services is not addressed by this fee mechanism.

General Comments on Rent Capture

Rent capture instruments are an effective means of aligning private costs with social costs, such that the operators experience the true costs associated with using the reefs. Fees allow management and government authorities to collect funds to pay for the resource management costs that they incur, as well as to help move towards an economically optimal level of use.

The capture of rent is most effective if fees are tied to profits or net incomes (before interest and taxes), and secondarily to the level of use. The beach fee charges as currently set are minimal and, although they vary roughly according to the type of use, are not linked to varying levels of producer surplus. The current efforts of the Montego Bay Marine Park to implement user fees should be encouraged. An *independent* administration of a program of rent capture that varies at least according to the level of use and the type of business (assuming that there is a certain level of "per use" profit associated with a particular activity) will help ensure that the funds are accessible by management authorities.

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[18] The Beach Control Act of 1956 established all rights of the foreshore and the floor of the sea to the Crown. Rights to the foreshore granted to private individuals before 1956, the date the Act was proclaimed, are maintained, along with rights by prescription granted to fishers (NRCA 1997, p.3 and p.13).

Under the current effectively open access management regime, one would predict that all rents would have dissipated; that the "profits" of operators would be zero. As outlined in this report, this is clearly not the case, although fishing rents are certainly minimal. The rapid socioeconomic assessment (Bunce and Gustavson 1998) provides some insights into why this might be so. In essence, the two most compelling explanations as to why there are still rents generated through the use of the Montego Bay Marine Park waters are: (i) there are socio-cultural and expertise barriers to entry; and (ii) the rents of the marginal or newer operators are zero because of the high costs associated with entry and the lower marginal returns.

Fishing rents are most likely maintained through socio-cultural and expertise barriers. The results of Bunce and Gustavson (1998) indicate that fishing activities are associated with a particular socioeconomic class and that fishers themselves do not become good at fishing until they have gained the necessary experience. Those outside of the fishing communities would likely find it difficult to fish profitably. It was even noted during interviews with Montego Bay fishers (Bunce and Gustavson 1998) that wealthier individuals not associated with the fishing communities will at times try fishing, but will soon give up due to low catches because they are unfamiliar with how or where to fish. The experience gained by the older fishers seems largely to be passed on through sustained involvement in fishing and interaction within the fishing communities themselves.

Spear fishers, who enjoy the largest rents, are less tightly linked to the fishing communities, and thus might be expected to be subject to fewer socio-cultural barriers of entry. However, experience and the unfamiliarity of many Jamaicans with the marine environment would still factor largely into their level of fishing success, and even their willingness to begin fishing in the first place. The overall effectiveness of any barriers of entry into fishing, however, is not absolute. More individuals are fishing (especially spear fishing) as is evident by the relatively recent and rapid increase in the number of fishers in Montego Bay (Bunce and Gustavson 1998). This increase in the number of fishers is expected to continue with the persistence of positive fishing rents.

The persistence of rents associated with the tourism sector is most likely largely due to new entrants facing higher costs and receiving lower yields or returns. For example, interviews with watersports operators (Bunce and Gustavson 1998) indicated that for some tourist services, such as the independent party cruise and glass-bottom boat operations, the market appears to be saturated or even declining, reducing gross returns. Existing, reportedly more marginal operators even expressed a desire to get out of the business, some unable to do so because of an inability to liquidate their capital investment. In such a market, there would be no more room for new entrants as they would face even lower marginal yields than the previously established businesses. Furthermore, for many tourism-related businesses, such as the hotel sector and the watersports operators, there are significant start-up costs and capital outlays, further deterring new entrants.

It must be added that the analysis of NPVs presented here was not able to distinguish between different types of operations within the tourism sector, with the exception of the aggregated sectors of accommodations, food and beverage, entertainment, transportation, and shopping, for the year 1996. Although there was an overall positive NPV associated with each, there may be dramatic differences between different types of operators within each category. For example, Bunce and Gustavson (1998) report that for some watersports operators, captured resource rents are indeed likely zero (e.g., independent glass-bottom boat operators).

Conclusions

One of the purposes of focusing on the most significant local use values associated with the coral reefs of the Montego Bay Marine Park is the added usefulness of providing a detailed benchmark to inform subsequent modeling of the complete set of benefits and costs. This study was not designed to be a cost benefit analysis (CBA), but to take the first steps towards achieving this by describing the NPVs associated with reef use. The values of the resources at risk reported here must be placed within the broader context of considering the complete set of true social costs and benefits when examining the economic efficiency of possible coral reef management interventions.

The existence of price distortions due to failures in the market may compromise the validity of the local use values reported here. The above analysis assumes that competitive markets are operating; that is, that no one individual or group of individuals can affect the price at which a good or service is sold, and that the price revealed by the market is the social price. Competition can be compromised through the operation of monopolies or oligopolies, or through specific government interventions or policies. Problems associated with imperfectly competitive markets are predominant in developing countries. Under severe price distortions, shadow pricing should be used. In other words, true social prices or values should ideally be found by looking for indicators that reveal the extent of the distortion. The extent to which market prices accurately reflected social values could not be explored in this study, yet the final site application and the results of Bunce and Gustavson (1998) indicate that overall there was a great deal of open competition between and within user groups, both domestically and internationally. The extent of price distortions is not expected to be large enough to compromise the validity of the results reported here.

Chapter 6

Non-use Valuation, Lexicographic Preferences and WTP

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Background

The research reported here is restricted to assessing the values associated with marine system biodiversity using the contingent valuation method (CVM). This chapter summarises the results and methodological issues encountered by the CVM sub-study carried out in Curaçao, the Netherlands Antilles and Montego Bay, Jamaica, and in particular the role of lexicographic preferences in environmental valuation.

CVM is a method that highlights the *utility* function approach. It relies on asking direct questions about the value of a particular good or service. An open-ended CVM would ask “How much would you be willing to pay to protect the coral reef?” while more structured questions might ask people to choose from a list of specific values. We use CVM because it is the only means we currently have available to estimate, ultimately, the non-use value of an environmental good. Because of the nature of the questions, however, CVM also may at times capture some use values. This is particularly the case when those being asked are obviously direct users of the asset (e.g., fishermen, divers, coral gatherers). In such cases, it is important to try to distinguish between the use and non-use components of the CVM.

All CVM has a number of challenges associated with it. These are sometimes called biases, because the respondent may have some inherent reason either to overstate or understate the value that they place on a good or service. CVM techniques have been well-developed over the past decades to allow researchers to eliminate most of these biases through the careful framing of questions and selection of respondents. The research in this project, however, breaks new ground because it addresses two additional sources of bias that are potentially relevant in biodiversity valuation. They include: (i) information constraints that arise because of the general unfamiliarity with the concept of biodiversity; and (ii) lexicographic preferences that arise when an individual places an infinite value on biodiversity because they would not be willing to sacrifice any of it for anything.

Although the CVM approach has been routinely used in assessing environmental benefits, no rigorous country-wide CVM analysis has been undertaken in the developing tropics of a marine environmental resource such as coral reef quality. Furthermore, few studies have taken account of the methodological issues raised by the possible existence of lexicographic preferences in the local population. Lexicographic preferences and their relationship to moral and ethical attitudes about the environment have been identified as a potential problem for employing CVM. Thus the project aimed to probe this issue and investigate how serious the problem might be in a developing country context. This study investigates the extent to which lexicographic preferences are pervasive, and develops CVM estimates for the improvement of coral reef biodiversity in Jamaica and Curaçao.

Empirically, it turns out that stated willingness-to-pay (WTP) depends, among other things, on the design of the constructed market and how responses are subsequently analyzed. Survey design has often become a contentious issue, particularly where large sums of money are involved. For example, as a counter to the possibly-large size of damage claims being made against Exxon, the company funded a series of studies which basically tried to discredit CVM as a method for valuing losses in passive use values. The government body responsible for issuing regulations on the assessment of damages from oil spills, the National Oceanic and Atmospheric Administration (NOAA), convened a panel of distinguished economists thought to have no vested interest in the CVM method to conduct hearings on the validity of the CVM method in 1992. Members of the panel were Robert Solow, Kenneth Arrow, Edward Leamer, Paul Portney, Roy Radnor and Howard Schuman. The panel’s report on their findings was published in January 1993, and was basically a cautious acceptance of CVM for valuing environmental damages including lost passive use values. These findings have recently been developed as a set of proposed guidelines for future legally-admissible CVM studies, which seem bound to at least influence the future development of the method. The principal recommendations were:

- a dichotomous choice format should be used;
- a minimum response rate from the target sample of 70% should be achieved;
- in-person interviews should be employed (not mail shots), with some role for telephone interviews in the piloting stages;
- WTP, not WTAC (willingness to accept compensation), measures should be sought;
- after excluding protest bids, a test should be made of whether WTP is sensitive to the level of environmental damage;
- CVM results should be calibrated against experimental findings, otherwise a 50% discount should be applied to CVM results;
- respondents should be reminded of their budget constraints; and,
- respondents should be given “adequate” information about the environmental change in question.

Two CVM surveys were designed; one for Jamaica and the other for Curaçao, and these followed the same layout and included the same type of questions. A total of 1058 surveys were carried out in Jamaica and 1152 in Curaçao. The main difference between the surveys, besides geographical and institutional context, arose in the development of the biodiversity improvement scenarios and management options to achieve them. The Curaçao study was complicated further by the need for translation into Dutch and Papiamentu, with the latter resulting in some simplification of the language. The Jamaican survey was designed and tested first and this informed the Curaçao survey.

The survey was designed where possible to accommodate the recommendations of the scientific panel, while also addressing information constraints and potential lexicograhic preferences. The survey instrument was successfully pretested in Jamaica through polling 110 respondents, half of which were tourists. Box 6.1 shows the basic structure of this survey instrument. It relies on an interview process that takes under one hour to complete, and elicits responses through a series of questions and information cards. Background information is provided at appropriate points in the interview process (e.g., Box 6.2.)

Box 6.1
Survey structure

The following shows the core questions asked of respondents in the modified and pretested survey. The questions shown here are a condensed version of the actual questions and supporting information cards. In addition, the survey elicits information from the respondent on socioeconomic factors such as sex, age group, religious belief, type of diet, education, occupation, and income. The survey also records “quality control” information provided directly by the surveyor.

Section A – Background Framing and Information

What in general do you think are the most important problems related to nature and human impact on the natural environment which you find personally worrying?

Have you heard of Montego Bay Marine Park?

Have you ever visited Montego Bay Marine Park?

What, if any, direct and indirect benefits do you currently get from using the natural marine environment and natural resources of the Montego Bay area?

Are you likely to visit Montego Bay Marine Park in the next 5 years?

How familiar were you with the causes of coral reef degradation before this interview?

Have you ever heard of the concept of biodiversity before?

How familiar were you with the concept of marine biodiversity before this interview?

Section B – Trust Fund

How much would you be willing to pay per year for the next 5 years to a trust fund to help restore the marine animal and plant biodiversity of Montego Bay from its current level of 75% to 100% abundance?

What is the reason for your not wanting to pay anything/refusing to answer? [or]

What is the reason for your wanting to pay to restore the marine biodiversity of Montego Bay?

Would you increase the amount specified for the trust fund if in addition to the restoration of Montego Bay other Jamaican coral reefs would be restored?

Do you think there would be any direct benefits to you from this project?

Imagine you were to leave Jamaica and never return, but otherwise your lifestyle and income remain unchanged. After leaving you never visit the Bay area or make any use of its resources again. Would you still be willing to pay for restoration and maintenance of the Montego Bay in the interests of biodiversity?

Under your current circumstances, instead of paying anything to the trust fund, would you be prepared to volunteer some of your time to help with projects and/or fund raising to increase the biodiversity of Montego Bay Marine Park, and if so how many hours per year for the next 5 years?

Section C – Lexicographic Preferences

Some people state that they believe moral rights exist which should be reflected in a human duty to avoid inflicting harm deliberately. To what extent do you think that such rights apply for the following: “We should avoid deliberately harming: (i) other humans now living; (ii) future human generations; (iii) marine animals; (iv) marine plants; and, (v) marine ecosystems.

In the case of Montego Bay Marine Park, do you believe the rights you have identified imply a duty to protect Montego Bay from harm regardless of the cost?

If actions currently harming Montego Bay (marine animals/plants/ecosystems) could be avoided without affecting the basic needs of Jamaicans would you accept a duty to protect marine animals/plants/ecosystems?

If preventing harm to Montego Bay (marine animals/plants/ecosystems) were to threaten the basic needs of some Jamaicans would you accept harm to Montego Bay animals/plants/ecosystems?

How do you think the rights you have identified for Montego Bay marine animals/plants/ecosystem should be protected?

Box 6.2
Survey background information

The following background information is provided to respondents during the contingent valuation survey to be conducted in Jamaica.

A. Background Information on Montego Bay

In 1992 a Rapid Ecological Assessment of Montego Bay Marine Park was conducted and the results identified causes of deterioration of the reef system. This study stated (p. 39): "The magnificent reefs described in historical studies from the north coast of Jamaica, particularly in the Montego Bay area, are in peril." Human pressure and changes have occurred in the following ways:

- bleaching events in the last few years
- over-fishing
- sedimentation
- mechanical damage
- nutrification
- dredging & filling of Seawind Island & Freeport in the 1960s, filling in mangrove forests & islands
- the reduction in the quality of water flowing into the Bay due to a growing population and poor infrastructure
- loss of coastal vegetation

Natural impacts have damaged the reef:

- Hurricane Allen (1980) devastated the north coast of Jamaica with an immediate effect of a 95% reduction in staghorn coral populations on the forereef. At Montego Bay north of the airport pre-hurricane staghorn populations covered 75% of the bottom but were reduced to 20% by 1982. Available space on the reef surface was quickly colonized by algae.
- In 1983-84 the Diadema sea urchin which feeds on algae was killed off. Thus, algae has become more dominant preventing coral regrowth.
- Hurricane Gilbert (1988) again damaged reef communities.

A healthy coral community depends upon the ability to resist change and be resilient in terms of recovery after disturbances. The human induced pressures reduce the ability of the reef to rebound from natural disturbances. Thus the coral ecosystem has lost resilience so that recovery is slow or may fail to occur. Jamaican reefs in general and Montego Bay in particular have been very slow to recover from the natural impacts of the 1980s. The current state of Montego Bay reflects:

- low diversity and small range of fish
- lack of large coral colonies and low diversity of larger reef sponges
- occurrence of acute sedimentation and nutrient loading reducing the diversity of plant and animal life on the sea bottom
- significant anchor damage on frequently visited reefs
- low coral diversity and dominance of brown algae on reef crests near shore.

B. Background Information on Marine Biodiversity

Biodiversity is defined as the totality of genes, species and ecosystems in a region. Genetic diversity refers to the variation of genes within species. Species diversity refers to the variety of species within a region. Ecosystem diversity refers to the variety of systems, of living things and their environment, within a region.

Marine biodiversity in the context of coral reefs refers to the different habitats for fish, coral, mollusks, shellfish and other sea animals, but also vegetation, fungi and bacteria. The kind and number of such habitats depend upon: the total number of coral species, dominant species in an area, and the complex patterns that occur in coral reefs over time and space.

Lexicographic preferences are signified by a discontinuity in the preference function. The aim of the survey was to identify the occurrence of such preferences and to see how far these might indicate a refusal to make trade-offs. The Montego Bay study also uses a non-monetary payment mechanism to check for trade-offs being made. That is, respondents are asked to trade their time instead of money. Those who show a positive willingness-to-pay in time or money are indicating that they would be prepared to make a trade-off. Finally, to aid cross comparison of results, the CVM was designed to separate the direct use values from the indirect and non-use values associated with the biodiversity of reef systems.

Results for Curaçao and Jamaica

Willingness to Pay Results: Bid Amounts

Respondents were asked to contribute towards a trust fund that would be managed by a marine park to increase marine biodiversity within the park boundaries. The payment was to be on a per annum basis for five years. The environmental improvement was described in terms of raising marine biodiversity within the areas by 25%.

The results show a fairly even split between positive bids and those refusing to bid or bidding zero. This holds for both tourists and locals in the Curaçao study, and for Jamaican tourists. However, in the Jamaican case the local population is much more likely to bid positively with 76% of locals doing so. The total sample mean is similar across both case studies at around $25. The local and tourist mean bids in Curaçao are very close, while in Jamaica the local bid is slightly higher. These results are interesting because a difference in bids for tourists and locals was hypothesised, and, early on in the project, the concern had been expressed to the research team that only tourists would be prepared to pay anything substantial.

Willingness to Pay Results: Reasons for Bids

The main concern here is with reasons for zero bids because these have in the past formed part of a process of classifying lexicographic preferences. These zero bid reasons can be split into those which are in accord with economic theory and those which are more problematic representing a protest which cannot be taken as reflecting zero value.

In the first group there are three reasons: a lack of income, regarding the improvement as unimportant, and having a preference for spending money on other goods and services. Out of these three reasons, the lack of income proved to be the largest overall category in both countries. An unusual category specific to this project, and in addition to the above three, is the feeling amongst some tourists (39% of tourists in Curaçao and 21% in Jamaica) that this really is not their problem and they would contribute only if the Park were in their own country. This can be regarded as a protest by the tourists either because they feel locals/residents should pay or they will derive no benefits after leaving.

Next are sets of reasons which constitute bias, often against an aspect of the WTP instrument. First are free riders who believe the improvement will go ahead and they therefore can gain the benefits without contributing. Only a very small percentage of the sample falls into that category (1-2%). Second is a more substantial set of respondents (the second largest set for Jamaica at 19% of the sub-sample) who feel paying is an inadequate solution and they therefore refuse to give a WTP bid. Reasons here include such things as wanting identifiable culprits to pay or having legislation imposed, and seeing the problem as one which requires a fundamental change in human behaviour which might be linked to a need for education. Third is a lack of faith in the proposed institution, which can be seen as just a way of raising money which will go into an organisation or individual's pocket and never be spent on the actual project proposed. Distrust of this sort was slightly more common in Curaçao. The final reason under this general set of bias problems is the rejection of the payment mechanism. Here a strong protest was found amongst the Curaçao sample (16%) and studying the actual stated reasons shows a general feeling that the Marine Park trust should be a government responsibility. The combined result of all these reasons under this category is to bias downward WTP because many of the respondents are concerned about biodiversity and place a positive value upon it. This is quite important given that 32% and 27% of zero bids for Curaçao and Jamaica respectively can be attributed to these four reasons.

Overall there is a similar distribution across the reasons in both countries with the exception of the protest against the institution in Curaçao and against individual monetary payment as a solution in Jamaica. Non-payment for 70% of the Curaçao sample and 65% of the Jamaican sample is given by three reasons: a lack of income (both countries), non-resident protest (both countries), and that general taxes should be used (Curaçao) or that paying would not solve the problem (Jamaica).

Lexicographic Preferences and WTP for Marine Biodiversity

One major difficulty with using CVM in the context of coral reef biodiversity is related to the existence of lexicographic preferences. Lexicographic preferences exist where decision-makers are unwilling to accept any trade-offs for the loss of a good or service. The literature demonstrates that, where such preferences are prevalent, CVM techniques are methodologically flawed. The first step of an applied CVM procedure should therefore be to determine the potential extent of such preferences. Recent work suggests that lexicographic preferences for biodiversity are exceedingly widespread in developed countries and that, moreover, the actual definition or understanding of biodiversity differs sufficiently among respondents. Under such conditions, the use of CVM techniques is questionable. This research tries to address the question of how to adapt CVM, taking account of the possibility that contingent valuation of coral reef biodiversity in developing countries may be constrained by lexicographic preferences.

Previous work on lexicographic preferences has relied upon a statement of belief in a position without consistency checks or developing a series of probing questions. In the current study, the survey instrument was designed to accommodate the presence of lexicographic preferences and to probe those claiming such a position more fully. This approach allows for the adjustment of a CVM survey instrument to detect the presence and extent of such preferences in the surveyed population, and also allows for the inclusion of variables reflecting those preferences for use in bid curve analysis. The methodology used had not been previously tested in a developing country context. Thus, in the presentation of results the comparison between the tourist and local sub-samples is of interest as a reflection of the relationship between contexts and preferences and in turn their relationship to stated WTP.

The method used in the surveys takes a rights-based ethical position as signifying an ethical stance compatible with the lexicographic preference hypothesis. Respondents were asked to state the extent to which they saw rights as relevant to present and future generations of humans, marine animals, plants and ecosystems. These general attributions of rights were then probed further in the context of the Marine Park because a general discontent with trade-offs may disappear upon the specification of circumstances. Beyond this respondents were asked to reflect upon the extent to which their refusal to trade is absolute by considering a potential conflict with their own standard of living. This allowed some refinement in the definition of various positions being adopted by the respondents and their stated acceptance of a position compatible with lexicographic preferences.

More than just attributing rights the respondents in the majority of cases are attributing an absolute right to protection from harm. Even aspects of the marine animals, plants and ecosystems are attributed these absolute rights by approximately 60% of the Curaçao sample and over 80% of the Jamaican sample.

Follow-up questions were designed to introduce the potential for needing to make trade-offs. Respondents who had attributed any rights were asked whether they believed the rights that they had attributed meant a personal responsibility to prevent harm regardless of the cost. The result is similar to the previous general attribution of rights question, that is, approximately 79% of the Jamaican and 68% of Curaçao sample answered affirmatively.

Next, questions were asked enabling the sample to be split into four categories (in addition to those denying any rights). These are:

- those who attribute rights and accept a strong personal responsibility to protect marine life and habitats from harm even when their standard of living is threatened;
- those who attribute rights and accept a personal responsibility to protect marine life and habitats from harm only if their own current standard of living is unaffected;
- those who withdraw rights and any personal responsibility to avoid harm to marine life and habitats when the cost of doing so is in terms of their current standard of living; and,
- those who reject rights and any personal responsibility to protect marine life and habitats from harm regardless of whether their own current standard of living is unaffected.

The results show that the two middle categories indicate a willingness to make trade-offs which is consistent with a modified lexicographic position: once a basic standard of living is obtained a stronger ethical position for other species is adopted. A readiness to consider the trade-off circumstances and the subjectivity of the relevant standard of living mean that individuals in these categories may be regarded as acting as utilitarians and weighing-up the trade-offs. The situation for Jamaica shows a dramatic reduction in those attributing absolute or strong rights from 79% down to 14%. Similarly, although slightly less dramatic, for Curaçao the reduction is from 68% to 28%. Despite this large reduction there is still a sizeable hard core of individuals taking a position consistent with strong lexicographic preferences. This leaves the question open as to how these individuals expect to protect the rights they hold so strongly, and how they would avoid having to make a trade-off decision, for example, where material goods are equated to the discharge of the moral duty being described. In order to try and address these issues another set of follow-up questions was asked.

Internal Consistency of Responses

First consider the zero bids which are taken as a rejection of a trade-off. The only data that are of interest with regards to the lexicographic position are taken to be those defined by the strong duty category. The survey allowed for bids by both time and money. That is, the project gave the scope for including voluntary work to improve marine biodiversity and this was seen as an important alternative in a developing country context where many may be on a low wage or in a non-monetary economy. The impact of this approach is to reduce the zero bid category considered here beyond that of the monetarily defined. Remember, those who show a positive WTP in time and/or money may be indicating that they would be prepared to make a trade-off (indifference) or that they are giving up a substantive part of their current living standard. The zero bidders as a sub-group of strong duty holders are quite small: 3.4% for Jamaica and 7.5% for Curaçao, both percentages representing fractions of the total population samples.

Next the reasons for giving a zero bid are analysed. These are divided into accepted economic reasons for a zero bid, i.e., income constraint, and non-zero value reasons. The outcome is to reduce the above stated protest zeros which are consistent with a strong lexicographic preference as defined by the strong duty, to 1.7% for Curaçao and 4.8% for Jamaica. This compares with 23.2% found for the UK (Spash and Hanley 1995).

How to Protect Rights?

Those protesting in terms of a zero bid and a strong duty position are in favour of legal and educational approaches to increasing the quality of biodiversity in the Marine Parks. In Jamaica 50% of these individuals opted for a purely legal approach, while in Curaçao 53% wanted either a legal and/or an educational approach.

As mentioned earlier, both zero and positive bid strong duty holders are potentially signifying lexicographic preferences. The biggest grouping of responses falls upon two methods for protecting the rights identified within the Marine Park. In Jamaica 66.4% and in Curaçao 48.3% of the respondents wanted rights to be protected by either a legal approach or education, or a combination of the two.

The overall picture can be viewed as a proportion of these individuals externalising the cost to other parties or organisations. Alternatively there may be a genuine failure to consider the cost of the proposed solution. The main category that avoids externalising the cost and maintains a position consistent with a strong lexicographic preference is that of the “lifestyle change”.

The implication for stated WTP is that in many cases those holding a strong duty position are prepared to pay for a different institutional framework if required to do so. This of course creates a practical problem for a CVM survey that, as part of the design, selects one institutional approach to the problem at hand. In addition, there is the theoretical problem that where respondents are prepared to pay for an institutional framework this fails to be a reflection of the resource value, but is rather a contribution to a social construct.

Bid Curve Analysis

Analysis of the determinants of WTP is particularly relevant to the purposes of the coral reef valuation project. The variables, which are hypothesized to determine variations in WTP, can be specified and studied via econometric analysis. In this section, bid curves are reported for the two case studies. These bid curves form the basis for providing informed estimates for the population WTP. The mean bids were of the order of $25 per person within the sample. These are, as shall be demonstrated below, an overestimate of the expected value of bids because of the influence of the zero bids and the breakdown of bidder characteristics.

A statistical anomaly involved in populations with lexicographic preferences is that the interpretation of a zero bid in a sample becomes problematic. The conventional approach of bid curve analysis, which typically relies simply on taking sample means, is likely to mis-estimate the true WTP. The high proportions of zero bids occurring in both surveys undertaken in this study imply that a more thorough bid curve analysis is required that permits decomposition of the determinants of the bids. Moreover, because of the truncated nature of the sample, standard regression techniques are inefficient and statistically biased. To circumvent this, tobit analyses in combination with maximum-likelihood estimation (MLE) techniques are used rather than standard regression (e.g., OLS) methods.

The tobit specification sets up a procedure that basically generates two answers:

$y = b_0 + b_1x_1 + b_2x_2 \ldots + b_nx_n$, and
$y = 0$ if RHS above < 0.

Table 6.1. Preferred tobit models

Variable	Meaning	Normalised Coefficient	Standard Error	Asymptotic t-ratio
Curaçao				
SEX	Gender	-0.17322	0.73843E-01	-2.3459
AGE	Age by category	0.05465	0.18042E-01	3.0288
EDUC	Level of educational attainment	0.18416	0.39794E-01	4.6278
KNOWMBD	Knowledge of Marine Biodiversity	0.05114	0.13414E-01	3.8126
BENUM	Number of Benefit Categories	0.18653	0.39808E-01	4.6857
RIGHTSEA	Marine animal/plant/ecosystem rights	0.15628	0.24749E-01	6.3143
NODUTY	No Rights/Duty to Marine Environment	-0.31661	0.11346	-2.7904
STRDUTY	Strong Duty	0.16615	0.80436E-01	2.0656
PROBC	Difficulty with Lexicographical Preferences	0.04113	0.19463E-01	2.1133
PREFINFO	Preference change and info effects	0.60101	0.74180E-01	8.1020
CONSTANT	b_0	-2.03850	0.21111	-9.6561
LNWTP3	Dependent; natural log of (WTP+1)	0.33092	0.11671E-01	
Jamaica				
TL	Tourist or local	-0.19667	0.83661E-01	-2.3508
ENVIROAT	Number of environmental concerns	0.05317	0.24215E-01	2.1959
INCOME	Level of gross income	0.06160	0.15320E-01	4.0273
NODUTY	No Rights/Duty to Marine Environment	-0.48570	0.13237	-3.6693
VISITC	Ever visited Marine Park	-0.22942	0.76518E-01	-2.9982
VISITF	Visit site in future	0.47212	0.12543	3.7641
KNOWCD	Knowledge of coral degradation	0.03859	0.12067E-01	3.1980
PREFINFO	Preference change and info effects	0.36412	0.18868	1.9298
INFO	Informed only	0.49011	0.17434	2.8112
PROBC	Difficulty with Lexicographical Preferences	0.08579	0.28718E-01	2.9872
CONSTANT	b0	-0.81805	0.23137	-3.5356
LNWTP3	Natural log of WTP	0.43953	0.14998E-01	

A maximum likelihood estimation (MLE) procedure sets up a likelihood function and through iteration provides an efficient solution to the above problem. Unlike OLS models which can be interpreted based on residual statistics (e.g., R-squared), MLE procedures are typically analysed based on the significance of individual explanatory variables (through t-statistics) and, when comparing models, through a likelihood ratio (LR) test based on a chi-squared distribution. Interpretation of the best model in this section relies on such tests, with all tests of significance reported at a 95% level of confidence. Results of the procedures are shown in Table 6.1.

WTP Determinants for Curaçao

A range of variables was available from the survey. A bid curve analysis, using a semilog-linear form, for Curaçao shows determinants of WTP as a set of standard socioeconomic variables, knowledge and the position taken towards rights. The socioeconomic variables are sex, age and education. The variable "knowledge of marine biodiversity" was derived from a survey question in which respondents used a ten-point scale to signify their prior knowledge of the concept after having had a description. Greater knowledge increases WTP. This is also true for the use related variable giving the number of benefits the individual derives from the Marine Park (e.g., swimming, diving, site seeing, sun bathing.)

A set of variables was also included to measure the ethical stance being taken by the respondent. First is the attitude of the individual towards rights. A seven-point scale was developed covering the attribution of a right to be protected from harm to marine animals, plants and ecosystems (RIGHTSEA). As can be seen rights for the marine environment are positively related to WTP, which means these individuals could be construed as making an implicit trade-off of their rights position and this was implied earlier by the development of the "strong duty" category. Here the data on personal duties is also incorporated in the equation.

Thus, the overall results for Curaçao show a model of WTP being dependent upon standard socioeconomic variables plus rights and duty based variables. The RIGHTSEA variable is a recognition at an aggregate level of rights in the marine environment. The STRDUTY and NODUTY variables are specific to the Marine Park itself and the extent to which individuals are prepared to prevent harm at the risk of a loss in their own living standards. In addition, a dummy variable called PREFINFO was included to account for whether individuals felt their preferences about marine biodiversity preservation had been changed by the survey.

WTP Determinants for Jamaica

A similar semi-log linear form of model was developed for Jamaica with a set of socioeconomic variables, knowledge and the position taken towards rights. The socioeconomic variables in this case are sex and income. Income replaces the age and education variables of the Curaçao model. This time the inclusion of a dummy variable for tourists versus locals was strongly significant and negatively correlated with tourists. The knowledge and use variables also again proved significant determinants of WTP. Knowledge of marine biodiversity (KNOWMBD) was found to be similar to that concerning reef degradation (KNOWCD) in terms of the equation and in this case the latter was used. Furthermore, the positive likelihood of future use of the Marine Park (VISITF) significantly increases WTP. Also, the relationship between WTP and having visited the Park in the past is negative (VISITC). This result is not uncommon for such surveys in that it implies that, once their initial curiosity is satisfied, individuals' utility from subsequent visits will tend to drop off. This is consistent with decreasing marginal utility in individual preference functions. In Jamaica the set of variables on ethical stance were less relevant. However some role for ethical positions is confirmed by the significance of the dummy variable rejecting any duty (NODUTY). This is also negatively correlated to WTP as was the case for Curaçao. Thus, the overall results for Jamaica are in line with those for Curaçao except in that the model lacks significant rights and strong duty variables.

Prediction of WTP

The expected WTP will depend on the location of the individual, their individual socioeconomic characteristics, and their attitudes towards rights. Simulations using the preferred models were conducted to estimate WTP and the probability that they would return a non-zero bid. Results are shown in Table 6.2.

First, we note that at the sample means, WTP in Curaçao is about $2.08 while in Jamaica it is $3.24. This difference is readily explained through the differences in the tourist/local mix in the sample. Tourists generally had the same WTP in Curaçao and Jamaica: $2.46 and $2.73 respectively. Jamaicans, on the other hand, were willing to pay almost double their counterparts in Curaçao.

Table 6.2. Predicted WTP for Curaçao and Jamaica as function of individual characteristics*

	P(>0)	E(WTP)
Curaçao		
Sample Means – All	58.33%	2.08
Sample Means – Typical Local	56.18%	1.85
Sample Means – Typical Tourist	61.15%	2.46
Locals with Strong Moral Duties/Rights	69.08%	4.05
Locals with No Moral Duties/Rights	17.82%	0.19
Tourists with Strong Moral Duties/Rights	74.18%	5.82
Tourists with No Moral Duties/Rights	22.01%	0.26
Jamaica		
Sample Means – All	65.77%	3.24
Sample Means – Typical Local	68.49%	3.75
Sample Means – Typical Tourist	62.51%	2.73
Locals with Moral Duties/Rights	70.72%	4.26
Locals with No Moral Duties/Rights	52.37%	1.66
Tourists with Moral Duties/Rights	64.22%	2.98
Tourists with No Moral Duties/Rights	45.17%	1.17

* P(>0) is probability of non-zero bid; E(WTP) is expected WTP in US$.

The importance of perceptions relating to rights and duties, however, is again illustrated in the WTP results. The simulations were conducted with the duty and right variables turned up to their highest and lowest possible combinations. The Curaçao set permitted a more extreme case because of the three variables, while the Jamaica is a softer comparison. The results show that people with some duty and rights perceptions are willing to pay about 2-3 times as much as those who have no such attachments; people with very strong perceptions will pay at least an order of magnitude more. Interestingly, in the Curaçao case, those with absolutely no moral attachment are expected to pay virtually nothing.

To extrapolate these figures to total populations requires making a number of assumptions relating to how the individual benefits can be transferred to total population benefits. In principle, we can initially assume that the sample characteristics for the stratified sub-samples (tourists and locals) represent population characteristics. Further, we can, as a starting point, apply these to only the adult populations because of the absence of children from the sample set. This will establish a lower bound estimate, and would be consistent with the assumption that adults also express preferences on behalf of their children. Based on these assumptions, and estimated adult populations of 90,000 in Curaçao and 1.6 million in Jamaica, we can attach a lower bound estimate of US$170,000 for Curaçao and US$6.0 million for Jamaica. As for WTP by tourists, given annual tourist arrivals of 175,000 adults in Curaçao and 500,000 adults in the Montego Bay area, and using the individualised WTP figures, WTP for tourists in Curaçao is $430,000 annually while in Jamaica it is $1.36 million annually. At 10% discount rates, these represent present values of $4.3 million in Curaçao and $13.6 million for Jamaica. Aggregating the conservative estimates for locals and tourists, we arrive at lumpsum WTP for coral conservation in Curaçao of approximately US$4.5 million. In Montego Bay, Jamaica, the corresponding figure is approximately US$20 million.

Conclusions

The goal of this study was to undertake a contingent valuation analysis of coral reef quality for amenity, biodiversity, and other values in Montego Bay, Jamaica, and reef areas along the south coast of Curaçao. Coral reef conservation benefits were to be valued in monetary terms with a view to identifying various economic and demographic characteristics of this valuation and its determinants (e.g., education, sex, and knowledge of biodiversity, local versus tourist). Although CVM is well-developed and routinely used in assessing environmental benefits, two broad areas of innovation were part of the current study in the context of coral reefs. First, a rigorous developing country CVM analysis was undertaken of an environmental resource which had previously been neglected, i.e., coral reef quality; most developing country CVM studies having focused on other issues (such as water quality) or on specific urban locations. Second, and more significantly from a research perspective, the recent CVM literature had identified the existence of lexicographic preferences as one of a number of outstanding methodological questions associated with biodiversity valuation that required further analysis, and the research addressed itself directly to this issue.

The lexicographic preference can be consistent with a positive or zero WTP. The expectation of protest responses associated with zero bids for reasons of non-zero value has been studied in a developed country context and has shown that around one fifth of respondents reject trade-offs when asked to pay to prevent environmental deterioration. A similar approach was adopted here in that the consistency of claiming a strong duty to protect the environment was contrasted with stated WTP in terms of a zero bid for reasons of non-zero value. In this case WTP was for an environmental improvement.

Zero bid reasons were identified as those which are in accord with economic theory and those which are more problematic representing a protest which cannot be taken as reflecting zero value. The combined result of all the reasons falling under the second category is to bias downward WTP because many of the respondents are concerned about biodiversity and place a positive value upon it. In the survey sample this proved to be a substantial group with 32% and 27% of zero bids for Curaçao and Jamaica respectively reflecting non-zero values. This excludes those in the “other” and “refuse/unable to answer” categories who may also place a positive value on biodiversity improvement.

Those claiming the strong duty accounted for the one third to one sixth of the sample. When the data were analysed for zero bids being given for reasons of non-zero value the sub-sample falls to a few percent. There was no apparent difference between the tourist and local sub-samples as might be expected if the result were due to the developing country context. However, the process adopted here for confirming respondents adoption of a strong duty was also effective in reducing the proportion claiming absolute rights.

While the finding of only a few percent of respondents in the protest-zero-lexicographic position does conflict with that of earlier studies some caution should be taken in generalising the result. As mentioned, a positive bid for an environmental improvement can be consistent with a lexicographic position because any increase in the highly ranked good will increase welfare regardless of the loss of those goods ranked as inferior. A second improvement or a reversal of the improvement would both elicit a zero WTP because the individual has no income left (or no spare income under modified lexicographic preferences). This raises the interesting possibility that those refusing to bid more for the improvement of other reefs that were classified as showing part-whole bias may have lexicographic preferences. In addition, the rights based position and implied duty does seem to influence bids as shown by the bid curve analysis. This result is very strong for Curaçao, but more limited for Jamaica.

In terms of the design of CVM, the study shows a methodology for classifying lexicographic type preferences. The second stage is then to develop checks for consistency in terms of WTP, and this was only partially achieved here because of the concentration on zero bidders and relative neglect of positive bidders in the analysis. However, the consistent results for the strong duty holders across the two countries shows they are in favour of alternative institutional approaches such as education, legal enforcement and to a lesser extent lifestyle changes. This, however, poses a problem for CVM as currently practised because it places the problem in a specific institutional setting when framing the WTP question.

Chapter 7

Montego Bay Pharmaceutical Bioprospecting Valuation

Chapter Acknowledgments

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Introduction

A preliminary review of issues and valuation methods showed that *utility*, *production* and *rent* valuation approaches can all be used to estimate the value of marine products through bioprospecting (Huber and Ruitenbeek 1997). The review confirmed that, for marine organisms, the biochemical *information* derived from these organisms is as important as the actual use of the organism itself. Appropriately, a key recommendation from this was that any chosen methodology should be capable of addressing information content in coral reef or marine organisms. Most *utility* oriented approaches are incapable of separating this information value. A second aspect of the review confirmed that institutional structures and revenue or rent sharing arrangements are key influencing variables in the valuation of marine products.

For these approaches to be successful, data must be available to translate sampling information (e.g., species types and counts) into final commercial products; these are usually translated through a series of “hit-rates.” While such hit rates are known for advanced stages of R&D, most of the literature relates to terrestrial organisms. A preliminary survey of primary marine bioassay data was therefore specifically conducted, with the confidential cooperation of a number of private companies and private research institutes (Putterman 1997). The exercise demonstrated that data collection of this sort was viable (Table 7.1).

Table 7.1. Preliminary survey of hit-rates from Caribbean marine organisms. Primary screening hit-rates from a collection of 20,000 Caribbean marine extracts fell into the indicated ranges.

Antiviral data	0.3% - 10.9%
Antimicrobial data (bacteria)	3.6% - 24.2%
Antimicrobial data (fungi)	9.0% - 9.6%
Enzyme data (protein phosphatases)	0.25% - 0.93%
Enzyme data (other)	0.05% - 0.65%

Source: Putterman (1997).

Appropriately, a more detailed analysis was pursued to place an economic value on marine pharmaceutical bioprospecting opportunities at Montego Bay. The study consisted of: (i) specific methodology selection and development based on a literature review and analysis; (ii) further contracting of firms active in Caribbean bioprospecting to obtain confidential information relating to hit rates; (iii) estimation of sales and cost information specific to Montego Bay; (iv) development of a hypothetical sampling program for Montego Bay, to form the basis for simulation studies; and, (v) economic modeling of values.

Model Selection and Key Valuation Issues

The review of methods and models relevant to pharmaceutical bioprospecting benefit valuation (Cartier and Ruitenbeek 1999 [Chapter 3]) provides a basis for demonstrating how modeling techniques have evolved, as well as for selecting a technique relevant to the Montego Bay situation. The literature review highlighted a number of factors that have tended to be crucial in the derivation of values in terrestrial bioprospecting valuation models (Table 7.2). First, it is clear that different models generally have different policy applications and, above all, selection of a relevant technique should be suited to the policy problem at hand. In the case of Montego Bay, a key aspect of the valuation research was to build awareness, but the valuation was primarily intended to assist in site specific priority setting and planning.

The model specification issues include: (i) estimation of gross vs. net economic values; (ii) estimation of private vs. social returns; (iii) capture of rent shares by local governments; (iv) estimation of average vs. marginal returns, and the role of redundancy and substitutability in each of these; and, (v) treatment of complexity through interdependence of discoveries and ecosystem yields.

Table 7.2. Comparative summary of pharmaceutical bioprospecting models

	Farnsworth & Soejarto (1985), Principe (1989ab), Pearce & Puroshothaman (1992ab)	Aylward (1993)	Mendelsohn & Balick (1995,1997)	Simpson, Sedjo & Reid (1996), Simpson & Sedjo (1996ab), Simpson & Craft (1996)	Artuso (1997)	Solow et al. (1993), Polasky & Solow (1995)	Ruitenbeek & Cartier (1999)
Model Attributes							
Analytical Specification Only						✔	
Terrestrial System Application	✔	✔	✔	✔	✔		
Marine System Application							✔
Policy Applications							
Education & Awareness	✔						
National Level Policies	✔	✔	✔		✔		✔
Private Profitability Analysis		✔		✔	✔		
Site Specific Planning				✔		✔	✔
General Economic Attributes							
Gross Economic Value	✔						
Net Economic Value		✔	✔	✔	✔	✔	✔
Private Costs	✔	✔	✔	✔	✔	✔	✔
Social Costs (including Institutional)		✔			✔	✔	✔
Time Delays		✔	✔	✔	✔	✔	✔
Average Species Value	✔	✔	✔		✔	✔	✔
Marginal Species Value				✔		✔	
Average Habitat Value		✔	✔		✔	✔	✔
Marginal Habitat Value				✔	✔	✔	✔
Specific Model Parameters							
Discovery Process Stages (Hit Rates)	**1**	**1**	**1**	**1**	**9**	**1**	**3**
Discovery Process Stages (Costs)	**1**	**1**	**1**	**1**	**9**	**1**	**1**
Revenue Sharing Treatment	■	■		✔	■	✔	✔
Redundancy/Interdependency				✔	■	✔	
Ecosystem Yield (Species-Area Relationship)				✔	✔	✔	✔
"Price Function" (Once Differentiable Value)				✔	✔	✔	✔
Industry Structure/Behavior						■	
Risk Preference/Aversion Behavior					■		■

✔ Explicitly Relevant or Incorporated

■ Treated Qualitatively or Partially

20-Mar-99

The relevance of these issues to Montego Bay, and their treatment within the model selection, is as follows:

- Gross vs. net values. The primary policy planning issue for Montego Bay is to look at net potential benefits accruing to bioprospecting, and to other reef uses. This requires some ability to deal with site specific costs, realizing, however, that expected sales revenues are likely to be common with any type of drug development … irrespective of product source.
- Social vs. private valuations. One component of the modeling literature is concerned with the general private profitability and incentive structures associated with drug production and marketing, and with R&D. These models typically incorporate taxation provisions within their various analytical stages. For Montego Bay, such analyses are of low priority concern. Of greater concern is the magnitude of social benefits, and the potential for capturing these efficiently. Private profitability is a concern to the extent that any revenue sharing arrangements must not discourage bioprospecting. A related aspect to this is the potential institutional overhead costs involved in maintaining a structure that oversees bioprospecting contracting. Social costs associated with such activities should be considered in any model developed for Montego Bay.
- Average vs. marginal values. This issue relates to whether the policy problem at hand is concerned with expected average values, or with marginal values of species and habitats. Much of the early literature was pre-occupied with average species values, even though site specific planning problems generally require translation of such values into marginal habitat values attributable to an ecosystem (rainforest or coral reef). Analysts have approached this problem through different means. Simpson *et al*. (1996) address the marginal species value to the value of a collection and translates these to marginal habitat values. Artuso (1997) essentially derives expected (average) values for species or samples and translates these to marginal habitat values using species-area relationships for hypothetical habitats. We shall in essence be following this latter approach, with a view to deriving, eventually, a marginal habitat benefit or "price". Consistent with the earlier literature in cost benefit analysis, we refer to such prices as "planning prices" to the extent that they are the relevant shadow prices to use for land use, investment, and other allocation decisions.
- Redundancy. The literature deals with related issues such as "redundancy", "substitutability" and "conditional probabilities" within the R&D process and discovery sequence. There remains, at this stage, debate over the extent to which redundancy of discoveries is an important issue. One perspective is that, if new discoveries have redundant attributes with those already discovered, then marginal species values will go down as more drugs are developed. A second perspective is that some bioprospecting in fact relies on looking for product redundancy, with a view to discovering cheaper sources of existing materials. For Montego Bay, we do not explore the redundancy or substitutability issue.
- Phase-specific costs. Most of the literature has assumed a single discovery phase and cost for the R&D process when, as noted by Artuso (1997), a more accurate modeling of the process would recognize that many of the success rates are in fact endogenously determined and the cost and success rates are co-determined within a firm's or industry's optimizing behavior. If one recognizes this separation, it implies that there are in fact in-built mechanisms that will tend to maintain the activity at some profitable level. Using a nine stage R&D process,

Artuso shows that this has important implications for genetic resource values, industry behavior, as well as for risk mitigation within the sector. For Montego Bay, we are primarily interested in the ecosystem values, although we acknowledge that some separation of R&D success rates and costs is important. The Montego Bay data are, however, constrained such that optimization studies are not feasible; we do, however, use a 3 stage R&D process to incorporate a number of the phase-specific results obtained from industry sources.

- Revenue-sharing. Many analysts have addressed "capturable value" but our concern here is to pay somewhat greater attention to institutional financial mechanisms such as royalty rates, revenue shares and sample fees, and to show how these mitigate risks in the bioprospecting process. Our model should, therefore, be capable of conducting some simple trade-off analyses to demonstrate the effectiveness in risk mitigation of different mechanisms.

Model Specification, Assumptions and Information Sources

In summary, the estimating model for Montego Bay bioprospecting focuses on a model of average social net returns, using localized cost information for Jamaica, and benefit values and success rates based on proprietary information for marine products in the Caribbean. The institutional costs associated with rent capture are included for Montego Bay. The adopted model uses some of the concepts incorporated in the terrestrial bioprospecting valuation models and builds on these for the marine environment by explicitly introducing parameters relating to *rent distribution* and complexity, as reflected by *ecosystem yield*. Sensitivity analyses demonstrate that these two parameters are likely to have the most significant impact on captured values, and on planning problems. Rent distribution is introduced as a policy variable, ecosystem yield is a measure of species and sample yield potentially available from the Montego Bay reef. We derive likely estimate ranges for the latter based on typical species-area relationships postulated in the island biogeography literature (Simberloff and Abele 1976, Quammen 1996, Reaka-Kudla 1997). Finally, the results are once differentiated to derive a marginal benefit function, which relates value to coral reef abundance or area, and can be interpreted as our estimate of coral reef "price" that would be applied within a planning framework. Similar to other models of this genre, social values are inferred from the behavior of private agents, and the model excludes any explicit estimation of option values.

Model Structure

While many of the models in the literature isolate terminal values of the R&D change, the model here is regarded as a current ecosystem planning model and thus discounts all values to the present, using the "sample" as the initial basis of analysis. The expected net sample value ($ENVN_t$) of N_t samples collected in year t, including collection costs, is thus:

$$ENVN_t = p\ N_t\ (1+r)^{-t}\ EVD_{t+\tau}(1+r)^{-\tau} - C\ N_t\ (1+r)^{-t}$$

where,

p is the cumulative probability of developing a commercial drug from a given sample
$EVD_{t+\tau}$ is the expected future value of a commercial drug, net of R&D costs
τ is the length of the R&D period
C is individual sample costs
r is discount rate (10% real)

Essentially, we take a future value of a drug and translate it into present value terms, recognizing that the sample is collected as part of a broader sampling program of N samples over a sampling program {N}.

We now introduce an ecosystem yield and capability function that constrains the total sampling of N available samples in a given area to a sustainable annual level (N_{max}). The expected value (EV) of the sampling program of length T is then:

$$EV = \sum_{t=0}^{T} ENVN_t$$

subject to,

$N_t \leq N_{max}$ for all t
$T = N/N_{max}$
$N = sS$
$S = cA^z$

where,

S is the number of species in an area, defined by the species area relationship parameters c and z, and s is the average number of samples available for any given species.

In addition, we introduce the following cost and revenue sharing parameters to reflect captures of values:

α = contingent royalty on final drug sales, expressed as a net profit share
f = a per sample fee that involves a transfer to local authorities for sample collection (or for multiple sample rentals)
I = institutional costs attributable to collection.

The rent capture, or local value to Jamaica, in this case is:

$$EV_J = \alpha\, EV - I + \sum_{t=0}^{T} f\, N_t (1+r)^{-t}$$

We also define global and Jamaican planning prices (P_G and P_J respectively) as the change in value as a result of a change in reef area, such that:

$$P_G = \partial EV/\partial A$$
$$P_J = \partial EV_J/\partial A$$

We note here that, as institutional costs are regarded as fixed, the planning prices are independent of such costs.

Revenues and Costs

Revenue and R&D cost estimates for product development are chosen to be in line with most of the received literature for bioprospecting on terrestrial species. Based on the models surveyed in Chapter 3, the expected value of new drug development, excluding R&D costs is estimated to fall in the range of $173 to $354 million, with a mean of $233 million; this value is the NPV in 1998$ discounted to the time at which a sample is taken. R&D costs, excluding sample collection, are estimated to fall in the range of $116 to $201 million, with a mean of $170. In our study we use an R&D cost of $160 million and a sales value of $240 million; this ratio of 1.5:1 is consistent with many of the other estimates in the literature, with the exception of Mendelsohn and Balick (1995, 1997), who calculate a moderate loss in NPV using their model for an individual firm.

The costs for sample collection were based on proprietary cost estimates relating to tropical sampling programs. These estimates place “material only” costs in the range of $6 - $35 per sample for Florida, and “all in” local costs of $40 - $80 per sample for the Indian Ocean and South Pacific. Costs for the Caribbean are in the range of $50 - $100 per sample using scuba; the survey indicated that samples that had undergone some primary screening could attract a premium of $75 per sample. Costs using submersible techniques were considerably higher: approaching $350 per sample. We note, however, that in all of these cases, the surveys showed costs below those cited by Newman (1995) for National Cancer Institute (NCI) bioprospecting programs in the South Pacific. The NCI programs typically involved costs of $500 per sample, which included shipment to and cold storage in the United States. For the purposes of our study, we have chosen a mid-point of $75 per sample for the Caribbean collection costs.

Institutional Parameters – Costs and Revenue Sharing

Cost estimates for the institutional requirements are based on discussions with Government of Jamaica, following an assessment of local capacity in various ministries. Based on current salary scales, overheads and training requirements, it is estimated that the system of permit validation, and associated checks, will involve annual costs of approximately $23,000; this is equivalent to one-part time professional and associated administrative and travel overheads. At a 10% discount rate, this amount is equivalent to $230,000 NPV and would be adequate to cover most of the country's requirements in the marine bioprospecting area. Allocation of this amount to any given area is methodologically problematic but, as noted later, the amount is small relative to other values and would not have a significant impact on planning decisions.

Revenue sharing simulations essentially show three scenarios in addition to the implicit status quo in which no revenue is collected by Jamaica. As a reference case, we select a net profit share level α =10% as a *maximum* capturable under typical regimes negotiated in the industry; this is also consistent with levels typically assumed by other analysts (Pearce and Puroshothaman 1992ab, Aylward 1993).[19] Two sensitivity scenarios are solved for within the model. One involves the "equivalent fee only" level that would generate approximately the same level of captured rent as in the base case; this is somewhat over $250 per sample and could be collected either through licensing or through multiple rentals of samples. In that scenario, the country foregoes any contingent compensation in the form of royalties. A second sensitivity scenario involves a similarly "revenue neutral" mix in which the net profit share drops to 8% and the sample fee is set at $50 per sample.

Sampling and Hit Rates

The model requires estimates of N_{max} and p. Sampling rate is perhaps one of the most overlooked parameters in other modeling efforts, yet it plays an important role in establishing ecosystem value. A very slow sampling rate depresses present values, while a very high sampling rate may not be ecologically sustainable; some observers have criticized aggressive marine bioprospecting

Box 7.1.
Examples of multistage marine bioprospecting programs

Two firms were contracted to provide detailed sample results for a collection of samples, assessing the number of hits to a preliminary stage of product development.

Firm A

A total sample set of 13,779 samples were analyzed for ten targets; not all samples were subjected to each target. At the primary screen, 5137 were isolated and passed on to subsequent screening and analysis. Through the next stages, 6-7 drug leads were eventually identified and were at various stages of preclinical trials and licensing prior to clinical trials. This implies a cumulative hit rate to the preclinical trial stage of 1:2120. We use Artuso's (1997) estimates for subsequent success rates for typical testing programs (0.4 for preclinical; cumulative 0.25 for 3 clinical stages; 0.9 for new drug approval) to arrive at a cumulative probability of 1:23,600 from that set of samples.

Firm B

A total sample set of 5400 samples was analyzed against multiple targets. Through two stages of screening, and further analyses, 4 leads were isolated and dereplicated. This implies a cumulative hit rate to the synthesis/modification stage of 1:1350. Using Artuso's estimates of success beyond this stage (same as above, and 0.5 for successful synthesis/modification), a cumulative probability of 1:30,075 is estimated for that set of samples.

for endangering some species. To ensure that a reasonable level of sampling occurs, a hypothetical program for Montego Bay was laid out using typical methodologies used by the NCI (Colin 1998). NCI observes that a team of up to 4 divers would generate at most 15 samples a day; this is regarded as a sustainable effort for Montego Bay (which has a relatively limited area of about 43 hectares) and is also consistent with logistical constraints of servicing a collection program. Assuming full time regular employment of the team over a ten-month period (avoiding the hurricane season), the model assumes a maximum annual sampling rate of 3300 samples. In sensitivity analyses we subsequently relax this constraint to illustrate the impact of an accelerated sampling program in which all samples are collected in a single year.

Various firms were contracted to provide information relating to marine bioprospecting success rates. Although the detailed information is proprietary, summary statistics adequate for modeling are presented here. The firms' programs generally implied success rates to final product development in the range of 1:25,000 to 1:50,000; these success rates incorporated screening against multiple targets (up to ten). Two specific examples serve to illustrate (Box 7.1). In the base case, we use a cumulative success rate of 1:30,000. This is higher than most terrestrial estimates (which are typically of the order of 1:100,000) and also higher than reported programs for shallow water marine invertebrates from the Pacific Ocean analyzed by

[19] The model expresses α as a net profit share of (maximum) 10%. Given the assumptions of a revenue:cost ratio of 1.5:1, this net profit share is equivalent to a gross royalty on final sales of approximately 3.3%. By comparison, Aylward (1993) cites 3% as a typical industry maximum gross royalty on untested samples.

Table 7.3 **Selected live coral estimates for Montego Bay**		
Source	Coral Abundance	Basis
Discovery Bay Marine Laboratory	30%-74%	Baseline estimate 1982 of 9 transects
Hughes 1994	5% – 12%	Shallow water surveys, 2 sites.
Sullivan and Chiappone 1994	15%-25%	Rapid ecological assessment
Hitchman 1997	<13%	14 samples sites in high impact area of Montego Bay and Bogue Lagoon
Hong Kong University of Science and Technology, ReefCheck 1997	22% [1997] <22% [preliminary 1998]	All of Caribbean, the 1997 Reef Check survey noted that low levels were "possibly reflecting losses due to bleaching and disease"
Gustavson 1998, Pers. comm.	25% of substrate	personal estimate
Jameson 1998, Pers. comm.	15% of substrate	personal estimate
Williams 1998, Pers. comm.	25%-50%+ of substrate	Reports from local fishers, divers and resource users; many good sites "at depth"
Ruitenbeek *et al*. 1999 World Bank Research Committee Least Cost Model	24%-38% of substrate	Model equilibrium predictions for low stress and high stress conditions, excludes fishery sector reforms
Ruitenbeek *et al*. 1999 World Bank Research Committee Least Cost Model	29%-43% of substrate	Model equilibrium predictions for low stress and high stress conditions, includes fishery sector reforms

the NCI (Newman 1995); these were estimated to generate commercial products at a rate of 1:80,000 at best. We use this poorer hit rate as a sensitivity case in our analyses.

Role of Coral Abundance

The amount of intact and live coral reef available in Montego Bay is the subject of some controversy, and the causes and extent of degradation remain the topic of open debate.[20] Literature has placed coral abundance as high as 74% and as low as 5% (Table 7.3). No systematic comprehensive surveys have been undertaken over the entire zone, and the nature of the estimates often differ methodologically. Moreover, there is significant local concern that overstating the amount of degradation may inadvertently deter tourists, even though most divers and tourists feel that the reef quality is quite good. For our purposes, we primarily rely on two results.

First, total coral area was analyzed based on GIS interpretation of polygons in the Coastal Atlas of Jamaica. This shows a total area of coral substrate of approximately 42.65 hectares. Second, long-term coral cover was based on fuzzy logic model calculations of the ecosystem, under various stress assumptions (Annex A). At current levels of fishing pressure, the equilibrium abundance level was predicted to be 39.8%; with expected reforms to the fishery, it is expected that damage will decrease and abundance would go up to 42.7%. We note that under sustained economic growth as forecast by local authorities, the model predicted that coral quality would decline to the region of 20% - 25% abundance. For the purposes of simulation, therefore, we take a 43% abundance level as a status quo scenario and a 25% abundance level as a degradation scenario. In terms of reef areas, these levels correspond to 18.34 hectares and 10.66 hectares respectively.

Ecosystem Yield and the Species-Area Relationship

Following Reaka-Kudla (1997), we take a standard species-area relationship for marine organisms of the form $S=cA^z$. In the reference case we take z=0.265, but a plausible range for this parameter is z=0.2 to z=0.3. Consistent with other findings, we assume each species yields on average three testable samples, each of which may in turn be assayed for multiple targets. The resultant number of “described species”, “expected species” and “expected samples” are shown in Table 7.3. The actual value for z for marine systems has continued to be the subject of lively debate, ever since Simberloff and Abele (1976) observed for a coral reef site that two small areas could harbor more different species than one of the same size. This would imply that a certain amount of fragmentation – or even die-back – was not necessarily bad, and that such isolation may in fact lead to increased speciation. The sensitivity of sample yield to this parameter is, however, of critical importance in deriving value estimates. Table 7.4 shows, for example, a variation from 10,600 to 47,400 expected species in the reference case.

Valuation Results and Discussion

Using typical cost estimates for Jamaica, and using typical hit rates and end-use values, scenario analyses were conducted using the parametric model. The reference case places marine bioprospecting values at just under $2600 per sample, or $7775 per species. The per species values are somewhat higher than typical estimates for terrestrial species; primarily because of the higher demonstrated success rates in terms of product development.

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[20] The coral reef ecosystem modeling work conducted by Mark Ridgley and Steve Dollar, and reported in Ruitenbeek *et al*. (1999), provides a comprehensive review of the degradation issues at Montego Bay.

Table 7.4.

Estimated coral reef species and samples based on species-area relationship*

	Reef Area (ha)	Described Species	Expected Species	Expected Samples	Survey Length (yrs)
z=0.200					
100% Cover	42.65	5,501	56,076	168,227	51.0
43% Cover (Reference Case)	18.34	4,647	47,366	142,099	43.1
25% Cover (Degradation Case)	10.66	4,169	42,497	127,492	38.6
5% Cover (Collapse Case)	2.13	3,022	30,801	92,404	28.0
z=0.265					
100% Cover	42.65	2,195	22,370	67,110	20.3
43% Cover (Reference Case)	18.34	1,755	17,887	53,660	16.3
25% Cover (Degradation Case)	10.66	1,520	15,492	46,477	14.1
5% Cover (Collapse Case)	2.13	992	10,113	30,340	9.2
z=0.300					
100% Cover	42.65	1,338	13,638	40,915	12.4
43% Cover (Reference Case)	18.34	1,039	10,588	31,763	9.6
25% Cover (Degradation Case)	10.66	883	8,998	26,994	8.2
5% Cover (Collapse Case)	2.13	545	5,552	16,656	5.0

*The benchmark global value from which these are derived is taken from Reaka-Kudla (1997) as 93,000 total described coral reef species from an area of 588,960 km^2. This implies by solution c=2,750 in the reference case where z=0.265. A ratio of 10.2 expected species for every currently described species is also based on Reaka-Kudla (1997, pp. 93f), who suggests this as a most likely ratio based on assessments of rainforest and coral reef species-area dynamics. Survey length is based on a maximum annual sampling of 3300 samples.

Using base case estimates of ecosystem yields for the Montego Bay area, coupled with the hypothetical sampling program that would be consistent with NCI standards for marine sampling, a base case value of $70 million is ascribed to the Montego Bay reefs; approximately $7 million would be realistically capturable by Jamaica under typical royalty regimes or sample rental arrangements. None of this value is captured under existing institutional arrangements.

The base case value of $70 million corresponds to equilibrium coral abundance levels of 43% on available substrate; ecosystem model predictions set this as a long-term equilibrium in the event of no additional stresses on the reef. Where current economic growth places new stresses on the reef, a predicted “degradation” to approximately 25% is set as a comparative case. Under this latter case, the global value of the reef would be $66 million: a loss of about $4 million.

The first differential of the benefit function is calculated to arrive at an ecosystem marginal “global planning price” of $530,000/ha or $225,000/% coral abundance. For Jamaica’s share, the relevant “local planning price” computes to approximately $22,500/% coral abundance. The model demonstrates the sensitivity of total and marginal values to ecosystem yield and institutional arrangements for capturing genetic prospecting value. For example, sensitivity analyses within the plausible range of species-area relationships generated global benefits for the Montego Bay reef of $54 to $85 million; reef prices ranged from $698,000/ha to $72,500/ha.

The relatively low “price”, and the apparently small drop in benefits from significant coral reef degradation, underlines the importance of the ecosystem yield. In effect, two factors contribute to this result. First, because of the non-linear relationship between species and area, a decrease in coral abundance does not translate one to one into a decrease in species or available samples. Second, the loss in available samples is not experienced immediately; annual sampling constraints under a sustainable program under NCI standards at Montego Bay would yield approximately 3300 samples annually. The economic effect of these “lost samples” is therefore discounted substantially, and would consequently have less of an impact on current management decisions.

Detailed sensitivity results are shown in Table 7.5. The analysis confirms that the impacts of the incremental institutional costs – for operating a national program consistent with the recommendations by Putterman (1998) – are minimal. It would appear therefore, that such institutional investments are warranted.

The first significant conclusion is that ecosystem values, in terms of prices that would enter a planning function for land allocation and investment decisions, are more sensitive to assumptions regarding ecosystem yield than they are to most economic parameters considered. At low values of z, implying relatively little response of species to changes in area, marginal values drop to as low as $3,000/% of coral abundance. This can also be demonstrated through the first differential of the value function (Figure 7.1). The marginal benefit curve is very steep at low levels of coral abundance, implying high values when the resource is about to “collapse”, but at the levels relevant for planning (generally taken to be between 20% and 50% coral abundance, planning prices are relatively low.

Second, the results demonstrate a number of important potential risk mitigation strategies. In the base case of a 10% net profit share, the expected value of the sampling generates a marginal benefit to Jamaica of $22,600/%. Conversion of this share to a $250 sample collection fee, or to rentals equivalent to this fee, would generate a similar price: $21,800/%

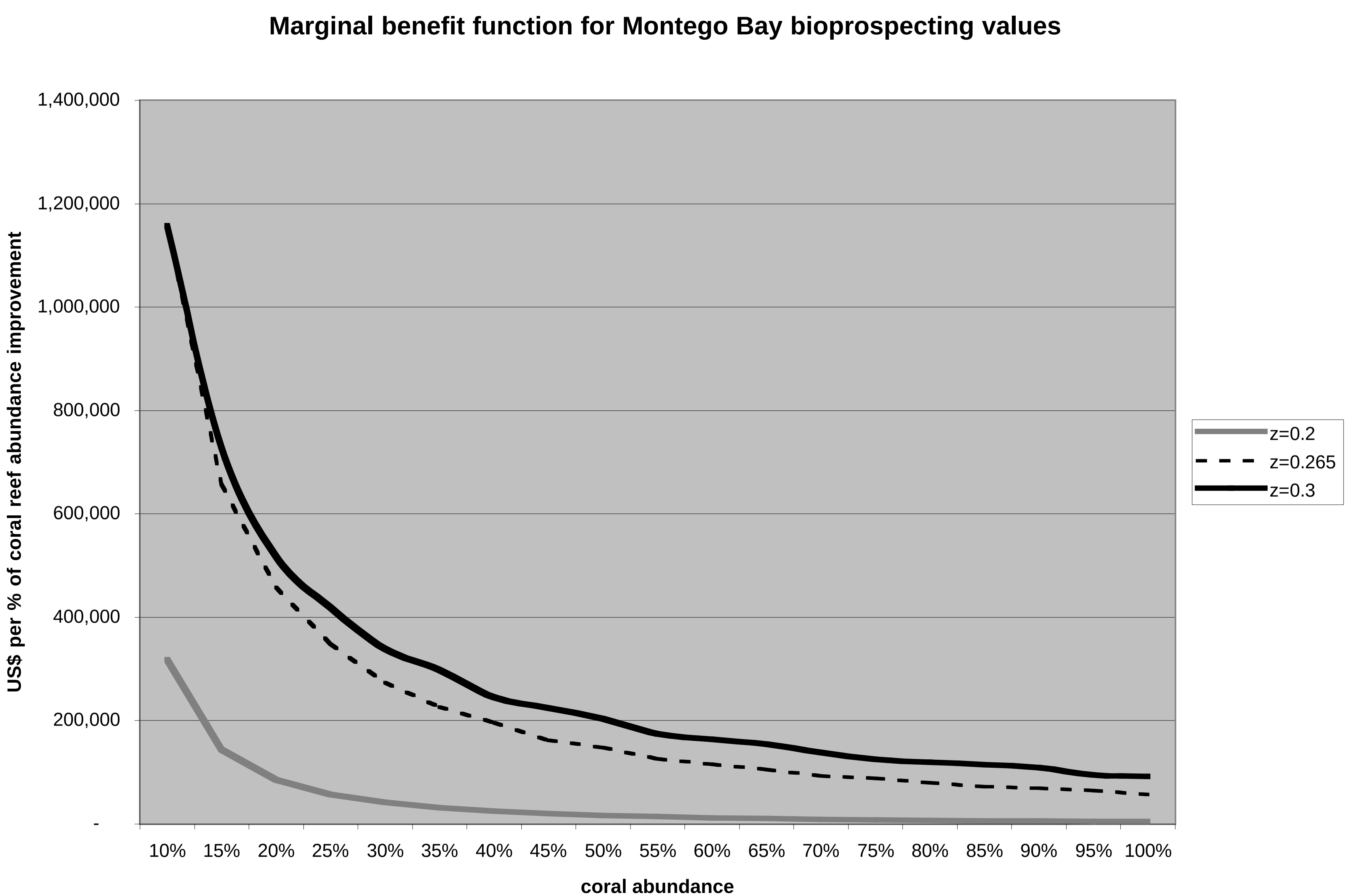
Table 7.5. Model results for marine pharmaceutical bioprospecting valuation – Montego Bay. Parametric assumptions relate to z-factor within species(S)-area(A) relationship $S=cA^z$, a contingent net profit share (α) and a fixed sampling feel level f ($/sample). Model solves for total samples (N) available at Montego Bay and the typical length (T) of sampling program that would be required to harvest these. Economic calculations relate to the expected net present value of the program to the world (NPV_G) and to Jamaica (NPV_J). A first differential of the function yields a global "price" (P_G) and Jamaican "price"(P_J) for coral reefs that could be applied within a planning framework equating marginal benefits to marginal costs.

Case	z	α	f ($)	N	T (yr)	PV_G (MM$)	PV_J (MM$)	P_G ($/%)	P_J ($/%)
Base Case Scenario at 43% Coral Abundance									
Reference*	0.265	10%	0	53,660	16.3	$70.09	$7.01	225,614	22,561
High z	0.3	10%	0	31,763	9.6	$54.46	$5.45	297,516	29,752
Low z	0.2	10%	0	142,099	43.1	$84.61	$8.46	30,901	3,090
Fee Only	0.265	0%	250	53,660	16.3	$70.09	$6.76	225,614	21,763
High z	0.3	0%	250	31,763	9.6	$54.46	$5.25	297,516	28,699
Low z	0.2	0%	250	142,099	43.1	$84.61	$8.16	30,901	2,981
Blended Revenue Shares	0.265	8%	50	53,660	16.3	$70.09	$6.96	225,614	22,402
High z	0.3	8%	50	31,763	9.6	$54.46	$5.41	297,516	29,541
Low z	0.2	8%	50	142,099	43.1	$84.61	$8.40	30,901	3,068
High R&D Cost	0.265	10%	0	53,660	16.3	$17.64	$1.76	56,783	5,678
[R/C Ratio=1.1:1]	0.265	0%	250	53,660	16.3	$17.64	$6.76	56,783	21,763
	0.265	8%	50	53,660	16.3	$17.64	$2.76	56,783	8,895
Low Hit Rate	0.265	10%	0	53,660	16.3	$25.02	$2.50	80,525	8,052
[1:80,000]	0.265	0%	250	53,660	16.3	$25.02	$6.76	80,525	21,763
	0.265	8%	50	53,660	16.3	$25.02	$3.35	80,525	10,795
Unconstrained**	0.265	10%	0	53,660	1.0	$139.07	$13.91	1,054,202	105,420
High z	0.3	10%	0	31,763	1.0	$82.32	$8.23	699,475	69,948
Low z	0.2	10%	0	142,099	1.0	$368.27	$36.83	2,145,937	214,594
Institutional***	0.265	10%	0	53,660	16.3	$70.09	$6.96	225,614	22,561
Degradation Scenario at 25% Coral Abundance									
Reference z	0.265	10%	0	46,477	14.1	$66.12	$6.61		
High z	0.3	10%	0	26,994	8.2	$49.37	$4.94		
Low z	0.2	10%	0	127,492	38.6	$84.06	$8.41		

*Uses study result hit rates of 1:30,000 and Sales:R&D Cost Ratio of 1.5:1. Prices P_G and P_J may be converted to $/ha basis by dividing by 0.4265.
** Assumes all samples are collected and subjected to preliminary screening immediately (in 1 year).
*** Includes institutional overheads of central government agencies.

coral cover. This price is maintained, of course, even if hit rates are lower or R&D costs go up as the value is linked only to the sampling program. It is likely that, in general, an appropriate risk mitigation strategy for Jamaica would likely involve some combination of royalty or profit share payment (α >0) and modest sample fee. Such a strategy would guaranty captured values of the same order as those expected in the reference case, but would reduce exposure to hit rate uncertainties, product marketing uncertainties, and ecosystem dynamics.

Figure 7.1



Marginal benefit function for Montego Bay bioprospecting values
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
-
US$ per % of coral reef abundance improvement
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%
coral abundance
z=0.2
z=0.265
z=0.3

In addition, we note that even with this sampling program there is, of course, no guaranty of a hit. One can, in fact, calculate the expected number of samples that must be collected to generate at least one hit. When the hit rate is 1:30,000, this works out to 21,000 samples and when it is 1:80,000 the expected number of samples is 55,000. This higher number is almost identical to the base case expectation that the system will yield 53,660 samples. In the mineral prospecting literature, the situation of not achieving a “hit” is referred to as “gambler’s ruin” and – while venture capital markets act to take on such risks, governments are often reluctant to enter into such arrangements. In this case, therefore, a public body would likely prefer some guarantied income, even if it means giving up some future royalty position.

Third, it is instructive to consider how values shift under an accelerated unconstrained sampling program. As noted by Evenson and Lemarié (1998), geographical considerations in optimal global search programs may imply intensifying searches in those areas with lower costs and higher potential yields. While we have not compared the Montego Bay site to other sites, the economic implication of such an intensified search is that samples should normally be gathered and screened as rapidly as possible in the preferred sites. Simulation results for Montego Bay show that relaxing the sampling constraint causes the base case expected value to double, from $70 million to $139 million. This comes as a consequence of accelerating expected discoveries, and thus diminishing the effects of discounting. The effects on planning prices are, however, more profound: in the base case these increase from $225,000 per % coral abundance to just over $1 million per % coral abundance. In the case where z=0.2, planning prices could exceed $2 million per % coral abundance, equivalent to some $5 million per hectare.

But logistically this latter result would require extraction of some 142,000 samples from the site over a ten month period; this would in turn require having almost 200 divers in the water daily, with their itinerant support structures for sample storage and analysis. In the case of Montego Bay, such activity levels far exceed the capacity of the support infrastructure, saying nothing about the potential impacts that such activities might have on the reef itself. Such collection realities are, in many cases, likely to constrain optimal search programs even at the most promising sites. But the results of the sensitivity analysis show us that concerns such as yield – and how a single site fits into a larger global picture – are important aspects of valuing coral reef biodiversity.

Chapter 8

Synthesis

Introduction

To consolidate the findings of the research, this brief final chapter provides a synthesis of the various benefit valuations done under this research program. 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 (Annex A) 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 reef (Table 8.1). 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 ($70 million) but changes in reef quality within the planning range (of 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 demonstration purposes. 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 underestimating in others. For

Table 8.1
Summary of valuation results – Montego Bay coral reef

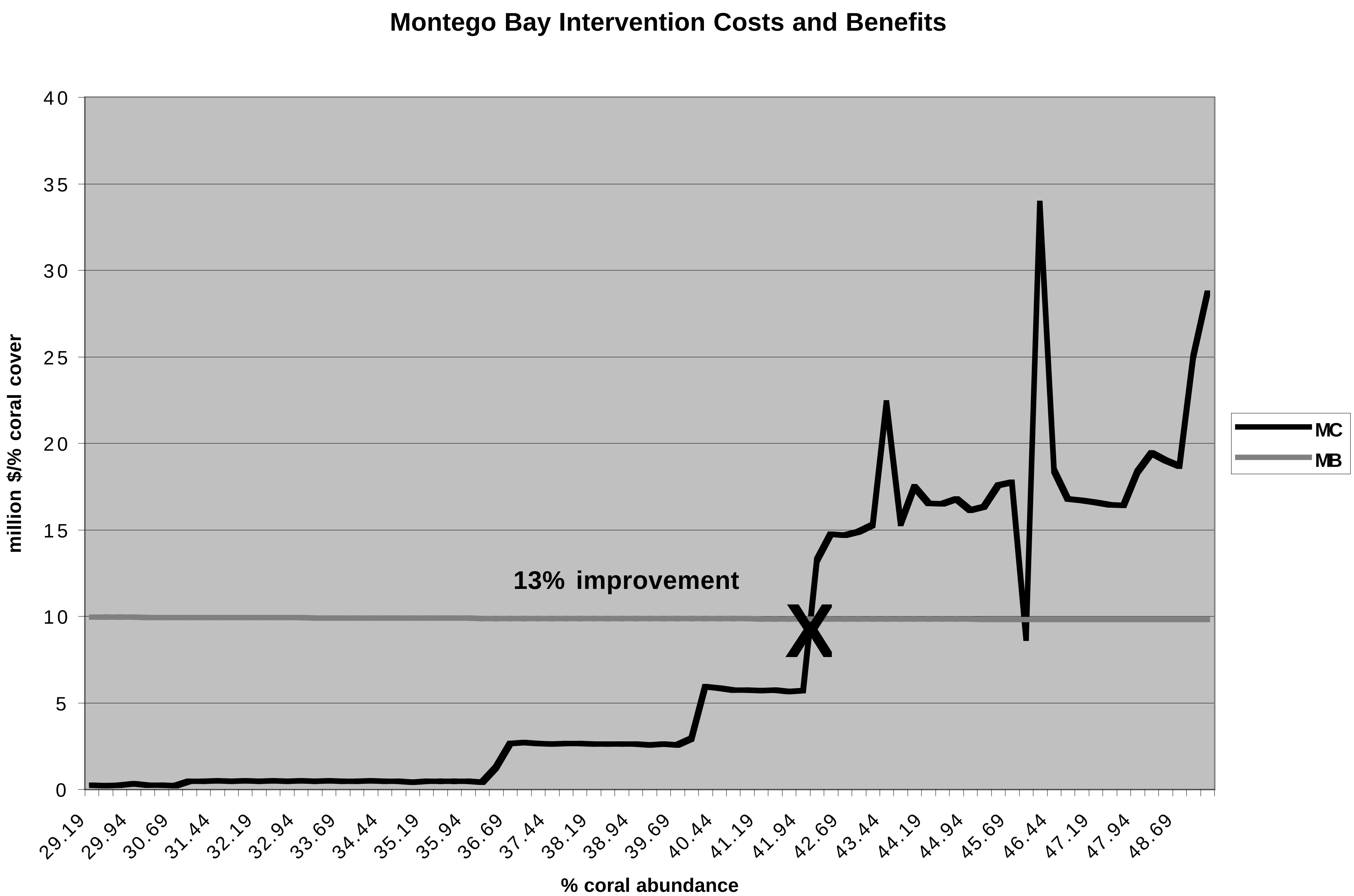
	Benefit	Price*	
	NPV (MM$)	MM$/%	MM$/ha
Tourism/Recreation	315.00	7.33	17.18
Artisanal Fishery	1.31	0.03	0.07
Coastal Protection	65.00	1.51	3.54
Local Non-use	6.00	0.24	0.56
Visitor Non-use	13.60	0.54	1.28
Subtotal	400.91	9.65	22.63
Pharmaceutical Bioprospecting (Global)	70.09	0.23	0.53
Total (Global)	471.00	9.88	23.16
Pharmaceutical Bioprospecting (Jamaica)	7.01	0.02	0.05
Total (Jamaica)	407.92	9.67	22.68

* Marginal benefits shown at typical current reef conditions.

erosion, for example, a degraded reef will still provide some limited erosion benefit for some time; an average price assuming a linear relationship will thus overstate the marginal benefit. For tourism, however, small changes in quality may have disproportionately larger impacts on arrivals if there is a perception that the reef is 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 there). In the case of the non-use values, the CVM survey explicitly included a degradation scenario, hence the end-points were well established (they represented 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 reef in its current condition is approximately $470 million, and that every 1% change in abundance is likely to generate a marginal benefit of approximate $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.

Figure 8.1



Montego Bay Intervention Costs and Benefits
million $/% coral cover
40
35
30
25
20
15
10
5
0
13% improvement
X
MC
MB
29.19
29.94
30.69
31.44
32.19
32.94
33.69
34.44
35.19
35.94
36.69
37.44
38.19
38.94
39.69
40.44
41.19
41.94
42.69
43.44
44.19
44.94
45.69
46.44
47.19
47.94
48.69
% coral abundance

Synthesizing Benefits and Costs for a Global Optimum

We juxtapose these marginal benefit calculations against a marginal cost function for the Montego Bay reef, as generated by a fuzzy logic based ecological-economic model (Annex A). This related research on cost effectiveness modeling of interventions suggested that up to a 20% increase in coral abundance may be achievable 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 $1 million per % of coral abundance to $29 million per % 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 in the areas of: 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 8.1.

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 (achieving a 20% coral reef improvement), would require additional benefits of some $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 ($70 million per 43% coral = $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 socioeconomic concerns. Valuation results consistently show 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 would 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 both to costs and benefits when dealing with complex non-linear systems such as coral reefs.
- greater emphasis at the local level on socioeconomic 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.

Annex A – Cost-Effectiveness Modeling Summaries

Extracted from: Ruitenbeek HJ, Ridgley M, Dollar S, Huber R (1998) Optimization of economic policies and investment projects using a fuzzy logic based cost-effectiveness model of coral reef quality: empirical results for Montego Bay, Jamaica. Coral Reefs [submitted 12/98].

Summary

For effective mitigation of human impacts, quantitative models are required that facilitate a comprehensive analysis of the effects of human activity on reefs. Fuzzy logic procedures utilized within this research project generate a complex dose-response surface that models the relationships among coral abundance and various inputs (e.g., physical damage, sedimentation, nutrient influx), within the context of the abiotic marine environment. This is linked to a nonlinear economic structure incorporating technical interventions (e.g., pollution treatment) and policy interventions (e.g., taxation) in eight economic sectors. Optimization provides insights into the most cost-effective means for protecting coral reefs under different reef quality targets.

The research demonstrates that: (i) it is feasible to use fuzzy logic to model complex interactions in coral reef ecosystems; and, (ii) conventional economic procedures for modeling cost-effectiveness can result in sub-optimal policy choices when applied to complex systems such as coral reefs. In Montego Bay, Jamaica, up to a 20% increase in coral abundance may be achievable through using appropriate policy measures having a present value cost of US$153 million over 25 years.

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 (1995). 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. 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 municipal requirements.

The model incorporates eight active intervention types for Montego Bay. The interventions, and their approximate costs, are (all figures in US$):

<u>Sediment Trap</u>. 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 prevents most of the sediments from entering Montego Bay; it also removes 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 $6 million, with annual operational costs of about $330,000. Smaller traps, at lower cost and efficiency, could be installed at various upstream locations.

<u>Planting of Trees in Upper Watershed</u>. This scenario reflects reforestation of the most degraded watershed areas around Montego Bay. This involves planting about 150,000 acres of trees, at a one time capital cost of almost $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.

<u>Aeration of Waste</u>. 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 $1 million, requiring also an additional $1 million annually for operation.

<u>Large Scale Centralized Treatment Facility</u>. 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 $50 million and annual operational costs of about $5 million. Smaller scaled down versions of this could also be constructed.

<u>Agricultural Extension</u>. 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 agroprocessing sectors. The intervention covers up to 10% of such enterprises in the area, and will cost $1.2 million to implement with an annual cost of about $120,000.

<u>Outfall and Pump</u>. This is a stand-alone intervention that would involve a sewage outfall and pump station to take the sediment beyond the reef edge (approximately 5 kilometers). The unit would cost about $1.8 million, along with $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.

<u>Household Solid Waste Collection</u>. 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 ($72,000) the operating costs are relatively high ($36,000 annually).

The effect this has on pollution loads will be to reduce sediment and nutrient loads from the household sector.

Hotel Tax. This intervention simulates the impact of a 25% land tax on the existing hotel/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 $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 A1. Under static conditions of no growth and no mitigative interventions, with all stresses essentially remaining at current levels, it can be expected that a long term equilibrium level of 43% coral abundance on available substrate would be expected. Table A1 also shows 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 A2. 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 totally 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 of what would otherwise happen, and it would result in a present value cost in excess of US$150 million.

The results in Table A2 show the impact of single interventions relative to a “do nothing” scenario. Because of the nonlinearity 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 A3. For 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 nonlinearity 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 nonlinearity of the coral quality response surfaces to individual interventions is shown in Table A2. 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 $ per % 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 A3. In a conventional separable model with monotonically increasing marginal costs (such as that in Figure 2.1 in the main text), 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 (MC) curve inherent in Table A3; while generally it is increasing there are some localized decreases. 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.

The fallacy of the conventional ranking procedures is also shown by inspection of the average costs of individual interventions (Table A2). 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, say, 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.

Table A1. Changes in Montego Bay 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	Δ Coral
Base Case Conditions - No Economic Growth	42.73%	
Doubling of:		
Pollution Loads (N, P & 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 & Sediment)	56.38%	+ 13.65%
Physical Damage	51.33%	+ 8.66%
Fishing Pressure	44.00%	+ 1.27%
All Inputs	76.18%	+ 33.45%

Table A2. Changes in Montego Bay coral reef quality arising from single interventions. Coral abundance levels show "25 year equilibrium," and resultant total cost (TC in millions $) and average costs (AC in millions of $ per additional % of coral abundance).

Intervention	Coral	Δ Coral	TC	AC
0. Base Case Conditions - High Economic Growth	28.94%	0.00%		
k1. Sediment Trap	32.13%	3.20%	9.30	2.91
k2. Planting of Trees in Upper Watershed	30.57%	1.63%	27.90	17.12
k3. Aeration of Waste	30.57%	1.63%	11.84	7.25
k4. Large Scale Centralized Treatment Facility	34.18%	5.24%	98.40	18.78
k5. Agricultural Extension	29.00%	0.07%	2.40	36.81
k6. Outfall and Pump	34.33%	5.39%	2.52	0.47
k7. Household Solid Waste Collection	30.73%	1.80%	0.43	0.24
k8. Hotel Tax	28.97%	0.03%	0.60	17.30
k1-8. All of the Above	49.17%	20.23%	153.40	7.58

Table A3. Optimization results for Montego Bay, showing levels of individual interventions required to achieve target coral reef quality, and resultant total cost (TC in millions $) and marginal costs (MC in millions of $ per additional % of coral abundance). Interventions are as follows: k1 = Sediment Trap; k2 = Planting of Trees in Upper Watershed; k3 = Aeration of Waste; k4 = Large Scale Centralized Treatment Facility; k5 = Agricultural Extension; k6 = Outfall and Pump; k7 = Household Solid Waste Collection; k8 = Hotel Tax.

ΔCoral (%)	k1	k2	k3	k4	k5	k6	k7	k8	TC	MC
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
10.00	0.73	0	0	0	0	1	1	0	9.75	2.60

… continued

Table A3 (continued)

ΔCoral (%)	k1	k2	k3	k4	k5	k6	k7	k8	TC	MC
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

Annex B – Three Jamaican Genetic Prospecting Case Studies

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Extracted from: Putterman DM (1998) Access to marine genetic resources in Jamaica: incorporating genetic resources utilization into integrated coastal zone management. A Study of Policies and Institutions. Study prepared for the World Bank. World Bank, Washington.

To illustrate genetic resources issues that Jamaica currently grapples with, three case studies involving actual use are presented here; specific information was compiled during field visits in 1998. In addition, each of these issues is examined in light of the policy recommendations made in the main report; alternate outcomes based upon application of the recommendations are explored. The "Policy Reform Scenarios" assume that all suggested regulations have been adopted, including the recommendations on community genetic resources tenure.

Marine Bioprospecting in Jamaican Coastal Waters

Current Situation

Interviews with research personnel at the University of the West Indies and at other institutions revealed that at least a half-dozen formal foreign research expeditions had collected marine genetic resources in Jamaican coastal waters over the past three decades. In addition, there was a general feeling that a number of unauthorized expeditions had collected in Jamaican waters, while numerous terrestrial expeditions had come through the island as well. In one case, a large oceanographic research institute based in the United States had sent a deep-sea submersible to collect sponges in 1993. The project, which was approved by the Jamaican government, listed one of its objectives as the development of new commercial products with pharmaceutical, agrochemical, or other industrial applications.

Although the government of Jamaica had issued a collecting permit for this project, ironically there was no mechanism to capture a portion of the value of these marine genetic resources for the source country, other than the obligation to leave taxonomic voucher specimens at UWI. Future expeditions to Jamaica may encounter difficulty obtaining a research permit from the NRCA, given the general anxiety over this inability to share in the benefits of this research, and the mistrust that it engenders.

Policy Reform Scenario

Under the proposed genetic resources regulations outlined in this study, foreign scientific organizations, whether private companies or non-profit oceanographic research institutes, would be required to contact the NRCA (or the Ministry of Commerce and Technology, depending on which body is given regulatory power) to discuss conditions for obtaining a combined collection and export permit. The NRCA would inform the applicant about the current regulations, including the requirement to obtain Prior Informed Consent from the appropriate stakeholder. The NRCA would also recommend counterpart organizations in Jamaica for assistance with obtaining a permit, and supply a list of suggestions, with UWI among the most likely candidates.

Assume that collection was planned in a protected area, for example Montego Bay Marine Park, and UWI was functioning as the local counterpart organization. To begin the process, UWI would contact the Montego Bay Marine Park Trust to obtain their Prior Informed Consent. Depending on the local regulations, the Marine Park Trust would either give its informed consent directly following discussions on benefit-sharing, or it would first hold meetings with local stakeholders to discuss their preferences directly (if collection were planned elsewhere within Jamaica’s Exclusive Economic Zone, UWI would contact the NRCA directly to obtain informed consent, because this submerged land is administered by this agency).

UWI would negotiate a research contract with the foreign research organization, consulting with the Marine Park in the process to incorporate preferred benefit-sharing provisions necessary to obtain their Prior Informed Consent. All parties could consult with appropriate members of the NRCA’s Genetic Resources Advisory Authority for advice on policy requirements at any time.

Benefits requested by the Marine Park Trust might include employment for local fishers as field hands, copies of all taxonomic voucher specimens, sourcing rights, and monetary benefits such as a share of rental fees (if any) and contingent benefits including royalties. The proportion of monetary income set aside for benefit sharing would be decided upon by the NRCA’s Genetic Resources Advisory Authority, while the portion of this set-aside due the

Marine Park Trust would be set by law. The Marine Park Trust in turn could use this income to fund park operations, to establish a community microenterprise fund, and so on.

When a draft contract has been agreed upon, it would be submitted to the Genetic Resources Advisory Authority along with proof of Prior Informed Consent and a completed permit application for review. Approval would require signatures by all parties to the negotiation, making the research contract a legally-binding agreement, and would be accompanied by a Certificate of Prior Informed Consent issued to UWI. Rejection would be accompanied by a detailed explanation and the opportunity to renegotiate the draft research contract.

International Private Sector Collaborations in Anticancer Research

Current Situation

A local company based in Montego Bay, known as Carib Bio-Medical Ltd., has been studying sea urchins, collected in Montego Bay since 1987, to develop a new treatment for cancer. The putative cancer treatment utilizes an extract of rapidly-dividing pre-embryonic cells derived from recently fertilized egg cells. Interviews with local conservationists revealed a perception that the work was about to yield a highly lucrative breakthrough in cancer research, although there had never been direct contact between the Managing Director of the company and the Montego Bay Marine Park. An application to the NRCA to collect large quantities of sea urchins to export processed samples for biochemical research in the United States, as well as preclinical and human trials in the Caribbean, first brought this research to the attention of the Jamaican government.

An interview with the Managing Director of Carib Bio-Medical Ltd. revealed that initial research efforts focused on terrestrial frogs, followed by sea urchins. The company had devoted much effort between 1987 and 1991 to collecting sea urchins from the bay, employing local fishers, extracting their gametes (sperm and egg cells), and returning the live sea urchins to the water. However, the company now claims that the extract, whose active ingredient contains the complex biomolecule known as ribonucleic acid (RNA), can be derived from the fertilized pre-embryonic cells of any animal species on earth.

At this point, with the results of approximately 100 human clinical trials in hand, the company has amassed a large amount of data associated with use of its advanced research material. The company *may* in the future decide to transfer the rights to its invention to a large pharmaceutical company, for evaluation and possibly additional human trials leading to regulatory approval. With little understanding of the project in Jamaica, and no mechanism to capture the benefits of this research for the nation as a whole, the project has generated a large amount of speculation.

Policy Reform Scenario

What would have happened had the suggested genetic resources regulations been in place before Carib Bio-Medical Ltd. had contacted the NRCA to obtain a permit for sea urchin collection? Under the proposed genetic resources regulations, the company would have been required to incorporate certain benefit-sharing provisions in any research contract it negotiated with foreign research partners. The permit application process would have required Carib Bio-Medical Ltd. to obtain Prior Informed Consent from the relevant stakeholder, in this case the Montego Bay Marine Park. As discussed above, the Marine Park could have either negotiated directly with the company, or consulted first with local stakeholders.

Given that Carib Bio-Medical Ltd. intended to fund its own advanced research and development, and as such there was no expectation of immediate revenue from this project, it would not have been appropriate to ask for up-front compensation in exchange for access to the sea urchins. However, a request to employ local fishers as sea urchin collectors probably would have been reasonable. Contingent compensation *would* have been appropriate in this circumstance, including royalties and sourcing rights. Thus, Carib Bio-Medical Ltd. should have signed a research contract with the Montego Bay Marine Park Trust incorporating these obligations.

There is an added complication in this case. After further research, Carib Bio-Medical Ltd. discovered that its putative cancer treatment can be purified not just from particular Jamaican genetic resources, but rather from virtually any animal species on Earth. *Given that the active principle is claimed to exist in all fertilized gametes, being a property intrinsic to all fauna on earth, it may be problematic to claim that this treatment falls under the genetic resources regulatory framework of Jamaica*. Consequently, it may prove difficult for Carib Bio-Medical Ltd. to convince large pharmaceutical investors to accept a clause in their research contract requiring that raw material be sourced from Jamaica. The difficulty would stem from the peculiar characteristic of the cancer treatment which is that it is a chemical component of all living organisms, rather than a genetic resource which is the property of Jamaica *per se*.

As final comment on this case study, it is noted that, according to Carib Bio-Medical Ltd., the cancer treatment can cure all forms of cancer other than soft-tissue sarcomas, with no side effects whatsoever. Further, the active principle concentrates within cancerous cells spontaneously, and as such could be used as a diagnostic tool for many forms of cancer. The active principle also involves the complex biomolecule known as ribonucleic acid (RNA), which is an extremely unstable molecule. Taken together, although Carib Bio-Medical Ltd. has stated that their cancer treatment has been tested on some 100 patients, the claims made for this treatment border on the incredible. Jamaican stakeholders should retain this perspective when contemplating the likelihood that this treatment will yield positive results following independent testing.

Biotechnology-Based Improvement of Jamaican Papaya Germplasm

Current Situation

The Jamaican papaya industry has developed into an important source of foreign exchange, with 1995 export sales of approximately $20 million. A local variety known as Sunrise Solo had been bred in the early 1980’s by Jamaican growers, adapted from papayas developed in Barbados and Hawaii. However, by the mid-1990s, problems with the Papaya Ringspot Virus, which causes stunting and production of poor quality spotted fruit, had reduced yields by 30-40%. During this time a non-profit industry association, the Jamaica Agricultural Development Foundation (JADF), contacted a Jamaican researcher studying at Cornell University for assistance with developing a strategy to combat the disease. After consultations with Cornell faculty and preliminary tests, a project to develop a virus-resistant transgenic plant was initiated, with funding provided in part by JADF.

Proprietary biotechnology available for the development of virus resistance, in the form of DNA clones encoding virus coat proteins, as well as the technology associated with its use, had been previously made available to Cornell researchers by scientists at Dupont, Monsanto, and other agricultural biotechnology firms. JADF on its own negotiated a research agreement with Cornell, which in turn was bound by prior agreements with the companies that had transferred the virus-resistance technology. Under the Cornell agreement, Jamaican researchers and growers would be free to use any improved varieties developed by the collaboration for local research and production for domestic markets. However, production of the transgenic plants for export would require the negotiation of a license incorporating a royalty percentage to be paid to the companies providing the original biotechnology. After the virus-resistant varieties had been developed, JADF learned that the companies were likely to charge no more than a nominal royalty, in line with company policy supporting agricultural development in developing countries.

Development of the transgenic papaya variety stimulated the government of Jamaica to develop a biosafety mechanism sufficient to ensure safe field testing of genetically modified organisms. At this point, JADF's remaining tasks include the negotiation of the licensing agreement for commercial production and export. When the NRCA was interviewed about this topic, it was apparent that the agency did not possess the most up-to-date information on the project.

Policy Reform Scenario

The case of the biotechnology research project to develop virus-resistant local papaya varieties illustrates well the value of certain kinds of biotechnology to Jamaican agriculture. Due to infection with the Papaya Ringspot Virus, crop losses in 1994 were 30-40%, while 1998 losses are estimated at 50%. The biotechnology process used to develop the new varieties (cloning of the viral coat protein gene into the plant cells) has, when used on other crop varieties against different plant viruses, reduced yield losses to nearly zero, without expensive and toxic chemical inputs used to control the insect "vectors" which spread the viral infections.

The research agreement developed between the Jamaica Agricultural Development Foundation and Cornell University incorporates a royalty-free license for production for domestic markets. Export production will first require the negotiation of a royalty percentage with Cornell's technology donors, among them Monsanto Corporation, DuPont and others. Although the parental lines of the Sunrise Solo variety were obtained from Hawaiian growers, which in turn were derived from growers in Barbados, because the lines were subject to some breeding in Jamaica in the early 1980s, they would probably fall under the purview of the genetic resources regulations. Thus, under the proposed genetic resources regulations, JADF would have had to apply to the NRCA for an export permit to export Jamaican papaya germplasm for scientific research. The NRCA in turn would have apprised the Growers Association of its obligation to negotiate a Material Transfer Agreement with Cornell University.

Given that the purpose of the proposed research was to develop virus-resistant varieties for use in Jamaica, there was already a clear public good built into this project. Cornell University was willing to sponsor the research, utilizing the proprietary technology licensed to it. Given that neither Cornell nor the technology donor companies intended to claim rights to the transferred papaya variety for private gain, it would not have been appropriate to charge an up-front fee to gain access to the germplasm. Indeed, in this case it is Jamaica that is seeking access to an extraneous resource, i.e. the proprietary virus-resistance biotechnology. As such, it is appropriate for the technology donors to claim certain contingent benefits on any commercial products developed from this research.

The actual agreement negotiated by JADF appears to be quite beneficial to Jamaican growers. However, rather than deferring negotiations on the actual royalty percentage to be charged Jamaican growers, it is recommended that future negotiations be held up-front, prior to the transfer of any germplasm and commitment of biotechnology research funds, to obtain agreement on the size of the royalty charge. Under the proposed genetic resources regulations, this issue would have come up during discussion of the draft Material Transfer Agreement submitted by JADF to the Genetic Resources Advisory Authority. The genetic resources regulations would also have allowed the government to monitor – and to learn from – the development of this highly creative research collaboration.

Annex C – Dissemination Strategy and Activities

This annex was prepared by Richard M. Huber. Papers referenced in this section may be obtained from the author at rhuber1@worldbank.org.

Introduction

As "Canaries of the sea", coral reefs are the marine ecosystems that are most sensitive to human impacts. They are also among the most biologically rich marine habitats and vital to the well being of millions of people. Unfortunately, 1997-98 was a devastating period for many of the world's coral reefs. Elevated sea surface temperatures (28-39ºC) in many tropical regions caused the most geographically widespread bleaching and heaviest mortality of corals ever documented in such a short period. According to The Global Coral Reef Monitoring Network's *Status of Coral Reefs of the World: 1998,* some areas (including the Maldives, Sri Lanka, Singapore, and large areas of Tanzania), had up to 95% coral mortality in shallow waters. As a result of these unprecedented events, there is elevated concern about coral reef degradation worldwide. The least cost and valuation approaches of this World Bank modeling research in particular, have merited much attention because they are useful decision support, policy and training tools for coral reef managers and government officials trying to save their valuable national resources.

The consolidated dissemination strategy for the two projects has 7 facets:

- The COCOMO decision support model;
- Workshops;
- Newsletter publications;
- Symposium papers and presentations;
- World Bank web site;
- ICZM decision support modeling book; and
- The ReefFix restoration demonstration program.

COCOMO (Coastal Conservation in Montego Bay)

COCOMO is a decision support coastal conservation model for Montego Bay that illustrates coastal problems and estimates the effect of human activities. It is also a tool for policy and capacity building in integrated coastal zone management. Montego Bay was chosen for modeling because it is the fastest growing urban center in Jamaica. For years, development has been ad hoc and relatively unplanned. This has resulted in the degradation of water quality and coastal resources and has caused significant impacts to the valuable coral reef ecosystem. To address these management challenges, a multivariate model is needed to assist the many different organizations with an integrated and cooperative solution.

Specifically, the applied COCOMO modeling research is assisting the Montego Bay Marine Park Trust with a coherent and comprehensive global program that:

- Raises awareness and promotes consensus-building on the part of stakeholders with regard to environmental priorities in Montego Bay, Jamaica;
- Gages the possibility of working on the Montego Bay environmental agenda over the next two to three years with the Trust, the Greater Montego Bay Redevelopment Corporation, and other agents;
- Identifies specific environmental investments with feasible, relatively low-cost solutions; and
- Initiates a process of dialogue with stakeholders to be followed up in the future by other meetings on a periodic (possibly yearly) basis.

The model's computerized user-friendly interface (Box C.1) is developed for policy makers, specialists and those interested in Montego Bay coastal issues. The interface uses extensive colorful graphic information to provide users with a quick overview of coastal issues and how development, fisheries, tourism, agriculture, industry and households impact the coast and the coral reef in Montego Bay. Stored within the model is up to date information on the coral reef ecosystem and associated marine life and information on what the coast and the coral reefs contribute to Montego Bay through fisheries, tourism, beach supply and coastal protection.

Different actions may be taken to protect the coastal zone and coral reefs of Montego Bay – some more cost effective than others. COCOMO predicts the least cost set of interventions to realize a specified coral reef health (expressed as percent coral cover) in the next 25 and 50 years. Thus, COCOMO can be used to quantify the impacts of development-related activities and set priorities for future coastal management actions.

In the process of using the model, the user obtains a unique awareness of the relationship between different coastal activities and communications among stakeholders is enhanced. In addition, COCOMO clearly demonstrates the need for coastal zone management by showing the impacts of status quo management on the valuable coral reef ecosystem and on the local economy.

Box C.1. COCOMO briefing notes for model users. The following is extracted from workshop notes provided to participants at a seminar in Montego Bay, intended to provide feedback on the development of a user-friendly model. (after Werners 1998).

The MoBay coast is a spectacular, unique, and nationally significant marine environment. It includes extensive living coral reefs and mangrove islands. The economy of MoBay is dependent upon a healthy marine environment. Over 500,000 tourists visit MoBay annually, primarily attracted by its beaches and the sea. Many jobs in the service industry are dependent on the water, an example being the cruise ship industry. However, the MoBay coast is fragile and easily damaged by human activities. Therefore, it has to be managed with great care and with understanding of the effects that human activities have on the coast.

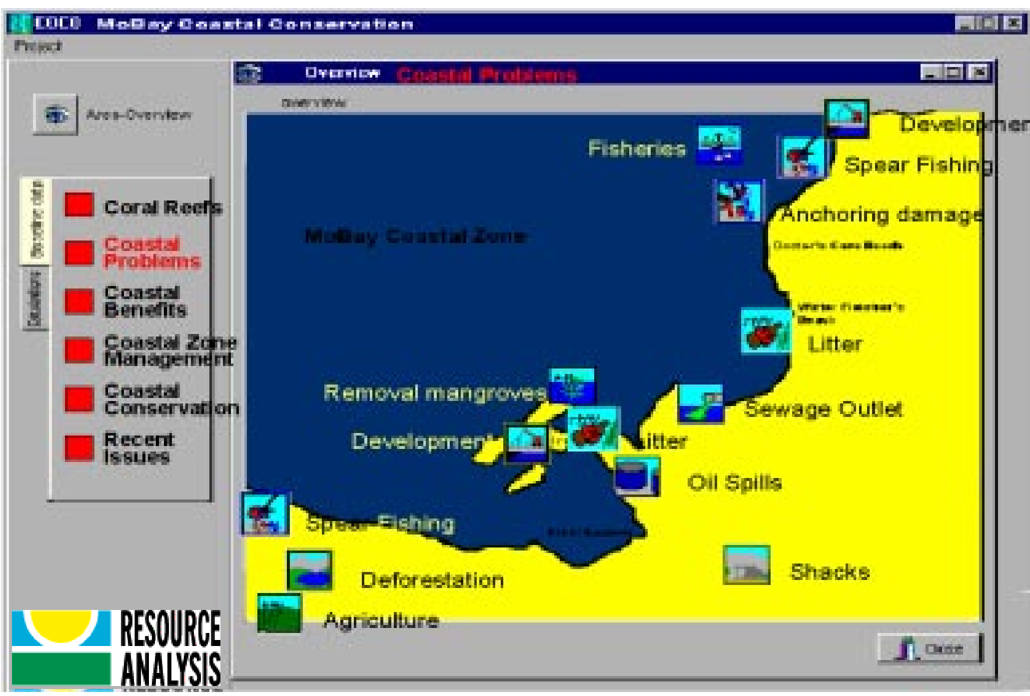
Montego Bay is the fastest growing urban center in Jamaica. For years, development has been *ad hoc* and relatively unplanned. This has resulted in the degradation of water quality in the bay and has caused significant impacts to the valuable coral reef ecosystem. The management of the bay cannot be carried out by one body alone. These issues therefore need to be addressed in an integrated and co-operative manner. Coastal zone management in Montego Bay involves the co-operation and co-ordination of many different organizations.

The model will show how development, fisheries, tourism, agriculture, industry and households impact the coast and the coral reef in MoBay. Furthermore it will hold up-to-date information on the coral reefs and marine life in MoBay. Hereafter the model will show what the coast and the coral reefs contribute to MoBay through fisheries, tourism, beach supply and coastal protection.

Different actions may be taken to protect the coastal zone and the coral reefs. For a number of these actions the model will estimate the coral reef health. Together with coral reef health, the model will calculate the costs of the actions. Finally the model will be able to predict the cheapest set of activities that has to be taken to realize a specified coral reef health.

Thus the model can be used to quantify the impacts of activities and put priorities for actions.

The model will create awareness for the relationship between different coastal activities and will assist in the communication between the various stakeholder groups, as well as agencies. In addition, it aims to demonstrate the need for coastal zone management and the impacts of status quo management on valuable coastal resources and the local economy.



More model-related information can be found on the internet at the following sites.

- For a general explanation of the CORAL ICZM model see: http://www.resource.nl/coral.htm
- For an online demo of an ICZM decision support system (COSMO-BIO) see: http://www.minvenw.nl/projects/netcoast/bioweb/index.htm
- To follow the development of the Montego Bay, Jamaica CORAL ICZM model see: http://www.island.net/~hjr/

Compact disc (CD) copies of the Montego Bay, Jamaica COCOMO model (PC compatible) will be available in mid-1999. The CD will also contain the CORAL ICZM decision support models for The Maldives and Curaçao.

Workshops

Format, audience and participants. Four certified workshops were held in Montego Bay that were a mixture of lecture and open forum with ample dissemination. Participants included representatives of government agencies (national, departmental and municipal levels), NGOs, CBOs, the private sector, and the academic community in Jamaica. Representatives of donors (World Bank) were also included.

Goals and objectives. The goals of the workshops were to obtain feedback on the findings of the applied modeling research in order to strengthen the validity of the model, ensure that the model was based on sound design and ICZM principles, and to identify potential avenues for strengthening regional and local capacity to manage these resources. Objectives of the workshops were to synthesize our understanding of the present and future impacts of economic activities on marine biodiversity and water resources in Montego Bay and identify priority areas for future research. The workshops also helped familiarize the private sector, water managers, donor agencies, and other stakeholders of the impact of economic development on marine biodiversity and water resources.

Workshop content and design. In the context of some of the Bank's ongoing activities, several stakeholders in the Montego Bay watershed have expressed their need and interest for a more comprehensive understanding of existing and planned development and conservation activities, especially in regards to water and aquatic resources. These workshops provide a forum for an initial discussion of these issues. In addition to being demand driven, these workshops are also advocacy driven.

The workshops were participant-oriented and highly interactive. The expert presenters employed a variety of didactic methods to ensure the interest and involvement of the participants.

Outcome. The immediate results of the workshops were:

- A specific list of recommendations for next steps towards improving the management of marine resources and coral reefs, particularly as it pertains to capacity building.
- A synthesis of the present understanding of the current and future impacts of economic activities on marine biodiversity and water resources in Montego Bay and a list of priority areas for future research.
- A better understanding by participants of the impact of economic activities on marine ecosystems and the benefits of ICZM.
- The initiation of a basin-wide network of stakeholders.
- A web-site and a hard-copy publications to disseminate our findings to a wider audience.

Impact Indicators. Indicators included the following:

- Increased involvement of diverse stakeholder groups in assessing the changes in marine biodiversity and in managing and decreasing the negative impacts on Montego Bay.
- Development of a network of policymakers and researchers – a community of practice – to enable the sharing of international experiences on coral reef restoration and to foster collaborative research on such activities.
- Preparation of an assessment report including an action agenda based on the workshop discussions.

Newsletter publications

Two articles, highlighting the models for The Maldives, Curaçao and Montego Bay, were produced for the ICZM newsletters Intercoast Network and Tropical Coasts. Both of these newsletters have international distribution. Response to the articles was strong and supportive. The citations for the articles are:

Huber RM, Jameson SC (1998) CORAL: A least cost management decision support model for coral reef ecosystems. Intercoast Network 32 (Fall), Narragansett RI.

Huber RM, Jameson SC (1998) Montego Bay, Jamaica: A case study in public-private partnerships for pollution prevention and management of a valuable coral reef ecosystem. Tropical Coasts, Manila, Philippines (Dec).

Articles are available from Richard Huber upon request to rhuber1@worldbank.org.

Symposium papers and presentations

Papers highlighting the models for The Maldives, Curaçao and Montego Bay were presented at the Ocean Community Conference '98 in Baltimore, Maryland and at the 1999 National Coral Reef Institute, International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring, and Restoration in Fort Lauderdale, Florida. The citations for the papers are as follows:

Huber RM, Jameson SC (1998) Integrated coastal zone management decision support modeling for coral reef ecosystems. Proceedings of the Ocean Community Conference '98, Baltimore MD.

Jameson SC, Huber RM, Miller M (1999) Restoration of a valuable coral reef ecosystem: ReefFix Montego Bay, Jamaica. Proceedings of the NCRI Conference on Scientific Aspects of Coral Reef Assessment, Monitoring, and Restoration, Ft. Lauderdale FL.

Articles are available from Richard Huber upon request to rhuber1@worldbank.org.

World Bank web site

The decision support models for The Maldives, Curaçao and Montego Bay, Jamaica will be on the World Bank Water web site. This will facilitate international use and distribution of the models. The web address for this site is:

http://wbln0018.worldbank.org/egfar/gfsc.nsf/MainView?OpenView

ICZM decision support modeling book

Ecological-economic models provide useful decision support tools for integrated coastal zone management of coral reefs in the developing tropics. The methodology will be outlined in a book being published as a result of this project, entitled: *Decision Support Modeling for the Integrated Coastal Zone Management of Coral Reefs in the Developing Tropics* (published in the summer of 1999). The contents will provide a framework for the application of similar models to other coastal areas around the world. The draft table of contents (Box C.2) shows the thrust of the book.

Box C.2
Draft Book Outline for Dissemination of Coral Reef Project Results

Title.	Decision Support Modeling for the Integrated Coastal Zone Management of Coral Reefs in the Developing Tropics
Contributors.	Leah Bunce, Cynthia Cartier, Steve Dollar, Kent Gustavson, Richard Huber, Steve Jameson, Dan Putterman, Mark Ridgley, Frank Rijsberman, Jack Ruitenbeek, Clive Spash, Jasper van der Werff ten Bosch, Susie Westmacott.
Publication.	mid-1999

Section I.	Decision Support Models for Integrated Coastal Zone Management
	Section Overview/ Context
Chapter 1.	Local Needs for Management of Coral Reefs in the Developing Tropics
Chapter 2.	ICZM and the State of Montego Bay Reefs
Section II.	Creating Models
	Section Overview/ Context
Chapter 3.	The Modeling of Economic Benefits and Least-Cost Interventions for Curaçao and the Maldives
Chapter 4.	Economic Benefit Model Focus for Curaçao and the Maldives – Contingent Valuation
Chapter 5.	The Modeling of Economic Benefits for Jamaica – Local Use Values
Chapter 6.	The Modeling of Economic Benefits for Jamaica – Bioprospecting Valuation
Chapter 7.	The Modeling of Economic Benefits for Jamaica – Non-Use Values
Chapter 8.	Interventions for Coral Reef Conservation – A Least-Cost Model
Chapter 9.	Integration of the Models for Decision Support in Jamaica
Section III.	Context for Model Application and the Future
	Section Overview/ Context
Chapter 10.	The Social Context for Local Management in Jamaica
Chapter 11.	Incorporating Genetic Resource Utilization into ICZM – Policies and Institutions in Jamaica
Chapter 12.	The Bank's Role, Dissemination, and Stakeholder Participation
Chapter 13.	Summary – The Future

ReefFix restoration demonstration program

Program goals

The goal of ReefFix is to design and implement a least cost ICZM coral reef ecosystem restoration and watershed management project and then transfer the information and technology to 20 other Caribbean countries facing similar challenges. Global Environment Facility Block A funds have been requested to implement the project. The project promotes the restoration, conservation and sustainable use of biodiversity in this region and promotes the sustainable use of coral reefs, watersheds and international waters.

At present, no country (or any of the over 100 marine protected areas) in the Caribbean is taking an integrated model-driven approach to watershed management for coral reef protection and management.

ReefFix is designed to improve the understanding and management of the region's coastal and marine resources through restoration demonstration and capacity building activities. As such, ReefFix will:

- support Caribbean efforts to implement the International Coral Reef Initiative (ICRI) at the national and regional level;
- carry out assessments designed to improve the understanding of the status and trends of coastal and marine resources in the Caribbean;
- strengthen monitoring of coastal and marine resources, including supporting the CARICOMP program and the IOC Global Coral Reef Monitoring Network;
- educate the public about the functions and services that coastal and marine ecosystems provide;
- collaborate and exchange information with other Caribbean coastal and marine research, education, conservation and training institutions;
- support education and training efforts and model demonstration programs aimed at improving the management and conservation of coastal and marine resources;
- generate revenues that will be used to help make the Montego Bay Marine Park (and selected other participating parks) financially self-sufficient over the long-term; and
- support ongoing Caribbean efforts to develop and implement ICZM plans and marine protected areas.

Unlike most marine projects that strive to do research in areas with beautiful natural surroundings and good environmental conditions, ReefFix will take a more management related approach. It will work in an area that suffers from many, if not all, of the watershed and marine ailments of Caribbean countries – an area that desperately needs ICZM and restoration – Montego Bay, Jamaica.

<u>ReefFix program components</u>

<u>1. ICZM Coral Reef Restoration and Watershed Management Demonstration</u>

The ICZM Coral Reef Restoration and Watershed Management Demonstration component is the operational aspect of the project. This component will work to restore and effectively manage coastal resources. In this process, ReefFix will use and develop cost effective techniques that can be replicated throughout the wider Caribbean.

The project will use several approaches to implement the ICZM Coral Reef Restoration and Watershed Management Demonstration component and address human activities in the coastal watershed and marine environment.

- Marine protected area management
- Management of land-based activities & coastal development
- Resource assessment, monitoring, restoration, & database creation
- Environmental impact assessment
- Community development
- Tourism & recreation management
- Economic incentives
- Regulation & enforcement
- Legal & institutional restructuring
- Public education & outreach

Combining these management approaches is critical for success. If used alone, these approaches tend to be ineffective over the long term. They must be strongly supported at scales ranging from the village to nation, and often at the regional scale as well. They must be oriented toward long term sustainability of coastal resources, and designed to be adaptive to different cultures/governments and changing situations without compromising effectiveness.

2. ICZM Capacity Building

The ICZM Capacity Building Program is the information and technology transfer component of ReefFix. This component will focus on regional capacity building and will draw on the successes of the Montego Bay Marine Park coral reef restoration and watershed management demonstration project.

Capacity building includes establishing and strengthening human resource and institutional capabilities for integrated coastal resources management, science, training and education.

A concerted effort must be made to enhance the capacities of countries responsible for valuable coastal resources to conduct science based research and to design and implement informed, effective integrated management systems. This implies not only the transfer of information, but more importantly, the exchange of experiential learning among countries of the region.

ReefFix will design and implement a program to build expertise in coral reef management and integrated coastal resources management. Presently, the shortage of trained personnel on many islands in the region requires the sharing of limited expertise through networking.

The project will draw on the talents and experience of other regional institutions and facilities in the design and implementation of its capacity building program.

ReefFix will also encourage the private sector's role in ICZM. It will seriously engage the private sector in the management of coral reefs and related coastal ecosystems by demonstrating to them, via workshops, educational material, media products, and technical assistance, the benefits of:

- Using appropriate technologies;
- Developing a trained and educated workforce; and
- Using innovative approaches to better environmental operating standards.

Specific objectives include:

- Develop a generic least cost ICZM decision support model template that can be custom tailored for any coral reef ecosystem in the Caribbean
- Develop a least cost ICZM coral reef decision support model for Montego Bay Marine Park
- Develop and Implement Montego Bay Watershed Management Action Plan
- Develop and Implement Fisheries Management Action Plan
- Implement Caribbean Wide Demonstration Action Plan

Expected outcomes are:

- A generic least cost ICZM decision support model template that can be custom tailored for any coral reef ecosystem in the Caribbean by inputting answers to model generated qu1. Coral Reef Restoration and Watershed Management Component
- A least cost ICZM decision support model for Montego Bay Jamaica that will run on a lap top computer - similar to those developed by the World Bank for The Maldives and Curaçao.
- A watershed management action plan of Montego Bay Jamaica that will over time: (i) improve water quality for the coral reef ecosystem (reduce eutrophication and sedimentation) and human users (reduce fecal coliform); and (ii) increase coral cover and decrease algal cover on marine park reefs.

- Ecotourism alternative income programs for retrained fishers in Montego Bay, Jamaica that will over time: (i) increase fish abundance; (ii) improve economic conditions for fishers; and (iii) make Montego Bay Marine Park financially self sustaining.
- Improved ICZM capacity for restoring coral reef ecosystems in 20 Caribbean countries as a result of the demonstration program including: (i) ReefFix coral reef watershed restoration handbook; (ii) ReefFix video; and (iii) ReefFix workshop materials.

Planned activities

The activities are split into a *Demonstration Phase* and a *Capacity Building Phase*.

1. ICZM Coral Reef Restoration and Watershed Management Demonstration Component

- CORAL ICZM Decision Support Modeling, to produce Montego Bay ICZM decision support model.
- Watershed Management, to: (i) establish Montego Bay Watershed Management Association via Montego Bay Marine Park; (ii) gather all existing watershed related baseline information; (iii) conduct supplemental baseline monitoring to determine land based pollution sources/sinks/loadings; (iv) incorporate all of the above baseline information into a USEPA BASINS type cost effective watershed assessment and management analysis system (with integrated GIS); and (v) draft Montego Bay watershed management action plan based on BASINS and CORAL analysis.
- Fisheries Management, to: (i) develop ecotourism alternative income programs for fishermen in cooperation with Montego Bay Marine Park; (ii) evaluate recruitment/restocking options; and (iii) evaluate alternatives to improve Bogue Lagoon water circulation.

2. Caribbean Capacity Building Component

- Enhance existing World Bank ICZM decision support model so it can be customized by user for any Caribbean site.
- Produce ReefFix handbook.
- Produce ReefFix video.
- Produce modeling and workshop educational materials.

Stakeholders involved

During a *Demonstration Phase* the focus will be on: Montego Bay businesses, community groups, NGOs, residents, educational institutions, and national and local government agencies. Specifically, Montego Bay Marine Park, Natural Resources Conservation Authority, Water Resources Authority, National Water Commission, Montego Bay Sewage Treatment Plant, Ministry of Agriculture Fisheries Division, Jamaica Tourist Board, Montego Bay Resort Board, Tourism Product Development Company, Jamaica Hotel & tourism Association, The Greater Montego Bay Redevelopment Company, and USAID will be major players.

During the *Capacity Building Phase* the focus will be on moving to other countries. In the 20 countries where workshops are held stakeholders involved will be similar to those listed above but with a local and national focus specific to the country involved.

Linkages

ReefFix has multi level linkages because the ICZM Demonstration Project component will restore a coral reef ecosystem and manage a watershed at a specific small island developing nation (Montego Bay, Jamaica). The ICZM Capacity Building Program component will transfer the information and technology to 20 countries (as identified by the International Coral Reef Initiative Tropical Americas Regional Report) throughout the wider Caribbean with coral reef eutrophication/sedimentation problems. These countries include: Bahamas, Barbados, Brazil, Cayman Islands, Colombia, Costa Rica, Cuba, Curaçao, Dominica, Dominican Republic, Ecuador, Grenada, Guadeloupe, Haiti, Martinique, Nicaragua, Panama, St. Lucia, Trinidad & Tobago and Venezuela.

On the Jamaica level, the project is directly linked to national priority programs of the Natural Resources Conservation Authority (NRCA) to manage watersheds and to establish and restore marine protected areas under the management of local NGOs. The NRCA delegated authority to manage the Montego Bay Marine Park to the Montego Bay Marine Park Trust (grantee). The project also meets many of the objectives outlined in the Montego Bay Marine Park Action Plans for Ecosystem monitoring, Community Relations, User Management and Financial Management and will integrate relevant existing park management activities into ReefFix operations wherever possible.

On the Caribbean level, ReefFix is linked to the Regional International Coral Reef Initiative (the World Bank sits on the ICRI Steering Committee), the UNEP Global Program of Action for the Protection of the Marine Environment from Land-based Activities and the IOC Global Coral Reef Monitoring Network. This project addresses the specific needs identified in a survey of the 25 Caribbean countries participating in the 1995 ICRI Regional Workshop held in Montego Bay, Jamaica. These needs, as outlined in the "Tropical Americas Regional Report on the Issues and Activities Associated with Coral Reefs and Related Ecosystems" (Woodley 1995), include: a need for integrated coastal zone management planning approaches (i.e., restoration, mitigation of specific impacts and determination of carrying capacities); capacity building in coastal/marine resource management; and increased research and monitoring capability.

Participants also identified a series of initial steps needed to provide a basis for increased regional collaboration, these include initiatives to strengthen management capabilities in special area management planning, education and environmental awareness programs and increased capacity at regional marine institutions.

On the world level, this project is directly linked to the priorities of the United Nations International Year of the Ocean (1998). It is also linked to World Bank ICZM coral reef ecosystem decision support modeling conducted by the LCSES Unit.

The International Coral Reef Initiative (ICRI) State of the Reefs Report (Jameson, *et al*. 1995) concludes that the coral reef ecosystems at greatest risk around the world are in South and Southeast Asia, East Africa, and the Caribbean.

The Caribbean Sea contains some of the world's most productive and biologically rich marine environments, including the world's second largest barrier reef – the Belize Barrier Reef. Unfortunately, reefs and other coastal environments throughout the region are under increasing assault. Pollution from sewage wastes and fertilizers, coastal erosion, over-fishing; and unmanaged coastal development are contributing to coastal decline. Recognizing the magnitude of these threats and the need for counter measures, the International Maritime Organization declared the Caribbean a "particularly sensitive area".

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The following provides the consolidated references and bibliography for research committee studies relating to cost effectiveness analysis and marine valuation, as well as for the background reports that were prepared in support of these.

[Consolidated by HJ Ruitenbeek and CM Cartier 20 March 1999]

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References

The following provides the consolidated references and bibliography for research committee studies relating to cost effectiveness analysis and marine valuation, as well as for the background reports that were prepared in support of these.

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