Chapter 12

Incorporating Genetic Resource Utilization into ICZM—Policies and Institutions in Jamaica

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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. The notion that developing countries can integrate the sustainable use of marine genetic resources into coastal zone planning is a new one. Several international treaties empower the Government of Jamaica under international law to enact regulations promoting this. The objectives of this chapter are to: i) provide the Government of Jamaica as well as private organizations, including non-government organizations (NGOs), private industry, and academia, with an assessment of Jamaican institutions with expertise relevant to the management of marine genetic resources; and, ii) provide a concise set of policy recommendations intended to enable Jamaica to capture the maximum value created by commercial research and development (R&D) with marine genetic resources.

The following section considers two Jamaican case studies involving genetic resources (R&D), then provides a brief review of commerce and policy issues related to genetic resources utilization. Subsequent sections summarize the results of an institutional assessment (conducted late February 1998), define components of a minimal policy on genetic resources utilization, and explore the development implications of claiming different kinds of rights to genetic resources research material. This chapter concludes by revisiting the Jamaican case studies of genetic resources utilization and providing alternative scenarios based upon the policy recommendations.

The development of marine genetic resources into new commercial products can be a powerful tool for conservation and economic development, and as such, marine genetic resources ought to be incorporated into integrated coastal zone management (ICZM) planning. However, while this chapter is intended as a contribution to the study of marine biodiversity, the reviews and recommendations contained herein are equally applicable to terrestrial genetic resources. Utilization of both marine and terrestrial genetic resources involves many common techniques and legal issues, while policy mechanisms to regulate the use of these resources are intimately linked. *As such, the policy recommendations in this chapter are intended to regulate the utilization of both marine and terrestrial genetic resources.*

Two Jamaican Case Studies—Statement of the Problem

To illustrate genetic resources issues with which Jamaica currently grapples, two case studies involving actual use are presented.

Marine Bioprospecting in Jamaican Coastal Waters

Interviews with Jamaican researchers 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 and on land. In one case, a large US oceanographic research institute 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 the University of the West Indies at Mona (UWI). Future expeditions to Jamaica may encounter difficulty obtaining a research permit from the Natural Resources Conservation Authority (NRCA), given the general anxiety over this inability to share in the benefits of research and the mistrust that it engenders.

Biotechnology Based Improvement of Jamaican Papaya Germplasm

The Jamaican papaya industry has developed into an important source of foreign exchange, with 1995 export sales of approximately US$20 million. A local variety known as Sunrise Solo had been bred in the early 1980s by Jamaican growers, adapted from papayas developed in Barbados and Hawaii. However, by the middle of the 1990s, problems with the Papaya Ringspot Virus, which causes stunting and production of poor quality spotted fruit, had reduced yields by 30% to 40%. During this time, a non-profit industry association, the Jamaica Agricultural Development Foundation, 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 the Jamaica Agricultural Development Foundation (JADF).

Proprietary biotechnology for the development of virus resistance 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 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. 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.

Introduction to Genetic Resources Issues—Commerce and Policy

Biologists describe the diversity of biological systems at three scales (for a review see Wilson 1992). Ecosystem diversity measures the diversity of biological processes and organization across a landscape. Species diversity is the level with which most are familiar, and is sometimes misunderstood as the only definition of biodiversity. At the smallest scale there is chemical and genetic diversity, a measure of the biological diversity within species and of the complexity of chemical interactions between species. Biodiversity at this scale is referred to as genetic resources—the source of industrial natural products and of new agricultural varieties. Genetic resources yielding potentially valuable chemicals, enzymes or genes include terrestrial and marine microbes (especially fungi, actinomycetes and archeae), plants, insects, venomous animals and marine organisms.

Although tropical rainforests are well known for high species diversity, numerous ecosystems, including marine environments, are valued for their high genetic resources diversity (also called "molecular diversity"). The molecular diversity among microbes, both terrestrial and marine, is likely to be orders of magnitude higher than that of plants and animals (Paleroni 1994). Harsh environments found on both land and sea are also a major source of molecular diversity, and have yielded valuable "extremophile" micro-organisms adapted to living under extremes of heat, cold, pH, or mineral concentration.

Commerce involving genetic resources can be divided into R&D versus production. Examples of production include sourcing plants or microbes for the 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".

Biological Diversity in the Sea

Marine genetic resources deserve special treatment, as little information is available on practical strategies for using this valuable biodiversity. Estimates of species diversity in the sea are growing, and one recent deep-ocean study put this number as high as 10 million, roughly comparable to that of terrestrial species diversity (reviewed in Norse 1993b). Higher marine species diversity is found in coastal ecosystems, and by far the greatest diversity is in the tropics, making the waters surrounding tropical developing countries the richest marine source in the world for molecular diversity. Examples of coastal ecosystems include coral reefs (with the highest species diversity), seagrass beds, oyster reefs, mangroves, salt marshes, and continental shelves.

Marine genetic resources known to yield useful chemicals, enzymes and genes include marine micro-organisms, plants, invertebrates and cartilaginous fishes. Coastal genetic resources are generally collected by scuba diving at depths of less than 100m or by dredging at depths of up to 500m to 1000m on the continental shelf (D'Auria *et al.* 1993). Taxonomic inventory of marine organisms differs from that of terrestrial organisms in that collection expeditions are somewhat costlier and samples must be frozen immediately, with the exception of marine micro-organisms, which are usually cultured.

The sea yields extraordinary molecular diversity. Marine genetic resources often contain unusual or highly complex molecular diversity not found in terrestrial organisms (Scheuer 1990). Marine invertebrates, usually sessile and/or soft-bodied, have intrigued marine natural products chemists for decades. Scientists have followed a so-called "bio-rational" approach to screening, arguing that, with such seemingly vulnerable body plans, these invertebrates must have evolved effective chemical defenses as a survival strategy. Preferred marine macro-organisms include sponges, cnidarians, bryozoans, molluscs, echinoderms and tunicates.

The potential molecular diversity among marine microbes is higher still. Many microbes, including dinoflagellates, can be cultured directly from the water column. New techniques are available for culturing symbiotic or commensal microbes such as bacteria, cyanobacteria and algae from the tissues of macro-organisms. Recent work on culturing micro-organisms isolated from the water column, from shallow water marine sediments including oil seeps, or from marine animal hosts has yielded a promising array of new chemicals (Fenical 1993). As the technology for culturing marine microbes develops, it is likely that interesting organisms will be discovered in a wide range of marine hosts. For this reason, conventional predictions about which marine species will yield economically valuable chemicals are probably no longer valid. If it is true that most, if not all, marine species provide critical microhabitats for commensal micro-organisms that may produce bioactive compounds, this would imply a greater value for all marine organisms, compounding the value of highly diverse ecosystems such as coral reefs.

The list of useful products derived from marine genetic resources is too long to chronicle here. Examples include anticancer compounds, antivirals, antibiotics, antifungals, anti-inflammatory agents and hormonal modulators (for reviews see Flam 1994; Wright and McCarthy 1994). Marine genetic resources have yielded industrial enzymes such as proteases and collagenases, and are also studied for clues to the development of new agrochemicals (for a review see Zilinskas *et al.* 1995).

Marine genetic resources are also the source of marine biomaterials and of extremely potent toxins, some of which may have applications as anticancer drugs or as diagnostic and research tools. Marine genetic resources are also of interest to the cosmetics industry, and may one day yield new sunscreens and other skin care products. For example, an anti-inflammatory agent derived from a tropical sea fan is currently under development as a skin care product by a major cosmetics firm (Jacob 1996). Finally, even higher marine animals have yielded promising new pharmaceutical leads. One example is squalamine, a potential anticancer drug isolated from cartilage of the dogfish shark *Squalus acanthias* (Moore *et al.* 1993).

Genetic Resources Markets

Large global markets exist for products derived from genetic resources. These are summarized in Table 12.1.

The Value-Adding Process of Research and Development

Unique among commercial uses of biodiversity, genetic resources R&D relies upon trade in information, rather than physical goods *per se*, to generate high value products. The size of samples collected for study can be quite small, typically less than 100g of material. Samples are studied to yield such *value-added research material* as small organic molecules called secondary metabolites, genes encoding proteins such as enzymes, or metabolic pathways linking enzymatic reactions together in a process known as microbial fermentation.

Genetic resources research can be divided into a series of value-adding processes, beginning with a biological inventory requiring accurate taxonomic identification of specimens. Inventory strategies include random inventories, bio-rational inventories which rely upon ecological evidence of inter-specific chemical interactions, and ethnobotanical inventories which gather information on traditional knowledge of useful plants. The choice of inventory strategy depends on the market sector, with nutraceuticals markets relying most heavily on ethnobotany, enzyme and microbes markets utilizing random and bio-rational inventories, and pharmaceuticals and agrochemicals relying on all three, but emphasizing random and bio-rational approaches.

Following inventory, the chemicals or genes are extracted from the genetic resource, and the extracts are screened with laboratory tests known as biological assays or "bioassays" to detect the desired biological activity.

Table 12.1. Estimated global sales from existing markets for products derived from genetic resources. The market sectors highlighted use variable percentages of genetic resources as starting material (i.e., approximately 40% for pharmaceuticals; 100% for agricultural seeds, nutraceuticals, enzymes and microbes).

Market sector	*Estimated global sales (billion US$)*	*Source*
Pharmaceuticals	256	Scrip (1996)
Pesticides	47	Burrill and Lee (1993); Moffat (1993); World Bank (1991)
Agricultural seeds (commercial sales)	13	Van Gaasbeek *et al*. (1994)
Nutraceuticals (herbal products, phytomedicines)	12.4	Brevoort (1996); Yuan and Hsu (1996)
Cosmetics (skin care products)	6	Niebling (1996)
Industrial enzymes	1.6	Stroh (1998)
Industrial microbes	0.68	Perez (1995)
Biotechnology enzymes	0.6	New York Times (1993)

Bioassays are used to guide the identification process until a pure enzyme or microbial strain or chemical compound (called a "lead compound") is isolated. Further commercial R&D may involve expensive animal and/or voluntary human testing.

Three Strategies for Research Collaboration

Because genetic resources research and development entails substantial financial risk to private companies seeking to develop commercial products, many firms seek out research collaborations as a risk reducing strategy to maximize their ability to discover promising new chemicals or genes. Three strategies—outsourcing, in-licensing, and joint venture partnering—are employed.

- *Outsourcing.* Outsourcing entails contracting with private organizations or individuals to supply certain value-adding services, such as sample collection, extraction, and bioassay. An entire industry has evolved to supply the outsourcing needs of large companies engaged in genetic resources R&D, involving suppliers such as natural products libraries, botanical garden collectors, oceanographic research institutes, academic researchers, and specialized companies offering bioassay services. Many of the highly publicized biodiversity prospecting contracts negotiated in recent years between private firms and research institutes or NGOs in biodiversity rich developing countries are examples of outsourcing by large R&D companies.
- *In-licensing.* By contrast, in-licensing entails acquiring the rights to valuable chemicals, genes or microbes which have been previously identified by an independent research group. Large R&D companies may in-license promising research material from other firms or from non-profit research institutes, including universities. In many developed countries, it is now common for universities to have specialized offices of technology transfer staffed by negotiators familiar with business contracts and intellectual property law. Technology transfer specialists actively seek private sector companies willing to in-license basic research discoveries, for an agreed on fee.
- *Joint venture partnering*. A third business strategy involves the creation of joint ventures. Typically, a genetic resources joint venture partnership would involve one company in a developed country and one in a biodiversity source country. Joint ventures involve shared financial risks and the proportional sharing of revenue or technology. Note that strong intellectual property protection is usually necessary to encourage joint venture development, particularly when technology transfer is inherent to the partnership (Mansfield 1995).

Benefit Sharing Mechanisms and Options for Compensation

It is customary to define all the obligations of research partners through prior negotiation utilizing legally binding research contracts or material transfer agreements

(MTAs; Barton and Siebeck 1994; Gollin 1995; Putterman 1996). Numerous mechanisms for compensation exist:

- *Rental fees*. It is customary to charge a rental fee (also known as *up-front* or *guaranteed compensation*) for the use of *value-added genetic resources research material* to private firms engaged in product development. Chemical or biochemical extracts of inventoried genetic resources represent the lowest end of the value-added chain, renting for tens to hundreds of dollars each. The value of extracts with a positive result on a good bioassay may increase two to ten-fold, and so on.
- *Rural employment*. Some genetic resources projects feature collaborations with integrated conservation and development projects (ICDPs) to employ rural people as biodiversity collectors or "parataxonomists". Some projects also feature profit sharing with local communities through trust funds as a way to generate incentive measures for conservation.
- *Licensing fees*. Developing country research institutes that have patented research material, novel uses or processes can charge up-front licensing fees to R&D firms willing to in-license these products for commercial development.
- *International technology transfer*. Technology transfer to developing countries enables these countries to generate value-adding information from genetic resources on their own, stimulating economic activity. Transfer of proprietary bioassays is one valuable option, as most developing countries generally lack the latest, most efficient and cost-effective biotechnology to discover new products with valuable biological activities.
- *Tropical disease research*. An intriguing area for technology transfer is the field of tropical disease research, consistently underfunded despite some 600 million cases world-wide (Gibbons 1992). Genetic resources can provide new therapeutics, such as the drug ivermectin, a fungal compound that has helped prevent some 1.5 million cases of river blindness in Sahelian Africa (World Bank 1993b). Given that some 80% of the world's population makes use of traditional medicine (Farnsworth *et al*. 1985), the opportunity exists to utilize new bioassay technology to evaluate the efficacy of these treatments to facilitate the development of new low cost phytomedicines for the poor (Iwu 1994).
- *Deferred or contingent compensation*. Most commercial firms prefer to lower the financial risk of R&D by deferring a portion of compensation. There are several mechanisms for doing this, including *royalties*, which are a percentage of revenues on final products. *Milestone payments* are lumpsum payments made upon the attainment of important regulatory milestones during the product development process, such as patenting, regulatory approval to commence human clinical trials, or successful completion of these trials. Like rental fees, contingent compensation increase with the amount of value added by the provider. Some genetic resources projects incorporate a benefit sharing mechanism with local communities by sharing royalties using a trust fund.
- *Sourcing and joint venture agreements*. Sourcing agreements made directly with developing countries enable poor rural populations in these countries to grow high value cash crops for processing into such commercial products as phytomedicines, cosmetics, pharmaceuticals, and agrochemicals. Joint venture development of these commercial products from genetic resources allows private companies in the biodiversity source country to market the product regionally, generating potentially large revenue streams and contributing to industrial development.

Relevant International Treaties

Several treaties contain provisions relevant to the utilization of genetic resources, in particular the Convention on Biological Diversity. This treaty, plus relevant provisions of the Convention on the Law of the Sea and the World Trade Organization (WTO) Agreement, are briefly reviewed below.

- *Convention on Biological Diversity*. Article One of the Convention on Biological Diversity describes its three objectives as "the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising out of the utilization of genetic resources." The rationale for the third objective is to create economic incentives to conserve biodiversity. Article 15 highlights the "sovereign rights" of parties over genetic resources, stating that governments have the right to regulate access to these resources on "mutually agreed terms" and with "prior informed consent". Article 15 seems to treat genetic resources as valuable national resources, akin to oil reserves or mineral deposits. This marks a significant departure from previous concepts of genetic resources, which have tended to treat these resources as the "common heritage of mankind". Other relevant issues covered by the convention include access to technology, including proprietary technology and biotechnology (Articles 16 and 19), and knowledge pertaining to traditional uses of genetic resources (e.g., ethnobotanical knowledge of the use of medicinal plants).
- *United Nations Convention on the Law of the Sea*. The United Nations (UN) Convention on the Law of the Sea specifically addresses marine scientific research issues, with implications for coastal areas including the continental shelf and other areas comprising Exclusive Economic Zones (EEZs). The Law of the Sea treaty states that coastal states shall grant their consent for marine scientific research projects by other states or competent international organizations in their EEZs or on their continental shelf, *but that coastal states may*

withhold consent to the conduct of a project if that project is of direct significance for the exploration and exploitation of natural resources, whether living or non-living (Articles 246.3 and 246.5a).

Based on these two treaties, some governments are exploring options to regulate access to marine natural products found in EEZs. Requiring marine research expeditions to negotiate contracts or MTAs when applying for marine collection permits is one relatively simple policy measure that would allow developing countries to benefit from marine genetic resources R&D. This strategy is discussed later in this chapter.

- *World Trade Organization Agreement*. The Trade-Related Intellectual Property subagreement (TRIPs) to the WTO Agreement calls for parties to adopt a wide range of intellectual property right (IPR) regimes, including patents, plant breeders rights, and trade secrets. Developing country parties are allowed a grace period, longest for the least developed countries, for implementing new IPR legislation. TRIPs does not make explicit reference to the rights of indigenous and local communities, although it does allow parties to develop *sui generis* (novel) plant variety protection, which some have interpreted as providing an opportunity to recognize rights to traditional knowledge regarding, for example, traditional landraces comprising subsistence farmers' crops.

Review of Relevant Jamaican Institutions and Policies

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 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. A review of Jamaican institutions is presented below. Overall, there appeared to be good appreciation of the value of private investment in genetic resources development as a tool for economic development and biodiversity conservation. Institutional strengths useful for designing and implementing genetic resources policy are highlighted.

The Government of Jamaica

Office of the Prime Minister

The Office of the Prime Minister does not regulate scientific research directly. However, the National Commission on Science and Technology (see below) is chaired by the Prime Minister himself.

Ministry of Foreign Affairs

Officially, all requests from abroad for access to Jamaican biological resources, for purposes of scientific research, are required to be made through the Ministry of Foreign Affairs. The Ministry in turn refers such requests to the NRCA for the issuing of permits. The Ministry of Foreign Affairs has jurisdiction over the EEZ, and will be developing a new policy on ICZM. As part of this process, the Ministry has proposed the creation of an interdisciplinary Council on Ocean and Coastal Zone Management.

Ministry of Commerce and Technology

The newly created Ministry of Commerce and Technology oversees the National Commission on Science and Technology, an interdisciplinary scientific body which advises government on relevant issues. The Ministry is charged with promoting private sector development and technology transfer in Jamaica.

Ministry of Environment and Housing

The Ministry of Environment and Housing coordinates closely with the NRCA over biodiversity issues. The Ministry has created a new Sustainable Development Council which draws upon a wide range of stakeholders including government, the private sector, NGOs, academia, and labor. The Ministry also participates in drafting environmental regulations and in implementing international environmental treaties.

Natural Resources Conservation Authority

The NRCA is the primary implementing agency of such environmental treaties as the Convention on International Trade in Endangered Species (CITES) and the Convention on Biological Diversity. Created by the NRCA Act of 1991, the NRCA has the power to delegate responsibility for managing protected areas to NGOs. The NRCA has jurisdiction over marine natural resources management of submerged coastal lands. The NRCA also issues permits for the import or export of species listed under CITES appendices. The NRCA has created the CITES Scientific Authority, an interdisciplinary advisory body comprised of scientists and conservationists, which advises the NRCA on the granting of permits for the import or export of listed species.

Draft amendments to the Wildlife Protection Act currently under consideration would grant the NRCA the power to regulate all scientific research with Jamaican biological resources. A permit mechanism is now under consideration. On 9 February 1998, the NRCA took an administrative decision to require all scientists, foreign and domestic, to submit a "Wildlife Application Form" to the Authority at least five weeks in advance of any scientific research on Jamaican flora and fauna species. The application is in the form of a questionnaire, allowing the NRCA to "maintain an efficient monitoring and inventory data base for living biological resources".

Ministry of Agriculture

Under the Ministry of Agriculture are two government agencies that may be relevant to the regulation of genetic resources utilization. The Fisheries Division has jurisdiction over management of marine natural resources in the water column, but not on submerged lands. A permit is required from the Fisheries Division for harvesting of these resources, mainly commercial fish species. The Forest Department has jurisdiction over natural resources management on public lands, including forest reserves. Note that jurisdiction over natural resources management within protected areas, whose management has been delegated by the NRCA to NGOs, is uncertain and in need of clarification.

Commissioner of Lands

The Commissioner of Lands, a quasi-private corporation, owns land rights to all Crown (public) lands, including forest reserves, and has the sole power to dispose of or acquire such land through sale or lease. Although private property rights are well defined in Jamaica, community land and/or resource tenure does not exist. The sole exceptions to this are the special community land rights defined by the 1739 Maroon treaties that established two special reserves for these communities, the descendants of freed slaves who fought British colonizers, in eastern and western Jamaica.

Ministry of Industry, Investment and Commerce

The Industry Section of the Ministry of Industry, Investment and Commerce processes patent applications in Jamaica for technical examination by other agencies. Existing intellectual property right mechanisms include patents, trademarks, industrial designs and copyrights. No formal trade secrets law exists, nor are there plant variety protection laws. Some 3,000 patents have been granted in Jamaica, and about 80 to 100 patent applications are filed annually, although the overwhelming majority of these are filed by foreign companies seeking pharmaceutical patents to prevent intellectual piracy (the unauthorized manufacture of proprietary products) in Jamaica.

Academia

University of the West Indies at Mona

Relevant academic departments at the UWI include the Centre for Marine Sciences and the Department of Life Sciences, both of which possess expertise in marine taxonomy. The Department of Life Sciences includes a marine invertebrate collection in the process of being catalogued, with at least 2,000 specimens representing over 250 species of coastal and deep ocean organisms. Mariculture expertise also exists within the departments, with current experiments focusing on tilapia aquaculture.

The Department of Chemistry employs natural products chemists and is equipped with most, although not all, laboratory equipment necessary for purification and structural determination of biologically active secondary metabolites. A Biotechnology Centre also exists within the School of Medicine, with expertise in microbiology and tissue culture. 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 MTAs, including such issues as copyrights, patents, and royalties.

Discovery Bay Marine Laboratory

The Discovery Bay Marine Laboratory, the main field research station overseen by the Department of Marine Sciences, is equipped for underwater sampling and possesses a wet laboratory through which sea water is pumped continuously for live organism experiments. A small dry laboratory contains basic chemistry equipment. The marine lab is used primarily by visiting scientists and their students from around the world. Adequate lab space exists to set up a small marine microbial culture project in the wet laboratory.

Institute of Jamaica

The Institute of Jamaica contains a large number of taxonomic collections, and it currently serves as the scientific focal point for Jamaica to the Convention on Biological Diversity.

Non-Government Organizations

Jamaica Conservation and Development Trust

The Jamaica Conservation and Development Trust's (JCDT) three-fold mission involves public education and environmental advocacy, as well as protected areas management. The JCDT manages the National Parks Trust, a trust fund which covers the partial operating expenses of the Blue and John Crow Mountains National Park. This park is also managed by the JCDT under an agreement with the NRCA. The JCDT identified the major threats to the Blue and John Crow Mountains area as subsistence agriculture on marginal lands (primarily steep and easily erodible slopes), as well as the related problem of squatters' settlements on park land.

Montego Bay Marine Park Trust

The Montego Bay Marine Park (MBMP) Trust manages the MBMP on behalf of the NRCA (see Chapter 2). As is the case with the JCDT, the Trust'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 has identified the major threats to the coral reef and adjoining Bogue Lagoon in Montego Bay as overfishing by artisanal fishers, as well as land based sources of marine pollution (primarily untreated sewage and a high silt load deposited into the bay by the Montego River and adjacent gullies; see Chapters 1 and 2).

National Environmental Societies Trust

The National Environmental Societies Trust (NEST) is a coalition of 26 active local NGOs in Jamaica which serves as a forum for debate, education and environmental action. NEST is comprised of three "focus groups" concerned with sustainable community development, ecosystems management, and public education. Many NGOs expressed great interest in possible applications of genetic resources, especially high value herbal products such as essential oils and botanical extracts, to the development of community enterprises.

Private Sector

Myers, Fletcher and Gordon

A private sector law firm specializing in corporate clients, Myers, Fletcher and Gordon employs several attorneys with a strong interest in environmental matters and relevant expertise in intellectual property and contract law. These personnel expressed a willingness to participate in genetic resources policy-making and its implementation.

Jamaica Promotions Corporation (JamPro)

JamPro is a quasi-private corporation that promotes economic development in Jamaica, including developing export markets and encouraging new private investment. JamPro has a Chemical Division which assists in such markets as minerals and chemicals, bottled water, herbal teas and other herbal products.

Federated Pharmaceuticals Ltd.

Federated Pharmaceuticals Ltd. is setting up a production line for herbal products under its Natural Products Division. Products to be manufactured include essential oils, extracts, tinctures and gums. Aside from technical expertise in marketing and product development, the company also possesses a small quality control laboratory for microbial testing and dosage standardization.

Genetic Resources Policy Recommendations

The development of marine genetic resources into new commercial products can be a powerful tool for conservation and economic development. The following policy recommendations are intended to incorporate the management of marine genetic resources into ICZM planning in Jamaica. Because the utilization of both marine and terrestrial genetic resources involves many common techniques and legal issues, the policy recommendations are intended to regulate the utilization of both marine and terrestrial genetic resources.

Obligations and Assumptions

In designing a set of genetic resources policy options for Jamaica, it is necessary to incorporate the following obligations under relevant international treaties to which Jamaica is a party:

Convention on Biological Diversity

- Create incentive measures to promote conservation and sustainable use of biodiversity (Article 11);
- Promote sovereign rights over biodiversity, including genetic resources (Articles 3 and 15.1);
- Ensure the fair and equitable sharing of benefits arising out of the utilization of genetic resources (Articles 1 and 15.7) or out of the utilization of knowledge, innovations and practices of indigenous and local communities (Article 8j), a.k.a. "traditional knowledge";
- Regulate access to genetic resources based upon mutually agreed terms (Article 15.4) and upon prior informed consent (Article 15.5);
- Create a mechanism to facilitate access to technology, including that which is relevant to the conservation and sustainable use of biological diversity, as well as biotechnology that makes use of genetic resources (Articles 16 and 19); and,
- Encourage cooperation between government authorities and the private sector in developing methods for the sustainable use of biological resources (Article 10e).

UN Convention on the Law of the Sea

- Develop a mechanism to grant or withhold consent for marine scientific research projects by other states or competent international organizations in the EEZ or on the continental shelf, wherein consent can be withheld if that project is of direct significance for the exploration and exploitation of natural resources, whether living or non-living (Articles 246.3 and 246.5a).

Additional Assumptions

The foregoing necessary obligations are insufficient, insofar as they do not take account of the effect that policy-making will have on private sector activities. Additional assumptions employed herein are summarized as follows:

- Private investment in genetic resources utilization can yield benefits, some of which can be distributed as public goods if properly channeled by government. Examples of public goods include local and national incentives for biodiversity conservation, opportunities for technology transfer, development of local (including community based) industries, and so on.
- Policy-making should avoid creating disincentives to private sector investment in genetic resources utilization. Strong disincentives to investment imply a large opportunity cost to Jamaica in terms of lost access to private capital and to sophisticated biotechnology necessary to develop high value products from genetic resources.
- Policy-making should encourage negotiations among private parties to the maximum extent possible. Private party negotiations (as opposed to centralized negotiations between private parties and the Government of Jamaica) increase opportunities for creative deal-making, enhancing opportunities to capture the benefits of genetic resources utilization. Allowing private party negotiations also creates an incentive to foreign investment.
- A genetic resources policy should be simple and transparent, involve minimal bureaucracy, and provide easy mechanisms for compliance.

Basic Components of Model Genetic Resources Legislation

Based on the foregoing obligations and assumptions, the following policy recommendations are intended to allow a developing country such as Jamaica to fulfill obligations under the Convention on Biological Diversity and the Convention on the Law of the Sea. The overall strategy guarantees benefit sharing and enhances community rights and national sovereignty while avoiding large disincentives to private sector investment. Biodiversity conservation projects and protected area managers can adopt regulations based on these components as well.

Summary of Policy Model

1. *Regulate access to genetic resources 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 or exported. Permits should be issued only after approving contracts.
2. *Establish sui generis (novel) rights to tangible property and traditional knowledge*. In order to define who has the right to participate in and benefit from the negotiation of contracts involving a transfer of genetic resources or traditional knowledge, it will be necessary to create rights to both the tangible and intangible (intellectual property) manifestations of these.
3. *Develop prior informed consent procedures*. In order 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 for the utilization of genetic resources.
4. *Create a national benefit sharing formula*. A national formula to convert a portion of monetary income derived from new product development into public goods is necessary to ensure fair and equitable sharing of benefits from genetic resources utilization.

First Model Component: Regulate Access to Genetic Resources 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 requiring a collector or scientist to sign a *contract* before samples are collected or exported.
- *Contractual agreements* have been used by both the biotechnology industry and academia to define rights to unpatentable biological material and "know-how". These contracts can be modified and applied to genetic resources and traditional knowledge to define rights and obligations of parties involved in collaborative research, including benefit sharing obligations.
- The issuing of biodiversity collection permits should be made contingent upon the signing of legally binding contracts.

It is recommended that the Government of Jamaica adopt a regulation requiring organizations that issue permits to ensure that an approved research agreement or MTA is signed by both provider and recipient of genetic resources or traditional knowledge *prior* to issuing permits. These agreements describe rights and obligations of providers and recipients of biological material being transferred for scientific research or commercial development (Gollin 1995). Contracts can also be adapted to define community rights to resources or traditional knowledge, the latter through a trade secrets mechanism as described below. Research contracts adapted to this purpose incorporate several basic features, including definition of ownership of the rights to the collected genetic resources or traditional knowledge, terms and conditions of the transfer of the collected resources, and compensation for the transferred material (for examples, see AUTM 1995; Downes *et al*. 1993; Putterman 1996).

Link the Approval of Biodiversity Collection Permits to the Negotiation of Legally Binding Contracts

- Many developing countries already have a *permit mechanism* in place for approving biodiversity collection or export. In these countries, it is probably easiest to require that a signed contract be approved by the government before issuing a biodiversity collecting or export permit.
- Even in the case of academic collecting, it is important to require a collecting permit and a research agreement. Many academic natural products research groups engage in "basic" research on collected biodiversity specimens, but retain the right to transfer interesting discoveries to the private sector at a later date for commercial evaluation and product development.
- However, if biodiversity collecting is intended solely for educational or basic research purposes, with no possibility of commercial application, it is unnecessary to stringently regulate this activity.

The recommended genetic resources regulation should give legal authority to each permit issuing organization to sign genetic resources contracts on behalf of the Government of Jamaica. Some draft contracts should be reviewed by an independent Genetic Resources Advisory Authority comprised of stakeholders and representing multidisciplinary expertise relevant to the type of genetic resources collection in question. It is not necessary to create a standing committee for this purpose. Volunteers should be called up as needed. Permit issuing organizations should be informed that *under no circumstances* are they to issue collection permits before an approved contract has been signed.

Genetic resources contracts should be available for use not only by the public sector, but by Jamaican private organizations as well, including NGOs, private enterprises, and even rural communities or ethnic groups. In order to enter into a valid contract, it will be necessary to identify a foreign recipient of the genetic resources or traditional knowledge, and a Jamaican provider of these material or information. Both provider and recipient would sign the contract to make it a legally binding document.

Should a recipient and provider sign a contract which calls for collection of traditional knowledge from Jamaican herbalists, it will be necessary to obtain local prior informed consent from the relevant herbalists before collection can proceed. These concepts of rights to traditional knowledge, as well as prior informed consent, are discussed below.

All organizations, public and private, would be required to submit draft signed contracts to the proposed independent and multidisciplinary Genetic Resources Advisory Authority for approval. These draft signed contracts would be made valid by a third signature provided by the Chair of this Authority. *All* contractual agreements would be subject to the same national benefit sharing formula to ensure equitable distribution of monetary benefits.

Guarantee Revenue Sharing Through Contractual Means

- *Research agreements* or *material transfer agreements* should be employed to define sharing of benefits generated by development of genetic resources or traditional knowledge, including monetary benefits.
- Contracts adapted to this purpose should incorporate several basic features, including definition of ownership of the rights to the collected genetic resources or traditional knowledge, terms and conditions of the transfer of the collected resources (including permitted uses), and compensation for the transferred material.

Two types of contracts, research agreements and MTAs, are recommended (see Box 12.1 for a summary of contractual terms). *Research agreements* are intended to define a research collaboration between Jamaican organizations and foreign for-profit research partners or academic partners engaged in research with clear commercial applications, such as natural products chemistry. It is recommended that draft research agreement be negotiated and signed by the foreign recipient of genetic resources and by the Jamaican provider of these resources. This draft research agreement should then be passed to the Jamaica Genetic Resources Contracts Review Committee (described below) for review and final approval.

MTAs are simple contracts to be used when substantial research collaboration is not anticipated. The MTA would be best used when a Jamaican provider organization is only facilitating access for non-commercial use such as academic collecting for taxonomy or ethnobotany, or for such routine purposes as teaching students. Their purpose is to define permitted uses of biodiversity taken out of Jamaica, and to reserve Jamaica's right to share in any benefits so derived, if any. It is recommended that MTAs not be subject to the same scrutiny as research agreements. It would *not be necessary* to obtain independent review by the Genetic Resources Advisory Authority. All MTAs should be pre-approved by the Genetic Resources Advisory Authority.

The Role of Government in Contract Review and Approval

- It is recommended that governments not play a direct role in private party negotiations, but rather retain the right to review draft contracts, and either approve them, reject them, or return them for modification, providing detailed comments and suggestions.

Box 12.1. Basic components of genetic resource material transfer agreements.

The following provisions are derived from published *material transfer agreements* (MTAs), which have been adapted for genetic resources utilization (Putterman 1996). Taken together, these comprise basic terms for a generic genetic resources research contract:

- *Genetic resources* are defined as tangible property, and ownership of this property is according to land use. Samples gathered from Crown land are publicly owned, samples from private land are owned by the landowner, and samples from communal land are owned by the community.
- Value-added research materials are defined as intellectual property according to inventorship.
- An option is provided to define intellectual property rights to *traditional knowledge* by transferring traditional knowledge confidentially as trade secrets.
- An option is provided to allow representatives of indigenous or other rural communities to sign on directly as parties to the MTAs, and a procedure for obtaining *prior informed consent* is outlined.
- Monetary and non-monetary compensation to the provider for supplying genetic resources or value-added research material to the recipient is specified.
- The recipient is free to conduct research and development with transferred material and to acquire intellectual property rights to inventions. Ownership of intellectual property is awarded according to inventorship, and shared inventorship is possible.
- Deferred compensation to the provider upon commercial development of the recipient's intellectual property derived from the transferred material is specified, including royalties and sourcing agreements. Monetary benefits are distributed through a trust fund mechanism where specified.

- It is recommended that governments create an *independent multidisciplinary committee* to review draft contracts, because it is highly unlikely that a single government agency has the technical expertise to perform this role.
- This proposed Genetic Resources Advisory Authority should include, as appropriate, scientists from relevant disciplines, ministerial staff, a contracts attorney, an NGO, and a representative with expertise in business.
- The committee would only convene *as needed to review collecting applications*, keeping regulatory costs low. Members would also pledge their availability to act as advisors to projects under negotiation, to fulfill government's need to maintain a predictable and transparent approach to regulation.
- Members of the Genetic Resources Advisory Authority would be required to sign confidentiality agreements.
- Depending on the availability of technical expertise, it may be advisable that the government *publish* a set of minimum acceptable terms for contracts to simplify the process of contract negotiations.

It is strongly recommended that government not play a direct role in private party negotiations. Rather, government should retain the right to review draft private party contracts, and either approve or reject them (rejection should be accompanied by a detailed explanation and suggestions for renegotiating acceptable terms). Because no single government agency in Jamaica has the technical expertise to perform this role, it is recommended that the government create an independent multidisciplinary committee to review draft research contracts. The NRCA is the logical agency to coordinate contractual review, given its role in issuing biodiversity collection permits, although this coordination role might also be appropriately placed within the Ministry of Commerce and Technology. A precedent already exists for independent review of regulatory decisions, whereby the NRCA draws upon outside scientific expertise for making decisions on the granting of export or import permits for endangered species, utilizing the CITES scientific authority described previously.

Within the Government of Jamaica, a precedent already exists for linking the review of draft contracts to licenses or permits. As part of a utility privatization strategy, the Office of Utility Regulation grants licenses to private entities wishing to function as electric utilities. The Office of Utility Regulation requires that draft contracts defining the terms under which electricity will be sold to consumers be submitted by applicants for approval prior to the granting of a utility license. Contracts are reviewed with consumer protection criteria in mind.

The Genetic Resources Advisory Authority should provide appropriate multidisciplinary expertise to apply consistent and independent criteria to review draft research agreements. Upon receipt of a draft research agreement, the coordinator of this Authority would contact one expert in each of the following areas to review the contract:

- A scientific representative from the relevant discipline (e.g., natural products chemistry, botany, agriculture, ethnobotany, etc.);
- A representative from the permit issuing organization in Jamaica;
- A lawyer with expertise in contracts;
- A person representing the organization with jurisdiction over lands covered by the proposed genetic resources collection;
- If the land in question is being managed with the help of an NGO, it would be appropriate to invite a representative of this NGO; and,
- A representative of private enterprise in Jamaica.

Suggested criteria by which the Genetic Resources Advisory Authority should evaluate draft research agreements include the following:

- Does the agreement clearly define the proposed research collaboration?
- Are rights to the transferred material and to subsequent derivatives or inventions clearly defined?
- In particular, and only if applicable, are community rights to tangible property or traditional knowledge clearly defined?
- If traditional knowledge is to be transferred, does the agreement include a trade secrets mechanism such as a confidentiality agreement?
- Does the agreement adequately describe how community prior informed consent was or will be provided?
- Does the agreement define how monetary or other benefits will be shared?
- Does the agreement include a reporting mechanism?

Blanket Agreements for Routine Teaching and Research Purposes

Because some collecting activities are purely academic, including collecting done for teaching purposes, it is recommended that the Government of Jamaica offer a simple variation on a MTA which would explicitly forbid the recipient from using the material for commercial purposes, or from transferring the material to third parties without written consent. It is recommended that the government negotiate *blanket agreements* with academic institutions to simplify routine transfers of genetic resources for teaching and research purposes. These blanket agreements would allow the use of pre-approved MTAs without the need for further government review.

For example, the Discovery Bay Marine Laboratory hosts a large number of students and foreign scientists every year, providing research and teaching facilities for a variety of basic research activities. It would be highly impractical to require every visiting scientist or student to apply for a separate permit with the government. Rather, the laboratory should negotiate a blanket agreement which would require every visiting scientist and student to sign a simple MTA forbidding any commercial use of collected material, or transfers to third parties for this purpose.

A Note on Compliance with Genetic Resources Regulations

It is impossible to prevent dishonest people from smuggling genetic resources samples out of Jamaica. The suggested regulations presented here are intended to give a simple framework for those seeking to comply with Jamaican law. For those who intend to break the law, these regulations provide the Government of Jamaica the legal standing to sue in a court of law. With the advent of electronic databases accessible by the internet, it is not difficult to monitor global patent systems. Because patent offices require full disclosure of inventions, it is possible to run periodic checks on patents in the industrialized world, perhaps in collaboration with international NGOs or legal firms willing to provide *pro bono* services. This can be done very inexpensively, without the need to create costly databases and hire dedicated staff.

Second Model Component: Establish Sui Generis (Novel) Rights to Tangible Property and Traditional Knowledge

- In order to define who has the right to participate in and benefit from the negotiation of contracts involving a transfer of genetic resources or traditional knowledge, it will be necessary to create rights to both the tangible and intangible (intellectual property) manifestations of these.
- *It is strongly recommended that governments refrain from nationalizing genetic resources, in order to make room for the creation of local rights, including community rights.* Local resource tenure systems are necessary for the creation of local incentives for sustainable biodiversity management.

In order to define who has the right to participate in and benefit from the negotiation of research contracts involving a transfer of genetic resources or traditional knowledge, it will be necessary to create rights to both the tangible and intangible (intellectual property) manifestations of these. Currently there are no regulations in Jamaica defining rights to genetic resources and traditional knowledge. Tangible property includes the physical embodiment of genetic resources and value-added research material derived from these. Intellectual property in this case refers to traditional knowledge rather than conventional notions of intellectual property such as industrial inventions. *In defining genetic resources rights, it is strongly recommended that the Government of Jamaica refrain from nationalizing these rights, in order to make room for the creation of local rights, including community rights.* A large and accumulating body of evidence suggests that local resource tenure systems are necessary for the creation of local incentives for sustainable resource management (for example, see BCN 1997; Posey 1996).

Genetic Resources as Tangible Property

- Tangible property includes the physical embodiment of genetic resources and simple research material derived from these, such as extracts.
- It is necessary to create tangible property rights to genetic resources found on public land (such as protected areas, submerged lands, etc.), and to define genetic resource rights for private landowners if land can be privately owned.
- Community resource rights can be defined for community land, or for land traditionally occupied by rural communities.
- Even if national law does not recognize community resource rights, it is still possible to define community rights to genetic resources in a *de facto* manner by contract. A portion of benefits flowing from genetic resources sampled on land adjacent to local communities can be returned to these communities according to the terms of the negotiated research agreement or MTA.

The definition of tangible property includes resource rights to genetic resources found on public land (including national parks, forest reserves, all submerged land including coastal shelves, and other Crown lands), as well as genetic resources found on private land and on community land, such as that owned by Maroon communities. Note that creating community rights to the use of genetic resources may prove the single most important measure available for creating local conservation incentives. Although protected area land may be property of the Crown, it is still possible to define community rights to genetic resources in a *de facto* manner by contract. In this scenario, a portion of benefits flowing from genetic resources sampled on land adjacent to local communities will be returned to these communities according to the terms of the negotiated research contract (for example, see Rubin and Fish 1994).

Treat Local Inventions and Traditional Knowledge as Intellectual Property

- "Intellectual property" for this purpose refers to traditional knowledge, innovations and practices, rather than to conventional notions of intellectual property such as industrial inventions.
- Numerous legal mechanisms to recognize and create rights to traditional knowledge have been proposed; however, many of these posit costly bureaucracy to track registered "inventions", or they create a legal basis for ownership which would be impossible to verify against fraudulent claims. For this reason, it is recommended to limit protection of traditional knowledge to that which is attainable through a modification of *industrial trade secrets legislation.*
- Modification of industrial trade secrets legislation would give communities the right to maintain traditional knowledge as confidential "trade secrets".
- A confidentiality clause could be written into research agreements defining use of traditional knowledge, whereby the recipient of such knowledge would be granted the right to use it in research and development, but could not divulge the knowledge publicly.
- Should the transferred traditional knowledge yield marketable products, benefit sharing arrangements in the contract would guarantee a premium benefit to the providers of the knowledge.
- *Use of traditional knowledge, confidentially or otherwise, should be linked to a prior informed consent mechanism*.

Numerous legal mechanisms to recognize and create rights to traditional knowledge have been proposed (for example, see Jabbour 1983; Posey 1996; Singh 1996; Swaminathan 1996). However, many of these proposals posit the development of a costly bureaucracy to track registered "inventions", or they create a legal basis for ownership which would be impossible to verify against fraudulent claims. It is recommended that the Government of Jamaica create a simple *sui generis* mechanism based on trade secret legislation to protect the rights of the holders of traditional knowledge. Trade secrets are a form of intellectual property protection, and trade secret legislation is a requirement for signatories to the WTO Agreement (Barton 1994b).

Trade secrets are a class of intellectual property which confers the legal right to withhold information on inventions. In the United States, a model statute called the Uniform Trade Secrets Act has been adopted by a majority of states. Under this legislation, information is eligible for trade secret protection if it derives independent economic value from not being generally known and is the subject of efforts that are reasonable under the circumstances to maintain its secrecy. In practice, trade secrecy is attained through *confidentiality agreements* and other contractual mechanisms. Information may be "misappropriated" (and hence, property rights violated) by either unauthorized use or disclosure of the trade secret or by acquisition of the trade secret by "improper means", including theft, bribery, misrepresentation, breach of duty to maintain secrecy, or espionage.

It is recommended that the Government of Jamaica pass a Traditional Trade Secrets Act which confers the legal right to withhold information on traditional knowledge. In this instance, traditional knowledge would be eligible for traditional trade secrets protection if it derived potential economic value in Jamaica from not being generally known and if it were the subject of reasonable efforts to maintain its secrecy. Herbalists and other traditional knowledge holders who wished to share their knowledge for sustainable use of genetic resources, including R&D, would have the right to insist on adding a *confidentiality clause* to relevant research agreements or MTAs. The confidentiality clause, discussed in Box 12.2, would treat the transferred traditional knowledge essentially as any industrial trade secret, allowing the knowledge provider to retain control over who uses the knowledge and how it is used.

Note that this concept of "traditional trade secrets" directly clashes with the notion of *academic freedom* as practiced by, for example, ethnobotanists, whose trade requires them to publish traditional knowledge in scholarly journals. It will be up to the individual knowledge holders, or the wider rural community, to decide whether or not to allow academic publication of traditional knowledge.

Although currently there are no industrial trade secrets laws in Jamaica, their eventual creation is assured given that Jamaica is a party to the WTO Agreement, which requires this under TRIPs. Use of traditional knowledge, confidentially or otherwise, should be linked to a prior informed consent mechanism as described in the following section.

Third Model Component: Develop Prior Informed Consent Procedures

- In order 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" for the utilization of genetic resources.

At the national level, setting up a Genetic Resources Advisory Authority, as suggested above, would be sufficient to ensure prior informed consent of the Government of Jamaica. Prior informed consent for collection in national parks, whose management has been delegated to local NGOs, should be coordinated by the managing NGO. It is strongly recommended that managing NGOs enlist local community opinion when weighing prior informed consent decisions. Implementing a workable prior informed consent requirement at the *community level* may be difficult, due to the large number of stakeholders involved. There is a critical role for NGOs in facilitating prior informed consent decisions by local communities. It is highly recommended that the Government of Jamaica encourage NGOs to become involved in the process of obtaining prior informed consent from local communities, and in monitoring subsequent agreements.

Implementing a Local Prior Informed Consent Procedure

- *Local* resource tenure, including *community* resource tenure, has been shown to create local conservation incentives. One way of giving communities the means to control resource decisions is to legislate a requirement for local prior informed consent.
- In practice, implementing a workable prior informed consent requirement at the local level may be difficult, due to the large number of stakeholders involved. There is a critical role for NGOs in facilitating prior informed consent decisions by local communities.
- National policies on community prior informed consent could range from actually holding community meetings with all local communities involved to merely posting notices in local newspapers or informing local government or community leaders of proposed projects and inviting public comment over a specified time period.
- Regardless of the procedure chosen, the owners or trustees of rights to genetic resources or traditional knowledge should understand the goals of the proposed sustainable use, including potential development of new products, their rights to tangible or intellectual property to be transferred, and opportunities to participate in or benefit from the proposed project.

National policies on community prior informed consent could range from actually holding community meetings with all local communities involved to merely posting notices in local newspapers or informing local government or community leaders of proposed projects and inviting public comment over a specified time period. Regardless of the procedure chosen, the minimum information describing proposed genetic resources projects that is recommended for making prior informed consent decisions is listed in Box 12.2

Note that creating a local prior informed consent requirement for genetic resources sampling may drive collectors to focus their efforts on Crown lands unencum-

Box 12.2. Minimal information necessary for prior informed consent decisions.

Responsibilities

It is the responsibility of the collector to ensure that this procedure is followed. In the case of *traditional knowledge* or community genetic resources, all contract negotiations shall include facilitators (e.g., local NGOs) who shall possess the necessary legal and business skills to negotiate fair terms and conditions of the transfer of resources or knowledge on the community's behalf.

Information Requirements for Prior Informed Consent

The collector shall ensure that the following information is communicated to stakeholders, whether through written or oral means, as appropriate:

- The purpose of the proposed research, including plans, if any, for commercial research and development;
- The research plan, including options, if any, for participation by stakeholders;
- Disclosure of the potential value of transferred resources or knowledge;
- Potential outcomes, including the likelihood of commercial success;
- Rights available to stakeholders under the law; and,
- Options for benefit sharing, including a full description of immediate and deferred or contingent benefits, the use of trust funds to capture monetary benefits, the possibility of in-kind contributions such as medical care, and so on.

Confidentiality

Both collectors and stakeholders have obligations regarding confidentiality, and collectors shall inform stakeholders of these obligations:

- Transferred knowledge may be regarded by stakeholders as their intellectual property. The collector shall inform stakeholders of their right to insist on treating transferred knowledge as *confidential* trade secrets. If requested to, the collector shall include a confidentiality clause in research contracts or *material transfer agreements* (MTAs) to ensure trade secret protection.
- The collector shall inform stakeholders that all contracts may contain proprietary information and if so, must be treated as *confidential* by all parties. While local communities shall be privy to details of contractual negotiations, it is recommended that written copies of signed research contracts or MTAs remain only with the collector and with the local facilitator, such as a local NGO. Redacted versions of contracts should be made freely available.

Reports and Monitoring

Stakeholders shall receive regular research reports, at least every six months, in order to foster trust and to encourage realistic expectations of the possibility of long-term benefits such as the development of commercial products.

Full Disclosure and Authorized Signatures

Full disclosure of how *prior informed consent* was obtained shall be included as an attachment to all negotiated draft research contracts or MTAs. In the case of local communities, this attachment shall include signatures of proper and acknowledged leaders of these communities, indicating that prior informed consent was given by said communities and that facilitators, such as local NGOs, were indeed authorized to negotiate research contracts or MTAs on behalf of these communities. This attachment, providing full disclosure, shall be necessary and sufficient for obtaining a *certificate of prior informed consent* from the government agency issuing collection permits.

bered by community resource tenure claims, including forest reserves and submerged lands of the coastal shelf. This is anticipated because sampling on such lands would require obtaining prior informed consent from only one entity, the government itself or perhaps a managing NGO, while in return the collector stands to gain access to a wide range of habitats or species. The alternative, obtaining prior informed consent from a large number of private landowners or from (at this point, largely hypothetical) managed lands which may have a community resource tenure system in place, could be costly and time consuming by comparison. For this reason, a national benefit sharing formula as described below would be crucial to ensuring that benefits from genetic resources utilization on Crown lands filter back to local communities.

It is recommended that the government require collectors of traditional knowledge to obtain prior informed consent from individual herbalists before being allowed to collect this knowledge. Herbalists should be given the right to insist on signing a *confidentiality clause* defining their right to transfer their knowledge as confidential trade secrets, and defining benefit sharing arrangements as well under the contract and under the national formula. Note that prior informed consent can be obtained on a case by case basis once collection has been approved and commenced.

Fourth Model Component: Create a National Benefit Sharing Formula

- A national formula to convert a portion of monetary income derived from new product development into public goods is necessary to ensure fair and equitable sharing of benefits from genetic resources utilization.
- An ideal revenue sharing arrangement would allow domestic research partners, including private companies, NGOs, and local communities, to keep a portion of their income in order to maintain incentives for private investment and innovation, while the remainder is set aside by government and applied to the creation of public goods.
- Developing a set of guidelines or even fixed percentages defining benefits sharing on up-front and deferred income (e.g., royalties on future products) would streamline the process of permit approval.

It is recommended that the Government of Jamaica develop a simple national benefit sharing formula that will streamline the process of contract negotiations and permit approval. For this purpose, it is important to distinguish between the academic and private sector use of genetic resources, and between up-front and deferred compensation.

Up-front monetary compensation in exchange for access to genetic resources is usually not possible with academic collectors. Even for private sector collectors, such as pharmaceutical companies, up-front compensation is usually relatively small. Because it is desirable to encourage research *collaborations* between local scientists and foreign organizations, including private companies, it is not recommended that the Government of Jamaica require the sharing of any more than a small percentage of up-front income realized by Jamaican collaborators. For example, in Costa Rica, the National Biodiversity Institute (INBio, a private non-profit Costa Rican research organization) shares just 10% of its up-front income from its bioprospecting contracts with the private sector. The money is deposited into a fund specifically earmarked for national parks conservation. The remaining 90% is used to pay the costs associated with INBio's research collaborations and for capacity building.

By contrast, deferred compensation, such as royalties, can be relatively large and, in any event, royalty income is usually provided free and clear of business expenses (i.e., it is all net income). For this reason, it is recommended that the Government of Jamaica establish a national benefit sharing formula which allows the original providers of genetic resources or traditional knowledge to keep a portion of this income, and sets aside the greatest percentage royalty income for biodiversity conservation, community economic development, or other government expenses. For example, national regulations might require that 10% of royalty income be due the stakeholders who gave their prior informed consent for collection activities to proceed, 10% be due the providers of the genetic resources (i.e., that Jamaican organization that signed the original contract), 40% of the income be due a biodiversity trust fund earmarked to pay for conservation and sustainable use activities in *all* protected areas, and the final 40% be returned to the national treasury for general government expenditures.

Genetic Resources Policy Applications

Scenario Analysis of Applications of Genetic Resources Policy Options

Four scenarios are analyzed for the manner in which the value of genetic resources varies according to different policy options.

Zero Compensation (Status Quo)

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. While scientists seeking access to Jamaican genetic resources are required to complete an NRCA questionnaire describing the proposed research, the Wildlife Research Application Form does not function as a research contract, nor does it define legal claims to collected resources. The government retains only veto power over proposed genetic resources projects.

Minimal Contingent Compensation (Royalties)

In this scenario, the Government of Jamaica would require all applicants for access to genetic resources or traditional knowledge to sign a research contract or MTA guaranteeing a royalty payment (contingent compensation) upon commercialization of any inventions derived from the transferred resources. Royalty claims are a risk free mechanism to share some of the benefits of genetic resources utilization, in the sense that the provider is not required to invest in research or collecting activities, only to allow access to the resources. However, royalty payments allow biodiversity rich source countries to capture only a relatively small portion of the total value of genetic resources. Because the process of research and development rarely yields successful commercial products, even in the case of the development of new herbal products and phytomedicines, it is unlikely that this strategy of minimal contingent compensation will yield *any* commercial benefits to Jamaica.

Contingent Compensation with Production (Royalties and Sourcing Rights)

In this scenario, the Government of Jamaica would again require all applicants for access to genetic resources or traditional knowledge to sign a research contract or MTA. 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. For example, the US National Cancer Institute incorporates language on sourcing rights into its standard natural products collection contract (NCI 1995). This strategy also relies solely upon contingent benefits (that is, it relies solely upon the successful development of new commercial products), and as such, this benefit sharing scheme is also unlikely to yield *any* benefits to Jamaica.

Up-Front Compensation for Value-Added Products (Rental Fees plus Royalties and Sourcing Rights)

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

It is instead recommended that the Government of Jamaica encourage the development of local value-adding research services, which could provide biodiversity samples, or advanced research material derived from these, directly to private industry for a fee. Examples of relatively low cost and technologically appropriate research activities, which add significant value to genetic resources, include biodiversity inventories (especially plant inventories), local studies of the efficacy of medicinal and aromatic plants, simple techniques for processing plant samples into botanical extracts, or soil samples into microbial cultures. "Rental" fees for access to this research material 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 research material can be derived from any source of genetic resources material, whether from plants, insects, or microbes. Research material can be quite basic, such as plant extracts, or it can be quite advanced, such as new plant based medicines with actual data derived from clinical trials. The cost of these different forms of research material to a foreign collaborator will vary according to the amount of value-adding research invested in the source country.

Note that value-added genetic resources research material *is* difficult to come by, particularly marine material. Developing the capacity to supply this material to the private sector would provide Jamaican organizations a clear competitive advantage over other sources of genetic resources material. Genetic resources utilization under this regulatory scenario would require a 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. Modest investments in value-adding technology would also be required. Several bilaterial and multilateral agencies have taken an interest in supporting these "bioprospecting" activities in recent years.

Novel Paradigms for Public and Private Sector Collaboration in the Sustainable Use of Genetic Resources

A new paradigm is emerging globally in which biodiversity rich developing countries seek to participate more actively in the development and marketing of new commercial products derived from natural products. Additionally, awareness among consumers is growing of the potential for good business practice to support environmental conservation, international development, and the welfare of indigenous peoples. However, policy alone is insufficient as marketing biological material for genetic resources development is a competitive business. In order to develop mutually beneficial collaborations, developing countries must be able to offer genetic resources and value-adding services to private firms in a manner which increases the likelihood of finding profitable new products, reducing the financial risk involved.

Advantages that may attract private firms to develop natural products collaborations with developing countries include local knowledge of flora, fauna and habitats, sample quality, sample resupply, adherence to local regulations, lower business costs, the opportunity to leverage additional capital, and access to markets. A novel strategy to encourage local investment in joint natural products enterprises in developing countries includes technology franchising, in which a senior firm grants limited rights to a valuable proprietary technology to a small or medium enterprise in exchange for certain returns generated by that technology. Joint venture creation between firms is another option.

Two Jamaica Case Studies Revisited

Two examples of ongoing and unresolved issues in genetic resources utilization in Jamaica were introduced at the start of this chapter. In the following section, these issues are re-examined in light of the policy recommendations made above, and alternate outcomes based upon application of the recommendations are explored.

Marine Bioprospecting in Jamaican Coastal Waters

Of the half-dozen or so instances of foreign researchers undertaking widespread collecting of diverse marine species for research involving biomedical, agrochemical, and cosmetics applications, not a single project involved sharing of benefits other than sharing of marine taxonomic voucher specimens with the University of the West Indies. Future applications for research permits may languish without a proper policy in place to capture genetic resources benefits. Under the proposed genetic resources regulations outlined in this paper, foreign scientific organizations, whether private companies or non-profit oceanographic research institutes, would be required to contact the relevant government department (e.g., the NRCA or the Ministry of Commerce and Technology) to discuss conditions for obtaining a collecting permit. The government would inform the applicant about current regulations, including the requirement to obtain prior informed consent from the appropriate stakeholder and to negotiate an approved research agreement or MTA. The government 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 (e.g., the Montego Bay Marine Park) and UWI is functioning as the local counterpart organization. To begin the process, UWI would contact the MBMP Trust to obtain prior informed consent. Depending on the local regulations, the MBMP Trust would either give its informed consent directly following discussions on benefit sharing, or would first hold meetings with local stakeholders to discuss their preferences directly (if collection was planned elsewhere within Jamaica's EEZ, UWI would contact the NRCA directly to obtain informed consent, because such submerged land is administered by this agency).

UWI would negotiate a research agreement with the foreign research organization, consulting with the MBMP 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 Genetic Resources Advisory Authority for advice on policy requirements at any time.

Benefits requested by the MBMP 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, to pay for park operations or to set up a micro-enterprise fund. The proportion of monetary income set aside for benefit sharing would be set by law. The MBMP Trust in turn could use this income to fund park operations, to set up a community micro-enterprise fund, and so on.

When a draft contract has been agreed upon, it would be signed by all parties and submitted to the Genetic Resources Advisory Authority along with proof of prior informed consent and a completed permit application for review. The Authority would either approve the contract and sign the permit, or reject the contract. Rejection would be accompanied by a detailed explanation and the opportunity to renegotiate the draft agreement.

Biotechnology Based Improvement of Jamaican Papaya Germplasm

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% to 40%, while 1998 losses have been 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, they would probably fall under the purview of the genetic resources regulations because the lines were subject to some breeding in Jamaica in the early 1980s. 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 MTA 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 MTA 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.

Chapter 13

Ecological Economic Decision Support Models for Coastal Zone Management in the Developing Tropics—Results, Dissemination, Policy Applications, and Future Directions

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Coral reef ecosystems throughout the world are in serious decline, being threatened by both localized anthropogenic stress as well as regional and global phenomena such as global warming (Bryant *et al*. 1998; Hodgson 1999; Hoegh-Guldberg 1999; Jameson *et al*. 1995; Wilkinson 1998; see Chapter 1). There may be some cause for optimism due to the remote locations of many coral reefs, the effective management of some, and the potential capacity of these ecosystems to recover (Wilkinson 1998), yet it is clear that effective integrated coastal zone management (ICZM) is necessary to help prevent further significant depletion. This final chapter serves to summarize the results of the research presented in this publication regarding the development of decision support models for the management of coral reefs in the developing tropics. The dissemination strategy is outlined and comments are offered regarding potential policy applications and future directions for research.

As introduced in Chapter 1, ICZM guides jointly the activities of two or more sectors or activities in the planning, development and implementation of projects. More formally, it is "...the integrated planning and management of coastal resources and environments in a manner that is based on the physical, socioeconomic, and political interconnections both within and among the dynamic coastal systems..." (Sorensen 1997). Or similarly, "ICZM is a process of governance and consists of the legal and institutional framework necessary to ensure that development and management plans for coastal zones are integrated with environmental (including social) goals and are made with the participation of those affected. The purpose of ICZM is to maximize the benefits provided by the coastal zone and to minimize the conflicts and harmful effects of activities upon each other, on resources and on the environment" (World Bank 1996, p.2). Guidelines and procedures have begun to emerge for the development of ICZM (e.g., Bower *et al*. 1994; Chua 1993; Clark 1995; Pernetta and Elder 1993; Sorensen 1997; World Bank 1993a, 1996).

A critical element in ICZM is the *integration*—in particular, the horizontal integration across economic sectors and management agencies in the planning and implementation (e.g., Clark 1995; Sorensen 1997). Coastal activities must be considered jointly because of their interdependence and expected non-additive cumulative impacts. But how are multiple economic sectors or human activities to be considered together? How is concern for the maintenance of the coastal ecosystems, which directly or indirectly support economic activities, to enter into the decisions? What should be the decision-making framework for determining which activities should be allowed to occur within the coastal zone, how should they be developed and operated, and what level of activity should be permitted? On what basis should conflicts between competing coastal resource users be decided? Answering such questions necessarily involves the joint consideration of multiple system parameters, multiple criteria, and diverse value sets.

Ecological economic decision support models can play a critical role. The family of ecological economic models includes those that recognize the validity of achieving an economically efficient management solution, yet concurrently and explicitly consider the limitations necessarily imposed on the scale and type of economic activities due to the characteristics and capacity of the natural environment. Ecological economic decision support models for ICZM should also allow for the accommodation of information regarding the socio-cultural context of the management environment, which has a critical role to play in the development of policy.

What are the characteristics of a useful decision support model? First and foremost, a useful decision support model needs to be capable of answering specific and relevant policy questions. To aid in the design and creation of such a model, one must be able to draw from an existing body of policy relevant research. As noted by Ruitenbeek *et al*. (Chapter 8), there is a great deal of scientific information available on coral reef biology and ecology. However, much of this information is not directly "policy relevant" and of little help to decision-makers or directly in the creation of a decision support model. Second, a model must be able to be understood and used directly by the targeted client group. Inputs must be relatively easy to provide, runs easy to conduct, and results easy to interpret. Third, a distinction must be made between the use of models intended primarily for scientific inquiry and those intended primarily to inform decision-making and policy—models with highly experimental constructs should be avoided for use as decision support tools. The theory on which decision support models are based should be relatively robust. For example, concerning the use of ecological models intended for use in decision-making, Friedland (1977) notes that "The basic objective in not the discovery of previously unknown truths but the collection and integration of existing knowledge and its presentation in a form useful in the policy-making process." This has direct ramifications for what type of model may be most appropriate. Finally, decision support models should be amenable to modification and revision of the data components, the specified relationships within the model, and the development alternatives or scenarios considered by the model. Again, it is imperative that the needs of the users be kept in mind. A model that uses data that are no longer valid for a particular locale, whose underlying ecological economic relationships are no longer accurate, or allows for no further modification or alteration of the specified development alternatives or scenarios, will prove to be of little use in the long run.

Results of the Modeling Projects

In 1995, work commenced under World Bank Research Committee funding on two streams of research concerning coral reefs in the developing tropics, namely: i) cost-effectiveness modeling of management interventions (i.e., a question of the "supply" of biodiversity as an economic asset); and, ii) marine system valuation (i.e., a question of the "demand" for biodiversity). Essentially, the least-cost modeling attempted to identify the cost curve for interventions to improve coral reef conditions, where the effects of various policy interventions and economic activities are linked to overall coral reef health and costs associated with making improvements (Chapters 3, 4 and 8). The marine system valuation model sought to identify the benefits that can be realized from sustaining or improving coral reef conditions (Chapters 5, 6 and 7).

The broad objective of the research was to assist policy-makers in the management and protection of coral reefs (Huber *et al*. 1994; Huber and Ruitenbeek 1997). The establishment of a cost-benefit methodology appropriate for use on coral reef systems in the developing tropics, and on marine systems in general, will assist in identifying appropriate institutional and policy interventions to help realize economically efficient uses of coral reefs while considering the impacts on and role of the supporting ecosystem. Such a cost-benefit analysis (CBA) "package" is represented by the integration of the cost-effectiveness and valuation models (Chapters 9 and 10). Three case study sites were selected on which to test the methodologies: i) Curaçao, the Netherland Antilles; ii) the Republic of the Maldives; and, iii) Montego Bay, Jamaica.

Coral-Curaçao

Rijsberman and Westmacott (1996; Chapter 3) developed a cost-effectiveness analysis model for coral reef management and protection for the south coast of Curaçao. The decision support model was developed to facilitate communication among stakeholders concerning development directions and environmental management strategies; the analysis of impacts on coral reef health of planned developments through the discharge of wastewater and sediment, thereby integrating land-use, tourism and conservation planning; and, the analysis of the cost-effectiveness of management interventions designed to maintain coral reef health. The model utilizes a structured computer interface.

Results of three modeling scenarios (a reference status quo development scenario and two alternative growth scenarios) indicate that Curaçao is likely to experience significant declines in coral reef health and abundance over the next 10 years. However, the modeling also indicates that interventions involving environmental protection strategies can halt this trend and, in some case, lead to the recovery of reefs above their current state of health. Recommended interventions include combinations of sewage treatment, appropriate waste disposal, and reductions of refinery pollution; the implementation of alternative means of beach maintenance and the reduction of waste from manufacturing and shipping were found not to be effective (Rijsberman and Westmacott 1996; Chapter 3). However, Rijsberman and Westmacott (1996; Chapter 3) also note that the modeling results may be specific to the spatial scale examined and that these latter interventions may indeed be cost-effective and appropriate within a smaller, local context.

Rijsberman and Westmacott (1996; Chapter 3) stress that the utility of the modeling tool can only be demonstrated through an application that intimately involves stakeholders in the scenario building and decision-making process. Coral-Curaçao allows one to rank the measures and explore the formulation of various combinations of measures to achieve a specific coral reef cover and diversity target. For example, to achieve a target average coral cover of 14% and diversity of 50% (as indexed by the model), an initial investment of 310 million NAF with a yearly operation and maintenance cost of 6 million NAF would be required (Rijsberman and Westmacott 1996; Chapter 3).

Coral-Maldives

Westmacott and Rijsberman (1997; Chapter 4) developed a cost-effectiveness analysis model for coral reef management and protection for North and South Male in the Republic of the Maldives. As a model developed parallel with Coral-Curaçao, the objective was to investigate whether a model adapted for the Maldives (Coral-Maldives) would provide a useful decision support tool. Chapter 4 describes the model and the results of initial analyses.

As with Coral-Curaçao, the Coral-Maldives model was designed to allow decision-makers to determine the relative cost-effectiveness of various environmental management interventions for various economic development options in terms of the improvements in coral reef health that are achieved (i.e., using indices of coral reef cover and rugosity as proxy measures). In addition, the impacts of the scenarios can be seen in terms of economic, social and environmental indicators that are selected at the outset of the analysis by the model user. Policy priorities and feasible management alternatives were identified through discussions with government agencies. Given the nature of the impacts on the coral reefs in the Republic of the Maldives, management interventions focus on minimizing physical damage (Westmacott and Rijsberman 1997; Chapter 4). Westmacott and Rijsberman (1997; Chapter 4) illustrate the use of the model through the presentation of example cases.

Westmacott and Rijsberman (1997; Chapter 4) note that there are an array of indicators that may be used to describe the potential for success or failure of a coastal zone management strategy—although the model is somewhat flexible, the set of coastal zone management indicators that can be selected and examined by the user is necessarily limited. Moreover, the use of intervention cost-effectiveness measures as they relate to changes in coral reef health alone may ignore other strategies critical to the success of a particular ICZM program (e.g., public health issues). It is suggested that the results of modeling scenarios for decision support, in the formulation of development or management plans, be placed within the context of social goals and requirements. As with Coral-Curaçao, the model may not adequately reflect localized conditions at a spatial scale below that incorporated within the model's components.

The Valuation of Coral Reef Benefits

In the process of arriving at a measure of total economic value (TEV), economic valuation studies of natural systems most often distinguish use from non-use values, and direct use from indirect use values. These distinctions most often reflect the method of estimation. During the specification of the design of the coral reef valuation for the Montego Bay Marine Park, it was decidedly more useful to distinguish between three classifications of marine biodiversity valuation: i) "supply-oriented" production valuation methods (i.e., production function contributions of marine systems to economic value); ii) "demand-oriented" utility valuation methods (i.e., contributions of marine systems to the utility of an individual or society); and, iii) "profit-oriented" rent capture valuation methods (i.e., contributions of marine systems through the distribution of use values as captured rent, profits or value added; Huber and Ruitenbeek 1997; Ruitenbeek and Cartier 1999). For the latter category, the potential contribution of coral reef biodiversity through the development of a bioprospecting venture was examined.

Production Function Contributions—Montego Bay Marine Park

Direct local use values were estimated by Gustavson (1998; Chapter 5) for two broad categories of uses—the near-shore fisheries and tourism. Indirect use values associated with coastal protection were also estimated. These local uses of the Montego Bay Marine Park waters were identified as the most significant during the final study site application, as well as being of the highest policy priority. The values reported by Gustavson (1998) represent the extent of the reef-derived production contributions at risk of being lost if conservation efforts prove inadequate.

Tourism services in Montego Bay include accommodations, food and beverage services, entertainment (including independent water sports and attractions), transportation, shopping, and other miscellaneous services. Net present value (NPV) estimates associated with tourism range from US$210 million (using a 15% discount rate) to US$630 million (using a 5% discount rate) in 1996. The NPV estimates in 1998 associated with fishing range from US$-1.66 million to US$7.49 million (constant 1996 dollars; using lower and upper estimate, respectively, of annual net values and a 5% discount rate; 10% and 15% discount rate estimates fall within this range). The NPV of the total amount of land at risk of erosion should the protective function of the coral reefs be compromised, based on approximately 250 acres being vulnerable, is estimated as US$65 million (constant 1996 dollars).

The median NPV from all local use values for the Montego Bay Marine Park was estimated to be US$381 million. Assuming a total reef area of 42.65 ha as a reference case, this translates to US$8.93 million/ha or US$0.893 million ha^{-1} yr^{-1} on an annualized basis (assuming a 10% discount rate).

Contributions to Utility—Montego Bay Marine Park and the South Coast of Curaçao

Spash *et al*. (1998; Chapter 6) utilized the contingent valuation method (CVM) to assess utility values associated with coral reef biodiversity in Montego Bay, Jamaica, and along the south coast of Curaçao. The study is particularly notable in that it examined utility values associated with a marine environmental resource (i.e., coral reef quality), which had previously been neglected by previous investigations. Moreover, the research made advances towards explicitly addressing sources of bias due to lexicographic preferences that arise when a respondent is unwilling to accept any trade-offs for the loss of a good or service (i.e., in seemingly refusing to make trade-offs, they are not behaving in accord with economic theory). For zero bids, distinctions were made between those who lack the income, regard the improvement as unimportant, prefer to spend money on other goods or services, or were protesting having to make such a choice. Among those giving protest zero bids, and thus providing a source of bias, were those who are "free riders", feel the payment is not an adequate solution, lack faith in the proposed institution, or reject the payment mechanism. The survey also explored the extent of right-based ethical positions that would be compatible with lexicographic preference. To aid in the comparison with the results of the local use and bioprospecting valuation studies in Montego Bay, the CVM was also designed to allow for the separation of the direct use values from the indirect and non-use values.

Survey respondents were asked to contribute towards a trust fund that would be managed by a marine park to increase biodiversity within the park boundaries. The payment was to be made on a per annum basis for five years and lead to a 25% increase in coral reef cover. Bid curve analysis (i.e., tobit analysis in combination with maximum-likelihood estimation) provided further information regarding the variables determining variations in WTP and refined the WTP estimates. At the sample means, WTP was estimated as US$2.08 per person in Curaçao and US$3.24 per person in Jamaica (Spash *et al*. 1998; Chapter 6). The difference was explained as due to the difference in the mix of tourists and local residents, with Jamaicans willing to pay almost double their counterparts in Curaçao. Using typical visitor and local population profiles and a 10% discount rate, this leads to a total estimated WTP of approximately US$4.5 million in Curaçao and US$20 million in Montego Bay, Jamaica (Spash *et al*. 1998; Chapter 6).

Potential Bioprospecting Contributions—Montego Bay Marine Park

The estimating model for Montego Bay bioprospecting focused on average social net returns utilizing localized cost information for Jamaica and benefit values and success rates based on proprietary information for marine products in the Caribbean (Ruitenbeek and Cartier 1999; Chapter 7). Parametric model assumptions included the specification of the species-area relationship and the institutional revenue sharing relationship (i.e., a contingent net profit share and a fixed sampling level fee). Sensitivity analysis explored the effects of variations in model parameters on the value estimate, including variations in the total area of available reef substrate with live cover and the specification of the species-area relationship as co-determinants of the expected number of samples available for testing. Other model scenarios included a fixed sampling fee only, blended revenue shares, high research and development (R&D) costs, low "hit rates", and a shortened sampling program. A marginal benefit function was derived which related the value or "price" of marine biodiversity to coral reef abundance.

A "base case" value of US$70 million was estimated for the reefs of the Montego Bay Marine Park, of which approximately US$7 million (i.e., 10%) would realistically be able to be captured by Jamaica under typical royalty or rental arrangements (Ruitenbeek and Cartier 1999; Chapter 7). The marginal value of reef for bioprospecting was found to be US$530,000/ha or US$225,000/% change in coral reef abundance (corresponding to a local Jamaican planning price of US$22,500/% change in coral reef abundance).

The Identification of Least-Cost Interventions—Montego Bay Marine Park

Similar to the Coral-Curaçao and Coral-Maldives models, Ruitenbeek *et al*. (1999a; Chapter 8) applied a fuzzy logic methodology to identify the least-cost interventions that would lead to an increase in coral reef abundance within the Montego Bay Marine Park. Fuzzy logic procedures are utilized within an ecological reef impact model to generate a complex dose-response surface that models the relationship among coral reef abundance and various inputs within the context of the abiotic marine environment. This is linked to a non-linear economic model describing current and future economic activities within eight sectors, technical and policy interventions, and pollution loads in Montego Bay. Optimization provides insights into the most cost-effective means for protecting coral reefs under different reef quality targets.

In Montego Bay, Jamaica, up to a 20% increase in coral abundance may be achievable through the use of appropriate policy measures with a present value cost of US$153 million over 25 years (Ruitenbeek *et al*. 1999a; Chapter 8). The specific policy measures considered included installation of a sediment trap on the Montego River, the planting of trees in the upper watershed, installation of a waste aeration system, installation of a large-scale centralized treatment facility, agricultural extension to provide waste reducing technologies, installation of an outfall and pump station, improved household solid waste collection, and implementation of a hotel tax. Some interventions were found to be relatively cost-effective. For example, household solid waste collection, installation of an outfall, and use of a sediment trap on the Montego River would impose a present value cost of US$12 million and result in an improvement in coral reef cover of over 10% (Ruitenbeek *et al*. 1999a; Chapter 8).

One key demonstration of the research was that conventional methodologies for measuring cost-effectiveness may result in sub-optimal policy solutions when applied to complex systems. This is because cost-effectiveness analyses tend to assume the separability and independence of individual interventions and the ability to treat benefits separately from costs (often when benefits can not be defined). When dealing with highly complex systems such as coral reefs, synergisms, feedbacks and other interdependencies between individual interventions and the resulting level of coral reef health can invalidate the recommendations arising from individually assessed policy interventions that are assumed to be able to be applied in a sequential, step-wise fashion. For example, reforestation was found to be part of the optimal intervention set at coral reef improvement targets of 14% and 20%, but were not part of the optimal intervention set for a 15% or 16% improvement (Ruitenbeek *et al*. 1999a; Chapter 8). As noted by Ruitenbeek *et al*. (1999a; Chapter 8), this means that coral reef health targets, in reference to the extent of the derived benefits, must be established before policy interventions are pursued.

Integrating the Results for Montego Bay Towards an Efficient Level of Intervention

A synthesis of the separate coral reef valuation studies for the Montego Bay Marine Park allows one to arrive at a total value and a net marginal benefit (or price) function (Ruitenbeek and Cartier 1999; Chapter 9). In order to arrive at a marginal benefit function, relating price to changes in coral reef abundance, further assumptions were required regarding the relationship between the categories of values and coral reef abundance or quality. Specifically, a linear relationship is assumed between reef quality and local use values and non-use utility values. This is most likely not the case, but assuming a less simplified relationship cannot be justified given our current knowledge. Only the results of the bioprospecting valuation model (Ruitenbeek and Cartier 1999; Chapter 7) allowed the specification of a different functional form. As noted by Ruitenbeek (Chapter 9), total net marginal values will likely be over-estimated in some instances and under-estimated in others.

The total benefit attributed to the coral reefs of the Montego Bay Marine Park is estimated at US$470 million; every 1% change in abundance is likely to generate a marginal benefit of US$10 million or, alternatively, the marginal price of coral reef is approximately US$23 million/ha (Chapter 9). Most of the value is attributed to tourism. Coastal protection and non-use utility benefits also contribute, but to a much lesser extent. Existing fisheries and the potential development of a bioprospecting program have a negligible effect on marginal values (Chapter 9).

Using the marginal cost function as reported in the least cost intervention study for the Montego Bay Marine Park (Ruitenbeek *et al*. 1999a; Chapter 8), in conjunction with the marginal benefit estimates, allows one to arrive at a global optimization. As reported by Ruitenbeek (Chapter 9), an optimal improvement of coral reef abundance of 13% is suggested (i.e., from approximately 29% live cover as estimated from model equilibrium conditions—see Ruitenbeek *et al* 1999a; Chapter 8—to approximately 42% live cover), requiring net expenditures of US$27 million. The required interventions would involve 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 analysis suggests that this optimization is fairly robust to changes in the net economic benefit estimates—benefits would need to be increased by US$275 million or decreased by US$300 million for the target coral reef quality improvement to change by more than 2% (Chapter 9).

The Human Context of Coral Reef Use

In addition to the application of cost-effectiveness analysis, resource valuation or CBA, it is key that decision-makers comprehensively and systematically consider the social, cultural and economic context of policy development and ecological change. Such context or "human framework" information does not traditionally form part of such analyses, in which quantitative monetary indicators or measures are often applied within an "automatic evaluation" decision-making environment (Anderson 1991), restricting further interpretation of the appropriate or optimal levels and types of interventions and policies necessary.

The economic valuation methodologies applied in these projects were designed to enumerate the total benefits currently received from the coral reefs, through both production function contributions and human utility (as well as potential rent or royalty benefits from the development of marine bioprospecting ventures). Such monetary benefits will, in theory, reflect the local set of values. However, much is lost in reducing the social, cultural and economic information to a single value metric. This was demonstrated through the development and application of a rapid socio-economic assessment methodology to provide an understanding of the coral reef user groups of the Montego Bay case study site (Bunce and Gustavson 1998a; Chapter 11). Such information will better enable the adaptation of management strategies to the user groups' use patterns, management priorities, and available resources. In essence, "human framework" information assists in identifying an economically efficient outcome that is also socially and culturally viable. This information has demonstrated utility in the development of effective policies and programs for the Montego Bay Marine Park (Bunce *et al*. 1999; Chapter 2).

Policy Context and Advice

Case Study—The Capture of Rent Generated From the Use of the Montego Bay Coral Reefs

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 rent generated from direct uses to pay for the necessary management, and potential enhancement, of the resource. In other words, there are social costs associated with the conservation and management of the resource that should be paid by the users.

As a component of the local use valuation study (Gustavson 1998; Chapter 5), current existing government charges, which 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), although it 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.

In principle, license fees are collected to pay for the government costs of regulating and administering the business or activity. No information was available on the actual costs associated with regulating the reef-related activities, yet it is likely that in all cases these costs are not recovered based on existing fee schedules. It was found that 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. None of these funds are explicitly directed to pay for the management of the Montego Bay Marine Park. No other government or management agency fees or charges are specifically linked to either tourism or fisheries related activities in the area. 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 the general government collectorate and thus are not explicitly available for use in marine park management. The current interest of Montego Bay Marine Park in implementing user fees should be encouraged.

Case Study—Institutions and Policy Advice for Bioprospecting in Jamaica

Putterman (1998; Chapter 12) offers specific policy and institutional strengthening advice with respect to the incorporation of genetic resource use into ICZM in Jamaica as a potentially powerful tool for conservation and economic development. Genetic or molecular diversity, a measure of the biological diversity within species, can be the source of new pharmaceuticals, industrial products and agricultural varieties. Many strategies for research collaboration, as a risk-reducing strategy to maximize the ability to discover promising new chemicals or genes, may be employed; as well, many benefit sharing mechanisms and options for compensation exist (see Chapter 12). As noted by Putterman (1998; Chapter 12), there are currently no Jamaican policies to regulate access to genetic resources. A review of Jamaican institutions and policies lead to the following key recommendations (Chapter 12):

- In the design of a set of resources policy options, incorporate obligations under the Convention on Biological Diversity and the United Nations Convention on the Law of the Sea, as well as take account of the effect that policy-making will have on private sector activities;
- Regulate access to genetic resources up-front with permits and contracts to define rights to these resources before samples are collected or exported;
- Establish *sui generis* (novel) rights to tangible property and traditional knowledge in order to define who has the right to participate in and benefit from the negotiation of contracts involving a transfer of genetic resources or traditional knowledge;
- Develop prior informed consent procedures in order to give the legal owners of rights to genetic resources and traditional knowledge a means to control use of these resources; and,
- Create a national benefit sharing formula to convert a portion of monetary income derived from new product development into public goods to ensure a fair and equitable sharing of benefits from genetic resources utilization.

Potential bioprospecting net present values are small in comparison to current local use values associated with tourism and coastal protection (Gustavson 1998; Ruitenbeek and Cartier 1999; Chapters 5 and 7) and, as noted above, are expected to have a negligible effect on marginal coral reef values. However, Ruitenbeek and Cartier (1999; Chapter 7) note that the impacts of the institutional costs associated with the operation of a national bioprospecting program in Jamaica, as recommended by Putterman (1998; Chapter 12), are minimal. The implementation of a bioprospecting program may be warranted. The question becomes one of the willingness of local management and stakeholders of the Montego Bay Marine Park to enter into such a venture.

Modeling Results and Policy Advice for the Use of Decision Support Models

More generally, beyond the specific policy and institutional questions that arise when one considers the potential development of a bioprospecting program in Montego Bay, policy questions arise from the overall least cost intervention and coral reef benefit modeling results. Ruitenbeek (Chapter 9) notes that if economic efficiency is the goal, both costs and benefits must be considered in research when dealing with complex non-linear systems such as coral reefs. Cost-effectiveness analysis alone may not be adequate. Ruitenbeek also calls for a greater emphasis at the local level on the socio-economic and management dimensions of direct uses, including the promotion of practical local management regimes that consider and involve affected stakeholders. This point is also emphasized by Jameson and Williams (Chapter 2) and Bunce and Gustavson (1998a; Chapter 11).

Dissemination

The least cost intervention and valuation approaches of this modeling research are useful decision support, policy and training tools for coral reef managers and government decision-makers faced with significant coral reef management issues. The consolidated dissemination strategy for the projects has the following facets:

- The launch of a "road show" to disseminate this publication that includes a CD-ROM of the COCOMO—COastal reef COasts in MOntego Bay decision support model (Chapter 10);
- The continuation of workshops supported by World Bank Knowledge Management, at both the national and local level, with the goals of obtaining feedback on the findings of the applied modeling research, identifying priority areas for future research, and identifying potential avenues for strengthening regional and local capacity to manage the coastal resources;
- The creation of user-driven programs on the World Bank Knowledge Management web sites (BIONODE and Water Resources) and other websites; and,
- Assistance to the Montego Bay Marine Park Trust in the preparation of a regional replicable project entitled ReefFix (Chapter 2).

The stakeholders involved in the case study sites have expressed their need and interest for a more comprehensive understanding of existing and planned development and conservation activities involving the coastal zone. Whether they be local fishers, water sports operators, hoteliers, local developers and entrepreneurs, local residents or visiting tourists, it is critical to fulfill these information requirements to achieve effective coastal zone management. The dissemination strategy is necessary to increase the involvement of the diverse stakeholder groups in assessing the changes in the marine environment and in mitigating or preventing the negative impacts on the coral reefs. The development of a network of policy-makers and researchers—a "community of practice"—to enable the sharing of international experiences on coral reef restoration and to foster collaborative research is also key.

COCOMO

COCOMO is a decision support coastal zone management model for Montego Bay that illustrates coastal problems and estimates the effects of human activities (Chapter 10). It is also a tool for policy development and capacity building in integrated coastal zone management (ICZM). The Montego Bay case study site was selected for the interactive modeling project because of the critical needs for such a tool. The urban center is experiencing rapid growth, with development often ad hoc and relatively unplanned. Many physical alterations to the coastal zone have occurred, including coastal infilling, mangrove destruction, and sedimentation, in addition to coastal nutrient enrichment, intensive fishing pressures, and extensive use by the water sports, diving, and tourism industries (Chapters 1 and 11). This has resulted in the degradation of water quality and coastal resources, and has caused significant impacts to the valuable coral reef ecosystem.

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

- Raises awareness and promotes consensus building on the part of the stakeholders with regard to environmental priorities in Montego Bay;
- Identifies the challenges of addressing coastal zone management issues in Montego Bay over the short and long-term with the various government and non-government organizations (NGOs) involved;
- Identifies specific environmental investments with feasible, relatively low cost solutions; and,
- Initiates a process of dialogue with stakeholders.

The model's computer user-friendly interface is developed for policy-makers, specialists and those interested in Montego Bay coastal issues. The interface uses extensive graphics 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 reefs of Montego Bay. Stored within the model is information on the coral reef ecosystem and associated marine life, as well as information on what the coral reefs contribute to Montego Bay through fisheries, tourism and coastal protection. Through the user interface, different actions may be taken to protect the coastal zone and coral reefs, some being more cost-effective than others. COCOMO predicts the least cost set of interventions to realize a specified coral reef abundance. Thus, the impacts from development-related activities can be explored and priorities set for future coastal management actions. In the process of using the model, the user obtains a unique awareness of the relationships between coastal activities and communication among stakeholders is enhanced.

ReefFix

An ICZM coral reef restoration, watershed management and capacity building demonstration project—ReefFix—is being implemented through the Montego Bay Marine Park (Chapter 2). ReefFix is the implementation phase of the decision support modeling results. The goal of the program is to design and implement a least cost coral reef restoration and watershed management project and then transfer the information and technology to other tropical American countries facing similar challenges. A key characteristic of ReefFix is that it takes an approach driven by specific policy needs related to the management of coral reefs that suffer from significant impacts (Chapters 1 and 2). The capacity building component includes the strengthening of human and institutional capabilities for integrated management, science, training and education (Chapter 2). It is seen as important not only to transfer the information to the developing country context, but to promote the exchange of experiential learning and to build local expertise in coral reef management.

The program has the following objectives (Chapter 2):

- Utilize the developed decision support model tool for the Montego Bay Marine Park (COCOMO) to provide information to local managers and decision-makers;
- Develop and implement a watershed management action plan for the Montego Bay Marine Park to improve marine water quality and increase live coral reef abundance;
- Develop and implement a fisheries management action plan for the Montego Bay Marine Park to increase fish abundance, improve economic conditions for fishers,

and help make the Montego Bay Marine Park financially self-sustaining; and,

- Implement a demonstration action plan for the tropical Americas that will improve ICZM capacity for the restoration of coral reef ecosystems in other countries. This may include application of a developed least cost ICZM decision support model template that can be custom tailored for other locales.

Process and Policy Applications

A rational economic optimization, considering solely the costs of management interventions in conjunction with the valuation of the total economic benefits received (e.g., Chapter 9), may seemingly reduce the role to be played by stakeholders and management agencies in the setting of goals and the expression of the diverse set of values likely represented by the various user groups. Indeed, it was the general approach of Rijsberman and Westmacott (Chapters 3 and 4) in the development and implementation of the Coral-Curaçao and Coral-Maldives decision support models to focus on the ability of decision-makers to analyze, through various user-defined scenarios, the cost-effectiveness of alternative interventions and the resulting economic, social and environmental conditions as reflected by various indicators. Their initial modeling approach does not go so far as to derive a global optimum, but focuses on providing a means by which decision-makers (and those simply with an interest) can explore management alternatives.

Defining an optimal solution through a decision support model does not necessarily negate local stakeholder involvement in management decisions; however, one must be cautioned against this occurring. The participation of stakeholders and management agencies must not be forgotten. The recommendations stemming from a normative model solution may not be adequate or feasible given the specific institutional and social context. Indeed, the success of any coral reef management program will be greatly affected by the social environment and the decision-making process itself. It is critical that stakeholders be involved in as many stages in the development of a management program as is practical, even if it is simply through an information sharing exercise. As has become increasingly evident in all environmental management processes, it is the *process* itself that often sets the stage for a successful management program. Without an open and participatory process, significant barriers to effective management can be expected to arise.

Decision support modeling should be implemented within a specific policy context. This is especially true concerning the valuation components for, as noted by Cartier and Ruitenbeek (Annex A), the choice of any one of a number of valuation techniques should be driven by the specific policy questions at hand or the analytical issues that need to be addressed. The policy questions define the data that is needed and the analyses that are required.

Although scenarios, resulting from the development of ecological economic decision support models as reported here, have defined specific policy recommendations regarding the types of interventions required and the level of coral reef health that should be achieved for specific study sites, it is as yet too early in the development and use of these models to recommend that the required investments be made. Further work involving the local study site stakeholders and management agencies, as described by the dissemination strategy above, is required to refine the recommendations and develop integrated coastal zone management programs. The design of specific interventions can be expected to require refinement based on a more in depth consideration of local social and institutional conditions through a more participatory process. In addition, although the results reported here derive from truly "state of the art" models, there were notable deficiencies in the amount and quality of the economic and ecological data available and notable deficiencies in the development of the science behind the model construction. In short, the models should not be used to dictate coral reef management directions, but are for use to help *support* such decisions.

Future Directions for Decision Support Models

One significant challenge in the study of complex nonlinear systems, such as coral reef ecosystems, is in providing an adequate description of the composition, functional relationships and behavior of the system in question. Ruitenbeek (Chapter 9) notes that research needs to show a greater emphasis on ecosystem analysis, with a focus on functional linkages and relationships. The development of ecological economic decision support models is hindered by a lack of understanding regarding the behavior of ecosystems. Ecosystem uncertainty may prevent useful rational economic analysis (Chapter 9).

Complex system modeling techniques such as fuzzy logic may prove more useful. The least cost intervention component of the decision support models presented here (see also Brown *et al*. 1996; Meesters *et al.* 1995, 1996a; Ridgley and Dollar 1996), demonstrate the utility of incorporating a fuzzy logic modeling environment when examining the behavior of a coral reef ecosystem in response to anthropogenic stress and intervention. Further research into the use of fuzzy sets in similar applications is warranted (Smith 1994). Yet, it may be that a combination of various techniques, be they linear deterministic models, complex simulation models, fuzzy logic models or neural networks, may be required in the exploration of the behavior of and interactions between ecological and economic systems.

The linking of disparate systems within a modeling environment is a continuing challenge being faced by the field of ecological economics, as well as by other trans-disciplinary fields of inquiry. The fields of conservation biology and economics have separately struggled with an inability to provide adequate explanatory links between economic activities and species or ecosystem decline. More generally, often the provision of a concise description or characterization of a complex ecological economic environment is required simply to facilitate decision-making in management. Indicators, as proxy variables or simplifications of a complex reality, often serve this function.

In the modeling efforts presented here, the primary indicator used for coral reef health was spatial coverage (i.e., percent of a total available substrate covered by live coral). This indicator provided a simple descriptive "link" between economic activities and the affected coral reef ecosystem. Moreover, the indicator formed the basis for decisions concerning the "best" management interventions in order to receive the greatest return in benefits and concerning the extent of the interventions warranted to achieve an economically efficient outcome. The obvious questions arise—is this indicator of coral reef health adequate and should other indicators be included in the modeling?

The properties of a "good" indicator for use in decision-making and policy development could be described as the following:

- The indicator design corresponds to the selected purpose and application;
- The value base behind the indicator design is explicit;
- The indicator provides a sufficient simplification or abstraction of the targeted system characteristics;
- The theory behind the design of the indicator is relatively robust;
- The sensitivity of the indicator to system parameter changes has been sufficiently explored and defined, and the indicator is sufficiently sensitive to meet the design purpose; and,
- The information provided by the indicator can be understood and applied by the user.

Most indicators cannot be expected to meet all of the above criteria; however, it remains the goal of indicator development to satisfy as many as is possible given the shortcomings of the level of available scientific knowledge and restrictions on research. It is asserted that coral reef cover is a reasonable indicator of coral reef health given these shortcomings, but future development of these decision support models may need to refine or modify the indicators utilized. The development of ecosystem indicators for use in decision-making and the development of policy is very much in its infancy, although progress is being made (e.g., Jameson *et al*. 1998, 1999; Chapter 1). How such indicators may form the "link" between ecological and economic components of complex systems models, and facilitate awareness and understanding, remains to be explored further.

As a final point regarding the further development and refinement of ecological economic decision support models for ICZM, any analysis must be able to explore the possible variations in the results and subsequent recommendations. It is imperative that decision support modeling involves a sensitivity analysis or some means with which to gage the risk or possible error associated with any one scenario. For example, the bioprospecting valuation modeling showed that the estimates of ecosystem yield were highly dependent on the assumed species-area relationship (Chapter 7). Relatively small variations in such non-linear relationships inherent within a model can lead to sizable variation in the outcome. Recommendations regarding optimal policy must bear these in mind. Caution is prudent until the science of decision support models and their application has developed to a point that warrants great confidence in the results.

As a final message upon closing, it is believed that the ecological economic decision support modeling work will prove useful in the development of effective ICZM programs in the developing tropics. Further research and refinements of the models, along with greater attention to the process of decision-making, should be seen as a necessary challenge, not as a hindrance. Given the emerging evidence that indicates we are facing an ecological crisis world-wide in the decline of coral reefs, management must move forward given the best set of decision support tools currently available.

Annex A

Review of the Empirical Biodiversity Literature

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The primary objective of this literature review is to illustrate the techniques that have been used and the results 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 annex 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.[1] Also, up-to-date online searchable databases relating to biodiversity issues are available from researchers active in the field.[2]

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 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" or "rent value" estimates (see summary in Box A.1). Value categories include recreation, harvested products, education and research, ecological functions, and existence and 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.

From the studies reviewed, the value estimates for uses and non-uses of coral reefs are categorized in Table A.1a (for habitats) and Table A.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 that, 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, that being 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.

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/yr. 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 that 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 A.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 A.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 (de Groot 1992; Driml 1999) 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

Box A .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.

Table A.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^{-1}yr^{-1} for cultural/artistic inspirational use, based on sales of books and films; $0.52/ha^{-1}yr^{-1} 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^{-1}yr^{-1} 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 and 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 and Moran (1994).
Conservation Value, Blanket Peat Bog Scotland (Hanley and 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 and 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 and 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 A.1a. continued

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 and Moran (1994).
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 and 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 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.

Table A.1a. continued

Ecosystem and Original Study	*Approach: Utility*	*Production*	*Rent*	*Valuation Results*	*Miscellaneous Notes including Secondary Sources*
Productive Use Values, Galapagos National Park (de Groot 1992)	★	★		Productivity Change: $\$0.40/ha^{-1}yr^{-1}$ (permitted) ornamental product sales; $\$0.70/ha^{-1}yr^{-1}$ local fish and crustacean harvest; $\$5.20/ha^{-1}yr^{-1}$ 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.
Wetland Valuation, Florida (Bell 1989)		★		Productivity Change: Marginal productivity of commercial marine species: $\$88/ha^{-1}yr^{-1}$; based on a wetland production function describing wetland/fisheries productivity linkage; and market prices of commercial species.	As reported in Barton (1994a).
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: $\$31/person^{-1}yr^{-1}$ WTP, for a consumer surplus of \$5 million/yr by visitors to maintain coral reef in current condition; and $\$49/person^{-1}yr^{-1}$ 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.

Table A.1a. continued

Ecosystem and Original Study	Approach: Utility	Approach: Production	Approach: Rent	Valuation Results	Miscellaneous Notes including Secondary Sources
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^{-1}yr^{-1} 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^{-1}yr^{-1}, for a total of 190,000-200,000).
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^{-1}day^{-1} 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^{-1}yr^{-1} 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^{-1}person^{-1} 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.

Table A.1a. continued

Ecosystem and Original Study	*Approach* Utility	Production	Rent	*Valuation Results*	*Miscellaneous Notes including Secondary Sources*
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/$ha^{-1}yr^{-1}$; 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.
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 22,000km^2 of reef protection.	As reported in Spurgeon (1992).
Coastal Protection, Indonesia Coral Reefs (Cesar 1996)		★		Productivity Change: NPV of coastal protection/km^2 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/$ha^{-1}yr^{-1}$ 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/$ha^{-1}yr^{-1}$ 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/$ha^{-1}yr^{-1}$ 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."

Table A.1a. continued

Ecosystem and Original Study	Approach: Utility	Approach: Production	Approach: Rent	Valuation Results	Miscellaneous Notes including Secondary Sources
Habitat/Refugia Galapagos National Park (de Groot 1992)		★		Benefit Transfer: $7/ha^{-1}yr^{-1}; 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^{-1}yr^{-1} 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 and Fisher 1994)		★		Productivity Change: $670,000/% 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).
Watershed Protection, Cameroon (Ruitenbeek 1992)		★		Productivity Change NPV: $12/ha^{-1}yr^{-1} watershed protection value of fisheries; $2/ha^{-1}yr^{-1}, flood control; $1/ha^{-1}yr^{-1}, 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

Table A.1a. continued

Ecosystem and Original Study	*Approach: Utility*	*Approach: Production*	*Approach: Rent*	*Valuation Results*	*Miscellaneous Notes including Secondary Sources*
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 spearfishing 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
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.* 1999a)		★		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 A.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 and Soejarto 1985)		★		$203 million per successful species per year; 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 per untested species per year 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 per per successful species per year given 40 plants responsible for all plant-based drugs; $18.8 million per untested species per year 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 per year; and host country's ability to capture 10% of the rent from the discoveries.	Extended by Aylward (1993): $150 per untested species per year 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): $7500 per untested species per year (1990$) 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 per 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 per untested species based on original study's stated success rate of 1:10,000. [sic.] {The correct calculation would show NPV $25.30 per untested species.}
Value of Plants and Land to the Pharmaceutical Industry, Rainforest Flora (Pearce and Puroshothaman 1992ab)	★	★	★	$390 million per successful plant species per year based on 1990 US gross drug sales; $7 billion/yr based on the value of lives saved ($4 million per 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 and 10% rent capture rates; success rates 1:10,000 and 1:1000; and, a 4.2 multipler toconvert US estimate to global estimate.

Table A.1b. continued

Ecosystem and Original Study	*Approach: Utility*	*Production*	*Rent*	*Valuation Results*	*Miscellaneous Notes including Secondary Sources*
Value of Biotic Samples (Reid *et al.* 1993b)			★	$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 per untested species. Based on "sample to lead" success rate of 1:10,000. [sic.] {The correct calculation would show NPV $5.25 per 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 and 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 and Aylward 1996)			★	Net Returns: $5 million (private); -$240 million (social); based on throughput of 2000 samples per year, protection for 500,000 species over 600,000 ha, $233 per sample royalty, $213 per sample in collection and 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 and Balick 1995, 1997)		★		IF all potential drugs are discovered: $449 million NPV per 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 per 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) 18 biodiversity "hot spots".

Table A.1b. continued

Ecosystem and Original Study	*Approach: Utility*	*Approach: Production*	*Approach: Rent*	*Valuation Results*	*Miscellaneous Notes including Secondary Sources*
Social Value of Marginal Species (Simpson and 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 and 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) 18 biodiversity "hot spots".
Value of Marginal Species when Research Intensity is Optimal (Simpson and 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 per new product; 5 year 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 of the 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 and 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 (1997) 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

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 overstate 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 non-linear, 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 that 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 overfishing 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 (e.g., 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 overestimate 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 dollars).

The Hodgson and Dixon (1988) cost-benefit analysis (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, net present value (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, overfishing, coral mining, and sedimentation. Each threat is analyzed in isolation from the others, and in terms of its net benefits on a per square kilometre basis. Therefore, a hypothetical reef area faces only one threat that 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 that 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 the 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, which damages the reef and reduces the price of the final product (net caught tropical fish command a higher price), is typically used for gathering marine fish. Based on the reported value of the Philippines' trade in aquarium fish, the author estimates that a 50% 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 is 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 A.1a. Bell (1989) takes a marginal valuation approach to fisheries in a Florida wetland. The incremental value of a hectare of wetland habitat is assumed to be equal to the marginal productivity of the wetland-dependant fisheries. The study estimates a non-linear bioeconomic production function for fisheries. The approach is similar to those described 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 A.1a, most of the studies focusing on coral reef recreation and tourism estimate consumer surplus using a travel cost method (TCM) or a CVM; however, three studies—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, while 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 A.1a includes the most recent estimate of the GBR'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 dollars) 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 dollars).

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.

The consumer surplus associated with visits to the region is calculated to be A$144 million/yr; the surplus associated with visits to coral sites within the region is A$106 million/yr. 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/yr; 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 related 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 Bonaire Marine Park. Arguing that quality diving is the primary attribute of Bonaire, the researchers calculate gross revenues from dive-based tourism of US$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 US$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 US$7.9 to US$8.8 million/yr; estimated consumer surplus is US$19 million/yr.

Arguing for a project appraisal approach for the valuation of resource protection, Pendleton (1995) also estimates the NPV 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% discount rate, the NPV of the park to the local economy is US$74.21 million and the NPV of consumer surplus enjoyed by tourists is US$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 the 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 Hodgson and Dixon (1988) CBA of logging in Bacuit Bay, Palawan, includes a benefit calculation for tourism. The productivity change and 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%/yr to a level of zero about half way through the forecast period. The present value 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 and the top of which 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 kilometre of reef basis and represent a 25 yr period discounted at 10%.

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 and pollution is based on cost estimates of the abatement measures that 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, and park and non-park expenses. Doing so, he arrives at US$1,300 per visitor for a Galapagos vacation experience. The analysis then assumes 40,000 tourists per year to arrive at a gross tourist revenue of US$52 million/yr. 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.[3] The average implicit price of a Galapagos vacation day turns out to be US$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 US$2,278 per visitor; including a minor tax brings the total price to US$2,318 per visit.

Although the price per visitor in the Edwards (1991) study is almost twice that used by de Groot (1992), gross tourist revenue calculated by Edwards is only US$39 million/yr compared to de Groot's US$52 million/yr. 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 per 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 per year. At the average (implicit) price of US$312, 7.3 days are demanded and the 125,000 visitor days per 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; and research and 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.

An inherent weakness of all of these studies, which base their methodologies on expenditure 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 United States and the United Kingdom. Costs associated with the research are excluded but, because the payment is coming from offshore, 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 (1992) 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 A.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 (1991b) 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 kilometre basis and discounted over a 25 year period, a range of values 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 (1992) assumes that 10% of the Galapagos fisheries is dependant 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 (1992) assumes a shadow price of 10% of the value of any activity directly or indirectly dependant upon this function. Activities included all the productive uses, ranging from recreation to education and research. According to de Groot (1992), 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 (e.g., micro-organisms to aid the degradation of toxic waste or 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 less applicable 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 research and development (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 that 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.[4] Impacts of GM crops and biotechnology in developing countries pose a wide range of policy issues that extend from food security to property rights and 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 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 add 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 A.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 (e.g., fertilizer and pesticide use, tillage, machinery) 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 Smale (1998).[5] Interestingly, in the preface to that volume, 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.

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, Evenson and Lemarié (1998, p.91) note: "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.

Table A.2. Early survey of the value of genetic contributions in agriculture.

Crop	*Location*[a]	*Production effect of genetic resources*	*Study*
Value to Cultivated Varieties			
Maize	USA 1985 to 1989	US$2.3 million/yr to North Dakota	Frohberg (1991)
Rice	Asia Green Revolution	US$1.5 billion/yr	Walgate (1990)
Wheat	Asia Green Revolution	US$2.0 billion/yr	Walgate (1990)
Barley	USA 1930 to 1980	50% of doubled yield increase	OTA (1987)
Sorghum	USA 1950 to 1980	1% to 2% yield increase	Miller and Kebede (1984)
Pearl millet	India 1992	US$200 million/yr	ICRISAT (1990)
Potato	USA 1930 to 1980	50% of a four-fold yield increase	OTA (1987)
Soybeans	USA 1902 to 1977	79% of 23.7 kg ha^{-1} yr^{-1} yield increase	Specht and Williams (1984)
Tomato	USA 1930 to 1980	50% of a three-fold yield increase	OTA (1987)
Value of Specific Genetic Traits Transferred to Cultivated Varieties			
Wheat	Turkey	Disease resistance: US$50 million/yr	Witt (1985)
Barley	Ethiopia	Protection from Yellow Dwarf Virus: US$160/yr to California	Witt (1985)
Hops		Reduced bitterness in beer: US$15 million/yr to British brewing industry	Witt (1985)
Beans	Mexico	Protection from bean weevil: 25% of stored beans in Africa; 15% in South America	Rhoades (1991)
Grapes	Texas	New root stock: revitalized European wine industry after decimation by louse infection	Rhoades (1991)

[a] In the case of the transfer of genetic traits, location refers to that of donor species.

Source: World Conservation Monitoring Centre (1992).

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. It is clear from the wide range of models that: i) they often attempt to address somewhat different policy problems; and, ii) they attempt, in various ways, to show 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, 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.* 1993b).

Table A.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 A.2). Such complexities further complicate numerical analyses in an area often complicated by secrecy agreements or other data gathering constraints.

Early Models of Gross Economic Benefits

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

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 (Pearce and Puroshothaman 1992ab; Principe 1989ab). These studies produced gross values attributable to the 40 "successful" plants that were responsible for all the plant-based drugs in the pharmaceutical industry.[6] A typical calculation is as follows:

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

where VPD = total value of plant-based drugs;
rp = percent of prescriptions containing one or more ingredients derived from plants;
S = total value of prescription drugs; and,
P_{avg} = 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 US$203 million to the United States. 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 US$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 US$390 million per plant, and possibly as high as US$7 billion per plant. The authors extend the model to calculate the average value of a hectare of rainforest:

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

where VRL = per hectare value of rainforest land;
NR = number of plant species at risk (60,000);
p = success rate of finding a new plant-based drug source (1:10,000 to 1:1,000);
r = royalty rate on a new drug source (5%);
a = amount of value that a host country can cap ture from a new drug source (10% to 100%);
VP = value of a plant-based drug source (US$0.39 to US$7.00 billion); and,
H = number of hectares of rainforest (1 billion).

Box A.2. Success rate determinants in pharmaceutical bioprospecting.

For a prospecting program as a whole, a high success rate is desirable. However, given that research and development (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 (e.g., 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; and,
- 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 novel compounds than material drawn from more studied sources (such as tropical forests).

The Artuso (1997) model allows for phase-specific success rates that 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.

Based on the preceding model and data assumptions, Pearce and Puroshothaman (1992ab) find values of tropical rainforest ranging between US$0.01/ha and US$21/ha.

As shown in the last column of Table A.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 US$203 million. At the time the article was written, the authors believed the probability of a plant becoming an drug source was one in 125 plants tested. Aylward used this probability to calculate the study's implied valuation of an untested species to be US$1.6 million (US$203 million/125 plants).

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 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 these limitations.

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 or sources 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 United States 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)[7], 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%.

R&D estimation work by DiMasi *et al*. (1991) is based on a survey of 12 United States pharmaceutical firms. The firms provided R&D cost and timing data for 93 NCEs that entered the "clinical" R&D phase during the 1970-82 period. The R&D process is divided into one preclinical phase, three clinical phases, and two 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 US$114 million (1987 dollars). This estimate was capitalized at 9% (Grabowski and Vernon 1990) to the point of new drug approval, thereby increasing the average R&D cost to US$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 that 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.[8]

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, including 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 (i.e., 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 (1993) 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 1:10,000, one new drug source is eventually identified.

The gross return of the resultant new drug 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}):

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

In the "private cost" version of the model, the private cost of pharmaceutical prospecting (PC^{PP}) 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.[9] Hence, the *social* cost of pharmaceutical prospecting (SC^{PP}) 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}, including 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:

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

$$NPR^{BS} = (PC^{BS} / PC^{PP}) \times NPR^{PP}$$

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 (1993) 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 model parameters are shown in Table A.3 and results of the models are in Table A.4.

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:

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

The private net royalty on biotic samples (NPR^{BS}) is calculated by adding to RY^{BS} the initial fees received by

Table A.3. Model parameters in Aylward (1993).

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

Table A.4. Results of the models of Aylward (1993).

Model component	*Net return (US$)*
Private Cost Model	
Total to pharmaceutical prospecting (NPR^{PP})	39.13 million
Total to R&D ($NPR^{R\&D}$)	38.71 million
Total to biotic samples (NPR^{BS})	0.42 million
Per biotic sample	21.23
Social Cost Model	
Total to pharmaceutical prospecting (NSR^{PP})	33.24 million
Total to R&D ($NSR^{R\&D}$)	30.91 million
Total to biotic samples (NSR^{BS})	0.68 million
Per biotic sample	33.91
Total to biodiversity protection (NSR^{BP})	1.66 million
Per tested species	165.79

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 a royalty per biotic sample (RY^{BS}) of US$233.12, a total net return to biotic samples (NPR^{BS}) of US$4.91 million, and a total net return to biotic samples (NSR^{BS}) of -US$0.98 million.

Mendelsohn and Balick (1995, 1997)

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, with sales of the new drug begin in year 11, reaching a peak in year 19. For the industry as a whole, sales level off after the peak year; for the firm holding the patent, revenue is quickly eroded in the post-period 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 A.5, the authors arrive at a NPV of US$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:

Table A.5. Model parameters in Mendelsohn and Balick (1995).

Model parameter	*Value*	*Source*
Patent period average sales for an average drug	US$29 million	OTA (1993)
Decay rate of post-patent sales	20%+	OTA (1993)
Patent life	20 yrs	not indicated
Production and marketing costs	60.6% of sales	OTA (1993)
Length of R&D period	10 yrs	Grabowski and Vernon (1990)
Present value of private R&D costs	US$125 million	OTA (1993)
Cost of capital in pharmaceutical industry	5%	OTA (1993)
Species hit rate	1:333	see text
Per biotic sample collection fee in developing countries	US$100	

- 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 to 75 different therapeutic uses); and,
- 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.[10]

From the above, there are approximately 375 plant-based drugs in the tropical forests.[11] About 47 plant-based drugs have already been discovered, leaving 328 yet to be discovered.

Given the NPV estimate of US$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 US$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 US$48/ha. Allocating US$147 billion over the 125,000 rainforest plant species implies that any one species is worth $1.2 million.

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 the "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 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:

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

To arrive at the present value expected cost of phase i ($PVEC_i$), for the duration of the phase (d_i), the average annual cost of the phase (EC_i/d_i) is discounted by the specified rate (r) 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.

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

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 A.6 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 is:

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

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, and 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:

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

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 A.6. R&D phase data used by Artuso (1997) for baseline analysis. 15,000 extracts were tested for 10 therapeutic targets. Assumed real discount rate was 8.5%.

Phase	*Phase duration (yrs)*	*Success rate (%)*	*Mean number of successes*	*Costs per trial (thousand US$)*	*Expected phase costs (thousand US$)*	*Present value of expected phase costs (thousand US$)*
Initial screening[a]	0.75	0.5	750	0.10	15,000	14,548
Secondary screening[a]	0.10	40.0	300	1	750	732
Isolation and dereplication[a]	0.50	10.0	30	20	6,000	5,712
Synthesis and modification[a]	1.50	50.0	15	250	7,500	6,585
Preclinical trials[b]	1.00	40.0	6	771	11,570	9,170
Clinical phase I[b]	1.35	75.0	4.5	3,137	18,822	13,557
Clinical phase II[b]	1.88	47.5	2.14	9,933	44,698	28,239
Clinical phase III[b]	2.49	70.0	1.50	18,817	40,222	21,282
NDA	3.00	90.0	1.35	1,000	1,496	633
Cumulative	**12.57**	**0.0009**	**1.35**	**33,930**	**146,058**	**100,457**

[a]Data based on various natural product screening programs.
[b]Data based on Burger (1990), DiMasi *et al*. (1991), and Hansen (1979).

Table A.7 shows the data and sources used in the *PVENR* calculation.

Accounting for the tax liability of a private firm (r in 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 in Table A.8.

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

Table A.7. Model parameters in Artuso (1997).

Model parameter	*Value*	*Source*
Sales revenues for new drug	Series	Grabowski and Vernon (1990), adjusted to 1994 prices
Sales decay	7.5%/yr in years 12 to 20	
Product life	20yrs	Vagelos (1991)
Global to US sales ratio	1.9	Grabowski and Vernon (1990); Joglekar and Patterson (1986)
Plant and equipment	50% of gross revenues in year 10; 67% occur in year 1; balance equally spread over years 2 to 10	Grabowski and Vernon (1990)
Administration and operating costs	40% of revenue	
Marketing	100% in year 1; 50% in year 2; 25% in year 3	
Tax rate	35%	
Discount rate	8.5%	Based on capital asset pricing model

US$7.3 million to US$18 million. Reducing the primary screening rate by 20% from 0.005 to 0.004 reduced the expected NPV of *N* extracts from US$7.3 million to US$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.

Table A.8. Results of the expected private NPV calculations of Artuso (1997).

	Before tax (US$)	*After tax (US$)*
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

A Model Addressing Marginal Economic Value

Simpson et al. (1996)

Simpson and colleagues (including Simpson and Craft 1996; Simpson and Sedjo 1996ab) 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 (i.e., the net value of a new drug) by a probability that an untested species will yield a commercially viable new drug source (i.e., 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 the 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, 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. This results in an even lower expected value of the marginal species.

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:

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

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

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

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

The equation for $v(n)$ 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:

$$p^* = (R + nc)/(n+1) \times R$$

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

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 ($EPVv^*$) is:

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

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 A.9. Given the cost and revenue data, for a collection of 250,000 species, the probability that 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 US$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 US$67. The loss in marginal value is because of the increased likelihood that the novel compound has already been found in another species.

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 US$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 in 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 US$0.74/ha in central Chile to US$20.63/ha in western Ecuador.

Table A.9. Model parameters and results in Simpson *et al.* (1996).

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

A Look at the Frontiers of Valuation and Modeling

This annex 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 (Chapter 6).

Of greatest research interest, however, is the field of biological prospecting valuation (Chapter 7). 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 in the Montego Bay pharmaceutical bioprospecting valuation research presented in 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 different policy applications. 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 versus 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; Polasky and Solow 1995; Solow *et al*. 1993). 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 "$ per 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, 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 that 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 (MCA), 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.

Endnotes

[1] The Canadian effort, maintained by Environment Canada, is available by subscription and is entitled "EVRI: Environmental Valuation Reference Inventory". At the end of 1998, it contained approximately 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, spearheaded by the New South Wales Government, is free of charge to use and is entitled ENVALUE. It relies on an extensive database 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.

[2] 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 internet site is located at: http://www.orst.edu/dept/ag_resrc_econ/biodiv/biblio.html.

[3] 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 (i.e., 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 the 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 (US$312), vacation days demanded would be 7.3, implying a total vacation cost of US$2,278.

[4] Genetically modified (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 United Kingdom (M. Gale, Director, press release, 8 March 1999) that Roundup Ready soya, which was genetically engineered to resist Roundup herbicide, saved farmers some US$30/ha because of a 40% 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 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.

[5] 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 farmers' 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 farmers better off, while in other areas (i.e., those with production constraints) the contributions of the genetic improvement are minimal and farm policy would be better targeted to production management.

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

[7] 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.

[8] Grabowski and Vernon (1990) may have implicitly deducted the cost of biotic samples because they used R&D cost estimates from Hansen (1979, 1980) that, according to DiMasi *et al*. (1991), included "discovery costs".

[9] 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 (1993) estimates the direct and opportunity costs of preserving 600,000ha of Costa Rican parkland. Direct cost is based on park budget projections; opportunity cost is based on local land prices and an estimate of 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.

[10] Given that each plant has six distinct extracts, 333 plants would provide about 2,000 extracts. If each of these is subjected to 500 screens, then these 333 plants would provide 1 million tests, which would yield one success.

[11] Assuming there are 125,000 plant species in the rainforest all yielding six extracts, there are then approximately 750,000 potential extracts which can each be subjected to 500 screens. At a success rate of one in one million, there would then be 375 potential drugs.

Annex B

Contingent Valuation as a Means of Valuing the Conservation of Coral Reefs: An Assessment of the Method

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The contingent valuation method (CVM) is a means of assigning monetary values to resources and service flows that are unpriced or under-priced by the market. CVM is based on neo-classical welfare economics, where the value of an environmental resource to an individual is expressed either as their maximum willingness-to-pay (WTP) to acquire or safeguard it, or else the minimum monetary compensation they would accept to go without an increase in that good or tolerate a decrease (willingness-to-accept compensation; WTAC). Given that it is "missing markets" that result in such environmental resources as clean air, coral reefs or biodiversity being unpriced, CVM relies on a constructed, hypothetical market to produce monetary estimates of value. The researcher obtains peoples' bids (either WTP or WTAC) for a specified change in the environmental good of interest *contingent* on the description of this hypothetical market. Thus, an individual's WTP or WTAC can be expected to depend on:

- The description of the contingent market;
- What they know about the environmental good, which depends partly on what they are told about it as part of the CVM survey;
- Their own preferences;
- Their budget constraints; and,
- The availability of substitutes and complements.

Empirically, it also turns out that stated WTP (throughout the rest of this annex, WTP will be used to refer to both itself and WTAC unless otherwise stated) also depends on the design of the constructed market and how responses are subsequently analyzed.

Historically, CVM developed through gradual acceptance and use by United States government agencies. An important milestone was the acceptance by the United States courts of the use of CVM in natural resource damage assessments under the 1980 Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). However, perhaps the most relevant event in the development of CVM was the case pursued by the State of Alaska and the federal government in the United States against Exxon as a result of the Exxon Valdez oil spill (Bateman and Willis 1999). This led to the establishment of the so-called Blue Ribbon Panel, out of which emerged National Oceanic and Atmospheric Administration (NOAA) guidelines on the use of CVM, especially regarding non-use values (Federal Register 1993, 1994). These guidelines are still the subject of some debate, but form the basis for the design elements presented in this annex.

Essentially, a CVM exercise consists of: i) describing the environmental change in question; ii) describing the contingent market; iii) establishing a bid vehicle and reason for payment; iv) seeking bids, either through an open-ended format, a bidding game, a payment card, or a single or double-bounded dichotomous choice mechanism; v) estimating mean or median WTP; iv) aggregating this average bid to a population total value; and, vii) carrying out reliability and validity tests of the CVM results.

Principal Problem Areas

The CVM method has been used to estimate the value of a wide variety of environmental resources, including air and water quality, outdoor recreation, and landscape and wildlife conservation. These applications have highlighted some general problems in CVM—namely, the concept of utilitarian values for environmental resources (Spash and Hanley 1995; Stevens *et al*. 1991); benefits transfer (Bergland *et al*. 1995); nesting and part-whole bias (Boyle *et al*. 1994); calibration and aggregation (Foster *et al*. 1998); and the concept of non-use values (Bishop and Welsh 1992). In addition, the ability of researchers using

CVM to value the different characteristics that make up, say, a pleasant landscape, has been limited (e.g., Hanley and Ruffell 1993). This has turned attention to other stated preference approaches, notably choice experiments (Adamowicz *et al*. 1994).

Early work (summarized in Mitchell and Carson 1989) tended to concentrate on what might be termed "design bias" effects; these included the impact on WTP of changes in the starting point in bidding games and tests for strategic behavior. Later, much attention was, in contrast, given to large differences between WTP and WTAC measures of value, which were inconsistent with mainstream welfare economics predictions. These differences have now been attributed to endowment effects (Knetsch 1989) and/or to substitution effects (Hanemann 1991). Another recent trend has been the large number of articles concerned with optimal design and subsequent econometric analysis of dichotomous choice models. Other papers (e.g., Munro and Hanley 1999) have shown that changes in the information set provided to respondents in a CVM survey can significantly affect their WTP, but that this is a desirable characteristic of the method.

Perhaps the four main current worries within CVM are: i) part-whole bias; ii) lexicographic preferences; iii) non-use values; and, iv) aggregation. These problems are now briefly described, before tentative best practice guidelines are outlined.

Nesting and Part-Whole Effects

It is well known that in CVM a good will be valued higher when valued in isolation than when as part of a more inclusive bundle. This is to be expected if goods within the bundle are substitutes for each other, to a degree, in terms of the utility they generate (Carson *et al*. 1998). This phenomenon has variously become known in CVM as embedding, nesting and part-whole bias, and may well exist for private market goods as well as for non-market goods. One possible "cure" for this problem is to ask respondents to bid for the more inclusive good first, and then to apportion some amount of this total bid to the good being valued.

Willis *et al*. (1993), for example, used this approach in their study of English environmentally sensitive areas (ESAs). Respondents were first asked to state a WTP amount, in terms of additional income tax, to maintain the entire ESA program in England and Wales. Residents and visitors were then shown pictorial and textual representations of what the landscape in either ESA would look like with and without the ESA scheme in place. Respondents stated which landscape they preferred and were then asked to allocate an amount for that landscape from their already declared ESA "budget", having been told that money "spent" on one ESA could not be spent on another (in other words, that there was an opportunity cost).

From the CVM literature and from economic theory, we know that this procedure will elicit lower bids for an individual ESA than when that ESA is bid for alone. This procedure might be seen as desirable in the sense that it presents a direct opportunity cost for bidding for any individual ESA (less can be "spent" on the other nine) and, also, that it produces more conservative value estimates. However, this procedure suffers from one major problem. As has been noted above, respondents who are not familiar with the good being valued must be given enough accurate and unbiased information to permit them to make well informed choices. ESAs are, for most individuals, unfamiliar goods in terms of the benefits they generate. Providing "full" information on each ESA in this instance would be an impractical task. Thus, this method of dealing with nesting effects is flawed. Additionally, one might ask why respondents should not first be asked to allocate some total for all public environmental spending, then allocate some of this to the ESA program, and then allocate some of this to a specific ESA. But why stop there? On the same logic, respondents should surely first be asked about how much they are willing to pay in taxes for total government expenditure. Yet this seems beyond the original intention or capabilities of CVM, especially when one considers the information issue.

Lexicographic Preferences

Both Stevens *et al*. (1991) and Spash and Hanley (1995) have found evidence that when people are asked to participate in CVM surveys concerned with wildlife protection, a proportion of these respondents have preferences that are at odds with the utilitarian ethic and the demand model underlying cost-benefit analysis (CBA). In essence, such individuals (approximately 25% of the sample in each case) refuse the concept of trading off income changes for changes in the level of environmental quality. Spash and Hanley (1995) argue that such preferences may be characterized as "lexicographic", derived from an ethical system based on rights. The implication is that WTAC amounts for such individuals will be infinite, and WTP amounts will be either zero (i.e., the individual protests) or a positive amount that does not vary with the level of environmental change involved. Since the behavior of such individuals does not correspond to the model underlying CBA, they are effectively disenfranchised by the CBA process. Identifying such individuals is clearly important, although what to do about them is much less clear. It also seems important to test, empirically, what determines such behavior and whether it is independent of the opportunity cost of, in this case, wildlife protection. The issue of lexicographic preferences in particular, and non-utilitarian ethics in general, within CBA is currently unresolved.

Non-Use Values and Obscure Resources

Non-use (passive use) values have long been a subject of some controversy in contingent valuation. Non-use values represent the utility derived from individuals from the existence of an environmental resource when they do not consume it *in situ* (e.g., by bird-watching or hunting). Arguments for and against the acceptability of non-use values can be found, for example, in Randall (1993) and Hausman (1993). An interesting finding in the CVM literature is that non-use values appear to exist for respondents who were not aware of the good before the survey took place. An example of this phenomenon is reported by Bishop and Welsh (1992) who note that the citizens of Wisconsin are apparently willing to pay US$12 million for preserving the striped shiner, a "...small minnow inhabiting the turbid depths of the Milwaukee River" of which few respondents were aware prior to the survey. Bishop and Welsh (1992, p.138) contend that these values are as real as non-use values for well-known resources such as the Grand Canyon: "...lack of knowledge cannot be taken as evidence that the existence of such resources lacks the ability to satisfy preferences…It could simply indicate the lack of past choice opportunities to motivate information gathering. In the case of the striped shiner, it is possible that people are concerned about the fate of endangered species, even obscure ones."

Thus, lack of *ex ante* knowledge is not a reason for a non-credible WTP value, especially as we have already argued that the CVM process is an information providing process that is *expected* to change preferences. Whether values for those in the sample who were ignorant of the resource prior to the survey can be used to say anything about the values of those outside the sample who have not so been informed is, however, a moot point.

Aggregation Problems

Some of the problems of aggregating benefit estimates in CVM studies are largely of a practical nature (e.g., estimating total visitors to a wilderness area). Estimates can, of course, be made. However, with regard to projects where the general public can be expected to benefit, two awkward questions arise. First, which population do we count as valid? Multiplying even very small per person values by national populations give rise to very large aggregate non-use values. Second, are the large aggregate values that arise credible? Bishop and Welsh (1992) refer to an "adding up" problem for non-use values whereby, possibly due to their symbolic value, individuals would give identical WTP values for *any* environmental good cause that they are made aware of, but their WTP for all of these projects added together would not be equal to the sum of these individual amounts.

For this reason, and also because of a worry that the very hypothetical nature of the CVM situation causes an inflation of stated values, economists have suggested "calibrating" CVM estimates when aggregated into smaller amounts (Foster *et al*. 1998; NOAA 1993). Foster *et al*. (1998) report ratios of stated to actual WTP for wildlife conservation in the United Kingdom in the range of 0.3 to 10.5 (with a mean of 2.93), although they also note that the methods adopted in the studies from which these numbers arise vary widely, making comparisons difficult. NOAA (1993) suggest a somewhat ad hoc calibration figure of 50% in the absence of an experimental study undertaken alongside any given CVM study, yet this neglects the probable range of calibration desirable in different contingent markets across the non-use/use and public/private good continuums.

Design Elements—A Best Practice Guide

In discussing current views on what constitutes "best" design in CVM, it is first necessary to describe the nature and evolution of United States government guidelines on the use of the technique, which seem likely to heavily influence the acceptability of CVM results in the United States. The wrecking of the oil tanker the Exxon Valdez off the coast of Alaska in 1989 was the somewhat unforeseen cause of a major spur to the development of CVM in terms of a legally acceptable method of valuing environmental damages in the United States. United States law had gradually seen the introduction of damage claims for environmental losses, principally under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) regulations of 1986 and the Oil Pollution Act of 1990. Following a famous judgment by the DC Court of Appeals (State of Ohio versus Department of the Interior), non-use (or more strictly, what has been termed "passive use" values, including the values derived from watching wildlife on TV, for example) were deemed relevant under this body of legislation in that persons could sue responsible parties for lost passive use values. This clearly had an enormous implication for Exxon since many of the environmental damages resulting from the spill (i.e., damage to wildlife and a pristine, fragile ecosystem) were likely to be passive use values, as opposed to actual active use values, since actual active use of the area was relatively modest.

As a counter to the possibly large size of damage claims being made against Exxon, the company funded a series of studies that basically tried to discredit CVM as a method for valuing losses in passive use values (Cambridge Economics 1992). 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 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 (Federal Register 15.1.93) 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 (Federal register 7.1.94). The principle recommendations were as follows:

1. A dichotomous choice format should be used;
2. A minimum response rate from the target sample of 70% should be achieved;
3. In-person interviews should be employed (not mail shots) with some role for telephone interviews in the piloting stages;
4. WTP, not WTAC, measures should be sought;
5. After excluding protest bids, a test should be made of whether WTP is sensitive to the level of environmental damage;
6. CVM results should be calibrated against experimental findings, otherwise a 50% calibration factor should be applied to CVM results;
7. Respondents should be reminded of their budget constraints; and,
8. Respondents should be given "adequate" information about the environmental change in question.

These measures are, at the very least, a rather strange mixture of theoretically based recommendation and crude "rules of thumb". Taken together, they make contingent valuation a very expensive exercise if implemented in full. It would be unfortunate if all CVM practitioners felt constrained to stick to these guidelines in future research, since the guidelines pose some awkward questions. These include:

- Are all "protest" bids giving the same signals and how should these signals be interpreted and utilized in any case?
- Can the 50% calibration factor be justified empirically?
- How can the weaknesses of the dichotomous choice design format be overcome?

How Should a CVM be Designed?

Credibility of Hypothetical Market

It is essential that the hypothetical market used be credible and, if possible, rely on routine or previously experienced behavior on the part of respondents. Such credibility can be tested for in focus groups (see below). Credibility as a concern extends to the bid vehicle used (thus respondents must be able to envisage that it could be collected); the bid vehicle should also be, as far as possible, uncontroversial.

Protest Bids

Protest bids (i.e., zero bids for reasons other than a true zero value being placed on the environmental change) should be identified, and reasons for them sought. CVM surveys that suffer from very high levels of protesting (e.g., more than 40% of all respondents) might be challenged as either having used a non-credible hypothetical market, having used a controversial bid vehicle, or having involved a radical change in implied property rights.

Information

Individuals need to be informed about all important aspects of the resource concerned and the nature of the change being considered. However, this information needs to be provided in a manner which ordinary people can comprehend (testing for comprehension is another function of focus groups). There is clearly a trade off between the amount of information provided and the extent to which people can assimilate and understand it within the normal time-span of a CVM survey. No firm guidelines can be provided here. Rather, the researcher must reach a common sense compromise. Focus groups can identify which aspects of the resource or resource change are deemed as most important by the individuals concerned.

Careful Survey Instrument Development

The key feature of any CVM study is the questionnaire itself. A successful questionnaire design is now recognized to involve three primary steps: i) use of focus groups to find out how respondents identify with the resource in question, what language they use to describe it, and their understanding of draft survey materials; ii) use of verbal protocols, whereby respondents complete draft questionnaires in a "thinking aloud" mode, to enable researchers to understand how people will react to survey questions and how they will form their answers; and, iii) pilot surveys to pre-test aspects such as design of dichotomous choice bid levels.

Choice of Bid Collection Technique

As was mentioned above, CVM researchers can use open-ended, bidding game, payment card, or discrete choice (referendum type) designs. The question of which is preferable is still largely unresolved. Bidding games often suffer from starting point bias, while payment cards suffer from anchoring effects. Open-ended designs may be more difficult for respondents to complete and may encourage more strategic behavior. Since the NOAA study recommends dichotomous choice approaches, much recent attention has been focused on this method.

In a closed-ended referendum, a single payment is suggested to which respondents either agree or disagree (i.e., a yes or no reply). The calculation of mean or median WTP from such responses is more complex than the alternatives above, since all that is revealed to the researcher is whether the respondent is willing to pay a particular sum (known as the offer price). The researcher must then either make assumptions about the underlying distribution of true WTP, or else use non-parametric techniques. Double-bounded referendum models present those respondents who say "no" to the first amount with a lower amount and those respondents who say "yes" to the first amount with a higher amount, thus eliciting increased information (e.g., Carson *et al*. 1994). Finally, uncertainty over valuation can be allowed for in both open and closed-ended valuation methods (e.g., Ready *et al*. 1999).

Discrete choice approaches have consistently produced higher estimates of value than open-ended approaches due to the phenomena of "yea-saying" and preference uncertainty. In addition, they require larger sample sizes, while the calculation of mean WTP is influenced by the functional form of the logit equation, the extent of any truncation used, and the design of bid levels (number and amounts). Finally, there is some evidence that discrete choice approaches suffer from higher hypothetical market bias than open-ended approaches, although strategic behavior is likely to be greater in open-ended formats, which may also result in a greater degree of non-response.

Means of Sample Collection

CVM responses may be collected by mail shot, face-to-face surveys or telephone surveys. Of these three alternatives, telephone surveys are usually considered least desirable. Face-to-face surveys are recommended by the NOAA panel, but the context in which the survey is conducted is important (e.g., shopping malls versus people's homes). Such surveys are also relatively expensive. Mail shots are prone to low response rates and non-response bias, and the order in which the questions are answered is hard to control. However, mail shots can be very cost effective. Some surveys comparing mail shot with face-to-face questioning have found no significant differences in WTP, so long as high response rates can be achieved (i.e., greater than 40%).

Tests of Sensitivity to Scope

It is important to show that WTP is sensitive to the scale of the environmental change involved, where "scale" is defined in accordance with respondents' perceptions. Thus, WTP to protect one coral reef should be less than WTP to protect all coral reefs, although marginal WTP is expected to decline. The NOAA guidelines also recommend such tests of scope.

Tests for Reliability and Validity

Tests for reliability and validity should be incorporated in every CVM. These tests will involve some or all of the following:

- *Convergent validity test*. Does CVM produce similar results for a given resource change as alternative valuation techniques?
- *Theoretical construct validity test*. Can WTP responses be explained statistically to a satisfactory level and in a way in accordance with theoretical expectations? For example, does WTP increase with income? The alternative hypotheses here are that WTP measures are random numbers and/or are not in accord with economic theory.
- *Test-retest criterion*. If the CVM survey is repeated on a different sample drawn from the same population, do statistically different results emerge?
- *Calibration*. Can CVM results be related to actual payments for the resource in question?

- *Debriefing*. Have respondents understood the questions asked of them? Have they valued the same change in resource allocation that the researcher wished?

Special Features of CVM in Developing Country Applications

Many applications of CVM now exist in developing countries (for a survey, see Wasike 1996). These may be seen to have resulted from both academic interest in whether CVM could be transferred to a developing country context, and from policy and project needs on the part of agencies such as the World Bank and the United States Agency for International Development (USAID). Examples of developing country applications of CVM include Adger *et al*. (1994) on the value of Mexican forests, Navrud and Mungatana (1994) on the recreational value of wildlife viewing in Kenya, and Swallow and Wouldyalew (1994) on tsetse fly control in Ethiopia. In addition, many authors have applied CVM in developing countries to issues of drinking water supply. These include Briscoe (1990) for Brazil, Whittington *et al*. (1990) for Haiti, and McPhail (1994) for Tunisia.

Issues emerging from these applications include:

- *Low income levels on the part of respondents*. Income is often strongly related to WTP in these surveys, yet income levels are often low. Some authors have experimented with WTP denominated in units other than money. Swallow and Woudyalew (1994) used willingness to contribute labor hours, while Shyamsundar and Kramer (1996) used rice as a means of payment.
- *Irregularity of income flows*. In subsistence and other types of farming, income flows may be very irregular. Combined with imperfect markets for credit, this means that the temporal nature of payments in a CVM may be important (Wasike and Hanley 1998).
- *Contextual impacts*. These include the presence of listeners during surveys and “prestige” effects. Whittington *et al*. (1993) found statistically significant effects on WTP of such contextual factors in Ghana.
- *Cultural views on environmental values*. The western notion of CBA as a means of taking decisions, and of individual preferences as the measure of environmental values, may fit poorly with prevailing cultural views and values.

However, the consensus emerging from the growing number of CVM applications in developing countries is that, provided the analysis is sufficiently attuned to local circumstances, the method can be successfully applied.

Annex C

Résultats des Recherches sur les Modèles de Soutien et Orientations Futures

Résumé rédigé par Kent Gustavson et Richard M Huber

Ce chapitre résume les résultats d'une recherche de cinq ans, financée par le Comité de recherche de la Banque mondiale et par des dons provenant des Pays-Bas, de la Suède et du Canada gérés par la Banque mondiale. La recherche a été réalisée sous la direction de Richard Huber (Banque mondiale). Les personnes suivantes y ont aussi participé ; ce sont, par ordre alphabétique : Rolf Bak (Institut néerlandais de recherche maritime), Steve Dollar (Université d'Hawaï), Kent Gustavson (Bureau d'étude Gustavson pour les ressources écologiques), Erik Meesters (Institut néerlandais de recherche maritime), Frank Rijsberman (Analyse de ressources), Jack Ruitenbeek (Bureau d'étude HJ Ruitenbeek de ressources), Susie Westmacott (Analyse de ressources).

Les écosystèmes de récifs coralliens à travers le monde décroissent à un rythme inquiétant : ils sont autant menacés par le stress anthropique localisé que par des phénomènes régionaux et mondiaux, comme l'effet de serre (Bryant *et coll.* 1998 ; Jameson *et coll.* 1995 ; Hodgson 1999 ; Hoegh-Guldberg 1999 ; Wilkinson 1998). Certains facteurs semblent cependant encourageants : plusieurs récifs coralliens sont isolés, d'autres sont gérés de manière efficace, et ces écosystèmes ont la capacité potentielle de se rétablir (Wilkinson 1998). Mais il est évident que la gestion efficace de la zone côtière intégrée (ICZM en anglais) est nécessaire pour empêcher un appauvrissement important. Ce chapitre résume les résultats de la recherche sur la création de modèles de soutien aux décisions pour la gestion des récifs coralliens dans la région des tropiques en voie de développement. La stratégie de dissémination y est décrite, et des commentaires sont offerts pour les applications éventuelles et orientations futures de recherche.

ICZM dirige les activités d'au moins deux secteurs de planification, d'élaboration et d'application de projets. Plus formellement, il consiste en «…la planification et la gestion intégrées des ressources et de l'environnement côtiers par des moyens reposant sur les interconnections physiques, socio-économiques et politiques, au sein des systèmes dynamiques côtiers…» (Sorensen 1997). Ou encore, « ICZM est un processus d'administration, comprenant les structures légale et institutionnelle nécessaires pour assurer que les projets de développement et de gestion pour les zones côtières sont intégrés aux objectifs environnementaux (sociaux inclus), et sont élaborés de façon à faire participer les personnes concernées. Le but de ICZM est de tirer le plus grand parti des zones côtières, tout en minimisant les conflits et effets néfastes des activités sur ces mêmes zones, sur les ressources et sur l'environnement. » (Banque mondiale 1996, p. 2). Des lignes directrices et des procédures commencent à apparaître visant le développement d'ICZM (Bower *et coll.* 1994 ; Chua 1993 ; Clark 1995 ; Pernetta et Edler 1993 ; Sorensen 1997 ; Banque mondiale 1993a, 1996).

L'intégration est un élément clef dans ICZM—en particulier, l'intégration horizontale à travers divers secteurs économiques et agences de gestion dans la planification et l'application (Clark 1995 ; Sorensen 1997). Les activités côtières doivent être considérées conjointement, à cause de leur interdépendance et de leur impact prévu - cumulatif et non-additif. Mais comment considérer ensemble plusieurs secteurs économiques et activités humaines? Comment intégrer un maintien des écosystèmes côtiers soutenant les activités économiques, directement et indirectement? Quelle devrait être le processus pour établir les activités devant être authorisées dans la zone côtière, comment devraient-elles être élaborées et mises en œuvre, et que doit être l'intensité de l'activité authorisée ? Sur quelles bases les conflits éventuels entre les usagers de la zone côtière devraient-ils être réglés ? Pour pouvoir répondre à ces questions, il faut considérer plusieurs paramètres, critères, et divers ensembles de valeurs.

Les modèles de soutien aux décisions économiques écologiques peuvent jouer un rôle important. Parmi eux, il y a ceux qui admettent la possibilité d'atteindre une solution de gestion efficace d'un point de vue économique, tout en considérant explicitement les limites qui doivent être imposées sur le niveau et le genre d'activité économique, à cause des caractéristiques et de la capacité du milieu naturel. Pour ICZM, ces modèles de soutien doivent aussi s'adapter à l'information sur le contexte socioculturel de l'environnement de gestion, lequel joue un rôle capital dans la création de principes directeurs.

Quelles sont les caractéristiques d'un modèle de soutien aux décisions ? Premièrement, il doit être capable de répondre aux questions spécifiques et pertinentes d'orientations. Pour faciliter l'élaboration et la création d'un tel modèle, il faudrait pouvoir compter sur une base existante de recherche déjà effectuée sur le sujet. Ruitenbeek *et coll.* (1999a, 1999b) ont remarqué que le manque d'informations sur l'écologie des récifs coralliens (c.-à-d. sur les relations et les liens fonctionnels) et les caractéristiques des économies qui ont un impact sur ces récifs ralentissent la création de modèles de soutien aux décisions économiques écologiques. La majorité de l'information disponible n'est pas directement « pertinente à la politique » et, dans ce contexte, ne facilite pas la tâche de prise de décision ou directement la création d'un modèle. Deuxièmement, un modèle doit être compris et utilisé directement par le groupe visé. La communication des données doit être relativement aisée, les essais faciles à faire, et les résultats faciles à interpréter. Troisièmement, on doit distinguer entre l'utilisation du modèle destiné surtout à la recherche scientifique et les modèles utilisés surtout comme information pour la prise de décision et les politiques—les modèles avec des constructions très expérimentales ne doivent pas être utilisés comme outils de soutien aux décisions. La théorie sur laquelle se basent les modèles de soutien aux décisions doit être relativement solide. Par exemple, en ce qui concerne l'utilisation de modèles écologiques destinés à être utilisés pour prendre des décisions, Friedland (1977) remarque que « l'objectif principal n'est pas la découverte de nouvelles vérités, mais la collecte et l'intégration de données existantes et leur présentation en une forme utile pour une prise de décision ». Ceci a des conséquences directes sur le genre de modèle approprié.

Finalement, les modèles de soutien aux décisions doivent être flexibles aux changements des éléments des données, des relations spécifiées dans le modèle, et à la création de solutions de rechange ou de scénarios considérés par le modèle. Aussi, il est important que les besoins des usagers soient pris en considération. Un modèle qui utilise des données qui ne s'appliquent plus à un lieu particulier, dont les relations économiques écologiques sous-jacentes ne sont plus correctes, ou qui ne permet plus le changement de solutions de rechange de développement ou de scénario, ne sera pas utile à long terme.

Résultats des projets de modélisation

Le travail de recherche a commencé en 1995 selon deux grandes lignes concernant les récifs coralliens dans la région des tropiques en voie de développement : (i) la modélisation rentable d'interventions gestionnaires (c.-à-d. l'offre de la biodiversité en tant que bien économique) ; et (ii) la détermination de la valeur du système marin (c.-à-d., la demande pour la biodiversité). Essentiellement, la modélisation à moindre coût est recherché pour identifier la variation des prix pour les interventions, afin d'améliorer les conditions des récifs coralliens, où les effets de diverses politiques d'interventions et activités économiques sont liés à la santé des récifs et aux coûts associés aux améliorations (Brown *et coll.* 1996 ; Huber et Jameson 1998a ; Huber *et coll.* 1994, 1996 ; Meesters 1995 ; Meesters et Westmacott 1996 ; Meesters *et coll.* 1995, 1996a, 1998 ; Ridgley et Dollar 1996 ; Ridgley *et coll.* 1995 ; Rijsberman 1995 ; Rijsberman et Westmacott 1996 ; Rijsberman *et coll.* 1995a ; Ruitenbeek *et coll.* 1999a, 1999b ; Westmacott 1996 ; Westmacott et Rijsberman 1997 ; Westmacott *et coll.* 1995). Le modèle de détermination de la valeur du système marin avait pour but d'identifier les bénéfices qui peuvent être réalisés en soutenant ou améliorant l'état des récifs (Gustavson 1998 ; Huber et Ruitenbeek 1997 ; Putterman 1998 ; Ruitenbeek et Cartier 1999 ; Spash *et coll.* 1998).

Les grandes lignes de la recherche consistaient à aider les décideurs dans la gestion et la protection des récifs coralliens (Huber et Ruitenbeek 1997 ; Huber *et coll.* 1994). L'établissement d'une méthodologie de coût-bénéfice appropriée à être utilisée sur les systèmes de récifs coralliens et les tropiques en voie de développement, et sur les systèmes marins en général, contribuera à des interventions politiques et institutionnelles adéquates pour faciliter une utilisation des récifs économiquement efficace, tout en considérant les impacts sur et le rôle des écosystèmes qui les soutiennent. Un tel groupe d'analyse de coût-bénéfice (ACB) est représenté par l'intégration des modèles de rentabilité et de détermination de valeur (Ruitenbeek et Cartier 1999). Trois sites ont été sélectionnés comme étude de cas pour tester la méthodologie: (i) Curaçao, les Antilles néerlandaises ; (ii) les Maldives ; et (iii) Montego Bay, Jamaïque.

Corail-Curaçao

Rijsberman et Westmacott (1996 ; cf. aussi Meesters 1995 ; Meesters *et coll.* 1996a ; Rijsberman *et coll.* 1995a ; Westmacott *et coll.* 1995) ont élaboré un modèle d'analyse de rentabilité pour la gestion des récifs coralliens et la protection de la côte sud de Curaçao. Le modèle de soutien aux décisions a été créer pour faciliter la communication entre les intéressés sur les orientations de développement et les stratégies de gestion environnementale ; l'analyse des impacts sur la santé des récifs coralliens des créations envisagées à travers les décharges des eaux résiduaires et des sédiments, intégrant ainsi l'utilisation de la terre, le tourisme et la planification de la conservation ; et l'analyse de la rentabilité des interventions gestionnaires ayant pour but de maintenir la santé des récifs coralliens. Le modèle utilise une interface structurée d'ordinateur.

Les résultats des trois scénarios (un scénario de création de référence statu quo et deux choix de scénario de croissance) indiquent qu'il est très probable que Curaçao connaîtra des réductions importantes dans la santé et l'abondance des récifs coralliens au cours des dix prochaines années. Néanmoins, la modélisation indique aussi que les interventions ayant trait aux stratégies de gestion environnementale peuvent freiner cette tendance et, dans certains cas, mener au rétablissement des récifs au-delà de leur état actuel. Les interventions suggérées incluent des combinaisons de traitement des eaux usées, une évacuation appropriée des déchets, et des réductions de la pollution des raffineries ; l'application de différents moyens pour préserver les plages et la réduction des déchets des industries et du transport maritime n'étaient pas efficaces (Rijsberman et Westmacott 1996). Par contre, Rijsberman et Westmacott ont aussi trouvé que les résultats de la modélistion peuvent êtres particuliers à l'échelle spatiale examinée, et que ces dernières interventions peuvent en effet être rentables et appropriées dans un contexte local plus petit.

Rijsberman et Westmacott (1996) soulignent que l'utilité d'un outil de modélisation ne peut être démontré qu'à travers un programme qui encourage une coopération étroite entre ceux qui sont concernés par la mise en œuvre du scénario et par la procédure de prise de décisions. Corail-Curaçao nous permet d'ordonner les mesures et d'explorer la formulation de diverses combinaisons de mesures afin d'atteindre un objectif spécifique pour la couverture et la diversité des récifs. Par exemple, pour atteindre une couverture de 14% et une diversité de 50% (comme indiqué par le modèle), il faudrait un investissement initial de 310 millions de NAF, avec un coût annuel opérationnel de 6 million de NAF (Rijsberman et Westmacott 1996).

Corail-Maldives

Westmacott et Rijsberman (1997 ; cf. aussi Brown *et coll.* 1996 ; Meesters et Westmacott 1996 ; Rijsberman 1995 ; Rijsberman et Westmacott 1996 ; Westmacott 1996 ; Westmacott et Rijsberman 1997) ont élaboré un modèle d'analyse de rentabilité pour la gestion et la protection des récifs coralliens au nord et au sud de Male, capitale des Maldives. En tant que modèle élaboré en même temps que celui de Corail-Curaçao, le but était d'examiner si un modèle adapté aux Maldives (Corail-Maldives) pourrait servir comme un outil utile de soutien aux décisions. Westmacott et Rijsberman (1997) décrivent le modèle et les résultats d'analyses préliminaires.

Ainsi qu'avec Corail-Curaçao, le modèle de Corail-Maldives était conçu pour permettre aux décideurs d'établir la rentabilité relative des diverses interventions de gestion environnementale pour diverses options de développement économique dans le cadre d'améliorations obtenues dans la santé des récifs (c.-à-d., utilisant des index de couverture et rugosité de récifs coralliens comme mesures provisoires). Les impacts des scénarios peuvent être des indicateurs économiques, sociaux et environnementaux qui sont sélectionnés dès le début des analyses par l'utilisateur du modèle. Les priorités des lignes directrices et les choix possibles de gestion ont été identifiés après des discussions avec des agences gouvernementales. Étant donné la nature des impacts sur les récifs coralliens dans les Maldives, les interventions de gestion ont pour objectif principal de minimiser les dégâts physiques (Westmacott et Rijsberman 1997). Westmacott et Rijsberman (1997) illustrent l'utilisation du modèle avec des exemples.

Westmacott et Rijsberman (1997) constatent qu'il existe un éventail d'indicateurs qui peuvent être utilisés pour décrire la réussite ou la défaite éventuelles d'une stratégie de gestion de zones côtières - bien que le modèle soit quelque peu flexible, l'ensemble des indicateurs de gestion des zones côtières qui peuvent être sélectionnés et examinés par l'usager est limité par nécessité. De plus, l'utilisation de mesures rentables qui ne sont liées qu'aux variations de la santé des récifs coralliens peut omettre d'autres stratégies très importantes pour le succès d'un programme particulier d'ICZM (par ex., les problèmes de santé publique). Les résultats de scénarios de modélisation pour le soutien aux décisions pourraient être mis dans le contexte de buts et exigences sociaux dans la formulation de projets de création et de gestion. Ainsi qu'avec Corail-Curaçao, le modèle peut ne pas bien refléter les conditions locales à une échelle spatiale en-dessous de celle qui est incorporée dans les éléments du modèle.

La détermination de la valeur des bénéfices des récifs coralliens

Pour arriver à une valeur économique totale (VET), les études d'évaluation économique des systèmes naturels font souvent la distinction entre les valeurs d'utilisation et les valeurs de non-usage, ainsi qu'entre les valeurs d'utilisation directe et les valeurs d'utilisation indirecte. Ces distinctions reflètent souvent la méthode d'estimation. Lors de la spécification de la structure d'évaluation des récifs coralliens pour le Parc marin de Montego Bay, il était beaucoup plus utile de différencier trois classifications d'évaluation de biodiversité marine : (i) les méthodes d'évaluation de production orientées vers l'offre (c.-à-d., la contribution de fonctions de production des systèmes marins à la valeur économique) ; (ii) les méthodes d'évaluation d'utilité orientées vers la demande (c.-à-d., la contribution des systèmes marins sur l'utilité d'un individu ou de la société) ; et (iii) les méthodes d'évaluation de récupération de rente orientées vers le profit (c.-à-d., la contribution des systèmes marins à travers la distribution de valeur d'utilisation comme rente récupérée, profits, ou valeur ajoutée ; Huber et Ruitenbeek 1997 ; Ruitenbeek et Cartier 1999). Pour la dernière catégorie, la contribution potentielle de la biodiversité des récifs à travers la création d'une entreprise de bioprospection à été examinée.

Fonctions de contribution de la production - Parc marin de Montego Bay

Les valeurs d'utilisation locales furent estimées par Gustavson (1998) pour deux larges catégories d'utilisation—les pêcheries à proximité de la côte et le tourisme. Les valeurs d'utilisation indirecte associée à la protection côtière ont aussi été estimées. Ces utilisations locales des eaux du Parc marin de Montego Bay étaient non seulement plus importantes pendant l'application au dernier site d'étude, mais aussi identifiées comme une haute priorité pour la politique générale. Les valeurs rapportées par Gustavson montrent à quel point la contribution des productions provenant des récifs risque être perdu si les efforts de conservation ne sont pas adéquats.

Les services de tourisme de Montego Bay comprennent les hôtels, les services de la restauration, les divertissements (y compris les sports et attractions nautiques indépendants), le transport, les achats, et autres services divers. Les estimations de la valeur actuelle nette (VAN) associée au tourisme sont de l'ordre de 210 millions de dollars US (à un taux d'escompte de 15%) à 630 millions de dollars US (à un taux d'escompte de 5%) en 1996. Les estimations de VAN en 1998 associées avec la pêche sont de -1,66 million de dollars US à 7,49 millions de dollars US (monnaie de base : dollars de 1996 ; en utilisant les extrêmes, respectivement, de valeurs nettes annuelles et un taux d'escompte de 5% ; les valeurs d'escompte de 10% et 15% sont dans cette intervalle). La VAN du total des terres en danger d'érosion si la fonction protectrice des récifs est compromise, basé sur les 125 hectares vulnérables, est estimée à 65 millions de dollars US (en dollars constants de 1996). La valeur médiane de VAN de toutes les valeurs d'utilisation locale pour le Parc marin de Montego Bay est d'à peu près 381 millions de dollars US. En prenant une superficie totale de récif de 42,65 hectare comme référence, ceci revient à 8,63 millions/ha de dollars US ou 0,893 million ha^{-1} $année^{-1}$ sur une base annuelle (avec un taux d'escompte de 10%).

Contributions à l'utilité — Parc marin de Montego Bay et côte sud de Curaçao

Spash *et coll.* (1998) ont utilisé la méthode des « enchères » (CVM) pour estimer les valeurs d'utilité associées à la biodiversité des récifs coralliens à Montego Bay en Jamaïque et le long de la côte sud du Curaçao. L'étude est particulièrement intéressante, parce qu'elle examine les valeurs d'utilité associées à une ressource environnementale marine (c.-à-d., la qualité des récifs coralliens), lesquelles avaient toujours été négligées dans le passé. De plus, la recherche a aussi contribué à déterminer les sources de parti pris quant aux préférences lexicographiques qui surgissent quand un répondant est réticent à accepter un arbitrage pour la perte d'un bien ou un service (c.-à-d., en refusant de faire des choix, ils n'agissent pas selon une théorie économique). Pour ces offres nulles, des distinctions ont été faites entre ceux qui manquent de moyens financiers, ceux qui considèrent les améliorations inutiles, ceux qui préfèrent dépenser l'argent sur d'autres biens ou services, ou ceux qui protestent d'avoir à faire un tel choix. Parmi ceux qui n'offraient aucune offre et donc faisaient preuve de parti pris, étaient inclus les resquilleurs : ils pensent que le paiement n'est pas une solution adéquate, n'ont pas confiance en l'institution proposée, ou rejettent le mécanisme de paiement. Le sondage a aussi exploré l'étendue de positions morales, basées sur le droit, qui seraient compatible avec les préférences lexicographiques. Pour faciliter la comparaison avec les résultats des études sur l'utilisation locale et les évaluations de bioprospection dans Montego Bay, la CVM a aussi été formulée pour séparer les valeurs d'utilisation directe et celle d'utilisation indirecte et de non-usage.

Les répondants étaient invités à contribuer à des fonds fiduciaires qui seraient gérés par un parc marin, afin d'augmenter la biodiversité à l'intérieur du parc. Le paiement serait fait une fois par an pendant cinq ans, et augmenterait le couvert de récif coralliens de 25%. L'analyse de la courbe d'offre (c.-à-d., l'analyse « tobit » et une estimation de maximum de vraisemblance) a four-ni de l'information sur les variables qui déterminent la variation de la disposition à payer (DAP) et a perfectionné l'estimation des DAP. Pour les moyennes des échantillons, la DAP était de 2,08 $ US par personne à Curaçao, et 3,24 $ US par personne en Jamaïque (Spash *et coll*. 1998). La différence entre les deux est expliquée par le mélange de touristes et de résidents, les Jamaïcains étant disposés à payer presque deux fois plus que leurs homologues à Curaçao. En utilisant le profil d'un visiteur et d'une population locale typique et un taux d'escompte de 10%, ceci se traduit en une valeur approximative de DAP de 4,5 million $ US à Curaçao et 20 million $ US à Montego Bay (Spash *et coll*. 1998).

Contributions éventuelles de bioprospection—Parc marin de Montego Bay

Le modèle pour estimer la bioprospection s'est concentré sur les revenus moyens net, utilisant les informations localisées des coûts pour la Jamaïque, ainsi que les valeurs de bénéfices et de taux de succès basées sur l'information propriétaire pour les produits marins dans les Caraïbes (Ruitenbeek et Cartier 1999). Les hypothèses du modèle paramétrique comprenaient la caractéristique des relations espèces/régions et la relation de partage de revenus entre les institutions (c.-à-d., un partage conditionnel du bénéfice net et un tarif d'échantillon à niveau fixe). L'analyse de sensibilité a exploré les effets des variations des paramètres du modèle sur la valeur estimée, y compris les variations dans la surface totale de substrat de récifs à couvert vivant disponible et la spécification des relations espèces/région comme co-déterminants du nombre attendu d'échantillons disponibles pour tester. D'autres options pour le modèle incluent un tarif de sondage fixe seulement, des parts de revenu mélangés, des coûts élevés de recherche-développement, des « taux de frappe » bas, et un programme de sondage raccourci. Une fonction d'avantage marginale qui reliait la valeur ou le « prix » de biodiversité marine à l'abondance de récif coralliens fut dérivé.

Une valeur de « cas de base » de 70 millions $ US a été calculée pour les récifs du Parc Marin de Montego Bay, de laquelle à peu près 7 millions $ US (c.-à-d., 10%) pourraient vraisemblablement être récupérés par la Jamaïque sous forme de redevances ou d'arrangements de rente (Ruitenbeek et Cartier 1999). La valeur marginale de bioprospection de récifs a été évaluée à 530 $ US/ha ou encore 225 000 $ US par pourcentage de variation de l'abondance de récifs coralliens (correspondant à un prix de planification local jamaïcain de 22 500 $ US par pourcentage de variation de l'abondance de récif corallien).

L'Identification d'Interventions à Moindre Coût—Parc Marin de Montego Bay

Comme pour les modèles de Corail-Curaçao et Corail-Maldives, Ruitenbeek *et coll*. (1999a ; cf. aussi Ridgley *et coll*. 1995 ; Ridgley et Dollar 1996 ; Ruitenbeek *et coll*. 1999b) ont appliqué une méthodologie de logique de l'incertain pour identifier les interventions à moindre coût qui mèneraient à une augmentation de l'abondance des récifs coralliens dans l'enceinte du Parc marin de Montego Bay. Les procédures de logique de l'incertain sont utilisées dans un modèle d'impact écologique sur les récifs coralliens pour générer une surface dose-réponse complexe qui émule la relation entre l'abondance des récifs coralliens et divers intrants dans le contexte de l'environnement marin abiotique. Ceci est relié à un modèle économique non linéaire qui décrit les activités économiques actuelles et futures dans huit secteurs, dans les interventions de politique et technique, et dans les frais de pollution à Montego Bay. L'optimisation nous donne des aperçus sur les moyens les plus rentables pour protéger les récifs coralliens pour divers niveaux recherchés de qualités de récifs.

Á Montego Bay en Jamaïque, une augmentation de jusqu'à 20% de l'abondance de récifs coralliens peut être atteinte avec l'utilisation de mesures appropriées à un coût réel de 153 millions $ US sur 25 ans (Ruitenbeek *et coll*. 1999a). Les mesures spécifiques de politiques considérées incluaient l'installation d'un piège de sédimentation sur la Rivière de Montego, la plantation d'arbres sur la crête élevée, l'installation d'un système d'aération de déchets, celle d'un centre de traitement à grande échelle, la vulgarisation agricole pour fournir des technologies qui réduisent les déchets, l'installation d'un émissaire d'évacuation et d'une station de pompage, l'amélioration de la récupération des ordures ménagères, et l'application d'une taxe hôtelière. Certaines interventions étaient relativement rentables. Par exemple, la récupération d'ordures ménagères, l'installation d'un émissaire d'évacuation et l'utilisation d'un piège de sédimentation sur la Rivière Montego imposeraient un coût actuel de 12 millions $ US et auraient pour conséquence d'améliorer le couvert de récif corallien par plus de 10% (Ruitenbeek *et coll*. 1999a).

Une démonstration clé de la recherche était que les méthodologies conventionnelles pour mesurer la rentabilité peuvent aboutir à des solutions qui ne sont pas optimales quand les politiques sont appliquées à des systèmes complexes. En effet, les analyses de rentabilité ont tendance à supposer que les interventions individuelles sont distinctes et indépendantes, et que les bénéfices peuvent être séparés des coûts (souvent quand les bénéfices ne peuvent pas être définis). Quand il s'agit de systèmes très complexes tels que les récifs coralliens, les synergies, les rétroactions et autres interdépendances entre les interventions individuelles et le niveau de santé qui en résulte des récifs coralliens peuvent invalider les recommandations des interventions d'une politique évaluée individuellement qui serait appliquée d'une manière séquentielle. Par exemple, le reboisement était l'une des interventions optimales pour une amélioration des récifs coralliens de l'ordre de 14% et 20%, mais ne figurait pas parmi les mesures optimales pour une amélioration de 15% ou 16% (Ruitenbeek *et coll*. 1999a). Ruitenbeek *et coll*. (1999a) ont remarqué que cela signifie que les objectifs de santé de récifs coralliens, en ce qui concerne les bénéfices secondaires, doivent être établis avant d'appliquer des politiques d'intervention.

Intégration des résultats de Montego Bay pour un niveau d'intervention efficace

La synthèse des diverses études d'évaluation de récifs coralliens pour le Parc marin de Montego Bay permet d'obtenir une fonction de valeur totale et de bénéfice marginal (ou prix) (Ruitenbeek et Cartier 1999). Pour obtenir la fonction de bénéfice marginal, reliant les prix aux variations d'abondance de récif corallien, il fallait ajouter d'autres hypothèses ayant trait au lien entre les catégories de valeur et l'abondance ou la qualité de récifs coralliens. En particulier, on présume qu'il existe une relation linéaire entre la qualité des récifs et les valeurs d'utilisation locale et les valeurs d'utilité de non-usage. Il est très probable que cela ne soit pas justifié, mais présumer une relation moins compliqué n'est pas non plus justifiable avec les données actuelles. Seuls les résultat du modèle d'évaluation de bioprospection (Ruitenbeek et Cartier 1999) permettaient la spécification d'une forme fonctionnelle différente. Les valeurs marginales nettes, comme le notent Ruitenbeek et Cartier (1999), seront probablement surestimées dans certains cas et sous-estimées dans d'autres.

Le bénéfice total attribué aux récifs coralliens du Parc marin de Montego Bay est évalué à 470 millions $ US ; chaque variation de 1% génère à peu près un bénéfice marginal de 10 millions $ US, ou encore le prix marginal des récifs coralliens est d'à peu près 23 million $ US /ha (Ruitenbeek et Cartier 1999). La majorité de la valeur est attribuée au tourisme. La protection côtière et les bénéfices d'utilité de non-usage contribuent aussi, mais à un moindre degré. Les pêcheries existantes et l'élaboration éventuelle d'un programme de bioprospection ont un effet négligeable sur les valeurs marginales (Ruitenbeek et Cartier 1999).

Il est possible d'atteindre une optimisation globale en utilisant la fonction de coût marginal élaborée dans l'étude de l'intervention à moindre coût pour le Parc marin de Montego Bay (Ruitenbeek *et coll*. 1999a), conjointement avec les approximations de bénéfice marginal. Une amélioration d'abondance des récifs coralliens de 13% est suggérée par Ruitenbeek et Cartier (1999 ; c.-à-d., d'un couvert approximatif de 29% évalué à partir des conditions d'équilibre du modèle - cf. Ruitenbeek *et coll*. 1999a - à un couvert de 42%), nécessitant des dépenses nettes de 27 millions $ US. Les interventions nécessaires entraîneraient l'installation de pièges de sédimentation, l'aération des déchets, l'installation d'évacuation de déchets, l'application d'une récupération améliorée de déchets solides, et l'application de stimulants économiques pour améliorer la gestion des déchets dans l'industrie hôtelière. Une analyse de sensibilité suggère que cette optimisation est assez résistante aux variations d'approximations des bénéfices économiques nets—les bénéfices devraient être augmentés de 275 millions $ US, ou diminués de 300 millions $ US, pour que l'amélioration visée de la qualité de récifs coralliens augmente de plus de 20% (Ruitenbeek et Cartier 1999).

La valeur humaine de l'utilisation des récifs coralliens

En plus de l'application de l'analyse de rentabilité, l'évaluation de ressources ou CBA, il est important que les décideurs considèrent d'une manière compréhensive et systématique le contexte social, culturel et économique de création de politiques et de changement écologique. Un tel contexte ou information sur la « structure humaine » ne font pas traditionnellement partie d'une telle analyse, dans laquelle des indicateurs ou mesures monétaires quantitatives sont souvent appliqués dans un environnement de prise de décision à « évaluation automatique », réduisant ainsi l'interprétation approfondie du niveau approprié ou optimal, et des types d'interventions et de politiques nécessaires.

Les méthodologies d'évaluation économique appliquées dans ces projets étaient destinées à énumérer les bénéfices totaux reçus actuellement des récifs coralliens, à travers les contributions de fonction de production et d'utilité humaine (ainsi que de rentes ou redevances éventuelles provenant de la création d'entreprises de bioprospections marines). En théorie, de tels bénéfices monétaires refléteront l'ensemble local de valeurs. Néanmoins, réduire l'information sociale, culturelle et économique en une seule valeur métrique résulte en une grande perte. Cette perte a été démontrée par la mise au point et l'application d'une méthodologie d'évaluation socio-économique rapide pour fournir une explication sur les groupes utilisant les récifs coralliens dans le cadre d'étude du site à Montego Bay (Bunce et Gustavson 1998a; Bunce *et coll.* 1999). Une telle information faciliterait l'adaptation de stratégies de gestion selon les profils d'utilisation des groupes, les priorités gestionnaires, et les ressources disponibles. En gros, l'information sur la « structure humaine » aide à identifier une solution économiquement rentable, aussi viable d'un point de vue social que culturel. Cette information a démontré une utilité dans l'élaboration de politiques et programmes efficaces pour le Parc marin de Montego Bay (Bunce *et coll.* 1999; cf. aussi Huber et Jameson 1998c).

Contexte d'orientation et conseils

Étude de cas — La récupération de rente provenant de l'utilisation des récifs coralliens de Montego Bay

La récupération d'au moins une partie de la rente, provenant d'utilisations directes, pour payer la gestion nécessaire et l'amélioration éventuelle de la ressource est un aspect particulièrement intéressant pour les autorités du Parc marin de Montego Bay, et pour toute autorité de systèmes marins côtiers. En d'autres termes, il existe des coûts sociaux associés à la conservation et la gestion de la ressource qui doivent être payés par les usagers.

En tant que composante de l'étude d'évaluation d'utilisation locale (Gustavson 1998), les frais gouvernementaux actuels, qui récupèrent peut-être une partie de la rente, ont été étudiés. Imposer des frais d'usage ne fait pas actuellement partie de la politique du Parc marin de Montego Bay (un mécanisme reconnu pour la récupération de la rente), bien qu'elle soit présente dans les étapes initiales. D'autres frais gouvernementaux, liés spécifiquement au tourisme ou aux activités liés aux pêcheries, peuvent récupérer une portion du surplus du consommateur ou du producteur, mais ne sont pas forcément destinés à ce but. Sont inclus les frais de permis d'affaires, de permis de pêcheries, de plage, et les taxes de départ de touristes.

En principe, les frais de permis sont perçus pour payer les coûts de régulation et d'administration des activités ou des affaires du gouvernement. Aucune information n'est disponible sur le coût actuel pour réguler les activités relatives aux récifs, mais il est très probable que ces coûts ne soient pas perçus selon le barème des frais en vigueur. En effet, les frais de plage en place étaient généralement bas et, bien qu'ils varient plus ou moins avec le genre d'utilisation, ne sont pas liés au niveau de surplus de producteurs. Aucun de ces fonds n'est explicitement destiné à financer la gestion du Parc marin de Montego Bay. Il n'existe pas d'autres frais gouvernementaux ou d'agence gestionnaire qui sont liés explicitement aux activités de tourisme ou de pêcherie dans la région. Les impôts de bénéfices des sociétés, ou l'impôt sur les bénéfices particuliers dans le cas de pêcheurs ou bénéfices distribués individuellement des entreprises de tourisme, peuvent aussi récupérer une partie de la rente. Néanmoins, les taxes sont payées à la perception générale du gouvernement et par conséquent ne sont pas disponibles pour l'utilisation dans la gestion du parc marin. Il est important d'encourager la tendance actuelle du Parc Marin de Montego Bay à instaurer des frais d'utilisation.

Étude de cas — Conseil pour les institutions sur l'orientation de la bioprospection en Jamaïque

Putterman (1998) donne des recommandations particulières sur la politique et le renforcement institutionnel en ce qui concerne l'incorporation de l'utilisation de ressources génétiques dans ICZM en Jamaïque, un outil potentiellement puissant pour la conservation et le développement économique. La diversité génétique ou moléculaire, une mesure de diversité biologique dans une espèce, peut engendrer de nouveaux produits pharmaceutiques et industriels, et de nouvelles variétés agricoles. Plusieurs stratégies pour la collaboration de recherche peuvent être employés en tant que stratégie réduisant le risque pour optimiser la capacité de découvrir de nouveaux produits chimiques ou gènes prometteurs ; de même, plusieurs mécanismes existent pour partager les bénéfices et options pour la compensation (cf. Putterman 1998). Actuellement, il n'existe pas de politique jamaïcaine pour contrôler l'accès aux ressources génétiques, comme le remarque Putterman (1998). Une révision des institutions et politiques jamaïcaines aboutit aux recommandations suivantes :

- Pour élaborer un ensemble d'options de politiques pour les ressources, il faut incorporer les obligations dans la Convention sur la diversité biologique et la Convention des Nations Unies sur la Loi de la mer ; il faut aussi tenir compte de l'effet de l'élaboration de politiques sur les activités du secteur privé ;
- Réglementer à l'avance l'accès aux ressources génétique par le biais de permis et de contrats qui définiraient les droits à ces ressources avant qu'il n'y ait prélèvement ou exportation d'échantillons;
- Établir des lois de *suis generis* (originelle) pour les propriétés tangibles et savoir traditionnel, afin de définir qui a le droit de participer aux négociations de contrats de transfert de ressources génétiques ou savoir traditionnel, et d'en tirer parti ;
- Développer a priori des procédures de consentement, afin de donner aux doyens légaux de droits sur les ressources génétiques et savoir traditionnel un moyen de contrôler l'utilisation de ces ressources ; et,

- Créer une formule de partage national pour convertir une partie du revenu monétaire du développement d'un nouveau bien aux biens publics, afin d'assurer un partage juste et équitable des bénéfices créés par l'utilisation de ressources génétiques.

Les valeurs actuelles nettes d'une bioprospection éventuelle sont petites par rapport aux valeurs d'usage local associées au tourisme et à la protection des côtes (Gustavson 1998; Ruitenbeek et Cartier 1999) et, comme mentionné ci-dessus, elles auront un effet négligeable sur les valeurs marginales de récifs coralliens. Néanmoins, Ruitenbeek et Cartier (1999) remarquent que les impacts des coûts institutionnels associés au déroulement du programme national de bioprospection en Jamaïque recommandé par Putterman (1998) sont minimes. C'est la volonté de la direction locale et des concernés locaux du Parc marin de Montego Bay de s'engager dans une telle entreprise qui est maintenant remise en question.

Résultats de modélisation et Conseil sur la politique pour l'utilisation de modèle de soutien aux décisions

En général, au-delà des questions particulières sur la politique et les institutions qui se posent quand on considère l'élaboration éventuelle d'un programme de bioprospection à Montego Bay, des questions de politique surgissent des résultats de la modélisation d'intervention à moindre coût et du bénéfice de récifs coralliens. Ruitenbeek et Cartier (1999) remarquent que, si l'efficacité économique est le but, les coûts et les bénéfices doivent être considérés dans le cadre de la recherche quant aux systèmes complexes non linéaires comme les récifs coralliens. Une analyse de coût-efficacité ne suffirait pas. Ruitenbeek et Cartier suggèrent aussi une plus grande attention au niveau local sur les dimensions socio-économiques et gestionnaires d'usages directes, y compris l'encouragement de régimes de gestion locale pratiques qui considèrent et incluent les personnes concernées. Cette suggestion est aussi soulignée par Bunce et Gustavson (1998a).

Dissémination

Les approches d'intervention et évaluation à moindre coût de cette recherche de modélisation sont un outil utile de soutien aux décisions, de politique et de formation pour les directeurs de récifs coralliens et pour les décideurs gouvernementaux qui font face à des problèmes majeurs de gestion de récifs coralliens. La stratégie de dissémination jointe pour les projets comporte les aspects suivants :

- Le lancement d'une exposition itinérante pour disséminer les résultats, qui inclurait un CD-ROM du COCOMO - Modèle de Soutien aux décisions du Récif Corallien de Montego Bay ;
- La prolongation des séminaires financés par la Gestion des Connaissances de la Banque mondiale, aux niveaux local et national, avec pour objectif de recevoir une rétroinformation sur les découvertes de la modélisation de recherche appliquée, identifier les régions prioritaires pour des recherches futures, et identifier des moyens éventuels pour renforcer la capacité locale et régionale pour gérer les ressources côtières ;
- La création de programmes pour les usagers sur les sites Internet de la Gestion de Connaissances de la Banque mondiale (BIONODE et Ressources d'Eau) et autres sites Internet ; et,
- L'aide aux fonds fiduciaires du Parc marin de Montego Bay pour la préparation d'un projet dénommé ReefFix qui peut être reproduit sur une échelle régionale (Jameson et Huber 1999).

Les parties concernées participant aux études de cas ont exprimé leur désir et intérêt pour une compréhension plus complète des activités de développement en cours et planifiées en ce qui concerne la zone côtière. Qu'ils soient des pêcheurs locaux, des organisateurs de sports nautiques, des hôteliers, des entrepreneurs et promoteurs locaux, des habitants locaux ou des touristes, il est important de répondre à ces demandes d'information pour avoir une gestion efficace de la zone côtière. La stratégie de dissémination est nécessaire pour augmenter la participation des divers groupes concernés dans l'évaluation des variations dans l'environnement marin, et dans l'atténuation ou la prévention des impacts négatifs sur les récifs coralliens. La création d'un réseau de décideurs et de rechercheurs—une « communauté de mise en pratique » —pour faciliter le partage d'expériences internationales sur la restauration des récifs coralliens et pour promouvoir la recherche conjointe est aussi important.

COCOMO

COCOMO est un modèle de soutien aux décisions pour la gestion de la zone côtière de Montego Bay qui illustre les problèmes côtiers et qui évalue les effets des activités humaines. C'est aussi un bon outil pour élaborer les politiques et renforcer la capacité dans la gestion des zones côtières intégrées (ICZM). Le site d'étude de cas de Montego Bay a été sélectionné pour le projet de modélisation interactif à cause des besoins critiques pour un tel outil. Le centre urbain croît rapidement, avec un développement souvent ad hoc et non planifié. Plusieurs changements physiques ont été effectués sur la zone côtière, y compris le remplissage de la côte, la destruction de mangroves et la sédimentation, en plus d'enrichissement nutritif côtier, pressions intensives de pêche, et utilisation extensive par les sports nautiques, plongeons, et industries de tourisme. Ces changement ont engendré une baisse de la qualité de l'eau et des ressources côtières, et ont eu des impacts sur l'écosystème précieux de récifs coralliens.

En particulier, la recherche de modélisation appliquée de COCOMO aide les fonds fiduciaires du Parc marin de Montego Bay avec un programme cohérent et compréhensif qui :

- Sensibilise et encourage l'unanimité de la part des parties concernées en ce qui concerne les priorités environnementales à Montego Bay ;
- Identifie les exigences qui existent pour combattre les problèmes de gestion de zone côtière à Montego Bay à long et à court termes avec les diverses organisations gouvernementales et non gouvernementales (ONG) concernées ;
- Identifie les investissements environnementaux réalisables, les solutions à coût relativement bas ; et,
- Établit un dialogue avec les parties concernées.

L'interface conviviale du modèle est créée pour les décideurs, les spécialistes, et ceux qui sont intéressés par les problèmes côtiers de Montego Bay. Elle utilise un grand nombre de graphique pour donner une vue d'ensemble rapide aux usagers sur les problèmes côtiers et comment le développement, les pêcheries, le tourisme, l'agriculture, l'industrie, et les ménages affectent la côte et les récifs coralliens de Montego Bay. L'information sur la contribution des récifs coralliens à Montego Bay à travers les pêcheries, le tourisme et la protection côtière est incorporée dans le modèle. Plusieurs décisions peuvent être prises sur l'interface de l'usager pour protéger la zone côtière et les récifs coralliens, certaines étant plus rentables que d'autres. COCOMO prédit l'ensemble d'intervention à moindre coût pour réaliser une abondance spécifiée de récifs coralliens. Par conséquent, les impacts des activités de développement peuvent être explorés, et des priorités peuvent être établies pour des décisions futures de gestion de côtes. En utilisant ce modèle, l'usager acquiert une conscience unique de la façon dont les relation entre les activités et les communications côtières parmi les parties concernées sont améliorées.

ReefFix

Un projet de restauration ICZM de récif corallien, gestion de crête et de démonstration de renforcement de capacité —ReefFix—est en train d'être élaboré à travers le Parc marin de Montego Bay. ReefFix représente la phase d'application des résultats de la modélisation de soutien aux décisions. Le but du programme est de mettre au point et d'appliquer un projet de restauration et de gestion de crête à moindre coût, et ensuite transférer l'information et la technologie à d'autres pays tropicaux américains qui ont des problèmes semblables. Une caractéristique importante du projet ReefFix est qu'il prend une direction guidée par des besoins spécifiques de politiques pour la gestion des récifs coralliens qui souffrent d'impacts considérables. L'élément de renforcement de capacité comprend le renforcement de capacités humaines et institutionnelles pour la gestion intégrée, la science, la formation et l'éducation. Il est important de ne pas seulement transférer l'information dans le contexte du pays en voie de développement, mais aussi d'encourager l'échange d'expérience et de créer une expertise locale sur la gestion de récifs coralliens. Le programme s'est fixé les objectifs suivant :

- Utiliser l'outil de modèle de soutien aux décisions développé pour le Parc Marin de Montego Bay (COCOMO) pour fournir l'information à la direction et aux décideurs locaux ;
- Mettre au point et appliquer un plan d'action pour la gestion des crêtes pour le Parc marin de Montego Bay, afin d'améliorer la qualité de l'eau marine et d'accroître l'abondance de récifs coralliens ;
- Mettre au point et appliquer un plan d'action pour la gestion des pêcheries pour le Parc marin de Montego Bay, afin d'accroître l'abondance de poissons, d'améliorer les conditions économiques pour les pêcheurs, et contribuer à rendre le Parc marin de Montego Bay autonome ; et,
- Appliquer un plan d'action pour la démonstration aux Amériques tropicales qui améliorera la capacité ICZM pour la restauration des écosystèmes de récifs coralliens dans d'autres pays. Le plan peut inclure l'application d'un format de modèle de soutien aux décisions à moindre coût de ICZM qui peut être adapter à d'autres localités.

Applications de procédures et de politiques

Une optimisation économique rationnelle, qui considère seulement les coûts d'interventions gestionnaires conjointement avec l'évaluation des bénéfices économiques totaux reçus (cf. solution pour Montego Bay donnée dans Ruitenbeek et Cartier 1999), peut réduire le rôle des concernés et des agences gouvernementales en ce qui concerne l'établissement de buts et l'expression de groupes divers de valeurs représentées par divers groupes d'usagers. En effet, c'était l'approche générale de Rijsberman et Westmacott (1996) et Westmacott et Rijsberman (1997) dans la mise au point et l'application des modèles de soutien aux décisions de Corail-Curaçao et Corail-Maldives afin de se concentrer sur la capacité des décideurs d'analyser, à travers plusieurs scénarios définis par les usagers, la rentabilité de différentes interventions et les conditions économiques, sociales et environnementales évidentes dans plusieurs indicateurs. Leur approche initiale n'aboutissait pas un « optimum global », mais se concentrait plutôt sur la création de moyens avec lesquels les décideurs (et toute personne avec un simple intérêt) pourraient explorer les possibilités de gestion.

Définir une solution optimale à travers un modèle de soutien aux décisions ne nécessite pas forcément la négation de la participation des parties concernées dans la décision gestionnaire, mais ceci n'est pas conseillé. La participation des parties concernées et des agences de gestion ne doit pas être oubliée. Les recommandations dérivées du modèle de solution normative peuvent ne pas être adéquates ou réalisables étant donné le contexte social et institutionnel particulier. En effet, le succès de tout programme de gestion de récifs coralliens sera affecté par l'environnement social et la procédure même de prise de décision. Il est important que les parties concernées participent à autant d'étapes que possible de mise au point du programme, même si cette participation est réduite à un partage d'information. Il devient de plus en plus évident dans les procédures de gestion environnementale que c'est le processus lui-même qui aboutit à un programme de gestion réussi. Sans une procédure ouverte et participatoire, des barrières importantes peuvent surgir quant à une gestion efficace.

La modélisation de soutien aux décisions doit être appliquée dans un contexte particulier de politique. Ceci est particulièrement vrai pour les éléments d'évaluation, car le choix d'une des techniques d'évaluation disponibles, comme l'ont remarqué Ruitenbeek et Cartier (1999), doit être poussé par des questions de politique particulières ou par des problèmes analytiques qui doivent être résolus. Les questions de politique définissent les données et les analyses qui sont nécessaires. La structure et l'utilisation des modèles de soutien aux décisions devrait êtres flexibles.

Bien que les scénarios aient défini les recommandations spécifiques quant aux genres d'interventions nécessaires et au niveau de santé des récifs coralliens atteints par les études de site, il est toujours prématuré, dans la création et l'utilisation de ces modèles, de recommander et d'élaborer des programmes de ICZM. Le développement d'interventions spécifiques nécessitera vraisemblablement des raffinements après une considération plus approfondie des conditions sociales et institutionnelles à travers une procédure participatoire. De plus, bien que les résultats annoncés dans ce rapport soient dérivés de modèles très avancés d'un point de vue technologique, il existe des lacunes sérieuses dans la quantité et la qualité de données économiques et écologiques disponibles, et des lacunes dans le développement de la science derrière la construction du modèle. En résumé, il n'est pas conseillé d'utiliser les modèles pour dicter les directions de la gestion des récifs coralliens, mais plutôt il faut les utiliser pour soutenir de telles décisions.

Directions Futures de Modèles de Soutien aux Décisions

Un défi important pour l'étude de systèmes complexes non linéaires, tels que les écosystèmes de récifs coralliens, est la fourniture d'une décision adéquate de la composition, relations fonctionnelles, et comportement du système en question. Ruitenbeek et Cartier (1999) et Ruitenbeek *et coll.* (1999a, 1999b) ont noté que la recherche doit se concentrer plus sur l'analyse des écosystèmes, avec une emphase particulière sur les liens et relations fonctionnelles. La création de modèles de soutien de décisions écologiques économiques est rendu difficile par un manque de compréhension du comportement des écosystèmes ; l'incertitude sur les écosystèmes peut empêcher une analyse économique rationnelle utile.

Les techniques complexes de modélisation, comme la logique de l'incertain, peuvent s'avérer plus utiles. L'élément d'intervention à moindre coût des modèles de soutien aux décisions, tel que résumé ici, démontre l'utilité d'incorporer un environnement de modélisation à logique floue quand il s'agit d'examiner le comportement de l'écosystème d'un récif corallien qui répond à un stress et une intervention anthropique. Des recherches approfondies sur l'utilisation d'ensembles flous dans des applications similaires sont nécessaires (Smith 1994). Néanmoins, il est possible qu'une combinaison de plusieurs techniques soit nécessaire pour explorer les comportements et interactions entre les systèmes écologiques et économiques, que ce soit des modèleslinéaires déterministes, des modèles de simulation complexes, des modèles de logique floue ou des réseaux neuraux.

Lier des systèmes différents dans un environnement de modélisation est un défi continuel rencontré par le domaine d'économie écologique, ainsi que d'autres domaines de recherche interdisciplinaires. Les domaines de biologie et d'économie de conservation ont souffert séparément d'une incapacité à fournir des liens exploratoires adéquats entre les activités économiques et la diminution d'espèce ou d'écosystème. En général, il est nécessaire de fournir une description ou caractérisation complexe, afin de faciliter la prise de décision dans la direction. Des indicateurs, comme les approximations de variables ou simplifications d'une réalité complexe, remplissent souvent cette fonction.

Dans les efforts de modélisation présentés ci-dessus, l'indicateur principal utilisé pour la santé du récif corallien était la couverture spatiale (c.-à-d., le pourcentage de substrat total disponible couvert par du corail vivant). Cet indicateur fournit un « lien » descriptif simple entre les activités économiques et les écosystèmes de récifs coralliens affectés. De plus, l'indicateur a formé la base pour les décisions concernant les « meilleures » interventions gestionnaires pour recevoir une rentabilité maximale de bénéfice, et concernant le degré d'intervention nécessaire pour atteindre un résultat économiquement efficace. Une question évidente se pose : cet indicateur de santé de récif corallien est-il adéquat, et devrait-on inclure d'autres indicateurs dans la modélisation?

Les propriétés d'un bon indicateur utilisé dans une prise de décision et dans l'élaboration d'une politique peut être décrit comme suit :

- La création de l'indicateur correspond au but et à l'application sélectionnés ;
- La valeur de base derrière l'indicateur est explicite ;
- L'indicateur fournit une simplification ou abstraction simple des caractéristiques visées du système ;
- La théorie derrière la création de l'indicateur est assez solide ;
- La sensibilité de l'indicateur aux changements de paramètre du système a été suffisamment étudiée et définie, et l'indicateur est assez sensible pour atteindre le but du développement ; et,
- L'information fournie par l'indicateur peut être comprise et appliquée par l'usager.

La plupart des indicateurs ne peuvent pas remplir les critères ci-dessus ; néanmoins, le but de la création d'indicateurs est toujours de satisfaire autant de critères que possible étant donné les déficits du niveau de connaissance scientifique disponible et les restrictions sur la recherche. La couverture de récif corallien est un indicateur raisonnable de santé de récif corallien avec ses carences, mais des développements futurs de ces modèles de soutien aux décisions nécessiteront un perfectionnement ou une modification des indicateurs utilisés. L'idée de création d'indicateurs d'écosystèmes pour être utilisés dans la prise de décision et dans l'élaboration de politique est encore relativement récente, bien que du progrès ait été fait (e.g., Jameson *et coll*. 1999). Dans quelle mesure l'indicateur peut former le « lien » entre les éléments écologiques et économiques de modèles de systèmes complexes, et faciliter la conscience et la compréhension... cela doit être exploré.

Un dernier point quant à la mise au point et à l'amélioration future de modèles de soutien aux décisions écologiques économiques pour ICZM : toute analyse doit être capable d'explorer les variations possibles dans les résultats et les recommandations qui s'en suivent. Il est impératif que la modélisation de soutien aux décisions comprenne une analyse de sensibilité ou un moyen pour évaluer le risque ou erreur possible associés à un scénario particulier. Par exemple, la modélisation d'évaluation de la bioprospection montrait que les approximations de rendement d'écosystème dépendait beaucoup des relations supposées des espèces/surface (Ruitenbeek et Cartier 1999). Des variations relativement petites dans de telles relations non linéaires qui sont inhérents dans un modèle peuvent entraîner des variations importantes dans le résultat. Les recommandations de politique optimale doivent considérer ces variations. La précaution est nécessaire jusqu'à ce que la science des modèles de soutien aux décisions et leur application soit perfectionnées de manière à avoir un plus grande confiance aux résultats.

Comme dernier message avant de conclure, le travail de modélisation de soutien aux décisions économiques écologiques sera utile pour l'élaboration de programmes ICZM efficaces dans les tropiques en voie de développement. Des recherches approfondies et des perfectionnements des modèles, ainsi qu'une attention plus grande au processus de prise de décision, doivent être considérés comme un défi nécessaire, et non comme un obstacle. Étant donné de nouvelles preuves indiquant que nous faisons face à une crise mondiale d'appauvrissement des récifs coralliens, la gestion doit aller de l'avant avec le meilleur ensemble d'outils de soutien aux décisions disponibles actuellement.

Annex D

Modelos de Apoyo a las Decisiones Ecológico-Económicas para la Gestión Integral de los Arrecifes de Coral en los Trópicos en Vías de Desarrollo—Resultados de Investigaciones y Orientaciones para el Futuro

Resumen preparado por Kent Gustavson y Richard M Huber

Este capitulo es un resumen de los resultados de una investigación realizada durante los últimos cinco años con el apoyo del Comité de Investigaciones del Banco Mundial y de los Fondos Fiduciarios de Holanda, Suecia y Canadá, administrados por el Banco Mundial. La investigación fue llevada a cabo bajo la dirección de Richard M Huber, líder del equipo (Banco Mundial), con la contribución de varios investigadores, como los mencionados a lo largo de este capitulo. Las principales contribuciones provinieron de (en orden alfabético) Rolf Bak (Instituto Holandés de Investigaciones Marinas), Steve Dollar (Universidad de Hawaii), Kent Gustavson (Gustavson Ecological Resource Consulting), Erik Meesters (Instituto Holandés de Investigaciones Marinas), Frank Rijsberman (Resources Analysis), Jack Ruitenbeek (HJ Ruitenbeek Resources Consulting), y Susie Westmacott (Resources Analysis).

Los ecosistemas de arrecifes de coral a nivel mundial están enfrentando una severa disminución, estando amenazados por presiones antrópicas localizadas así como también por causa de fenómenos regionales y globales naturales como el calentamiento global (Bryant *et al*. 1998; Hodgson 1999; Hoegh-Guldberg 1999; Jameson *et al*. 1995; Wilkinson 1998). Todavía puede haber alguna causa para ser optimista dada la remota ubicación geográfica de muchos arrecifes de coral, la gestión efectiva de algunos, y la capacidad potencial de recuperación de estos ecosistemas (Wilkinson 1998), aunque ya es claro que la gestión integral efectiva de las zonas costeras (GIZC) es necesaria para ayudar a prevenir su agotamiento y deterioro posterior. Este capitulo es un resumen de los resultados obtenidos durante la investigación con relación a modelos para apoyar la toma de decisiones para la gestión de los arrecifes de coral en las zonas tropicales en vías de desarrollo. Se expone la estrategia de diseminación y se ofrecen comentarios en cuanto a las aplicaciones potenciales de política y la dirección de futuras investigaciones.

GIZC presta una orientación integral a las actividades de dos o más sectores en la planificación, desarrollo, e implementación de proyectos. De una manera más formal, es "…la planeación y la gestión integral de recursos y ambientes costeros en una forma que está basada en las interconexiones físicas, socioeconómicas y políticas dentro y entre los sistemas dinámicos de las zonas costeras…" (Sorensen 1997). Similarmente, "la GIZC es un proceso de gobierno y consiste de un marco legal e institucional necesario para asegurar que los planes de desarrollo y de gestión para las zonas costeras sean integrados con metas ambientales y sociales, y sean elaborados con la participación de aquellos afectados. El propósito de la GIZC es maximizar los beneficios proporcionados por la zona costera y minimizar los conflictos y efectos dañinos entre las diversas actividades, sobre los recursos naturales y el medio ambiente" (World Bank 1996, p. 2). Han comenzado a surgir lineamientos y procedimientos para el desarrollo de la GIZC (e.g., Bower *et al*. 1994; Chua 1993; Clark 1995; Pernetta y Elder 1993; Sorensen 1997; World Bank 1993a, 1996).

Un elemento esencial de la GIZC es la *integración*—particularmente, la integración horizontal a lo largo de sectores económicos y agencias de gestión en la planeación e implementación (e.g., Clark 1995; Sorensen 1997). Las actividades costeras deben ser consideradas en conjunto dada su interdependencia e impactos acumulados no aditivos (impactos independientes) esperados. Pero ¿de qué manera los múltiples sectores económicos o actividades humanas van a ser considerados conjuntamente? ¿De qué manera la preocupación para el mantenimiento de los ecosistemas costeros—los cuales apoyan directa o indirectamente las actividades económicas—va a ser incorporada en la toma de decisiones? ¿Cuál debería ser el marco para la toma de decisiones con el fin de determinar que actividades deberían ser permitidas dentro de la zona costera?, ¿Cómo deberían esas actividades ser desarrolladas y operadas? ¿Qué nivel de actividad debería ser permitido? ¿Sobre que base los conflictos entre diferentes usuarios de recursos costeros deberían ser resueltos? Dar respuesta a tales preguntas necesariamente implica la consideración conjunta de parámetros de sistemas múltiples, criterios múltiples, y distintos valores.

Los modelos para apoyar la toma de decisiones ecológico-económicas pueden jugar un papel fundamental. La familia de modelos ecológico-económicos incluye aquellos que reconocen la validez de alcanzar una solución económicamente eficiente para la gestión, aunque simultánea y explícitamente considera las limitaciones necesariamente impuestas sobre la escala y el tipo de actividades económicas debido a las características y a la capacidad del ambiente natural. Los modelos de apoyo a las decisiones ecológico-económicas para la GIZC también deberían permitir acomodar información relacionada con el contexto socio-cultural en el que se efectúa la gestión, el cual tiene un papel esencial que jugar en el desarrollo de políticas.

¿Cuáles son las características de un modelo útil de apoyo al proceso de toma de decisiones? Primeramente, un modelo útil de apoyo a la toma de decisiones debe poder responder preguntas específicas y relevantes asociadas con el diseño de política. Para ayudar en el diseño y creación de tal modelo, uno debe poder avanzar en su construcción a partir del conjunto existente de investigaciones relevantes en el área del la formulación e implementación de políticas. Como ha señalado Ruitenbeek *et al*. (1999a, 1999b), la falta de información respecto a la ecología de los arrecifes de coral (i.e., nexos funcionales y relaciones) y las características de las economías que los afectan actualmente dificultan el desarrollo de modelos efectivos de apoyo en toma de decisiones ecológico-económicas. Gran parte de la información científica existente no es directamente "relevante para el diseño de política" y, en este contexto, es de poca ayuda a los tomadores de decisiones; o directamente en la creación de un modelo de apoyo a la toma de decisiones. Segundo, un modelo debe ser capaz de ser entendido y utilizado directamente por un grupo meta de clientes. Los insumos deben ser relativamente fáciles a proveer, las pruebas fáciles de conducir, y los resultados fáciles de interpretar. Tercero, se debería distinguir entre el uso de modelos previstos mayormente para investigaciones científicas y aquellos dirigidos para informar procesos de toma de decisiones y diseño de políticas—se debería evitar el uso de modelos altamente experimentales como herramientas de apoyo en la toma de decisiones. La teoría en la cual se basan los modelos de apoyo a la toma de decisiones debería ser relativamente robusta. Por ejemplo, respecto al uso de modelos ecológicos previstos para su uso en toma de decisiones, Friedland (1977) observa que "El objetivo básico no es el descubrimiento de verdades previamente desconocidas sino la recolección e integración del conocimiento existente y su presentación en una forma útil en el proceso de diseño de políticas." Esto tiene ramificaciones directas sobre cual tipo de modelo es el más apropiado. Finalmente, los modelos de apoyo en el proceso de toma de decisiones deberían ser susceptibles a la modificación y revisión de sus componentes de información; de las relaciones especificadas dentro del modelo; y de las alternativas de desarrollo o escenarios considerados por el modelo. Nuevamente, es imperativo mantener en mente las necesidades de los usuarios. Un modelo basado en información que ya no es válida para una zona particular, cuyas relaciones ecológicas y económicas subyacentes ya no son más precisas, o que no es lo suficientemente flexible para soportar modificaciones o alteraciones de los escenarios o alternativas de desarrollo especificados, será de poco uso en el largo plazo.

Resultados de los Proyectos con Modelos

En 1995, con fondos del Comité de Investigaciones del Banco Mundial, se inició el trabajo en dos áreas de investigación con relación a los arrecifes de coral en zonas tropicales en vías de desarrollo: (i) uso de modelos costo-efectivos para intervenir en la gestión (i.e. la "oferta" de la biodiversidad como activo económico); y (ii) valoración de sistemas marinos (i.e., la "demanda" por biodiversidad). Esencialmente, el uso de modelos costo-efectivos buscó identificar la curva de costos para aquellas intervenciones dirigidas a mejorar las condiciones de los arrecifes de coral; en donde los efectos de las diferentes intervenciones de política y actividades económicas están vinculados a la salud general del arrecife de coral y a los costos asociados con efectuar las mejoras (Brown *et al*. 1996; Huber y Jameson 1998; Huber *et al*. 1994, 1996; Meesters 1995; Meesters y Westmacott 1996; Meesters *et al*. 1995, 1996, 1998; Ridgley y Dollar 1996; Ridgley *et al*. 1995; Rijsberman 1995; Rijsberman y Westmacott 1996; Rijsberman *et al*. 1995a; Ruitenbeek *et al*. 1999a, 1999b; Westmacott 1996; Westmacott y Rijsberman 1997; Westmacott *et al*. 1995). El modelo de valoración del sistema marino intentó identificar los beneficios que pueden ser obtenidos a partir de mejorar o sostener las condiciones del arrecife de coral.

El objetivo amplio de las investigación fue ayudar a los diseñadores de política en el manejo y protección de los arrecifes de coral (Huber y Ruitenbeek 1997; Huber *et al*. 1994). El establecimiento de una metodología costo-beneficio apropiada, a ser usada en los sistemas de arrecifes de coral en los trópicos en desarrollo y en sistemas marinos en general, ayudará a la identificación de intervenciones institucionales y de política más convenientes; y así ayudará a lograr usos económicamente eficientes de los arrecifes de coral, y que a la vez toman en cuenta los impactos sobre y el papel del ecosistema que sustenta la vida en los arrecifes de coral. Este tipo de "paquete" basado en el análisis costo-beneficio (ACB) está representado por la integración de los modelos de costo-efectividad y de valoración (Ruitenbeek y Cartier 1999). Se escogieron tres lugares para estudios de caso en donde probar las metodologías: (i) Curaçao, en las Antillas Holandesas; (ii) la República de las Islas Maldivas; y, (iii) la Bahía de Montego en Jamaica.

Coral- Curaçao

Rijsberman y Westmacott (1996; también ver Meeseters 1995; Meesters *et al*. 1996a; Rijsberman *et al*. 1995a; Westmacott *et al*. 1995) desarrollaron un modelo de análisis costo-efectividad para la gestión y protección del arrecife de coral en la costa sur de Curaçao. El modelo de apoyo en la toma de decisiones fue diseñado para facilitar la comunicación entre los grupos de interés involucrados con respecto a las orientaciones del desarrollo y las estrategias de gestión ambiental; y el análisis de los impactos sobre la salud del arrecife producidos por los desarrollos planificados—a través de la descarga de aguas residuales y sedimentos—de tal manera que se integrase la planificación del uso del suelo, el turismo y la conservación; y, el análisis costo-efectividad de las intervenciones en la gestión diseñadas para mantener la salud del arrecife de coral. El modelo utiliza una estructura computarizada basada en la interacción.

Los resultados de los tres escenarios modelados (un escenario de desarrollo representativo del *status quo* y dos escenarios de crecimiento alternativos) indican que Curaçao es muy probable que experimente disminuciones significativas en la salud del arrecife de coral y abundancia durante los próximos 10 años. Sin embargo, el modelo también indica que las intervenciones que involucran estrategias de protección ambiental pueden detener esta tendencia y, en algún caso, conducir a la recuperación del arrecife por encima de su actual nivel de salud. Las intervenciones recomendadas incluyen combinaciones de tratamientos de desagües, disposición apropiada de desechos sólidos, y reducciones en la contaminación de las refinerías. Medidas alternativas para el mantenimiento de las playas y la reducción de desechos generados por la industria manufacturera y el transporte marítimo no fueron encontradas como medidas efectivas. Sin embargo, Rijsberman y Westmacott (1996) también reconocen que los resultados de los modelos pueden ser específicos a la escala espacial examinada y que estas últimas intervenciones ciertamente pueden ser costo-efectivas y apropiadas en un contexto local más reducido.

Rijsberman y Westmacott (1996) destacan que la utilidad del modelo solamente puede ser demostrada mediante una aplicación que íntimamente involucre a los grupos de interés en la construcción del escenario y en el proceso de toma de decisiones. Coral-Curaçao le permite a uno ordenar y priorizar las medidas y explorar la formulación de diferentes combinaciones para obtener una meta específica en términos de la extensión y diversidad del arrecife. Por ejemplo, para lograr una meta promedio del 14% con respecto a la cubierta de coral en el arrecife y del 50% con respecto a la diversidad (indexado de acuerdo al modelo), se requiere una inversión inicial de 310 millones NAF, con un costo anual de operación y de mantenimiento de 6 millones NAF (Rijsberman y Westmacott 1996).

Coral-Maldivas

Westmacott y Rijsberman (1996; también ver Brown *et al*. 1996; Meesters y Westmacott 1996; Rijsberman 1995; Rijsberman y Westmacott 1996; Westmacott 1996; Westmacott y Rijsberman 1997) desarrollaron un modelo de análisis costo-efectividad para la gestión y protección del arrecife de coral en el North y South Male en la República de las Maldivas. Como fue un modelo desarrollado paralelamente con Coral-Curaçao, el objetivo fue investigar si un modelo adaptado para las Maldivas (Coral-Maldivas) proporcionaría una herramienta útil para la toma de decisiones. Westmacott y Rijsberman (1997) describen el modelo y los resultados del análisis inicial.

Como con el modelo Coral-Curaçao, el modelo Coral-Maldivas fue diseñado para que las autoridades encargadas pudiesen determinar el costo-efectividad relativo de diferentes intervenciones de gestión ambiental para variadas opciones de desarrollo económico en términos de las mejorías en la salud del arrecife de coral que son obtenidas (i.e., utilizando índices de la cubierta del arrecife de coral y de la rugosidad como medidas aproximadas). Además, los impactos de los escenarios pueden ser vistos en términos de indicadores económicos, sociales, y ambientales elegidos por el usuario del modelo desde el inicio del análisis. Las prioridades de política y las alternativas de gestión viables fueron identificadas mediante discusiones con agencias gubernamentales. Dada la naturaleza de los impactos en los arrecifes de coral en la República de las Maldivas, las intervenciones de gestión se enfocan en minimizar el daño físico (Westmacott y Rijsberman 1997). Westmacott y Rijsberman (1997) ilustran el uso del modelo mediante la presentación de casos.

Westmacott y Rijsberman (1997) señalan que hay un gran número de indicadores que pueden ser utilizados para describir el potencial de éxito o fracaso de una estrategia de gestión de la zona costera—y, aunque el modelo es algo flexible, el grupo de indicadores de gestión en zonas costeras que puede ser seleccionado y examinado por el usuario es limitado. Además, en tanto las intervenciones y medidas costo-efectivas se relacionan solamente con los cambios en la salud del arrecife de coral, ellas pueden ignorar otras estrategias críticas para el éxito de un programa particular para la gestión integral de la zona costera (GIZC) (e.g., aspectos de salud pública). Se sugiere que los resultados de los escenarios en los modelos para apoyar la toma de decisiones, en la formulación de planes de desarrollo o de gestión, sean ubicados dentro del contexto de metas y requerimientos sociales. Así como con Coral-Curaçao, el modelo puede no reflejar adecuadamente las condiciones locales a una escala espacial menor a la incorporada en los componentes del modelo.

La Valoración de los Beneficios de los Arrecifes de Coral

En el proceso para llegar a una medida del valor económico total (VET), los estudios de valoración económica de sistemas naturales mayormente distinguen los valores de uso de los valores que no implican un uso, y valores de uso directo de valores de uso indirecto. Estas distinciones mayormente reflejan el método de estimación. Durante la especificación del diseño de la valoración de arrecifes de coral para el Parque Marino de la Bahía de Montego, fue definitivamente más útil distinguir entre tres clasificaciones para la valoración de la biodiversidad marina: (i) métodos de valoración de la producción "orientados a la oferta" (i.e., contribuciones de los sistemas marinos a la utilidad de un individuo o la sociedad); (ii) métodos de valoración de la utilidad "orientados a la "demanda" (i.e., contribuciones de sistemas marinos a la utilidad de un individuo o la sociedad); y, (iii) métodos de valoración de la renta capturada orientados a la ganancia (i.e., contribuciones de sistemas marinos a través de la distribución de valores del uso tales como la renta capturada, ganancias o valor agregado; Huber y Ruitenbeek 1997; Ruitenbeek y Cartier 1999). En la última categoría, se analizó la contribución potencial de la biodiversidad de los arrecifes de coral a través del desarrollo de una iniciativa de bioprospección.

Contribuciones de las Funciones de Producción — Parque Marino de la Bahía de Montego

Los valores locales de uso directo fueron estimados por Gustavson (1998) para dos categorías generales de uso—pesca cerca de la costa y turismo. Los valores de uso indirecto asociados con la protección costera también fueron estimados. Estos usos locales de las aguas del Parque Marino de la Bahía de Montego fueron identificados como los más significativos durante la aplicación final del estudio en el sitio, así como los más prioritarios al nivel del diseño de política. Los valores reportados por Gustavson (1998) representan la magnitud de las contribuciones en la producción derivada del arrecife, en riesgo de perderse si los esfuerzos de conservación prueban ser inadecuados.

Los servicios turísticos en la Bahía de Montego incluyen alojamiento, comida, bebida, entretenimiento (incluyendo deportes y atracciones acuáticas), transporte y tiendas, y otros servicios diversos. Estimaciones del valor presente neto (VPN) asociadas con el turismo se ubican en un rango que va desde US$ 210 millones (usando una tasa de descuento del 15%) hasta US$ 630 millones (usando una tasa de descuento del 5%) en 1996. Las estimaciones del VPN en 1998 asociadas con la pesca se calculan entre -US$ 1.66 millones y US$ 7.49 millones (dólares constantes de 1996; utilizando estimados inferiores y superiores, respectivamente, de los valores netos anuales y a una tasa de descuento del 5%; los estimados hechos a tasas de descuento del 10% y 15% caen dentro de este rango). Si es que la función de protección desempeñada por los arrecifes de coral fuera comprometida, sobre la base de que aproximadamente 250 acres son vulnerables, luego el VPN del volumen total de tierra en riesgo de erosión es estimado en US$ 65 millones (en dólares constantes de 1996). La mediana del VPN tomando en cuenta todos los valores de los usos locales para el Parque Marino de la Bahía de Montego fue estimada en US$ 381 millones. Asumiendo una área total de arrecifes de 42.65 hectáreas como un caso de referencia, esto se traduce en US$ 8.93 millones/hectárea o US$ 0.893 millones de ha^{-1} $año^{-1}$ sobre una base anualizada (asumiendo una tasa de descuento del 10%).

Contribuciones a la Utilidad — Parque Marino de la Bahía de Montego y la Costa Sur de Curaçao

Spash *et al*. (1998) utilizó el método de valoración contingente (MVC) para evaluar los valores de la utilidad asociados con la biodiversidad de los arrecifes de coral en la Bahía de Montego, en Jamaica, y a lo largo de la costa sur de Curaçao. El estudio es particularmente notable por haber examinado los valores de la utilidad asociados con un recurso ambiental marino (i.e., la calidad del arrecife de coral), lo cual había sido negado por investigaciones previas. Adicionalmente, la investigación logró avances para abordar de manera explícita fuentes de sesgo debido a las preferencias lexicográficas que surgen cuando la persona entrevistada no desea aceptar ningún "trade-off" por la pérdida de un bien o servicio (i.e., al rechazar un "trade-off", la persona entrevistada no se comporta de acuerdo a lo señalado por la teoría económica). Para precios iniciales iguales a cero, se efectuaron distinciones entre aquellos que carecen de ingresos, aquellos que consideran las mejorías como de menor importancia, aquellos que prefieren gastar su dinero en otros bienes o servicios, o aquellos que protestaron por tener que ejercer tal elección. Entre aquellos que protestaron con los precios iniciales, proporcionando así una fuente de sesgo, estuvieron aquellos "polizones" (free riders), aquellos que sienten que el pago no es una solución adecuada, aquellos que han perdido la fe en la institución propuesta, o aquellos que rechazan el mecanismo de pago. La encuesta también exploró el grado de las opiniones correctamente sustentadas en consideraciones éticas que serían compatibles con las preferencias lexicográficas. El MVC fue diseñado para facilitar la comparación con los resultados de los estudios de valoración de los usos locales y de la bioprospección en la Bahía de Montego. El MVC también fue diseñado para permitir la separación de los valores de uso directo de los indirectos y de los valores no asociados con uso alguno (non-use values).

Se les pidió a los participantes en la encuesta una contribución para un fondo fiduciario que podría ser administrado por un parque marino para incrementar la biodiversidad dentro de las fronteras del parque. El pago tendría que ser donado anualmente por un periodo de cinco años y lograría un crecimiento del 25% en la cobertura del arrecife de coral. El análisis de la curva de precios (i.e. un análisis "tobit" en combinación con una estimación de máxima probabilidad) proporcionó información adicional respecto a las variables que determinan las variaciones en la "disposición a pagar" (DAP) y refinó los estimados de la "disposición a pagar" (DAP). En el promedio, la DAP fue estimada en US$ 2.08 por persona en Curaçao y US$ 3.24 por persona en Jamaica (Spash *et al*. 1998). La diferencia fue explicada por la combinación de turistas y residentes locales, con los jamaiquinos dispuestos a pagar casi el doble que sus contrapartes en Curaçao. Utilizando perfiles típicos de visitantes y la población local y a una tasa de descuento del 10%, se calcula una DAP estimada en aproximadamente US$ 4.5 millones en Curaçao y US$ 20 millones en la Bahía de Montego, Jamaica (Spash *et al*. 1998).

Contribuciones Potenciales de la Bioprospección — Parque Marino de la Bahía de Montego

El modelo para la bioprospección en la Bahía de Montego se enfocó en los rendimientos netos sociales promedios, basándose en información local sobre costos y en valores de beneficios, y en tasas de descuento exitosas - basadas en información de los propietarios - para los productos marinos en el Caribe. (Ruitenbeek y Cartier 1999). Los supuestos del modelo respecto a los parámetros incluyeron la especificación de la relación entre especies y área y la relación de participación institucional de los ingresos fiscales (i.e., un reparto de las ganancias netas contingentes y una tarifa fija para muestreo). El análisis de sensibilidad exploró los efectos que las variaciones en los parámetros del modelo tenían sobre el estimado del valor, incluyendo variaciones en el área total del sustrato disponible en el arrecife con una cobertura biológicamente viva y la especificación de la relación entre especies y área como codeterminantes del número esperado de muestras disponibles para pruebas. Otros escenarios del modelo incluyeron una tarifa fija en el muestreo, un enfoque combinado con participación de ingresos fiscales, costos altos de investigación y desarrollo, tasas muy bajas, y un programa de muestreo más corto. Una función de beneficios marginales fue derivada la cual relacionó el valor o el "precio" de la biodiversidad marina con la abundancia del arrecife de coral.

Para un "caso base" se estimó un valor de US$ 70 millones para los arrecifes del Parque Marino de la Bahía de Montego, de los cuales aproximadamente US$ 7 millones (i.e., 10%) realistamente podrían ser captados por Jamaica bajo arreglos típicos de regalías o rentas (Ruiteenbeek y Cartier 1999). El valor marginal del arrecife para bioprospección se estimó en US$ 530,000/ha o US$ 225,000 por el cambio porcentual en la abundancia del arrecife de coral (correspondiente a un precio de planificación local jamaiquino de US$ 22,500 por el cambio porcentual en la abundancia del arrecife de coral).

La Identificación de Intervenciones de Menor Costo - Parque Marino de la Bahía de Montego

De manera muy similar a los modelos Coral-Curaçao y Coral-Maldivas, Ruiteenbeek *et al*. (1999a; también ver Ridgley y Dollar 1996; Ridgley *et al*. 1995; Ruitenbeek *et al*. 1999b) aplicó una metodología lógica probabilística para identificar las intervenciones de menor costo que conducirían a un incremento en la abundancia del arrecife de coral dentro del Parque Marino de la Bahía de Montego. Los procedimientos lógicos probabilísticos son utilizados dentro de un modelo ecológico de impacto en el arrecife para generar una compleja configuración dosis-respuesta que modela la relación entre la abundancia del arrecife de coral y varios insumos dentro del contexto de un medio marino abiótico marino. Esto está vinculado a un modelo económico no lineal que describe las actividades económicas actuales y futuras dentro de ocho sectores, las intervenciones técnicas y de política, y las cargas de contaminantes en la Bahía de Montego. La optimización proporciona pistas acerca de los medios más costo-efectivos para la protección de los arrecifes de coral bajo diferentes metas de calidad del arrecife.

En la Bahía de Montego, Jamaica, se puede lograr hasta un incremento del 20% en la abundancia de coral mediante el uso de medidas apropiadas de política con un costo en valor presente de US$ 153 millones para un periodo de 25 años (Ruitenbeek *et al*. 1999a). Las medidas de política específicas consideradas incluyen la instalación de una trampa de sedimentos en el río Montego, el sembrío de árboles en las cuencas altas, la instalación de un sistema de ventilación de desechos, la instalación de una planta de tratamiento centralizada de gran escala, la extensión agrícola para proporcionar tecnologías que reducen desperdicios, la instalación de un emisor submarino y una estación de bombeo, mejoras en la recolección de desechos sólidos domésticos, y la implementación de un impuesto a los hoteles. Se encontró que algunas intervenciones eran relativamente costo-efectivas. Por ejemplo, la recolección de desechos sólidos domésticos, la instalación de un emisor, y el uso de una trampa de sedimento en el Río Montego impondrían un costo en valor presente de US$ 12 millones y resultaría en una mejoría en la cobertura del arrecife de coral de más del 10% (Ruitenbeek *et al*. 1999).

Una demostración clave de la investigación fue que las metodologías convencionales para medir el costo-efectividad pueden resultar en soluciones subóptimas de política cuando son aplicadas a sistemas complejos. Esto se debe el análisis costo-efectividad tiende a asumir que la separación e independencia de intervenciones individuales y la posibilidad de tratar separadamente los beneficios de los costos (por lo general cuando los beneficios no pueden ser definidos). Cuando se trata de sistemas altamente complejos tales como los arrecifes de coral, las sinergías, retroalimentaciones y otras interdependencias entre intervenciones individuales y el nivel resultante de salud del arrecife de coral pueden invalidar las recomendaciones que provienen de intervenciones de política individualmente evaluadas, las cuales se asume es posible aplicarlas en una forma secuencial, por etapas. Por ejemplo, se encontró que la reforestación formaba parte del conjunto de intervenciones óptimas para metas consistentes con mejoras del arrecife de coral de 14% y 20%, pero no formaba parte del conjunto de intervenciones óptimas para mejoras del 15% o 16% (Ruitenbeek *et al*. 1999). Como han señalado Ruitenbeek *et al*. (1999), esto significa que las metas fijadas para la salud del arrecife de coral, en referencia al grado de los beneficios derivados, deben ser establecidas antes de que se persigan las intervenciones de política.

Integrando los Resultados Obtenidos para la Bahía de Montego Hacia un Nivel Eficiente de Intervención

Una síntesis de los diferentes estudios de valoración de los arrecifes de coral para el Parque Marino de la Bahía de Montego nos permite llegar a una función de beneficios (o precios) marginales netos (Ruitenbeek y Cartier 1999). Para poder llegar a una función de beneficios marginales, relacionando el precio con cambios en la abundancia del arrecife de coral, supuestos adicionales fueron requeridos respecto a la relación entre las categorías de valores y la abundancia o calidad del arrecife de coral. Específicamente, se asume una relación lineal entre la calidad del arrecife y los valores de uso local y los valores utilitarios no asociados con el uso. Probablemente este no es el caso, pero asumir una relación menos simplificada no puede ser justificado dado nuestro actual conocimiento. Solo los resultados del modelo de valoración de la bioprospección (Ruitenbeek y Cartier 1999) permitieron la especificación de una forma funcional diferente. Como han señalado Ruitenbeek y Cartier (1999), los valores marginales netos totales probablemente serán sobrestimados en algunas instancias y subestimados en otras.

El beneficio total atribuido a los arrecifes de coral del Parque Nacional de la Bahía de Montego ha sido estimado en US$ 470 millones, cada cambio en 1% en la abundancia es probable que genere un beneficio marginal de US$ 10 millones o, alternativamente, el precio marginal del arrecife de coral es de US$ 23 millones/ha (Ruitenbeek y Cartier 1999). La mayor parte de este valor se atribuye al turismo. La protección costera y los beneficios utilitarios no asociados con el uso también contribuyen, pero en una proporción mucho menor. Las pesquerías existentes y el desarrollo potencial de un programa de bioprospección tienen un efecto mínimo en los valores marginales (Ruitenbeek y Cartier 1999).

Utilizando la función de costos marginales presentada en el estudio de intervenciones de menor costo para el Parque Marino de la Bahía de Montego (Ruitenbeek *et al*. 1999a), conjuntamente con los estimados de beneficios marginales, permite llegar a una optimización global. De acuerdo a lo reportado por Ruitenbeek y Cartier (1999), se sugiere una mejora óptima de la abundancia del arrecife de coral del 13% (i.e., de aproximadamente 29% de cobertura biológica estimado a partir de las condiciones de equilibrio del modelo—véase Ruitenbeek *et al*. 1999a — a aproximadamente 42% de cobertura biológica), requiriendo gastos netos de US$ 27 millones. Las intervenciones requeridas involucrarían la instalación de una trampa de sedimentos, la ventilación de desechos, la instalación de un emisor para desagües, la implementación de un sistema mejora o de recolección de desechos sólidos domésticos, y la implementación de incentivos económicos para mejorar la gestión de desechos por parte de la industria hotelera. El análisis de sensibilidad sugiere que esta optimización es bastante robusta a cambios en los estimados de los beneficios económicos netos—los beneficios necesitarían ser aumentados en US$ 275 millones o disminuidos en US$ 300 millones para que la meta propuesta respecto a mejora en la calidad del arrecife de coral cambie en más del 2% (Ruitenbeek y Cartier 1999).

El Contexto Humano del Uso del Arrecife de Coral

Además de la aplicación del análisis costo-efectividad, la valoración de recursos o el análisis costo-beneficio (ACB), es clave que los tomadores de decisiones consideren de manera integral y sistemática el contexto social, cultural y económico asociado con el desarrollo políticas y el cambio ecológico. Dicho contexto o información con "enfoque humano" tradicionalmente no forma parte de tales análisis, en los cuales los indicadores o medidas monetarias cuantitativas frecuentemente han sido aplicados dentro de un ambiente caracterizado por la "evaluación automática" de la toma de decisiones, limitando la posterior interpretación de los niveles óptimos o apropiados y los tipos de intervenciones y políticas necesarias.

Las metodologías de valoración económica aplicadas en estos proyectos fueron diseñadas para enumerar los beneficios totales recibidos de los arrecifes de coral, a través de contribuciones de la función de producción y de la utilidad humana (así como también los beneficios potenciales por regalías o rentas obtenidos por el desarrollo de iniciativas de bioprospección). Tales beneficios monetarios reflejarán, en teoría, el conjunto local de valores. Sin embargo, se pierde mucho cuando se reduce la información social, cultural y económica a un valor métrico singular. Esto fue demostrado mediante el desarrollo y aplicación de la metodología de evaluación socioeconómica rápida para proporcionar un entendimiento de los diferentes grupos de usuarios de los arrecifes de coral en el lugar del estudio de caso de la Bahía de Montego (Bunce y Gustavson 1998a; Bunce *et al*. 1999). Este tipo de información facilitará una mejor adaptación de las estrategias de gestión a los patrones de uso de los grupos de usuarios, así como a sus prioridades de gestión y a sus recursos disponibles. En esencia, la información con "enfoque humano" ayuda a identificar un resultado económicamente eficiente que también es social y culturalmente viable. Esta información ha demostrado su utilidad en el desarrollo de políticas y programas efectivas para el Parque Marino de la Bahía de Montego (Bunce *et al*. 1999; véase también Huber y Jameson 1998c).

Contexto y Recomendaciones de Política

Estudio de Caso — La Captura de Rentas Generadas por el Uso de los Arrecifes de Coral en la Bahía de Montego

De gran interés para las autoridades responsables de la gestión del Parque Marino en la Bahía de Montego, así como también para los administradores de cualquier sistema marino costero, es poder captar al menos una proporción de la renta generada por los usos directos con el fin de poder financiar la gestión necesaria del recurso, incluyendo posibles mejoras al mismo. En otras palabras, hay costos sociales asociados con la conservación y la gestión del recurso que deberían ser pagados por los usuarios.

Como un componente del estudio de valoración de los usos locales (Gustavson 1998), los cobros efectuados actualmente por el gobierno, los cuales pueden capturar una proporción de la renta, fueron explotados. Actualmente, no es parte de la política del Parque Marino de la Bahía de Montego cobrar tarifas (un mecanismo explícitamente reconocido para capturar la renta) a sus usuarios, aunque se está en las etapas iniciales del comienzo de tal programa. Otros cobros del gobierno, que están específicamente vinculados ya sean a las actividades relacionadas con el turismo o con las pesquerías, pueden capturar una proporción del excedente del productor o del consumidor, pero no son explícitas ni necesariamente diseñados con esa finalidad. Estos incluyen los derechos de licencias para los negocios, licencias para pesca, derechos uso de playa, e impuestos turísticos a salida de los visitantes.

En principio, los derechos por licencias son recolectados para pagar los costos incurridos por el gobierno en la administración y regulación de un negocio o actividad. No hubo información disponible sobre los costos reales asociados con la regulación de las actividades llevadas a cabo en los arrecifes de coral, aunque es muy posible que en todos estos casos estos costos no sean recuperados a partir de los programas de tarifas existentes. Se encontró que los derechos de uso de playa son actualmente mínimos y, aunque varían de acuerdo con el tipo de uso, no están vinculados a los diferentes niveles del excedente del productor. Ninguno de estos fondos está explícitamente orientados a pagar los costos asociados con la gestión del Parque Marino de la Bahía de Montego. Ninguna otra tarifa o cargo del gobierno o agencia responsable de la gestión está específicamente ligada ya sea a actividades relacionadas al turismo o la pesca en el área. Impuestos a las ganancias corporativas, o impuestos al ingreso personal en el caso de los pescadores o de las ganancias individualmente distribuidas en los negocios relacionados al turismo—también pueden captar una porción de la renta. Sin embargo, los impuestos son pagados al organismo gubernamental recaudador de impuestos, y de esa manera no están disponibles para ser utilizados en la gestión del parque marino. El interés actual del Parque Marino en la Bahía Montego para implementar derechos de uso debería ser apoyado.

Estudio de Caso — Instituciones y Recomendaciones de Política para la Bioprospección en Jamaica

Putterman (1998) ofrece recomendaciones específicas para el fortalecimiento institucional y de política con respecto a la incorporación del aprovechamiento de recursos genéticos dentro de la GIZC (gestión integral de la zona costera) en Jamaica como una herramienta potencialmente poderosa para la conservación y el desarrollo económico. La diversidad genética o molecular, una medida de la diversidad biológica entre especies, puede ser la fuente de nuevos productos farmacéuticos, productos industriales y variedades agrícolas. Muchas estrategias para la colaboración en la investigación—como una estrategia que reduce riesgos para maximizar la posibilidad de descubrir nuevos químicos o genes—pueden ser empleadas. Así también, existen muchos mecanismos de reparto de beneficios y opciones de compensación (ver Putterman 1998). De acuerdo a Putterman (1998), actualmente no existe ninguna política en Jamaica que regule el acceso a recursos genéticos. Una revisión de las instituciones y políticas jamaiquinas conduce a las siguientes recomendaciones (Putterman 1998):

- En el diseño de un conjunto de opciones de política sobre recursos naturales, se deben incorporar las obligaciones de la Convención sobre Diversidad Biológica y de la Convención de las Naciones Unidas sobre la Ley del Mar, así como también se le debe tomar en cuenta el efecto que el diseño de políticas tendrá en las actividades del sector privado;
- Regular el acceso a los recursos genéticos desde un principio por medio de permisos y contratos para definir los derechos a estos recursos antes de que sus muestras sean recolectadas o exportadas;
- Establecer derechos (novedosos) *sui generis* sobre la propiedad tangible y el conocimiento tradicional para así definir quien tiene derecho de participar y beneficiarse en la negociación de contratos que implican la transferencia de recursos genéticos o del conocimiento tradicional;
- Desarrollar procedimientos de consentimiento previamente informados con el fin de dar a los propietarios legales de los derechos a los recursos genéticos y al conocimiento tradicional un medio de controlar el uso de estos recursos; y,
- Crear una formula nacional para el reparto de beneficios con la finalidad de convertir una proporción del ingreso monetario derivado del desarrollo de nuevos productos en bienes públicos; para asegurar un reparto justo y equitativo de los beneficios por la utilización de los recursos genéticos.

Los valores presentes netos potenciales por la bioprospección son pequeños en comparación a los valores de los usos locales actuales asociados con el turismo y la protección costera (Gustavson 1998; Ruitenbeek y Cartier 1999) y, como se señalo anteriormente, se anticipa que estos tendrán un efecto insignificante sobre el valor marginal de los arrecifes de coral. Sin embargo, Ruitenbeek y Cartier (1999) señalan que los impactos de los costos institucionales asociados con la operación de un programa de bioprospección nacional en Jamaica, de acuerdo a lo recomendado por Putterman (1998), son mínimos. La implementación de un programa de bioprospección puede estar garantizada. La pregunta es si existe la voluntad de los administradores locales y de las partes interesadas en el Parque Marino de la Bahía de Montego para involucrarse en este tipo de iniciativas.

Modelando Resultados y Recomendaciones de Política para el Uso de Modelos de Apoyo a la Tomas de Decisiones

Generalmente, más allá de preguntas especificas sobre políticas e institucionales que surgen cuando uno considera el desarrollo potencial de un programa de bioprospección en la Bahía de Montego, surgen cuestiones de política asociadas con las intervenciones de menor costo y con los resultados de la modelación de los beneficios del arrecife de coral. Ruitenbeek y Cartier (1999) notan que si la eficiencia económica es la meta, tanto los costos y los beneficios deben ser considerados en la investigación cuando una trata con sistemas complejos no lineales tales como los arrecifes de coral. El análisis costo-efectividad por si solo no puede ser adecuado. Ruitenbeek and Cartier (1999) también llaman la atención sobre la necesidad de poner un mayor énfasis a nivel local sobre las dimensiones socioeconómicas y relativas a la gestión asociadas con los usos directos, incluyendo la promoción de regímenes locales prácticos para la gestión que consideran e involucran a todas las partes afectadas. Este punto también es destacado por Bunce y Gustavson (1998a).

Diseminación

Las aproximaciones de estas investigaciones—basadas en la intervención de menor costo y en la valoración—sobre los modelos presentados son herramientas de apoyo a la toma de decisiones, para el diseño de política y para la capacitación de los administradores de los arrecifes de coral y tomadores de decisiones en el gobierno que se ven enfrentados a asuntos significativos respecto a la gestión de los arrecifes de coral. La estrategia consolidada de diseminación para los proyectos ha tenido las siguientes fases:

- El lanzamiento de una "gira" para diseminar los resultados lo que incluye un CD-ROM del COCOMO—el modelo de apoyo a las decisiones—cuyas siglas significan arrecifes COsteros en la COsta de la bahía de MOntego;
- La continuación de talleres apoyados por la unidad de Gestión del Conocimiento del Banco Mundial, local y nacionalmente, con las metas consistentes en obtener retroalimentación en cuanto a los hallazgos de investigaciones aplicadas con modelos, identificación de áreas prioritarias para investigaciones futuras, e identificación de posibilidades potenciales para fortalecer la capacidad regional y local en la gestión de recursos costeros;
- La creación de programas propiciados por los usuarios en la página web de la unidad de Gestión del Conocimiento del Banco Mundial (BIONODE y Recursos Acuáticos) y en otras páginas web; y
- Apoyo al Fondo del Parque Marino de la Bahía de Montego en la preparación de un proyecto replicable regionalmente, conocido como ReefFix (Jameson y Huber 1999).

Las partes interesadas involucradas en los estudios de caso expresaron la necesidad y su interés en lograr un entendimiento más completo en cuanto a las actividades de desarrollo y conservación, en marcha y programadas, que involucran a la zona costera. Ya sea que se trate de pescadores locales, operadores de deportes acuáticos, hoteleros, empresarios locales, residentes locales o turistas, es clave satisfacer estos requerimientos de información para lograr una gestión efectiva de la zona costera. La estrategia de diseminación es necesaria para incrementar la participación de los diversos grupos de interés en la evaluación de los cambios en el medio marino y en la mitigación o prevención de impactos negativos sobre los arrecifes de coral. El desarrollo de una red de tomadores de decisiones e investigadores—"una comunidad de practicantes"—para así poder compartir experiencias internacionales en la restauración del arrecife de coral y donde se fomenten esfuerzos de colaboración para la investigación es un aspecto clave.

COCOMO

COCOMO es un modelo de apoyo a la toma de decisiones en la gestión de la zona costera de la Bahía de Montego que ilustra los problemas costeros y estima los efectos de las actividades humanas. También sirve como una herramienta para el desarrollo de políticas y construcción de capacidades para la gestión integrada de zonas costeras (GIZC). El estudio de caso en la Bahía de Montego fue seleccionado para el proyecto de modelación interactivo debido a las necesidades críticas que existen por este tipo de herramienta. El centro urbano se está experimentando un rápido, con un desarrollo por lo general *ad hoc* y sin planificación. Han ocurrido muchas alteraciones físicas en la zona costera, incluyendo rellenos sanitarios en el litoral, destrucción de manglares, y sedimentación; además de un enriquecimiento de nutrientes en el litoral, presiones intensivas sobre las pesquerías, y un uso extensivo por los deportes acuáticos, buceo, e industrias de turismo. Esto ha resultado en la degradación de la calidad del agua y de los recursos costeros, y ha causado impactos significativos al valioso ecosistema de arrecifes de coral.

Específicamente, la investigación aplicada a partir de la utilización del modelo COCOMO está brindando asistencia al Fondo Marino de la Bahía de Montego con un programa integral y coherente que:

- Aumenta la conciencia y promueve la construcción de consenso por parte de los grupos de interés con respecto a las prioridades ambientales en la Bahía de Montego;
- Identifica los desafíos para abordar los asuntos relativos a la gestión de la zona costera en la Bahía de Montego, en e corto y largo plazo, con la ayuda de las diferentes

organizaciones gubernamentales y no gubernamentales involucradas (ONGs).

· Identifica inversiones ambientales específicas con soluciones factibles y de bajo costo; y,
· Inicia un proceso de diálogo entre los grupos de interés.

La conexión a la computadora del modelo, de fácil uso para los usuarios, ha sido desarrollada para diseñadores de política, especialistas, y todos aquellos interesados en asuntos costeros en la Bahía de Montego. El mecanismo de conexión hace uso intensivo de gráficos para proporcionar a los usuarios una breve visión general de asuntos costeros y como la urbanización, pesca, turismo, agricultura, industria y los hogares impactan en la zona costera y en los arrecifes de coral de la Bahía de Montego. La información sobre el ecosistema de arrecifes de coral y la vida marina asociada se encuentra almacenada dentro del modelo, así como también la información sobre la contribución del arrecife a la Bahía de Montego a través de las pesquerías, el turismo, y la protección costera. A través de la conexión del usuario, diferentes acciones pueden ser adoptadas para la protección de la zona costera y de los arrecifes de coral, algunas siendo más costo-efectivas que otras. COCOMO predice el grupo de intervenciones de menor costo para alcanzar una abundancia especificada en el arrecife de coral. De tal manera que, los impactos vinculados a desarrollos (e.g., urbanización) pueden ser explorados y se pueden establecer prioridades para futuras acciones para la gestión costeras. En el proceso de utilizar el modelo, el usuario obtiene una conciencia única de las relaciones entre las actividades costeras. Asimismo, la comunicación entre las partes involucradas es mejorada.

ReefFix

Un proyecto demostrativo consistente en la restauración de los arrecifes de coral en el contexto de la GIZC, la gestión de cuencas y la construcción de capacidades—ReefFix—está siendo implementado en el Parque Marino de la Bahía de Montego (Jameson y Huber 1999). ReefFix es la fase de implementación de los resultados del modelo de apoyo a la toma de decisiones. La meta del programa es diseñar e implementar un proyecto de restauración de los arrecifes de coral y manejo de cuencas de menor costo y luego transferir la información y la tecnología a otros países tropicales de América que estén enfrentando desafíos similares. Una característica clave de ReefFix es que éste adopta un enfoque impulsado por necesidades específicas de política relacionadas a la gestión de los arrecifes de coral que experimentan impactos significativos. El componente dirigido a la construcción de capacidades incluye el fortalecimiento de las capacidades humanas e institucionales para la gestión integral, la ciencia, la capacitación y la educación. Se reconoce que no sólo es importante transferir información a los países en desarrollo, sino también fomentar el intercambio de lecciones aprendizaje con base a experiencias y construir el conocimiento local (el *expertise*)para la gestión de los arrecifes de coral.

El programa tiene los siguientes objetivos:

- Utilizar el modelo de apoyo a la toma de decisiones para del Parque Marino de la Bahía Montego (COCOMO) para proporcionar información a los administradores y tomadores de decisiones locales;
- Desarrollar e implementar un plan de acción para la gestión de cuencas para el Parque Marino de la Bahía de Montego para mejorar la calidad del agua marina e incrementar la abundancia biológica de los arrecifes de coral;
- Desarrollar e implementar un plan de acción para la gestión de pesquerías en el Parque Marino en la Bahía de Montego para incrementar la abundancia de peces, mejorar las condiciones económicas de los pescadores, y ayudar al Parque Marino de la Bahía de Montego para que sea autosostenido desde el punto de vista financiero;
- Implementar un plan de acción demostrativo para las Américas tropicales el cual mejorará la capacidad de la GIZC para la restauración de ecosistemas de arrecife de coral en otros países. Esto puede incluir la aplicación de un modelo GIZC de menor costo para apoyar la toma de decisiones que pueda ser adaptado de acuerdo a las necesidades locales.

Proceso y Aplicaciones de Política

Una optimización económica racional, considerando exclusivamente los costos de las intervenciones de gestión conjuntamente con la valoración de los beneficios económicos totales recibidos, (e.g., véase la solución para la Bahía de Montego proporcionada en Ruitenbeek y Cartier 1999), puede que aparentemente reduzca el rol de las partes interesadas y de las agencias de gestión en el proceso de fijación de metas y en la manifestación de diversos valores representados por los diferentes grupos de usuarios. En efecto, el enfoque general de Rijsberman y Westmacott (1996) y de Westmacott y Rijsberman (1997)—en el desarrollo e implementación de los modelos de apoyo a la toma de decisiones Coral-Curaçao y Coral-Maldivas—fue concentrarse en la capacidad de las autoridades (tomadores de decisiones) para analizar, a través de diferentes escenarios definidos por el usuario, el costo-efectividad de intervenciones alternativas y las condiciones económicas, sociales y ambientales resultantes de acuerdo a lo reflejado por varios indicadores. La aproximación inicial del modelo no llega tan lejos como para derivar óptimo global, pero se enfoca en proveer un medio por el cual los tomadores de decisiones (y aquellas personas interesadas) puedan explorar alternativas de gestión.

La definición de una solución óptima mediante un modelo de apoyo a la toma de decisiones no necesariamente impide la participación de las partes interesadas localmente en las decisiones de gestión, sin embargo, se deben tomar las precauciones necesarias para que esto no ocurra. La participación de las partes interesadas y las agencias responsables de la gestión no debe ser olvidada. Las recomendaciones generadas por la solución de un modelo normativo puede que no sea adecuada o factible dado el contexto institucional y social específico. En efecto, el éxito de cualquier programa de gestión de arrecifes de coral será grandemente afectado por el entorno social y por el proceso mismo de toma de decisiones. Es crítico que las partes interesadas estén involucradas en el mayor número de etapas del desarrollo de un programa de gestión en tanto sea práctico, aún si es simplemente a través de un ejercicio para compartir información. Como ha llegado a ser crecientemente evidente en todos los procesos de gestión ambiental, es el *proceso* en sí mismo el que frecuentemente juega el papel clave para un programa de gestión exitoso. Sin un proceso abierto y participativo, es de esperarse que surjan barreras significativas a la gestión efectiva.

Los modelos de apoyo a la toma de decisiones deberían ser implementados dentro de un contexto específico de política. Esto es especialmente cierto respecto a los componentes de la valoración, como ha sido señalado por Ruitenbeek y Cartier (1999). La selección de una técnica de entre un número de técnicas de valoración debería ser dirigida por preguntas específicas de política a la mano o por los aspectos analíticos que necesitan ser abordados. Las preguntas políticas definen la información que se necesita y el análisis que es requerido. El diseño y utilización de los modelos de apoyo a la toma de decisiones deben estar sujetos a mejoras.

Aunque los escenarios—resultantes del desarrollo de los modelos de apoyo a las decisiones ecologico-económicas como los reportados en este artículo—hayan definido recomendaciones específicas de política en cuanto a los tipos de intervenciones requeridas y el nivel de salud del arrecife de coral que debería alcanzarse en los lugares estudiados, todavía es demasiado temprano el desarrollo y uso de dichos modelos como para poder recomendar que las inversiones requeridas ya sean efectuadas. Se requieren investigaciones adicionales que involucren a las partes interesadas y a las agencias de gestión presentes en el lugar donde se lleva a cabo el estudio de caso, tal como se describe anteriormente en la estrategia de diseminación, para refinar las recomendaciones y desarrollar programas de gestión integral en zonas costeras. El diseño de intervenciones específicas podría requerir un refinamiento basado en una consideración más profunda de las condiciones locales sociales e institucionales a través de un proceso más participativo. Adicionalmente, aunque los resultados presentados aquí se derivan de modelos basados en "el estado del arte", se reconoce que existieron deficiencias notables en la cantidad y calidad de la información ecológica y económica disponible, así como importantes deficiencias en el desarrollo de la ciencia que subyace a la construcción del modelo. En resumen, los modelos no deberían ser utilizados para dictar las orientaciones de la gestión de los arrecifes de coral, pero son para ayudar a *sustentar* tales decisiones.

Futuras Orientaciones para los Modelos de Apoyo a la Toma de Decisiones

Un desafío significativo en el estudio de sistemas complejos no lineales, tales como los ecosistemas de arrecife de coral, está en proporcionar una descripción adecuada de la composición, relaciones funcionales y comportamiento del sistema en cuestión. Ruitenbeek y Cartier (1999) y Ruitenbeek *et al*. (1999a, 1999b) señalan que la investigación mostrar un mayor énfasis en el análisis de ecosistemas, con un enfoque en encadenamientos y relaciones funcionales. El desarrollo de modelos de apoyo a la toma de decisiones ecológico-económicas está siendo obstruido por la falta de entendimiento respecto al comportamiento de ecosistemas; la incertidumbre sobre el funcionamiento del ecosistema puede impedir el análisis económico racional útil.

Las técnicas de modelación de sistemas complejos tales como las técnicas lógicas probabilísticas pueden ser más útiles. El componente de intervenciones de menor costo de los modelos de apoyo a la toma de decisiones, de acuerdo a lo resumido aquí, demuestra la utilidad de incorporar un entorno de modelación lógico y probabilístico cuando se examina el comportamiento de un ecosistema de arrecife de coral en respuesta a intervenciones o presiones antrópicas. La investigación posterior acerca del uso de técnicas probabilísticas en aplicaciones similares está garantizada (Smith 1994). Aunque pueda ser que tal vez se requiera una combinación de diferente técnicas — tales como modelos lineales determinísticos, modelos de simulaciones complejas, modelos lógicos probabilísticos o redes neurálgicas – para la exploración del comportamiento y de las interacciones entre sistemas ecológicos y económicos.

La vinculación de sistemas dispares dentro de un entorno de modelación es un desafío continuo al cual se enfrenta el campo de la economía ecológica, así como también otras áreas interdisciplinarias. Areas tales como la biología de la conservación y la economía han luchado por separado con una incapacidad de proporcionar vínculos adecuados entre las actividades económicas y el declive de especies o ecosistemas. Generalmente, una descripción o caracterización concreta de un ambiente ecológico económico complejo es requerida sencillamente para facilitar la toma de decisiones en la gestión. Los indicadores, como variables aproximadas o simplificaciones de una realidad compleja, muchas veces cumplen esta función.

En los esfuerzos de modelación presentados aquí, el indicador principal utilizado para la salud del arrecife de coral fue la cobertura espacial (i.e., el porcentaje del sustrato total disponible cubierto por arrecifes de coral vivos). Este indicador proporcionó un "vinculo" descriptivo sencillo entre las actividades económicas y el ecosistema de arrecife de coral afectado. Además, este indicador formó la base para decisiones respecto a las "mejores" intervenciones en la gestión con el fin de recibir el mayor rendimiento en beneficios y respecto al grado de las intervenciones garantizadas para obtener un resultado económicamente eficiente. Esto genera una pregunta obvia—¿es este indicador de la salud del arrecife de coral adecuado, o acaso deberían otros indicadores ser incluidos en el modelo?

Las propiedades de un "buen" indicador a ser usado en el proceso de toma de decisiones y en el desarrollo de políticas podrían ser descritas como sigue:

- El diseño del indicador corresponde al propósito y aplicación escogidos;
- La base de valor subyacente al diseño del indicador es explícita;
- El indicador proporciona una simplificación o abstracción suficiente de las características del sistema "meta";
- La teoría detrás del diseño del indicador es relativamente sólida;
- La sensibilidad del indicador a los cambios en los parámetros del sistema ha sido suficientemente explorada y definida, y el indicador es suficientemente sensible para satisfacer el propósito de su diseño; y,
- La información proporcionada por el indicador puede ser entendida y aplicada por el usuario.

No se puede esperar que la mayoría de los indicadores satisfagan todos los criterios mencionados anteriormente; sin embargo, permanece como meta principal en el desarrollo de indicadores satisfacer tantos como sea posible dada las limitaciones del nivel de conocimiento científico disponible y las restricciones en la investigación. Se afirma que la cobertura de los arrecifes de coral es un indicador razonable de la salud del arrecife de coral dadas estas limitaciones, pero el futuro desarrollo de estos modelos de apoyo a la toma de decisiones puede necesita refinar o modificar los indicadores utilizados. El desarrollo de indicadores ecosistémicos para ser usados en la toma de decisiones y en el desarrollo de políticas está en su infancia, aunque progresos están siendo hechos (e.g., Jameson *et al.* 1999). Cómo es que tales indicadores pueden formar el "nexo" entre los componentes ecológicos y económicos de modelos de sistemas complejos, y a la vez facilitar la conciencia y entendimiento—es una pregunta que todavía necesita ser investigada.

Como un punto final relacionado a un posterior desarrollo y perfeccionamiento de modelos de apoyo a la toma de decisiones ecológico-económicas para una GIZC, cualquier análisis debe ser capaz de explorar las posibles variaciones en los resultados y en las subsiguientes recomendaciones. Es indispensable que los modelos de apoyo a la toma de decisiones incluyan un análisis de sensibilidad o algún medio con el cual medir el riesgo o los posibles errores asociados con cualquiera de los escenarios. Por ejemplo, el modelo de valoración de la bioprospección mostró que los estimados de la productividad del ecosistema fueron altamente dependientes de relación especie-área asumida (Ruitenbeek y Cartier 1999). Relativamente pequeñas variaciones en este tipo de relaciones no lineales intrínsecas al modelo pueden conducir a grandes variaciones en el resultado. Las recomendaciones relacionadas a la política óptima deben tener esto en cuenta. La cautela es prudente hasta que la ciencia de modelos de apoyo a la toma de decisiones y sus aplicaciones se hayan desarrollado hasta un punto que garantice gran confianza en los resultados.

Como un mensaje final, se cree que el trabajo con modelos de apoyo a la toma de decisiones ecológico-económicas probará ser útil en el desarrollo de programas efectivos para la GIZC en los trópicos en vías de desarrollo. Investigaciones y perfeccionamientos posteriores de los modelos, junto con una mayor atención a los procesos de toma de decisiones, deberían ser vistos como un desafío necesario, y no como un impedimento. Dada la evidencia emergente que indica que estamos enfrentando una crisis ecológica a nivel mundial con la desaparición de los arrecifes de coral, la gestión debe avanzar dada el mejor paquete de herramientas actualmente disponible para apoyar la toma de decisiones.

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References

Background and Related Working Papers

Brown B, Bythell J, Clark S, Edwards A, Meesters E, Westmacott S (1996) Cost-effectiveness analysis of coral reef management and protection: a case study for the Maldives, formulation of the ecological response model. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

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. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Cartier CM, Ruitenbeek HJ (1998) Preliminary review of studies and models for marine biodiversity valuation. Internal working paper prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Gustavson K (1998) Values associated with the local use of the Montego Bay Marine Park. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES)of the World Bank, Washington, DC

Hanley N (1996) Contingent valuation as a means of valuing the conservation of coral reefs in Jamaica: a state-of-the-art assessment of the method. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Huber RM, Dollar S, Mathur SC, Ruitenbeek HJ (1994) Cost-effectiveness analysis in integrated coastal zone management: a least cost model for coral reef environments in the developing tropics. Report to the World Bank Research Committee, World Bank, Washington, DC

Huber RM, Dollar S, Mathur SC, Ridgley M, Rijsberman F, Ruitenbeek HJ (1996) Cost-effectiveness analysis in integrated coastal zone management: a least cost model for coral reef environments in the developing tropics. Phase I: a prototype model. Report to the World Bank Research Committee, World Bank, Washington, DC

Huber RM, Ruitenbeek HJ (eds) (1997) Marine system valuation: an application to coral reef systems in the developing tropics. Interim Report to World Bank Research Committee, Project #RPO 681-05, World Bank, Washington, DC

Meesters EH (1995) Cost-effectiveness analysis of coral reef management and protection: a case study of Curaçao: I. Coral reef data collection and analysis. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Meesters EH, Bak RPM, Westmacott S (1995) A fuzzy logic model to predict coral reef development under nutrient and sediment stress. Report prepared for Resource Analysis and the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Meesters EH, Bak RPM, Westmacott S (1996) A fuzzy logic model to predict coral reef development under nutrient and sediment stress in Curaçao. Phase 3 report, ecological model definition. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Meesters EH, Westmacott S (1996) Cost-effectiveness analysis of coral reef management and protection. a case study of the Maldives. Formulation of the ecological response model. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Putterman DM (1997) Review of marine genetic resource R&D issues (Annex 6). In: Huber RM, Ruitenbeek HJ (eds) Marine system valuation: an application to coral reef systems in the developing tropics. Interim Report to World Bank Research Committee, Project #RPO 681-05, World Bank, Washington, DC

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. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Ridgley M, Dollar S (1996) A coral-reef impact-assessment model using fuzzy rule-based logic, Phase II Interim Report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Ridgley M, Dollar S, Bailey K (1995) Overview of the development of a prototype model to estimate future pollution-induced coral reef impacts. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Rijsberman F (1995) Cost-effectiveness analysis of coral reef management and protection: a case study of the Maldives. First visit report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Rijsberman F, Westmacott S (1996) Cost-effectiveness analysis of coral reef management and protection: a case study for Curaçao. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Rijsberman FR, Westmacott S, Hirsch D (1995) Cost-effectiveness analysis of coral reef management and protection, a case study of Curaçao: phase 1 report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Ruitenbeek HJ, Cartier CM with contributions from Bunce L, Gustavson K, Putterman D, Spash CL, van der Werff ten Bosch JD, Westmacott S, Huber R (1999) Issues in applied coral reef biodiversity valuation: results for Montego Bay, Jamaica. World Bank Research Committee Project RPO#682-22 Final Report, World Bank, Washington, DC

Ruitenbeek HJ, Ridgley M, Dollar S, Huber R (1999) 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 – A least cost model for coral reef management and protection. World Bank Research Committee Project RPO#680-08 Final Report, World Bank, Washington, DC

Spash CL, van der Werff ten Bosch JD, Westmacott S, Ruitenbeek HJ (1998) Lexicographic preferences and the contingent valuation of coral reef biodiversity in Curaçao and Jamaica. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Westmacott S (1996) Cost-effectiveness analysis of coral reef management and protection, a case study of the Maldives: phase 2 report - model definition and data collection. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Westmacott S, Klinckhamers P, Fernandes L, Rijsberman F (1995) Cost-effectiveness analysis of coral reef management and protection, a case study of Curaçao: Phase 2: field visit project report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Westmacott S, Rijsberman F (1997) Cost-effectiveness analysis of coral reef management and protection: CORAL, a coral reef management model for the Republic of the Maldives. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Papers Arising from the Research

Bunce L, Gustavson K (1998) Coral reef valuation - a rapid socioeconomic impact assessment of primary users of the Montego Bay Marine Park, Jamaica. Paper presented to Coastal Zone Canada 98, 30 August-3 September 1998, Victoria, BC

Bunce L, Gustavson K, Miller M, Williams J (1999). The human side of management: a case study analysis of the socioeconomic framework of Montego Bay Marine Park. Coral Reefs (in press).

Gustavson K, Williams J (1999) Local use valuation as information towards the creation of effective marine park management in the developing tropics. Paper presented to Coastal Zone 99, 24-30 July 1999, San Diego, CA

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

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

Huber RM, Jameson SC (1998c) 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) 5(2) - 6(1) (December, 1998 - January, 1999)

Jameson SC, Huber RM (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

Meesters EH, Bak RPM, Westmacott S (1996) A fuzzy logic model to predict coral reef dynamics. 8th International Coral Reef Symposium, Panama, Abstracts, p 131

Meesters EH, Bak RPM, Westmacott S, Ridgley M, Dollar S (1998) A fuzzy logic model to predict coral reef development under nutrient and sediment stress. Conservation Biology 12(5):957-965

Rijsberman FR, Westmacott S (1997) Use of decision support tools for coastal zone management in Curaçao and Jamaica. Paper presented at the Seminar on Integrated Coastal Zone Management for the Caribbean, Caribbean Council for Science and Technology, 24-27 June, Trinidad

Ruitenbeek HJ, Ridgley M, Dollar S, Huber RM (1996) Use of fuzzy logic in a coral reef management model: preliminary results for Montego Bay, Jamaica. Fourth Biennial Meeting International Society for Ecological Economics, Boston University, Boston, MA

Ruitenbeek HJ, Ridgley M, Dollar S, Huber R (1999) 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 (in press)

Spash CL (1998a) Environmental values, attitudes and ethics: non-compensatory choices in a developing country context. Paper presented at 25th Anniversary of Doctoral Program, 17 April, University of Wyoming

Spash CL (1998b) Informing and forming preferences in contingent valuation: a case study. Paper presented to the World Congress of Environmental and Resource Economists, 25-27 June, Venice, Italy

Consolidated Bibliography

Adamowicz W, Louviere J, Williams M (1994) Combining revealed and stated preference methods for valuing environmental amenities. Journal of Environmental Economics and Management 26(3):271-292

Adger N, Brown K, Cervigni R, Moran D (1994) Towards estimating total economic value for forests in Mexico. Working Paper GEC-9421, CSERGE

Adger WN, Brown K, Tompkins E, Bacon P, Shim D, Young K (1999) Evaluating trade-offs between uses of marine protected areas in the Caribbean. In: Kirkpatrick C, Lee N (eds) Integrated appraisal and sustainable development in a developing world. Edward Elgar, Cheltenham

Ajzen I, Brown TC, Rosenthal LH (1996) Information bias in contingent valuation: effects of personal relevance, quality of information and motivational orientation. Journal of Environmental Economics and Management 30(1):43-57

Artuso A (1997) Drugs of natural origin: economic and policy aspects of discovery, development and marketing. Haworth Press, Binghamton, NY

Artuso A (1998) Creating linkages between valuation, conservation and sustainable development of genetic resources (Chapter 14). In: Evenson RE, Gollin D, Santaniello V (eds) Agricultural values of plant genetic resources, CAB International Publishing, Wallingford, Oxon

Association of University Technology Managers (AUTM) (1995) Uniform biological material transfer agreement. AUTM, Norwalk, CT

Atkinson MJ, Smith SV (1983) C:N:P ratios of benthic marine plants. Limnology and Oceanography 28(3):568-574

Aylward BA (1993) The economic value of pharmaceutical prospecting and its role in biodiversity conservation. Discussion Paper 93-05. International Institute for Environment and Development, London

Aylward BA, Echeverría J, Fendt L, Barbier E (1993) The economic value of species information and its role in biodiversity conservation: case studies of Costa Rica's National Biodiversity Institute and pharmaceutical prospecting. Report to Swedish International Development Authority. LEEC, London and INBIO, San José

Ayyub B, McCuen R (1987) Quality and uncertainty assessment of wildlife habitat with fuzzy sets. Journal of Water Resources Planning and Management 113(1):95-109

Baarse G, Rijsberman FR (1986) Ecology and tourism: protecting the coast of the Dutch island of Texel. Project Appraisal 1(2):75-87

Baarse G, Rijsberman FR (1987) A policy analysis approach to the problem of sea level rise. In: Wind HQ (ed), Impacts of sea level rise on society. Balkema Publishers, Rotterdam, pp 21-76

Bak RPM, Nieuwland G (1995) Long-term change in coral communities along depth gradients over leeward reefs in the Netherlands Antilles. Bulletin of Marine Science 56:609-619

Balarin J (1998) Participatory aquatic resource management. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn

Ballance R, Pogany J, Forstner H (1992) The world's pharmaceutical industries: an international perspective on innovation, competition and policy. Elgar, Aldershot

Barbier EB, Acreman M, Knowler D (1997) Economic valuation of wetlands: a guide for policy makers and planners. RAMSAR Library, Gland

Barbier EB, Aylward BA (1996) Capturing the pharmaceutical value of biodiversity in a developing country. Environmental and Resource Economics 8:157-181

Barbier EB, Burgess JC, Folke C (1994) Paradise lost: the ecological economics of biodiversity. Earthscan, London

Bardossy A, Duckstein L (1995) Fuzzy rule-based modeling with applications to geophysical, biological, and engineering systems. CRC Press, Boca Raton, FL

Baron J, Maxwell NP (1996) Cost of public-goods affects willingness-to-pay for them. Journal of Behavioural Decision Making 9(3):173-183

Barton DN (1994a) Economic factors and valuation of tropical coastal resources. SMR Report. Centre for Studies of Environment and Resources, University of Bergen, Bergen

Barton JH (1994b) Ethnobotany and intellectual property rights. In: Ethnobotany and the search for new drugs. Ciba Foundation Symposium 185. Wiley & Sons, Chichester

Barton JH, Siebeck WE (1994) Material transfer agreements in genetic resources exchange – the case of the International Agricultural Research Centres. Issues in Genetic Resources 1. International Plant Genetic Resources Institute, Rome

Bateman IJ, Munro A, Rhodes B, Starmer C, Sugden R (1997) Does part-whole bias exist?: an experimental investigation. Economic Journal 107(441):322-332

Bateman I, Willis KJ (1999) Contingent valuation of environmental preferences: assessing theory and practice in the USA, Europe, and developing countries. Oxford University Press

Bell FW (1989) Application of wetland valuation theory to Florida fisheries. Florida Sea Grant College and Department of Economics, Florida State University

Bennett JW (1984) Using direct questioning to value the existence benefits of preserved natural areas. Australian Journal of Agricultural Economics 28:136-152

Bergland O, Magnussen K, Navrud S (1995) Benefits transfer: testing for accuracy and reliability. Discussion Paper 95-03, Department of Economics, Agricultural University of Norway

Bernard HR (1989) Research methods in cultural anthropology. Sage Publications, London

Biodiversity Conservation Network (BCN) (1997) Annual report: evaluating an enterprise-oriented approach to community-based conservation in the Asia/Pacific region. World Wildlife Fund, Washington, DC

Birkeland C (1997) Status of coral reefs in the Marianas. In: Grigg RW, Birkeland C (eds) 1997 Status of coral reefs in the Pacific. Sea Grant College Program, School of Ocean and Earth Science and Technology, University of Hawaii, pp 89-100

Bishop R, Walsh M (1992) Existence values in benefit-cost analysis and damage assessment. Land Economics 68:405-414

Blamey RK, Hundloe TJ (1993) Characteristics of recreational boat fishing in the Great Barrier Reef Region. Report to the Great Barrier Reef Marine Park Authority, Townsville

Bockstael NE, McConnell KE (1980) Calculating equivalent and compensating variation for natural resource facilities. Land Economics 65:57-63

Bower BT, Ehler CN, Basta DJ (1994) A framework for planning for integrated coastal zone management. National Ocean Service, National Oceanic and Atmospheric Administration (NOAA-ORCA), Washington, DC

Boyle K, Desvouges W, Johnson F, Dunsford R, Hudson S (1994) An investigation of part-whole biases in contingent valuation. Journal of Environmental Economics and Management 27(1):64-83

Brevoort P (1996) The US botanical market – an overview. HerbalGram 36:49-57

Brown B, Bythell J, Clark S, Edwards A, Meesters E, Westmacott S (1996) Cost-effectiveness analysis of coral reef management and protection: a case study for the Maldives, formulation of the ecological response model. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Brown B, Dawson Shephard A, Weir I, Edwards A (1990) Effects of the degradation of the environment on local reef fisheries in the Maldives. Final report to ODA. University of Newcastle Upon Tyne, Newcastle

Brown GM Jr, Goldstein JH (1984) A model for valuing endangered species. Journal of Environmental Economics and Management 11:303-9

Bryant D, Burke L, McManus J, Spalding M (1998) Reefs at risk: a map-based indicator of potential threats to the world's coral reefs. World Resources Institute, Washington, DC

Buddemeier RW (1999) Is it time to give up? Plenary Abstracts, International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring and Restoration, April 14-16, 1999, Ft. Lauderdale, FL, p 40

Bunce LL, Gustavson KR (1998a) 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. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Bunce L, Gustavson K (1998b) Coral reef valuation - a rapid socioeconomic impact assessment of primary users of the Montego Bay Marine Park, Jamaica. Paper presented to Coastal Zone Canada 98, 30 August-3 September 1998, Victoria, BC

Bunce LL, Gustavson KR, Miller M, Williams J (1999) The human side of reef management: a case study analysis of the socioeconomic framework of Montego Bay Marine Park. Coral Reefs (in press)

Burrill GS, Lee KB (1993) Biotech 94', long-term value, short-term hurdles: the industry annual report. Ernst & Young, San Francisco, CA

Buzzard S (1990) Surveys: avoiding the common problems. In: Finsterbusch K, Ingersoll J, Llewelly L (eds) Methods for social analysis in developing countries. Westview Press, Boulder, CO

Cambridge Economics (1992) Contingent valuation: a critical assessment. Cambridge, MA

Carson R, Flores N, Hanemann M (1998) Sequencing and valuing public goods. Journal of Environmental Economics and Management 36(3):314-323

Carson RT, Mitchell RC (1993) The issue of scope in contingent valuation studies. American Journal of Agricultural Economics 75(5):1263-1267

Carson RT, Mitchell RC (1995) Sequencing and nesting in contingent valuation surveys. Journal of Environmental Economics and Management 28(2):155-173

Carson RT, Mitchell RC, Hanemann WM, Kopp RJ, Presser S, Ruud PA (1992) A contingent valuation study of lost passive use values resulting from the Exxon Valdez oil spill. Report to the Attorney General of the State of Alaska

Carson R, Wilks L, Imber D (1994) Valuing the preservation of Australia's Kakadu Conservation Zone. Oxford Economic Papers 46:727-749

Cartier CM, Ruitenbeek HJ (1998) Preliminary review of studies and models for marine biodiversity valuation. Internal working paper prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Cartier CM, Ruitenbeek HJ (1999) Review of the biodiversity valuation literature (Chapter 3). In: Ruitenbeek HJ, Cartier CM with contributions from Bunce L, Gustavson K, Putterman D, Spash CL, van der Werff ten Bosch JD, Westmacott S, Huber R. Issues in applied coral reef biodiversity valuation: results for Montego Bay, Jamaica. World Bank Research Committee Project RPO#682-22 Final Report, World Bank, Washington, DC

Cernea M (ed) (1985) Putting people first: sociological variables in rural development. Oxford University Press, Oxford

Cesar H (1996) Economic analysis of Indonesian coral reefs. World Bank Environment Department, Washington, DC

Cesar H (1998) Indonesian coral reefs: a precious but threatened resource. In: Hatziolos ME, Hooten AJ, Fodor M (eds) Coral reefs: challenges and opportunities for sustainable management. Proceedings of an Associated Event of the Fifth Annual World Bank Conference on Environmentally and Socially Sustainable Development. World Bank, Washington, DC, pp 163-171

Chambers R (1994) The origins and practice of participatory rural appraisal. World Development 22(7):953-969

Chua TE (1993) Essential elements of integrated coastal management. Ocean and Coastal Management 21(1-3):81-108

Clark CW (1976) Mathematical bioeconomics: the optimal management of renewable resources. John Wiley and Sons, New York

Clark JR (1995) Coastal zone management handbook. CRC Press Inc, Boca Raton, FL

Colin P (1998) Marine pharmaceuticals from the reef: a view from the field. In: Hatziolos ME, Hooten AJ, Fodor M (eds) Coral reefs: challenges and opportunities for sustainable management. World Bank, Washington, DC, pp 76-78

Cummings RG, Brookshire DS, Schulze WD (eds) (1986) Valuing environmental goods: an assessment of the contingent valuation method. Rowman and Allanheld, Totowa

D'Auria MV, Paloma LG, Minale L, Riccio R, Zampella A, Debitus C (1993) Metabolites of the New Caledonian sponge *Cladocroce incurvata*. Journal of Natural Products 56(3):418-423

Dahuri R (1996) Preliminary approaches to economic valuation of coastal resources in Indonesia. Paper presented to the 7th Biannual Workshop on Economy and Environment in South-East Asia, Singapore

Danielson LE, Leitch J A (1986) Private versus public economics of prairie wetland allocation. Journal of Environmental Economics and Management 13(1):81-92

Davis WS, Simon TP (1995) Biological assessment & criteria: tools for water resource planning and decision making. CRC Press, Boca Raton, FL

de Groot RS (1992) Functions of nature: evaluation of nature in environmental planning, management and decision making. Wolters-Noordhoff

D'Elia CF, Buddemeier RW, Smith SV (eds) (1991) Workshop on coral bleaching, coral reef ecosystems and global change: report on proceedings. Maryland Sea Grant College. 17-21 June 1991, Brickell Point Sheraton, Miami, FL

D'Elia CF, Webb KL, Porter JW (1981) Nitrate-rich groundwater inputs to Discovery Bay, Jamaica: a significant source of N to local reefs? Bulletin of Marine Science 31:903-910

Desvouges WH, Johnson FR, Dunford RW, Boyle KJ, Hudson SP, Wilson KN (1993) Measuring natural resource damages with contingent valuation: tests of validity and reliability. In: Hausman JA (ed) Contingent valuation: a critical assessment. North-Holland, Amsterdam

Dexter LA (1970) Elite and specialized interviewing. Northwestern University Press, Evanston

DiMasi JA, Hansen RW, Grabowski HG, Lasagna L (1991) Cost of innovation in the pharmaceutical industry. Journal of Health Economics 10:107-142

Dixon JA (1992) Meeting ecological and economic goals: the case of marine parks in the Caribbean. Paper presented to the Second Meeting of the International Society for Ecological Economics, 3-6 August 1992, Stockholm

Dixon JA (1993) Economic benefits of marine protected areas. Oceanus (fall):35-40

Dixon JA, Scura L, van't Hof T (1993) Meeting ecological and economic goals: marine parks in the Caribbean. Ambio 22(2-3):117-125

Downes D, Laird SA, Klein C, Carney BK (1993) Biodiversity prospecting contract. In: Reid WV, Laird SA, Meyer CA, Gámez R, Sittenfeld A, Janzen DH, Gollin MA, Juma C (eds) Biodiversity prospecting: using genetic resources for sustainable development. World Resources Institute, Washington, DC, pp 255-287

Driml SM (1994) Protection from profit: economic and financial values of the Great Barrier Reef World Heritage Area and other protected areas. Research Publication 34, Great Barrier Reef Marine Park Authority, Townsville

Driml SM (1997) Bringing ecological economics out of the wilderness. Ecological Economics 23:145-153

Driml SM (1999) Dollar values and trends of major direct uses of the Great Barrier Reef Marine Park. Research Publication 56. Great Barrier Reef Marine Park Authority, Townsville

Driml SM, Hundloe TJ, Blamey RK (1997) Understanding Great Barrier Reef economics. Proceedings 1: The Great Barrier Reef, Science, Use and Management, A National Conference. James Cook University, Townsville

Eakin CM, McManus JW, Spalding MD, Jameson SC (1997) Coral reef status around the world: where are we and where do we go from here? Proceedings of the 8th International Coral Reef Symposium 1:277-282

Economist (1992) A modern smokestack industry. 14 November:110

Edwards SF (1991) The demand for Galapagos vacations: estimation and application to wilderness preservation. Coastal Management 19:155-169

Eskeland G (1992) Demand management in environmental protection: fuel taxes and air pollution in Mexico City. Country Economics Department, World Bank, Washington, DC

Espeut P (1992) Fishing for finfish in Belize and the south coast of Jamaica: a socio-economic analysis. Research Report 3. ICOD/ UWI/ Jamaica/ Belize Reef Fisheries Management Planning Project 1989-1992. Centre for Marine Science Research, University of the West Indies at Mona, Kingston, Jamaica

Espeut P, Grant S (1990) An economic and social analysis of small-scale fisheries in Jamaica. Prepared for the FAO. Institute of Social and Economic Research, University of the West Indies at Mona, Kingston, Jamaica

Evenson RE, Gollin D, Santaniello V (eds) (1998) Agricultural values of plant genetic resources, CAB International Publishing, Wallingford, Oxon

Evenson RE, Kislev Y (1976) A stochastic model of applied research. Journal of Political Economy 84(2):265-281

Evenson RE, Lemarié S (1998) Optimal collection and search for crop genetic resources. In: Smale M (ed) Farmers, gene banks and crop breeding: economic analyses of diversity in wheat, maize and rice. Kluwer, Boston, pp. 79-92

Farnsworth NR, Akerele O, Bingel AS, Soejarto DD, Guo Z-G (1985) Medicinal plants in therapy. Bulletin of the World Health Organization 63:965-81

Farnsworth NR, Soejarto DD (1985) Potential consequences of plant extinction in the United States on the current and future availability of prescription drugs. Economic Botany 39(3):231-240

Federal Register (1993) Natural resource damage assessments under the Oil Pollution Act of 1990. Federal Register 15.1.93, pp. 4601-4614

Federal Register (1994) Natural resource damage assessments : proposed rules. Federal Register 7.1.94, pp. 1139-1184

Fenical W (1993) Chemical studies of marine bacteria: developing a new resource. Chemical Reviews 93(5):1673-1683

Flam F (1994) Chemical prospectors scour the seas for promising drugs. Science 266:1324-5

Floudas C, Pardalos P (eds) (1992) Recent advances in global optimization. Princeton University Press, Princeton, NJ

Foster V, Bateman I, Harley D (1998) Real and hypothetical willingness to pay for environmental preservation: a non-experimental comparison. In: Acutt M, Mason P (eds) Environmental valuation, economic policy and sustainability. Edward Elgar, Cheltenham

Friedland EI (1977) Values and environmental modeling. In: Hall CAS, Day JW Jr. (eds) Ecosystem modeling in theory and practice: an introduction with case histories. John Wiley and Sons, New York, pp 115-131

Gibbons A (1992) Researchers fret over neglect of 600 million patients. Science 256:1135

Ginsburg RN (comp) (1994) Proceedings of the colloquium on global aspects of coral reefs: health, hazards and history, 1993. Rosenstiel School of Marine and Atmospheric Science, University of Miami, FL

Gill PE, Murray W, Wright MH (1981) Practical optimization. Academic Press, London

Gollin D, Smale M (1998) Search modeling for traits (Chapter 2). In: Evenson RE, Gollin D, Santaniello V (eds) Agricultural values of plant genetic resources. CAB International Publishing, Wallingford, Oxon

Gollin M (1995) Biological materials transfer agreements. Bio/Technology 13:243

Gorman M (1995) Tanga Coastal Zone Conservation and Development Programme report on socio-economic study/ participatory rural appraisal

Grabowski HG, Vernon JM (1990) A new look at the returns and risks to pharmaceutical R&D. Management Science 36(7):804-821

Greater Montego Bay Redevelopment Corporation (GMRC) (1996) Greater Montego Bay Area Plan 2014. Draft Technical Report. Commissioned by the Greater Montego Bay Redevelopment Company. Prepared by Planning and Design Quorum Inc, 4 Queens Drive, Montego Bay, Jamaica

Gregory R (1986) Interpreting measures of economic-loss: evidence from contingent valuation and experimental studies. Journal of Environmental Economics and Management 13(4):325-337

Gren I-M (1995) The value of investing in wetlands for nitrogen abatement. European Review of Agricultural Economics 22:157-172

Grigg RW (1997) Hawaii's coral reefs: status and health in 1997, the International Year of the Reef. In: Grigg RW and Birkeland C (eds) Status of coral reefs in the Pacific. Sea Grant College Program, School of Ocean and Earth Science and Technology, University of Hawaii, HI

Gustavson K (1998) Values associated with the local use of the Montego Bay Marine Park. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES)of the World Bank, Washington, DC

Gustavson K (1999) Economic production from the coral reef fisheries of Jamaica and captured ecosystem values. PhD Dissertation. University of Victoria, Victoria, BC

Gustavson K, Williams J (1999) Local use valuation as information towards the creation of effective marine park management in the developing tropics. Paper presented to Coastal Zone 99, 24-30 July 1999, San Diego, CA

Gutierrez B, Pearce DW (1992) Estimating the environmental benefits of the Amazon forest: an intertemporal valuation exercise. GEC Working Paper 92-44. Centre for Social and Economic Research on the Global Environment, London

Hammack J, Brown G (1974) Waterfowl and wetlands: towards bioeconomic analysis. Johns Hopkins Press, Baltimore, MA

Han SP (1977) A globally convergent method for nonlinear programming. Journal of Optimization Theory and Applications 22:297

Hanemann WM (1991) Willingness to pay and willingness to accept: how much can they differ. American Economic Review 81(3):635-647

Hanemann WM (1994) Valuing the environment through contingent valuation. Journal of Economic Perspectives 8(4):19-43

Hanley N (1996) Contingent valuation as a means of valuing the conservation of coral reefs in Jamaica: a state-of-the-art assessment of the method. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Hanley N, Craig S (1991) Wilderness development decisions and the Krutilla-Fisher model: the case of Scotland's Flow Country. Ecological Economics 4:145-64

Hanley N, Ruffell R (1993) The contingent valuation of forest characteristics: two experiments. Journal of Agricultural Economics (May)

Hanley N, Spash CL (1993) Cost-benefit analysis and the environment. Edward Elgar, Aldershot

Hansen RW (1979) The pharmaceutical development process: estimates of current development costs and times and the effect of regulatory changes. In: Chien RI (ed) Issues in pharmaceutical economics. Lexington Books, Lexington, MA

Hansen RW (1980) Pharmaceutical development costs by therapeutic categories. University of Rochester Graduate School of Management Working Paper GPB-80-6. University of Rochester

Hartell J, Smale M, Heisey PW, Senauer B (1997) The contribution of genetic resources and diversity to wheat productivity: a case from the Punjab of Pakistan. Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) Economics Working Paper 97-01. CIMMYT, Mexico

Harvard Business School (1992) INBio/Merck Agreement: pioneers in sustainable development. NI-593-015. Harvard Business School, Boston, MA

Hatziolos ME, Hooten AJ, Fodor M (eds) (1998) Coral reefs: challenges and opportunities for sustainable management. World Bank, Washington, DC

Hausman J (1993) Contingent valuation: a critical assessment. North Holland, Amsterdam

Henkel J (1998) Drugs of the deep: treasures of the sea yield some medical answers and hint at others. FDA Consumer (January/February)

Hitchman NDS (1997) Eutrophication: the death angel covering coral reefs in Montego Bay, Jamaica. BA Honors Thesis. Environmental Science and Public Policy, Harvard-Radcliffe Colleges, Cambridge, MA

Hodgson G (1997) Reef Check core methods. http://www.ust.hk/~webrc/ReefCheck/methods.html

Hodgson G (1998) Reef Check and sustainable managment of coral reefs. In: Wilkinson CR (ed) Status of coral reefs of the world: 1998. Global Coral Reef Monitoring Network, AIMS, Queensland, pp.165-168

Hodgson G (1999) A global coral reef assessment. Marine Pollution Bulletin 38(5):345-355

Hodgson G, Dixon JA (1988) Logging versus fisheries and tourism in Palawan. Occasional Paper 7. East-West Environment and Policy Institute, Honolulu, HI

Hoegh-Guldberg O (1999) Climate change, coral bleaching and the future of the world's coral reefs. Marine and Freshwater Research (in press)

Hoehn JP, Randall A (1987) A satisfactory benefit cost indicator from contingent valuation. Journal of Environmental Economics and Management 14(3):226-247

Holder JS (1991) Managing the Caribbean Environment as Tourism's Resource. Paper presented at the seminar on Tourism, Health and the Environment. PAHO, 31 October – 3 November 1991, Tobago

Huber RM, Dollar S, Mathur SC, Ruitenbeek HJ (1994) Cost-effectiveness analysis in integrated coastal zone management: a least cost model for coral reef environments in the developing tropics. Report to the World Bank Research Committee, World Bank, Washington, DC

Huber RM, Dollar S, Mathur SC, Ridgley M, Rijsberman F, Ruitenbeek HJ (1996) Cost-effectiveness analysis in integrated coastal zone management: a least cost model for coral reef environments in the developing tropics. Phase I: a prototype model. Report to the World Bank Research Committee, World Bank, Washington, DC

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

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

Huber RM, Jameson SC (1998c) 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) Volume 5, No.2 – Volume 6, No.1 (December, 1998 – January, 1999)

Huber RM, Ruitenbeek HJ (eds) (1997) Marine system valuation: an application to coral reef systems in the developing tropics. Interim Report to World Bank Research Committee, Project #RPO 681-05, World Bank, Washington, DC

Hughes TP (1994) Catastrophes, phase shifts, and large scale degradation of a Caribbean coral reef. Science 265:1547-1551

Hundloe T (1990) Measuring the value of the Great Barrier Reef. Journal of the Royal Australian Institute of Parks and Recreation 26(3):11-15

Hundloe T, Vanclay F, Carter M (1987) Economic and socio economic impacts of crown of thorns starfish on the Great Barrier Reef. Report to the Great Barrier Reef Marine Park Authority, Townsville

Imber G, Stevenson G, Wilks L (1991) A contingent valuation survey of the Kakadu Conservation Zone. Resource Assessment Commission Research Paper 3. Australian Government Publishing Service, Canberra

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (1990) ICRISAT's contribution to pearl millet production. ICRISAT, Cereals Program, Andhra Pradesh

Interorganizational Committee on Guidelines and Principles for Social Impact Assessment (ICGPSIA) (1994) Guidelines and principles for social impact assessment. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, DC

IUCN (1993) Reefs at risk: a program for action. Rue Mauverney 28, CH-1196, Gland

Iwu MM (1994) African medicinal plants and the search for new drugs based on ethnobotanical leads. In: Ethnobotany and the search for new drugs. Ciba Foundation Symposium 185. John Wiley & Sons, Chichester

Jabbour A (1983) Folklore protection and national patrimony: developments and dilemmas in the legal protection of folklore. Copyright Bulletin 17:10-14

Jacob M (1996) Marine organisms yield new cytotoxic agents, nutrients. Genetic Engineering News 16(3):1-9

Jameson SC (1997) Analysis of Louis Berger water quality data with respect to coral reef ecosystem health and eutrophication. Memo to Richard M Huber, The World Bank, Washington, DC

Jameson SC, Erdmann MV, Gibson Jr GR, Potts KW (1998) Development of biological criteria for coral reef ecosystem assessment. Atoll Research Bulletin No. 450 (September 1998), Smithsonian Institution, Washington, DC, http://www.epa.gov/owow/oceans/coral

Jameson SC, Erdmann MV, Gibson GR Jr., Potts KP (1999) Charting a course towards predictive monitoring: Coral reef bioindicators – where are we? And where do we go from here? Bulletin of Marine Science (in press)

Jameson SC, Huber RM (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

Jameson SC, McManus JW, Spalding MD (1995) State of the reefs: regional and global perspectives. International Coral Reef Initiative, US Department of State, Washington, DC

Joglekar P, Paterson ML (1986) A closer look at the returns and risks of pharmaceutical R&D. Journal of Health Economics 5:153-177

Johannes RE (1975) A comparison of nutrient-limited productivity in *Sargassum natans* from neritic versus oceanic waters of the Western North Atlantic Ocean. Limnology and Oceanography 40:625-633

Johannes R (1981) Words of the lagoon. University of California Press

Johnson J (1998) Tourism in Jamaica: an economic analysis of 1997. Prepared for the Jamaica Tourist Board, Pacific Analysis Inc, Victoria, BC

Kahneman D, Knetsch JL (1992) Valuing public goods: the purchase of moral satisfaction. Journal of Environmental Economics and Management 22(1):57-70

Kainuma M, Nakamori Y, Morita T (1991) Development of an intelligent decision support system for environmental modeling and planning. Research Report 128. National Institute for Environmental Studies, Japan

Karr JR (1991). Biological integrity: a long-neglected aspect of water resource management. Ecological Applications 1:66-84

Karr JR, Chu EW (1999) Restoring life in running waters: better biological monitoring. Island Press, Washington, DC

Karr JR, Fausch KD, Angermeier PL, Yant PR, Schlosser IJ (1986) Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey, Special Publication 5

Kerans BL, Karr JR (1994) A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecological Applications 4:768-785

Kleypas JA, Buddemeier RW, Archer D, Gattuso J, Langdon C, Opdyke BN (1999) Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. Science 284:118-120

Knetsch JL (1989) The endowment effect and evidence of non-reversible indifference curves. American Economic Review 79(5):1277-1284

Knetsch JL (1994) Environmental valuation: some problems of wrong questions and misleading answers. Environmental Values 3(4):351-368

Knetsch JL, Sinden JA (1984) Willingness to pay and compensation demanded: experimental evidence of an unexpected disparity in measures of value. Quarterly Journal of Economics 99(3):507-521

Kosko B (1992) Neural networks and fuzzy systems: a dynamical systems approach to machine intelligence. Prentice-Hall, Englewood Cliffs

Kosko B (1993) Fuzzy thinking. Hyperion, New York

Lang C, L'Eplattenier G, Reymond O (1989) Water quality in rivers of western Switzerland: application of an adaptable index based on benthic invertebrates. Aquatic Science 51:224-234

Lapointe BE (1999) From the President's desk. Reef Line 11(2):2 and 15 (The Quarterly Journal of ReefRelief), Key West, FL

Lapointe BE, Littler MM, Littler DS (1997) Macroalgal overgrowth of fringing coral reefs at Discovery Bay, Jamaica: bottom-up versus top-down control. Proceedings of the 8th International Coral Reef Symposium 1: 927-932

Leeworthy VR (1991) Recreational use value for John Pennekamp Coral Reef State Park and Key Largo National Marine Sanctuary. Strategic Assessment Branch, Ocean Assessments Division, National Oceanic and Atmospheric Administration (NOAA), Rockville, MD

Lenat DR (1988) Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. Journal of the North American Benthological Society 7:222-233

Maddala GS (1983) Limited-dependent and qualitative variables in econometrics. Cambridge University Press, Cambridge

Maher WA, Norris RH (1990) Water quality assessment programs in Australia: deciding what to measure and how and where to use bioindicators. Environmental Monitoring and Assessment 14:115-130

Malinvaud E (1972) Lectures on microeconomic theory. North-Holland, Amsterdam

Mansfield E (1995) Intellectual property protection, direct investment, and technology transfer. IFC Discussion Paper 27. IFC, Washington, DC

Marshall C, Rossman G (1993) Designing qualitative research. Sage Publications, Newbury Park

Mathworks (1998) MATLAB™: The language of technical computing, version 5.2. Mathworks, Natick, MA

McAllister DE (1988) Environmental, economic and social costs of coral reef destruction in the Philippines. Galaxea 7:161-178

McAllister DE (1991a) Estimating the pharmaceutical values of forests, Canadian and tropical. Canadian Biodiversity 1(3):16-25

McAllister DE (1991b) What is a coral reef worth? Sea Wind 5(1):21-24

McClanahan TR (1995) A coral reef ecosystem-fisheries model: impact of fishing intensity and catch selection on reef structure and processes. Ecological Modelling 80:1-19

McManus JW, Ablan MC (eds) (1997) ReefBase: a global database on coral reefs and their resources. User's guide version 2.0. International Center for Living Aquatic Resources Management (ICLARM), Makati City

McManus JW, Ablan MC, Vergara SG, Menez LA, Reyes KP, Gorospe ML, Halmarick L (1997) Reefbase aquanaut survey manual. International Center for Living Aquatic Resources Management (ICLARM) Educational Series 18, ICLARM, Manila

McNeill D, Freiberger P (1993) Fuzzy logic. Simon & Schuster, New York

McPhaill AA (1994) Why don't households connect to the piped water system? Observations from Tunisia. Land Economics 70(2):189-196

Meesters EH (1995) Cost-effectiveness analysis of coral reef management and protection: a case study of Curaçao: I. Coral reef data collection and analysis. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Meesters EH, Bak RPM, Westmacott S (1995) A fuzzy logic model to predict coral reef development under nutrient and sediment stress. Report prepared for Resource Analysis and the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Meesters EH, Bak RPM, Westmacott S (1996a) A fuzzy logic model to predict coral reef development under nutrient and sediment stress in Curaçao. Phase 3 report, ecological model definition. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Meesters EH, Bak RPM, Westmacott S (1996b) A fuzzy logic model to predict coral reef dynamics. 8th International Coral Reef Symposium, Panama, Abstracts, p 131

Meesters EH, Bak RPM, Westmacott S, Ridgley M, Dollar S (1998) A fuzzy logic model to predict coral reef development under nutrient and sediment stress. Conservation Biology 12(5):957-965

Meesters EH, Bos A, Gast GJ (1992) Effects of sedimentation and lesion position on coral tissue regeneration. Proceedings of the 7th International Coral Reef Symposium 2:681-688

Meesters EH, Westmacott S (1996) Cost-effectiveness analysis of coral reef management and protection. a case study of the Maldives. Formulation of the ecological response model. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Mendelsohn R, Balick MJ (1995) The value of undiscovered pharmaceuticals in tropical forests. Economic Botany 49(2):223-228

Mendelsohn R, Balick MJ (1997) Notes on economic plants. Economic Botany 51(3):328

Mestel M (1999) Drugs from the sea. Discover 20(3):70-75

Miller FR, Kebede Y (1984) Genetic contributions to yield gains in sorghum, 1950 to 1980. In: Fehr WR (ed) Genetic contributions to yield gains of five major crop plants. Crop Science Society of America Special Publication 7. American Society of Agronomy, Madison, WI

Mitchell R, Carson R (1989) Using surveys to value public goods: the contingent valuation method. Resources for the Future, Washington, DC

Moffat AS (1993) New chemicals seek to outwit insect pests. Science 261:550-1

Moore KS, Wehrli S, Roder H, Rogers M, Forrest JN, McCrimmon D, Zasloff M (1993) Squalamine: an aminosterol antibiotic from the shark. Proceedings of the National Academy of Science 90:1354-1358

Munasinghe M, McNeely J (1994) Protected area economics and policy: linking conservation and sustainable development. World Bank, Washington, DC

Munda G (1995) Multicriterion evaluation in a fuzzy environment: theory and applications in ecological economics. Physica-Verlag, Heidelberg

Munro A, Hanley N (1999) Information, uncertainty and contingent valuation. In: Bateman IJ, Willis KG (eds) Contingent valuation of environmental preferences: assessing theory and practice in the USA, Europe, and developing countries. Oxford University Press

Munro JL (1983) Jamaican fisheries trends. International Center for Living Aquatic Resources Management (ICLARM) Stud Rev 7:1. ICLARM, Manila

Myers N (1988) Threatened biotas: 'hot spots' in tropical forests. Environmentalist 8:187-208

Narain U, Fisher A (1994) Modeling the value of biodiversity using a production function approach. In: Perrings C, Maler K-G, Folke C, Jansson B-O, Holling CS (eds) Biodiversity conservation: policy issues and options. Kluwer Academic Publishers, Dordrecht

National Cancer Institute (NCI) (1995) Letter of Collection. NCI, Office of Technology Development, Bethesda

National Oceanic and Atmospheric Administration (NOAA) (1993) Report of the NOAA panel on contingent valuation. Federal Register 58(10):4601-4614

Natural Resources Conservation Authority (NRCA) (1997) Towards a beach policy for Jamaica (a policy for the use of the foreshore and the floor of the sea). Green Paper 2/97. Natural Resources Conservation Authority, Ministry of Environment and Housing, Kingston, Jamaica

Navrud S, Munagtana (1994) Environmental valuation in developing countries: the recreational value of wildlife viewing. Ecological Economics 11:135-151

New York Times (1993) Strange oases in sea depths offer map to riches. William J. Broad, 16 November

Newman D (1995) Marine bioprospecting. In: Hooten AJ, Hatziolos ME (eds) Sustainable financing for coral reef conservation: proceedings of a workshop. Environmentally Sustainable Development Proceedings Series 9, World Bank, Washington, DC, pp 38-42

Nicholson WE (1994) A project for the assessment of the Montego Bay Marine Park's impact on the local fishing industry. An ICOD/CCA/NRCA Fisheries Project. Montego Bay Marine Park, Montego Bay, Jamaica

Niebling K (1996) Biotech and drug firms claim territory in cosmeceutics. Genetic Engineering News 16(7):1-27

Norse EA (1993a) Chapter 3: Marine and terrestrial conservation. In: Global marine biological diversity: a strategy for building conservation into decision making. Island Press, Washington, DC

Norse EA (ed) (1993b) Global marine biological diversity, a strategy for building conservation into decision making. Island Press, Washington, DC

O'Callaghan Consulting Services Limited (1992) Environment study report. Greater Montego Bay Redevelopment Corporation, Montego Bay, Jamaica

Ogden J, Alcolado P, Alleng G, Bonair K, Laydoo R, Bone D, Klein E, Penchaszadeh P, Buchan K, Walker S, Bush P, Cortes J, DeMeyer K, Garcia J, Garzon-Ferreira J, Gayle P, Guzman H, Gerace D, Geraldes F, Jordan-Dahlgre E, Ruiz-Renteria F, Kjerfve B, Koltes K, Parker C, Oxenford H, Patt A, Azueta J, McField M, Peralta R, Pors L, Ramirez J, Rojas-Galaviz J, Ryan J, Singh J, Smith S, Tschirky J, Varela R, Woodley J, Linton D, Wiebe W, Zieman J (1997) Caribbean Coastal Marine Productivity (CARICOMP): A research and monitoring network of marine laboratories, parks, and reserves. Proc 8th International Coral Reef Symosium 1: 641-646

Oppenheim AN (1992) Questionnaire design, interviewing and attitude measurement. Pinter Publishers, New York

Orbach MK, Johnson JC (1989) The transformation of fishing communities: a public policy perspective. In: Thomas JS, Maril L, Durrenberger EP (eds) Marine resource utilization: a conference in social science issues. University of South Alabama Publication Services, Mobile, AL

Organization of American States (OAS) (1994) Economic analysis of tourism in Jamaica. Technical Report of the OAS National Program of Technical Cooperation with the Jamaica Tourist Board and the Ministry of Industry, Tourism, and Commerce. OAS, Washington, DC

Office of Technological Assessment (OTA) (1987) Technologies to maintain biological diversity. OTA -F-330. US Government Printing Office, Washington, DC

Office of Technological Assessment (OTA) (1993) Pharmaceutical R&D: costs, risks, and rewards. US Government Printing Office, Washington, DC

Paleroni NJ (1994) Some reflections on bacterial diversity. ASM News 60(10):537-540

Pardey PG, Skovmand B, Taba S, Van Dusen ME, Wright BD (1998) The cost of conserving maize and wheat genetic resources *ex situ*. In: Smale M (ed) Farmers, gene banks and crop breeding: economic analyses of diversity in wheat, maize and rice. Kluwer, Boston, MA, pp 35-53

Patton MQ (1990) Qualitative evaluation and research methods. Sage Publications, Newbury Park

Pearce DW, Moran D (1994) The economic value of biodiversity. IUCN/Earthscan, London

Pearce DW, Puroshothaman S (1992a) Protecting biological diversity: the economic value of pharmaceutical plants. Discussion Paper 92-27. Centre for Social and Economic Research on the Global Environment, London

Pearce DW, Puroshothaman S (1992b) The economic value of plant-based pharmaceuticals. In: Swanson T (ed) Intellectual property rights and biodiversity conservation. Cambridge University Press, Cambridge

Pendleton LH (1995) Valuing coral reef protection. Ocean and Coastal Management 26(2):119-131

Perez P (1995) Environmental biotechnology – business opportunities for the next five years. Ninth International Biotechnology Meeting and Exhibition. Biotechnology Industry Organization, San Francisco, CA

Pernetta J, Elder D (1993) Cross-sectoral, integrated coastal area planning: guidelines and principles for coastal area development. International Union for the Conservation of Nature and Natural Resources (IUCN) and World Wildlife, Gland

Perrings C, Walker BW (1995) Biodiversity loss and the economics of discontinuous change in semiarid rangelands. In: Perrings C, Maler K-G, Folke C, Holling CS, Jansson B-O (eds) Biodiversity loss: economic and ecological issues. Cambridge University Press, Cambridge, pp 190-210

Phillips DJH (1980) Quantitative aquatic biological indicators. Applied Science Publishers Ltd, London

Pido MD (1995) The application of rapid rural appraisal techniques in coastal resources planning: experience in Malampaya Sound, Philippines. Ocean and Coastal Management 26(1):57-72

Pido MD, Chua TE (1992) A framework for rapid appraisal of coastal environments. In: Chua TE, Scura LF (eds) Integrative framework and methods for coastal area management. International Center for Living Aquatic Resources Management (ICLARM) Conference Proceedings 37, ICLARM, Manila, pp 135-148

Pido MD, Pomeroy RS, Carlos MB, Garces LR (1996) A handbook for rapid appraisal of fisheries management systems. International Center for Living Aquatic Resources Management (ICLARM), Manila

Pigott JD, Land LS (1986) Interstitial water chemistry of Jamaica reef sediment: sulfate reduction and submarine cementation. Marine Chemistry 19:355-378

Pigou AC (1920) The economics of welfare. Macmillan, London

Plan Development Team (PDT) (1990) The potential of marine fisheries reserves for reef management in the US South Atlantic. National Oceanic and Atmospheric Administration (NOAA), Technical Memorandum NMFS-SEFC-261 Contribution No. CRD/89-90/04

Polasky S, Pavich S, Jaspin M (1997) Bibliography on the conservation of biological diversity: biological/ecological, economic and policy issues. Department of Agricultural and Resource Economics, Oregon State University, OR

Polasky S, Solow A (1995) On the value of a collection of species. Journal of Environmental Economics and Management 29:298-303

Pollnac RB (1998) Rapid assessment of management parameters for coral reefs. Coastal Resources Center, University of Rhode Island Press, RI

Pollnac RB, Sondita F, Crawford B, Mantjoro E, Rotinsulu, Siahainenia (1997) Socioeconomic aspects of resource use in Bentenan and Tumbak. CRC/URI CRMP, Jakarta, pp 79, www.indomarine.or.id/pesisir/

Posey DA (1996) Traditional resource rights: international instruments for protection and compensation for indigenous peoples and local communities. IUCN, Gland/Cambridge

Powell MJD (1978) The convergence of variable metric methods for nonlinearly constrained optimization calculations. In: Mangasarian OL, Meyer RR, Robinson SM (eds) Nonlinear programming 3. Academic Press, London

Prescott-Allen R, Prescott-Allen C (1988) Genes from the wild: using wild genetic resources for food and raw materials. Earthscan, London

Principe P (1989a) The economic significance of plants and their constituents as drugs. In: Wagner H, Hikino H, Farnsworth N (eds) Economic and medicinal plant research 3. Academic Press, London, pp 655-656

Principe P (1989b) The economic value of biological diversity among medicinal plants. OECD, Paris

Putterman DM (1996) Model material transfer agreements for equitable biodiversity prospecting. Colorado Journal of International Environmental Law and Policy 7(1):145-173

Putterman DM (1997) Review of marine genetic resource R&D issues (Annex 6). In: Huber RM, Ruitenbeek HJ (eds) Marine system valuation: an application to coral reef systems in the developing tropics. Interim Report to World Bank Research Committee, Project #RPO 681-05, World Bank, Washington, DC

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. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Quammen D (1996) The song of the dodo: island biogeography in an age of extinctions. Simon & Schuster, New York

Randall A (1986) The possibility of satisfactory benefit estimation with contingent markets. In: Cummings RG, Brookshire DS, Schulze WD (eds) Valuing environmental goods: an assessment of the contingent valuation method. Rowman & Allanheld, Totowa

Randall A (1993) Passive use values and contingent valuation. Choices 8(2):12-15

Randall A, Stoll J (1980) Consumers' surplus in commodity space. American Economic Review 70(3):449-455

Ready R, Navrud S, Duborg R (1999) How do respondents with uncertain willingness to pay answer contingent valuation questions? Paper presented to EAERE conference, June, Oslo

Reaka-Kudla ML (1997) The global biodiversity of coral reefs: a comparison with rain forests. In: Reaka-Kudla ML, Wilson DE, Wilson EO (eds) Biodiversity II: understanding and protecting our biological resources. Joseph Henry Press, Washington, DC, pp 83-108

Reaka-Kudla ML, Wilson DE, Wilson EO (eds) (1997) Biodiversity II: understanding and protecting our biological resources. Joseph Henry Press, Washington, DC

Reef Check (1997) Reef Check 97 Press Conference Background Material, 16 October 16. Institute for Environment and Sustainable Development, Hong Kong University of Science and Technology, http://www.ust.hk/~webrc/ReefCheck/reef.html

Reid WV, Laird SA, Gámez R, Sittenfeld A, Janzen DH, Gollin MA, Juma C (1993a) A new lease on life. In: Reid WV, Laird SA, Meyer CA, Gámez R, Sittenfeld A, Janzen DH, Gollin MA, Juma C (eds) Biodiversity prospecting: using genetic resources for sustainable development. World Resources Institute, Washington, DC, pp 1-52

Reid WV, Laird SA, Meyer CA, Gámez R, Sittenfeld A, Janzen DH, Gollin MA, Juma C (1993b) Biodiversity prospecting: using genetic resources for sustainable development. World Resources Institute, Washington, DC

Renard Y (1991) Institutional challenges for community-based management in the Caribbean. Nature and Resources 27(4):4-9

Resource Analysis and Coastal Zone Management (CZM) Centre (1994) COastal zone Simulation MOdel (COSMO): manual. Resource Analysis and Coastal Zone Management Centre, National Institute for Coastal and Marine Management, The Hague

Resource Analysis and Delft Hydraulics (1993) How to account for impacts of climate change in integrated coastal zone management: concepts and tools for approach and analysis. World Coast Conference 1993, 1-5 November 1993, Noordwijk, The Netherlands

Rhoades RE (1991) The world's food supply at risk. National Geographic 179(4):74-103

Richmond RH (ed) (1993) Proceedings of the Seventh International Coral Reef Symposium. 22-27 June 1992, University of Guam Marine Lab, Mangilao, Guam

Ridgley M, Dollar S (1996) A coral-reef impact-assessment model using fuzzy rule-based logic, Phase II Interim Report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Ridgley M, Dollar S, Bailey K (1995) Overview of the development of a prototype model to estimate future pollution-induced coral reef impacts. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Ridgley M, Rijsberman FR (1992) Multicriteria evaluation in a policy analysis of a Rhine estuary. Water Resources Bulletin 28(6):1095-1109

Rijsberman F (1995) Cost-effectiveness analysis of coral reef management and protection: a case study of the Maldives. First visit report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Rijsberman FR, Koudstaal R (1989) Development and application of a framework for analysis for integrated coastal resources management in an international context. In: Magoon OT (ed), Coastal Zone 1989. ASCE, New York, pp 58-71

Rijsberman F, Westmacott S (1996) Cost-effectiveness analysis of coral reef management and protection: a case study for Curaçao. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Rijsberman FR, Westmacott S, Hirsch D (1995a) Cost-effectiveness analysis of coral reef management and protection, a case study of Curaçao: phase 1 report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Rijsberman FR, Westmacott S, Waardenburg D (1995b) CORONA: coastal resources management roleplay. Trainers' manual. Resource Analysis, Delft, and CZM Centre, National Institute for Coastal and Marine Management, the Hague

Risk MJ (1992) Musings on monitoring. Reef Encounter 12:7-9

Rosenberg DM, Resh VH (1993) Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York

Rowe R, d'Arge R, Brookshire D (1980) An experiment on the economic value of visibility. Journal of Environmental Economics and Management 7:1-19

Rubin SM, Fish SC (1994) Biodiversity prospecting: using innovative contractual provisions to foster ethnobotanical knowledge, technology and conservation. Colorado Journal of International Environmental Law and Policy 5:23-58

Ruitenbeek HJ (1989) Social cost-benefit analysis of the Korup project, Cameroon. WWF, Godalming

Ruitenbeek HJ (1992) The rainforest supply price: a tool for evaluating rainforest conservation expenditures. Ecological Economics 6(1):57-78

Ruitenbeek HJ (1996) Distribution of ecological entitlements: implications for security and population movement. Ecological Economics 17:49-64

Ruitenbeek HJ, Cartier CM with contributions from Bunce L, Gustavson K, Putterman D, Spash CL, van der Werff ten Bosch JD, Westmacott S, Huber R (1999) Issues in applied coral reef biodiversity valuation: results for Montego Bay, Jamaica. World Bank Research Committee Project RPO#682-22 Final Report, World Bank, Washington, DC

Ruitenbeek HJ, Ridgley M, Dollar S, Huber RM (1996) Use of fuzzy logic in a coral reef management model: preliminary results for Montego Bay, Jamaica. Fourth Biennial Meeting International Society for Ecological Economics, Boston University, Boston, MA

Ruitenbeek HJ, Ridgley M, Dollar S, Huber R (1999a) 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 – A least cost model for coral reef management and protection. World Bank Research Committee Project RPO#680-08 Final Report, World Bank, Washington, DC

Ruitenbeek HJ, Ridgley M, Dollar S, Huber R (1999b) 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 (in press)

Saade ME (1996) Adoption and impact of high yield wheat varieties in northern Tunisia. CIMMYT Economics Working Paper 96-03. CIMMYT, Mexico

Sagoff M (1988) The economy of the earth. In: MacLean D (ed) Cambridge studies in philosophy and public policy. Cambridge University Press, Cambridge

Sagoff M (1996) On the value of endangered and other species. Environmental Management 20(6):897-911

Sahney AK (1982) Sample survey of the fishing industry in Jamaica - 1981. Presented at the WECAF Conference, FAO, 17-21 May 1982. Data Collection and Statistics Branch, Data Bank and Evaluation Division, Ministry of Agriculture, Kingston, Jamaica

Samples KC, Dixon JA, Gowen MM (1986) Information disclosure and endangered species valuation. Land Economics 62(3):306-312

Sawyer DA (1992) Taka Bone Rate: management, development and resource valuation of an Indonesian atoll. Masters Thesis. Dalhousie University, Halifax, NS

Scanlan PM (1988) The dolphins are back: a successful quality model for healing the environment. Productivity Press, Portland, OR

Scheuer PJ (1990) Some marine ecological phenomena: chemical basis and biomedical potential. Science 248:173-7

Schonhuth M, Kievelitz U (1994) Participatory learning approaches. Rapid rural appraisal/ participatory appraisal. An introductory guide. Schriftenreihe der GTZ, No. 248

Scrip Newsletter, January 1996, p 37

Sen A (1988) The standard of living. Cambridge University Press, Cambridge

Shyamsundar P, Kramer RA (1996) Tropical forest protection: an empirical analysis of the costs borne by local people. Journal of Environmental Economics and Management 31(2):129-144

Simberloff DS, Abele LG (1976) Island biogeography theory and conservation practice. Science 191:285-286

Simpson RD, Craft AB (1996) The social value of using biodiversity in new pharmaceutical research. Discussion Paper 96-33. Resources for the Future, Washington, DC

Simpson RD, Sedjo RA (1996a) Investments in biodiversity prospecting and incentives for conservation. Discussion Paper 96-14. Resources for the Future, Washington, DC

Simpson RD, Sedjo RA (1996b) Valuation of biodiversity for use in new product research in a model of sequential search. Discussion Paper 96-27. Resources for the Future, Washington, DC

Simpson RD, Sedjo RA, Reid JW (1996) Valuing biodiversity for use in pharmaceutical research. Journal of Political Economy 104(1):163-184

Singh GN (1996) Community Intellectual Rights Act. In: Egziabher TBG (ed) A case for community rights. Third World Network, Penang

Smale M (1995) “Maize is life”: Malawi’s delayed green revolution. World Development 23(5):819-831

Smale M (ed) (1998) Farmers, gene banks and crop breeding: economic analyses of diversity in wheat, maize and rice. Kluwer, Boston, MA

Smale M, Heisey PW, Leathers HD (1995) Maize of the ancestors and modern varieties: the microeconomics of high yielding variety adoption in Malawi. Economic Development and Cultural Change 43(2):351-368

Smith PN (1994) Application of fuzzy sets in the environmental evaluation of projects. Journal of Environmental Management 42:365-388

Solow A, Polasky S, Broadus J (1993) On the measurement of biological diversity. Journal of Environmental Economics and Management 24:60-68

Sorensen J (1997) National and international efforts at integrated coastal zone management: definitions, achievements, and lessons. Coastal Management 25:3-41

Soule DF (1988) Marine organisms as indicators: reality or wishful thinking? In: Soule DF, Kleppel GS (eds) Marine organisms as indicators. Springer-Verlag, New York, pp 1-11

Spash CL (1993a) Economics, ethics, and long-term environmental damages. Environmental Ethics 15(2):117-132

Spash CL (1993b) Estimating the importance of inviolable rights: the case of long-term damages and future generations. Scottish Economic Society

Spash CL (1994) Double CO_2 and beyond: benefits, costs and compensation. Ecological Economics 10(1):27-36

Spash CL (1997) Ethics and environmental attitudes with implications for economic valuation. Journal of Environmental Management 50(4):403-416

Spash CL (1998a) Environmental values, attitudes and ethics: non-compensatory choices in a developing country context. Paper presented at the 25th Anniversary of Doctoral Program, 17 April 1998, University of Wyoming, WY

Spash CL (1998b) Informing and forming preferences in contingent valuation: a case study. Paper presented to the World Congress of Environmental and Resource Economists, 25-27 June 1998, Venice, Italy

Spash CL (1998c) Investigating individual motives for environmental action: lexicographic preferences, beliefs and attitudes. In: Lemons J, Westra L, Goodland R (eds) Ecological sustainability and integrity: concepts and approaches. Kluwer Academic Publishers, Dordrecht

Spash CL, Hanley N (1995) Preferences, information and biodiversity preservation. Ecological Economics 12(3):191-208

Spash CL, van der Werff ten Bosch JD, Westmacott S, Ruitenbeek HJ (1998) Lexicographic preferences and the contingent valuation of coral reef biodiversity in Curaçao and Jamaica. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Specht JE, Williams JH (1984) Contributions of genetic technology to soybean productivity – retrospect prospect. In: Fehr WR (ed) Genetic contributions to yield gains of five major crop plants. Crop Science Society of America Special Publication 7. American Society of Agronomy, Madison, WI

Spencer Davies P, Brown BE (1992) Identification of a coral reef management strategy in developing countries. I: Main report and recommendations. Report to the Commission of the European Communities

Spurgeon J (1992) The economic valuation of coral reefs. Marine Pollution Bulletin 24(11):529-536

Stevens TH, Echeverria J, Glass RJ, Hager T, More TA (1991) Measuring the existence value of wildlife: what do CVM estimates really show? Land Economics 67(4):390-400

Stroh WH (1998) Industrial enzymes market: growth experienced from new products and movement into global market. Genetic Engineering News 5(1):11

Sullivan K, Chiappone M (1994) Montego Bay Marine Park, Jamaica: rapid ecological assessment. Conservation Data Centre, Nature Conservancy, and Natural Resources Conservation Authority, Arlington, VA

Swallow BM, Woudyalew M (1994) Evaluating willingness to contribute to a local public good: application of contingent valuation to tsetse control in Ethiopia. Ecological Economics 11:153-161

Swaminathan MS (ed) (1996) Agrobiodiversity and farmers' rights: proceedings of a technical consultation on an implementation framework for farmers' rights. MS Swaminathan Research Foundation, Madras

Swanson TM (1996) The reliance of northern economies on southern biodiversity: biodiversity as information. Ecological Economics 17(1):1-8

Taylor FF (1993) To hell with paradise: a history of the Jamaican tourist industry. University of Pittsburgh Press, Pittsburgh, PA

Tomascik T (1993) Coral reef ecosystems: environmental management guidelines. Environmental Management Development in Indonesia Project (EMDI) Environmental Reports 35. School for Resource and Environmental Studies, Dalhousie University, Halifax, NS

Tomascik T, Sander F (1985) Effects of eutrophication on reef building corals: I. Growth rate of the reef building coral *Montastrea annularis*. Marine Biology 87:143-155

Tomascik T, Sander F (1987) Effects of eutrophication on reef building corals: III. Reproduction of the reef building coral *Porites porites*. Marine Biology 94:77-94

Townsley P (1993) A manual on rapid appraisal methods for coastal communities. Bay of Bengal Programme, Madras, India

United States Agency for International Development (USAID) (1996) Montego Bay Environmental Monitoring Program. Final report. Prepared by Hay B, Louis Berger International Inc, Needham, MA

United States Department of Commerce (USDOC) (1994) Florida Keys National Marine Sanctuary draft management plan/environmental impact statement. Volumes 1-3. USDOC, Office of Ocean and Coastal Resource Management, Silver Spring, MD

United States Environmental Protection Agency (USEPA) (1990a) Biological criteria: national program guidance for surface waters. EPA-440/5-90-004, USEPA, Office of Water, Office of Regulations and Standards, Criteria and Standards Division, Washington, DC

United States Environmental Protection Agency (USEPA) (1990b) Near coastal program plan for 1990: estuaries, November 1990. EPA-600-4-90/033, USEPA, Washington, DC

Vagelos PR (1991) Are prescription drug prices too high? Science 252:1080-1084

Van Gaasbeek AF, Heijbroak AMA, Baandrager P, Boers GJ (1994) The world seed market: developments and strategy. Rabobank Nederland Agribusiness Research, Utrecht

Veghel MLJ (1994) Polymorphism in the Caribbean reef building coral *Montastrea Annularis.* Ph.D. Disseration, University of Amsterdam

von Altrock C (1995) Fuzzy logic and neurofuzzy applications explained. Prentice-Hall, Englewood Cliffs

Walgate R (1990) Miracle or menace: biotechnology and the Third World. Panos Dossier (3). Panos Institute, London

Wasike W (1996) Contingent valuation of river pollution control and domestic water supply in Kenya. PhD Dissertation, University of Stirling, Stirling, Scotland

Wasike W, Hanley N (1998) The pricing of domestic water services in developing countries: a contingent valuation application to Kenya. International Journal of Water Resources Development 14(1):41-54

Weber J, Saunders L (1996) Managing a coral reef ecosystem in Indonesia. Paper presented to the 4th Biennial Meeting of the International Society for Ecological Economics, Boston, MA

Werners S (1998) Development of the user-friendly computer model COCOMO for coastal conservation in Montego Bay. Status report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC. Mimeo

Westmacott S (1995) Decision support in coastal zone management. International Institute for Hydraulic and Environmental Engineering (IHE) and Resource Analysis, Delft

Westmacott S (1996) Cost-effectiveness analysis of coral reef management and protection, a case study of the Maldives: phase 2 report - model definition and data collection. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Westmacott S, Klinckhamers P, Fernandes L, Rijsberman F (1995) Cost-effectiveness analysis of coral reef management and protection, a case study of Curaçao: Phase 2: field visit project report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Westmacott S, Rijsberman F (1995) CORAL, a coastal management model for the sustainable development of coral reef areas. Physics and Chemistry of the Earth 20(3-4):245-250

Westmacott S, Rijsberman F (1997) Cost-effectiveness analysis of coral reef management and protection: CORAL, a coral reef management model for the Republic of the Maldives. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

White AT (1989) Two community-based marine reserves: lessons for coastal management. In: Chua TE, Pauly D (eds), Coastal area management in Southeast Asia: policies, management strategies and case studies. ICLARM Conference Proceedings 19. International Center for Living Aquatic Resources Management (ICLARM), Manila

White AT, Hale LZ, Renard Y, Cortesi L (1994) Collaborative and community-based management of coral reefs: lessons from experience. Kumarian Press, West Hartford, CT

Whittington D, Brisco J, Mu X, Barron W (1990) Estimating willingness to pay for water services in developing countries. Economic Development and Cultural Change 38(4):293-311

Whittington D, Lauria D, Wright A, Choe K, Hughes J, Swarna V (1993) Household demand for improved sanitation services in Ghana. Water Resources Research 29(6):1539-1560

Wilkinson CR (ed) (1998) Status of coral reefs of the world: 1998. Global Coral Reef Monitoring Network, AIMS, Queensland

Williams ID, Polunin NVC (1999) Large scale correlations of macroalgal cover and fish abundance on Caribbean reefs. Manuscript.

Willig RD (1976) Consumer's surplus without apology. American Economic Review 66(4):587-597

Willis K, Garrod G, Saunders C (1993) Valuation of the South Downs and Somerset Levels Environmentally Sensitive Areas. Centre for Rural Economy, University of Newcastle on Tyne, Newcastle

Wilson EO (1992) The diversity of life. Harvard University Press, Cambridge

Wilson JG, Jeffrey DW (1994) Benthic biological pollution indices in estuaries. In: Kramer KJ (ed) Biomonitoring of coastal waters and estuaries. CRC Press, Boca Raton, FL, pp 311-324

Witt S (1985) Biotechnology and genetic diversity. California Agricultural Lands Project, San Francisco, CA

Woodley JD (1995) Tropical Americas regional report on the issues and activities associated with coral reefs and related ecosystems. International Coral Reef Initiative, US Department of State, Washington, DC

Woodley JD (1999) Sea-urchins exert top-down control of marcoalgae on Jamaican coral reefs (1). Coral Reefs 18:192

Woodley JD, Gayle PMH, Judd N (1999) Sea-urchins exert top-down control of marcoalgae on Jamaican coral reefs (2). Coral Reefs 18:193

World Bank (1991) Agricultural biotechnology, the next "Green Revolution"? Technical Paper 133. World Bank, Washington, DC

World Bank (1993a) Nordwijk guidelines for integrated coastal zone management. World Bank, Washington, DC

World Bank (1993b) World development report: investing in health. World Bank, Washington, DC

World Bank (1996) Guidelines for integrated coastal zone management. Environmentally Sustainable Development Studies and Monographs Series 9. World Bank, Washington, DC

World Conservation Monitoring Centre (WCMC) (1992) Global biodiversity: status of the earth's living resources. Chapman and Hall, London

World Conservation Monitoring Centre (WCMC) (1994a) Case study: biodiversity and the pharmaceutical industry. World Conservation Monitoring Centre, Cambridge

World Conservation Monitoring Centre (WCMC) (1994b) Case study: the use of plant genetic resources in agriculture. World Conservation Monitoring Centre, Cambridge

Wright A, McCarthy PJ (1994) Drugs from the sea at Harbor Branch. Sea Technology 35(8):10-18

Wright MG (1995) An economic analysis of coral reef protection in Negril, Jamaica. Working Paper 11. Centre for Environment and Development, University of the West Indies at Mona, Kingston, Jamaica

Yuan R, Hsu M (1996) Herbal medicines, part 1. Genetic Engineering News 16(2):29-32

Zadeh L (1965) Fuzzy sets. Information and Control 8(3):338-353

Zilberman D, Yarkin C, Heiman A (1998) Institutional change and biotechnology in agriculture: implications for developing countries. In: Smale M (ed) Farmers, gene banks and crop breeding: economic analyses of diversity in wheat, maize and rice. Kluwer, Boston, MA, pp 191-204

Zilinskas RA, Colwell RR, Lipton DW, Hill RT (1995) The global challenge of marine biotechnology: a status report on the United States, Japan, Australia and Norway. Maryland Sea Grant Publication, College Park MD