## Chapter 4

# Cost-Effectiveness Analysis of Coral Reef Management and Protection: A Case Study of the Republic of the Maldives

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The specific objective of the research is to develop a quantitative ecological economic model of coastal zones in the developing tropics, designed to assist in the formulation, evaluation and ranking of various cost-effective coastal zone management plans. The Republic of the Maldives, where the coral reefs are in many areas still relatively undisturbed but where development is rapidly changing these coral reef systems, was utilized as a case study site. The condition of the coastal zone is represented by an indicator of coral reef health that is measured in terms of coral cover and rugosity (an indicator of the structural development of the reef). In order to cope with the difficulties of assessing the benefits of improved coastal zone management, the research has been limited to assessing the costs of management using a framework that focuses on four main steps: i) the specification of economic sector interventions; ii) the modeling of the changes of these interventions on production and consumption; iii) the quantification of the physical response of these in terms of the wastes and physical damage generated; and, iv) the modeling of the impact of the wastes and physical damage on reef health. The final cost of each intervention is then computed, taking into account potential negative costs (e.g., from production changes). This enables interventions to be formulated in such a way as to incur the minimum costs while retaining a certain quality of reef.

The two objectives of the Maldives case study are:

1. To test and validate the cost-effectiveness analysis model of coral reef protection and management developed for Jamaica (Chapter 8) and Curaçao (Chapter 3); and,
2. To investigate whether the cost-effectiveness analysis model can be a useful tool for decision support for coastal zone management for the Republic of the Maldives.

The second objective required the establishment of a wider framework of multi-criteria decision-making in integrated coastal zone management (ICZM). This involved cooperating closely with local decision-makers and experts in order to shape the final product into a useful tool. The involvement of local decision-makers and experts was achieved through a series of workshops and consultations. The project was divided into four main phases:

1. *Project preparation*. The site was identified, contacts established and a detailed work plan was developed (Rijsberman 1995).
2. *Fieldwork*. The fieldwork involved problem formulation and data collection (Westmacott 1996).
3. *Model development*. This required the development of the socio-economic model (Westmacott and Rijsberman 1997) and the ecological response model (Meesters and Westmacott 1996). The cost-effectiveness methodology is incorporated in the linking of these two models. The computer user interface was also developed in this phase.
4. *Testing and validation*. This involved presentations of the model to those involved in its development and lead to the final revisions.

Research began during the fall of 1995. This chapter presents the results of the final report, which was completed early in 1997. Further detail can be found in Westmacott and Rijsberman (1997) and within the companion CD-ROM.

The area defined in the model is that of North and South Male within the Republic of the Maldives. This specific study site was selected as it is the most developed and contains some of the most densely populated islands. For modeling, the two atolls have been divided into 10 sections based on physical location (i.e., inner atoll islands or outer/surrounding islands and reefs, subsequently dividing east to west and north to south; Figure 4.1).

## Description of the Coral-Maldives Model

Coral-Maldives is a coastal zone management decision support system that incorporates a cost-effectiveness analysis for coral reef management. The decision support system is structured in such a way that different users are able to explore a series of different coastal zone management options under varying assumptions for exogenous variables (e.g., population growth rates). The analysis allows the users to focus on the most cost-effective options for coral reef management and protection for the various economic development options. The impacts can be seen in terms of economic, social and environmental indicators that are selected at the outset of the analysis. In addition to the selected indicators, the user is able to explore more detailed information relating to the economy, reef health and coastal erosion. The final step of the analysis shows a scorecard of all the selected indicators. The user can also use the cost-effectiveness analysis to rank the coastal zone management strategies in terms of cost per unit gain in reef health.

The user is able to structure analysis through the user definitions of indicators, scenarios and strategies and the final formulation of cases. First, users can choose which indicators to select in the analysis. This means they are able to include specific aspects of interest to themselves as well as more general coastal zone management aspects. In the case where the model does not adequately cover all the interests of the user and where more research has been undertaken, additional indicators can be added to the analysis. Second, the user is able to define the scenarios. The scenarios represent a series of overall growth rates or policy decisions. The economic development and environmental protection options have been selected through discussions with various government agencies involved in coastal zone management within the Republic of the Maldives. The user is again free to define different combinations of these developments and protection measures. Once the definition of scenarios and formulation of strategies has been carried out, the user is able to select combinations of these (cases) for the analysis. The decision support system allows the user to delete less favorable cases so as to keep the analysis tractable.

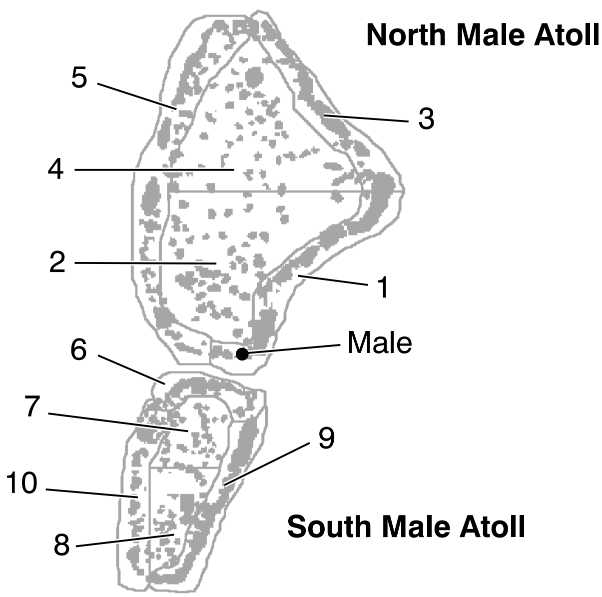


**Figure 4.1.** Sections of North and South Male utilized in the model.

### *Structure of the Decision Support System and the Coral-Maldives Model*

The Coral-Maldives decision support system consists of the following:

- A user interface;
- The computational model in a spreadsheet;
- The database of model parameters in the spreadsheet; and,
- The database of information contained in interactive text and graphic files available to the user.

The steps involved in the analysis can be seen in Figure 4.2. The interface helps the user to assess the problems and issues found in the coastal zone and define the objectives of the analysis and the criteria or indicators with which to measure the success of each plan. The user definitions include scenarios, economic development and environmental protection options. The user can work through different options, saving each with a name and a description. These are then combined into cases in the analysis and analyzed on an individual basis and in a comparisons of all cases.

The user definitions (scenarios, economic development and environmental protection options) drive the socio-economic model, which results in a set of impacts distributed over the area. The impacts are measured by sediment loadings and levels of physical damage. These are then used as input into the ecological response model, which estimates changes in reef health over the impact areas. These changes will, in turn, affect the health of the reef fisheries, which has a feedback effect on commercial fisheries production. The costs of the environmental protection options and the changes in the reef health are considered in the cost-effectiveness analysis, which allows

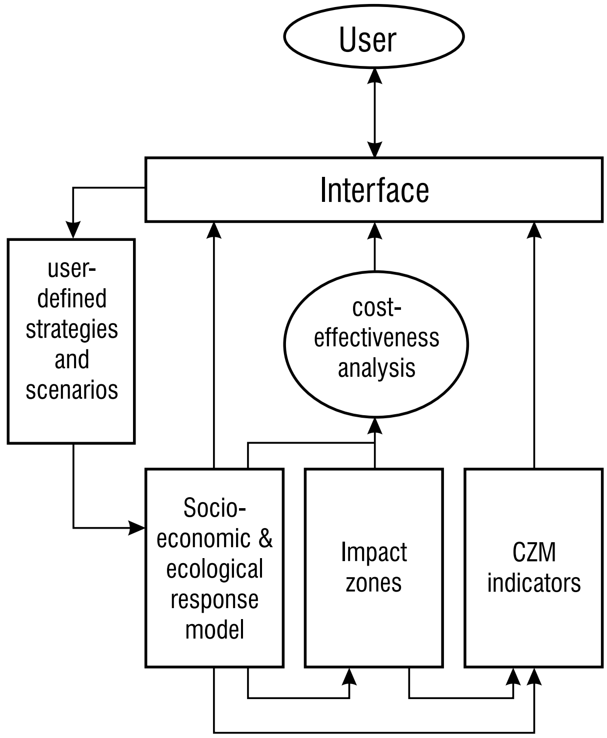


**Figure 4.2.** Structure of the Coral-Maldives decision support system.

a ranking in terms of total cost per unit change in reef health. Two indicators of reef health are used—coral cover and rugosity. The user defines scenarios and strategies. The scenarios are exogenous developments, such as overall economic growth and population growth, which are used to drive the socio-economic model. The strategies are combinations of economic developments and environmental protection measures.

### *User Definitions*

The model is driven by user-defined scenarios relating to external growth factors and policies. Growth is distributed throughout the islands through the definition of economic development options. Furthermore, the user can define various environmental protection measures and can examine the impacts of these under different scenarios. During the analysis, the user selects a growth scenario, an economic development scenario and a set of environmental protection measures that form a case. This is then compared to a reference case, which is defined as the projected situation in the year 2005 if no additional environmental protection measures are taken. This allows the analysis of only the environmental protection measures or of the coastal zone management strategies (i.e., economic and environmental options) or analysis of strategies under different scenarios.

The available user definitions are assumed to represent the major issues currently of concern in the coastal zone within the Republic of the Maldives:

1. Growth scenarios, defined for the study site and at the national level, including overall economic growth; population growth rates; investment in boats; an increase in number of tourists; an increase in price of foreign aggregate (alternative construction material); and the discount rate.
2. Economic development options, defined at the island level, including an increase in the number of houses; an increase in the number of resort rooms; an increase in the capacity for boats through development and/or expansion of harbors and jetties; and protection of islands against coastal erosion and flooding through construction of seawalls or groynes.
3. Environmental protection options, defined for the study area, including reduction of pollution through treatment of wastewater by means of sewage treatment plants, septic tanks and outfalls; a setback policy for resorts; protected areas/marine parks; reduction of the areas available to mining through land use regulations; limitations to the use of coral in construction; reduction of sedimentation from construction through the use of sheet piling; construction of open jetties to minimize erosion; and education and awareness campaigns.

### *Population Growth and Migration Patterns*

Population growth and the migration to Male is one of the major issues of concern at present in the Maldives. The model addresses this through user-defined scenarios. The user has several options. The first step is to define the natural growth rates for Male and the outer islands. These have been seen to differ and are, therefore, specified separately by the user. In addition to these growth rates, the user has the option to specify an out-migration rate. This represents potential decentralization policies, providing housing and services out of the Male area. Once the growth rates are established, the user can specify houses to be developed on each island. This defines the spatial distribution of population, based on current population densities and housing patterns, and assumes that people will remain on an island outside of Male if housing is provided. If housing is not provided, based on current migration patterns, it is assumed that people will migrate to Male. In the case of new land being created, the user specifies a number of houses for the reclaimed land and the model calculates the land area required based on an assumed area required per house.

## *Economic Growth*

The model contains a simple sector economic module. The fishery and tourism sectors are modeled, with the remaining sectors being aggregated. The total GDP figure used by the model takes into account that for North and South Male only and not that for the whole of the Republic. This division is based on fisheries production data and the tourism capacity of the atolls. The overall GDP is based on 1993 data.

The economy grows according to a growth rate specified by the user. The growth in the fisheries is based on two limiting factors. The first is the fishing capacity. This can be expanded through an investment in boats, specified by the user in terms of total number of boats. The second limiting factor is the available fish stocks. The model takes into account the state of the reef and, therefore, the potential density of reef fish based on a study by Brown *et al*. (1990) showing a relationship between reef fish density and the rugosity of the reef. As a result, this also affects the tuna fisheries through the availability of baitfish, which is dependent on the reef condition.

Tourism is limited by the demand from the international market or the capacity of the resorts based on the number of beds. The exogenous character of the growth of the international tourism market means it is dealt with as a scenario variable defined by the user. The capacity of the area to accept this demand is again user defined. Decisions can be made to expand existing resorts or create new resorts. Development can also be limited through setback policies.

The remaining economic sectors, which are combined, are modeled from the overall growth rate specified in the scenarios and fisheries and tourism GDP. The scenario provides a new overall GDP for the year selected. This GDP is then re-distributed in the economy through changes seen in the fisheries and tourism sectors, the remaining GDP belonging to the aggregated sectors. Although this simple model allows a clear and transparent modeling of the economy, it does omit several important side effects of changing the sector balance. For example, growth in tourism may increase GDP in the transportation sector, which in turn has an effect on the boat building industry and, perhaps, also provides employment for coral miners, currently working in a declining industry. This version of the model does not model these links between the sectors.

## *Economic Development Options*

The economic development options spread the economic activity and the population spatially through the islands. These activities produce impacts on the reefs through sediment loadings and physical damage. Impact zones are used as input into the ecological response model. To minimize the impacts, the user is able to undertake a series of environmental protection measures.

### Housing Development and Tourism Development

Housing and tourism activities increase the number of people on an island. Insufficient housing development for the growth in population will result in the excess population migrating to Male. An island can be developed as either a tourist island or a local island. The population on the tourist islands is related to the number of rooms, the quality of the resort, and the occupancy rate. The presence of people produces wastewater that is discharged off the reef. Any construction will place a demand on construction materials that is assumed to be coral rock unless otherwise specified. Any land reclamation depends on the additional houses constructed, expansion of the resorts or harbors developed. An estimation of the area that a house or resort room occupies is taken as the basis of the calculation. There is also an estimation made as to the current availability of land for each island.

### Development of the Island's Accessibility

The user can define an investment in the number of boats in the specification of the scenarios. These are then distributed over the islands in the development options as expansion or construction of existing or new structures in the form of harbors or jetties. The size of the harbor or jetty is defined by the size of the boats with which it must be able to cope. Jetties and harbors do, however, create sediment loading, which can be minimized through sheet piling. They also create potential erosion that can, in the case of the jetties, be minimized through the design of the jetty on piles. In some cases, access channels are also required, which add to the localized erosion problems. Land reclamation will occur in the areas where harbors are developed. This assumes that the dredged material is dumped on the edge of the island to create new land areas. Again, this has a sediment loading effect.

### Coastal Protection

Island development may lead to a certain level of instability through land reclamation and other activities such as the construction of jetties. This will lead to erosion of the island. There is also a certain level of natural erosion seen; however, this is not accounted for in the model as the islands are relatively dynamic and the seasonal changes, in many cases, transport the sediment from one part of the island to another, reversing direction at the change of season.

### Environmental Protection Measures

Environmental options are available to the user to minimize the impacts of economic development on the reef. Taking each measure separately, the user can define, for example, different levels of treatment or the number of protected areas. These can then be formulated into strategies (i.e., combinations of individual measures). These strategies should be formulated with the objectives of the plan in mind. This will also aid the user in the first stages of the analysis to selectively delete those less successful or unfeasible strategies. Strategies may be unfeasible for financial or social reasons. Each measure or combination of measures has an associated reduction in the loading modeled in terms of the sediment produced or the level or physical damage seen. In addition, each measure has an associated cost. This varies depending on the measure and the scale in which the measure is implemented.

### Sewage Treatment and Disposal

Sewage from the islands can be treated in several ways. These are through construction of septic tanks, primary treatment plants or secondary treatment plants. Each treatment type results in a different level of reduction to the loading. The ecological response model only accounts for sediment loadings. Any level of treatment has an associated cost that also includes the cost of installing a sewage system. Disposal is either in the near-shore, where any remaining sediment will be discharged over the reef, or through a deep water outfall, which is assumed to result in no additional sediment on the reef. This version of the model does not allow for specification of environmental measures per island or per section. Later versions could include a different option for each level of treatment (e.g., secondary wastewater treatment) that is more appropriate to each population. Current data limitations meant that this would not have produced realistic or useful results.

### Control of Sediment Movement

One major impact from construction activities, such as harbor development and land reclamation, is the spread of sediment during the construction phase. One method to minimize this impact is through the use of sheet piling. This is used to surround the land reclamation works or harbor dredging activities. It is assumed this will reduce the sediment loading onto the reef by 80%. In order to maintain natural sediment movements around the islands and reduce any potential for erosion through the construction of jetties, design standards can be enforced, specifying that all jetties should be built on piles. This reduces the erosion effect of the jetties.

### Restricted and Protected Areas

In the model, coral is mined over the reef flats or concentrated to a single reef or faro. Mining a faro may be a more costly procedure, but will, however, reduce the overall area of reef destroyed. The user is able to define which percentage of coral rock is mined from which location. Setback policies can be implemented on the tourist islands. This limits the number of resort rooms through the size of the island. It is assumed that, by implementing a setback policy, no land reclamation is allowed to take place. Protected areas can also be defined for each section. It is assumed that, on each area, the impact from sediment and physical damage is reduced to a minimum. In some cases, this may result in regeneration of the reef.

### Coral Mining

The user can limit the use of coral in construction of resorts and housing and in the construction of coastal protection structures. The alternative available for housing and resort construction is concrete block. This is a less expensive option than coral rock; the costs of the measure are, therefore, negative. However, it will reduce the demand for coral rock, increasing unemployment among miners but reducing the reef areas subject to physical damage. This also applies to coastal protection options, where the alternatives are the more expensive imported materials. The actual price of these imported materials can be regulated by taxes and duties defined by the user in the scenarios.

### Cost of the Environmental Interventions

Each environmental intervention has a cost. This is modeled in terms of investment cost and maintenance cost and discounted to the base year. The discount rate is defined by the user as part of the scenario. In most cases, the maintenance cost is a percentage of the investment that is set in the definitions of the model parameters. In some cases, such as sewage treatment plants, scale factors are applied (i.e., the smaller the installation, the more expensive it is per unit capacity).

## *Summary of the Impacts From Economic Development and Environmental Protection*

The major impacts on the reefs in the Maldives are through sedimentation and the production of rubble (Meesters and Westmacott 1996). In addition, constructions such as harbors and jetties cause erosion. Some impact coefficients used in the model are based on observations, while others are based on best estimates due to lack of more detailed data. The project fieldwork report (Westmacott 1996) outlines the data collected in detail.

### *Sediment and Rubble Impacts*

Sediment and rubble are produced by the socio-economic activities and limited through the environmental protection options. The extent of the impact is dependant on the options chosen and the scale of the developments or mitigation efforts. Rather than modeling the dispersion of sediment and production of rubble in a dilution/dispersion model, Coral-Maldives makes use of impact zones. This style of modeling was selected due to the relatively little data available on the spread of the sediment and production of rubble. Three impact zones are defined—high, low and minimal. The distance these extend from the construction or outfall depends on the activity's size. The area of each impact zone is then calculated using the average reef width. The impact zones are calibrated using as many actual sets of observed data as possible. The resulting impact zones are then combined with the database formulated from the results of the ecological response model, providing, for example, total areas of reef lost.

### *Erosion*

As with the modeling of sediment and rubble, there was little data available to develop a deterministic model of erosion. The results of the model are again based on a scaling, making use of field observations. Areas eroded are computed on the basis of exposure of the island and previous observations of eroded areas where human influence has played a role. During the fieldwork, there was no specific measuring of eroded areas. As a result, the data used in this version of the model is very approximate.

### *Reef Health*

The ecological response model of reef health under impact of sediment and rubble is described in Meesters and Westmacott (1996). The model was developed using fuzzy logic, a method able to capture expert knowledge on the behavior of a system. Experience of the Jamaica case study (Ridgley and Dollar 1996; Chapter 8) was utilized. The main impact factors considered in the Maldives were those relating to sedimentation and the production of rubble. These are outputs of the socio-economic activities. Levels of sedimentation and rubble are directly dependant on the user's definitions of both island development and environmental protection.

A set of base reef conditions are defined for each section. These combine with the sediment and rubble values resulting from the environmental protection measures taken and the economic development options and are used as the input values for the ecological response model. The outputs of the model are the reef health descriptors used in the cost-effectiveness analysis (i.e., coral cover and rugosity). Rugosity is subsequently used as an input for the fisheries module, affecting the density of reef fish to be found on the reefs.

## Case Studies in Coral-Maldives

Cases pre-defined in the model are developed as examples to show the user the options available in the model and to illustrate how the model can be used to explore different economic developments and environmental protection options. The user is entirely free to define those scenarios and alternatives of interest to him or her. The structure of the decision support system should assist the decision-maker in the selection of the "best" strategy. This may be a decision on where to locate certain developments or which environmental protection options are the most cost-effective. Coral-Maldives allows combinations of scenarios and strategies to be examined. The following cases have been selected by the authors to illustrate the potential and the limitations of the model.

### *Scenarios*

Scenarios can be used to explore different population growth patterns and set the boundaries for different levels of economic activity. Three scenarios have been developed as an example. First is a reference scenario (REF) that is based on past trends in the population with high growth on Male and lower growth on the surrounding islands. Different levels of economic activity have also been examined. REF is based on the growth rates seen in 1995 with a slow increase in the fishing fleet of 5 boats per year. Foreign aggregate is also assumed to be slowly increasing by 1%/yr.

A second scenario (POP) reflects a decrease in population growth rate to 3%/yr. This may be related to sustained high levels of economic growth and the desire to have less children. There is also a move away from fisheries into, perhaps, the tourism industry. This is seen by the low increase in the fishing fleet of 2 boats per year. The increase in price of foreign aggregate is negative; this represents policy options to reduce import tax or subsidize its import to increase the use of imported materials above that of coral rock.

The third scenario (OUT) examines the changes in population caused by a gradual 2%/yr out-migration. This could be the result of a decentralization policy or low economic growth rates, making areas out of Male more attractive again. The values used in these scenarios can be seen in Table 4.1.

The impacts of the scenarios can be seen in Table 4.2. The estimates are simulated over the 10 year period. The different population growth rates make significant differences, particularly when looking at housing demand. The POP scenario would require provision of half the number of houses compared to the REF scenario. The population growth on the outer islands is relatively small compared to the high growth that can be seen on Male. These scenarios indicate that the housing situation on Male, currently reaching its maximum capacity, is a high priority issue in island development.

The demand for resort rooms indicates that, if this growth in tourist numbers is going to continue at a rate of 14%/yr, the capacity is unlikely to be totally satisfied. Even at the lower growth of 8%/yr, as seen in the OUT scenario, the capacity demand remains high. With the size of resorts in general varying between 100 to 200 rooms, satisfying the 8%/yr growth could mean the construction of 100 to 150 resorts. This rate of construction is unlikely to be reached in the next 10 years. The current total number of resorts in North and South Male is 70.

The fisheries are, as of 1996, not threatening the fish stocks; however, with a large increase in the fishing fleet (e.g., 150 boats in 10 years), the catch of reef fish closes on the maximum sustainable catch. These results are based on the majority of the human population migrating to Male and there being no additional construction on the island.

The change in the price of foreign aggregate is controlled by the user. A 1% decrease per year leads to a price of $150/m$^3$. In the model, the price of coral rock increases at a fixed rate of 5%/yr. It may be that the user will also want to change this parameter in future versions of the model to reflect certain taxes on the use of coral rather than simply prohibiting its use. In the model, the price of imported aggregate will not affect the use of coral until either there are measures taken that prohibit the use of coral rock or the price falls below that of coral rock. In a 10 year period, this will occur at a decrease in price of over 15%/yr.

### *Economic Development Strategies*

There are four main options available to the user for economic development of the islands. These are the provision of housing, the development of resorts, an increase in the island's accessibility and coastal protection. Three strategies relating to housing development have been formulated to show the different options available. In addition, several different options relating to the development of resorts and coastal protection have been examined. The first strategy, REF, is again a reference strategy that does not include any specific measures to be taken. NOMIG aims to provide housing for the natural population growth on each island. There are several variations of this strategy allowing a comparison of developing the northern or southern islands. The final strategy, RECLAIM, looks at the possibility of reclaiming large areas of land for housing. The model enables the user to look at the impact this will have on the housing situation on Male as well as on the environment. In addition to the basic strategy, a variation that includes coastal protection for reclaimed areas is examined. These strategies are described in Table 4.3.

A few selected criteria (Table 4.4) highlight the main differences between the economic development strategies.

**Table 4.1.** Example growth scenarios (REF=reference scenario; POP=population growth rate scenario; OUT=out-migration scenario).

| | *Units* | *REF* | *POP* | *OUT* |
|---|---|---|---|---|
| Overall economic growth rate | %/yr | 6 | 6 | 4 |
| Growth in number of tourists | %/yr | 14 | 14 | 8 |
| Investment in boats | number | 50 | 20 | 100 |
| Change in price of foreign aggregate | %/yr | 3.5 | -1 | 3.5 |
| Population growth on Male | %/yr | 6 | 3 | 6 |
| Population growth on inhabited islands | %/yr | 4 | 3 | 4 |
| Out-migration from Male | %/yr | 0 | 0 | 2 |
| Discount rate | % | 6 | 6 | 6 |
| Number of years | number | 10 | 10 | 10 |

**Table 4.2.** Impacts of the growth scenarios (REF=reference scenario; POP=population growth rate scenario; OUT=out-migration scenario).

| | *Units* | *REF* | *POP* | *OUT* |
|---|---|---|---|---|
| Population in 2005 | number | 125,000 | 96,000 | 104,000 |
| Population on Male in 2005 | number | 112,000 | 84,000 | 95,000 |
| Housing demand | number | 6,700 | 3,000 | 4,000 |
| Demand for resort rooms | number | 7,000 | 7,000 | 2,800 |
| Fisheries catch as percent of maximum | % | 77 | 70 | 87 |
| Price of foreign aggregate | US$/$m^3$ | 230 | 150 | 230 |

**Table 4.3.** Description of economic development strategies.

| *Scenario* | *Housing* | *Resorts* | *Accessibility* | *Coastal protection* |
|---|---|---|---|---|
| REF | No specific action, resulting in the population moving to Male | No tourist developments | No further developments | No coastal protection |
| NOMIG | Construction of houses on local islands to meet demands of natural population growth; remaining population stays on Male although no specific housing or reclamation is carried out | NOMIG: no tourist developments; NOMIG-N: four tourist developments in the North of 100 rooms each; NOMIG-S: four tourist developments in the South of 100 rooms each | Expansion or construction of the harbors where additional houses are built; jetties built for the tourist resorts | No coastal protection |
| RECLAIM | Large reclamation projects, housing the Male population growth on Vilingili (500) and Hulule (2,000) | No tourist developments | Expansion or construction of the harbors where additional houses are built | RECLAIM: no coastal protection; RECLAIM-C: sea walls constructed around reclaimed areas |

**Table 4.4.** Results of the economic development scenarios (REF, NOMIG and RECLAIM defined as in Table 4.3).

| *Criteria* | *Units* | *REF* | *NOMIG* | *RECLAIM* |
|---|---|---|---|---|
| Population of Male | number | 86,300 | 84,000 | 60,300 |
| Density on Male | number/$km^2$ | 51,000 | 50,000 | 36,000 |
| Density on Hulule and Vilingili | number/$km^2$ | 480 | 630 | 40,000 |
| Density on other inhabited islands | number/$km^2$ | 3,100 | 4,200 | 4,200 |
| Housing demand | number | 2,960 | 2,700 | -300 |
| Area reclaimed | $m^2$ | 0 | 7,400 | 341,000 |
| Area of reef lost | $m^2$ | 173,000 | 186,000 | 266,000 |

As yet, none of these have any environmental protection measures to minimize the impacts. The model can also be used to see which areas are more heavily impacted through certain developments. For example, the development of four new resorts of 100 rooms each in the south is predicted to result in the loss of 208,000m$^2$ of reef, while if occurring in the north the loss is predicted to be 206,000m$^2$ of reef. Thus, the costs of retaining coral reef health can be expected to be greater in the south due to the more fragile systems that exist there as predicted by the model.

The REF economic development scenario, with sustained high population growth, leaves a housing demand of approximately 3,000 houses. The reclamation of 0.8km$^2$, along with the loss of 340,000m$^2$ of reef through mining and sedimentation, could satisfy that demand. Over a 20 year period, the demand is predicted to rise to 18,000 houses. Satisfying this through reclamation would require a total of 2km$^2$ of land to be reclaimed. This would keep the housing density of Male and on reclaimed land at approximately 50,000 people per square kilometre. The model indicates a potential high risk of coastal erosion. However, further verification is required due to the preliminary nature of the data. Protecting the coastline, now extended to 5km due to the reclamation, would cost in the region of US$14 million based on the use of coral rock. Imported aggregates would cost approximately US$60 million. The coral reef loss would be 500,000m$^2$, as opposed to 600,000m$^2$ if coral were to be mined. These areas are, however, less than 1% of the total reef area of North and South Male.

### *Environmental Protection Options*

As described previously, there are a series of environmental protection options aimed to minimize the impacts of developments on the reefs. These can be examined on an individual basis or combined into strategies (i.e., groups or combinations of measures). In order to formulate effective strategies, the user can begin by examining each measure on an individual bases. Table 4.5 describes a series of measures defined for this analysis. As the first step in the analysis, the aim is to explore the effectiveness of each of the measures in terms of changes to reef health and impact areas affected.

Figures 4.3 to 4.5 show the results of the cost-effectiveness analysis for the three indicators of coral reef health (i.e., rugosity, coral cover and area of reef lost or gained). There is some difference in the ranking of the strategies, depending on the indicators chosen. In all three cases, however, sheet piling is the most expensive option when considering coral reef protection. The wastewater treatment measures are also high in cost. Sheet piling would not, at a first glance, seem a useful option. However, it may create protection for the reefs surrounding the islands. This could provide a valuable natural coastal function and an additional attraction for the island as a resort. These issues go beyond the initial costing carried out in this version of Coral-Maldives.

Wastewater treatment measures are expensive when considering the range of options available for coral reef management and protection. However, what is not seen in only examining these indicators is the public health impact of clean wastewater and disposal beyond the reef. With the cost-effectiveness utilizing social indicators as a gage, these options may be higher in the ranking. It may be that no level of risk is acceptable for the public.

The most cost-effective measures would appear to be those focusing on land use regulations. This may be in the restriction of coral mining areas or the provision of alternatives to the coral mining industry. Likewise, protection of certain areas predicts an improvement in the reef health, assuming that impacts from sedimentation and physical damage are reduced to a minimum. These have similar cost-effectiveness; however, the exact ranking varies considerably between each indicator. This demonstrates the differences due to the selection of the particular indicator of coral reef health.

The effects of the individual measures are not cumulative. The results given above can be used as an indicator to prioritize which measures to take. The next step in the formulation of environmental protection options is to look at combinations of measures (i.e., strategies). The user may have specific information on the budget available for these interventions. The costs shown in this analysis are the total discounted 1995 dollar costs over the 10 year period. Table 4.6 provides descriptions and the values used for the combinations of measures formulated for the analysis. Each strategy aims to focus on a specific issue, goal or type of measure, covering control through land use regulations, reduction in sediment reaching the reef, and regulations focusing on the tourist resorts.

Figures 4.6 to 4.8 show the cost-effectiveness results of implementing the environmental protection strategies. Sediment mitigation through the use of sheet piling appears to have limited effect. This may be for two reasons. First, the developments in this example are small harbor extensions and, in some cases, the associated reclamation is only a few hundred square metres. Surrounding works with piling is going to have a more dramatic effect the larger the reclamation and harbor works. Second, the area of coral gained clearly reflects the implementation of

**Table 4.5.** Description of environmental protection measures.

| *Measure* | *Description* |
|---|---|
| Outfall (OUT) | Disposal of sewage through outfalls on each island; orientation of the outfalls is towards the inside of the atolls. |
| 10 marine parks (10MP) | A marine park is established in each section of $0.5km^2$ each. |
| Setback (SET) | Setback policy for tourist islands is implemented, generating no cost but may limit the number of rooms able to be constructed. |
| Prohibit coral use for resorts (RES) | This measure does not allow resorts to use coral rock for construction of resort rooms or sea defenses on resorts. |
| Prohibit all use of coral rock (ALL) | Neither locals nor resorts are permitted to use coral rock for construction of houses and rooms or sea defenses. |
| Mining 100% from Faro (100F) | Mining demand is satisfied through the selective mining of one reef to a depth of 15m. |
| Prohibit local use of coral (LOC) | This measure does not allow local islands to use coral rock for construction of houses or local sea defenses. |
| 5 marine parks in the South (MPS) | A marine park is established in each section of South Male of $0.5km^2$ each. |
| 5 marine parks in the North (MPN) | A marine park is established in each section of North Male of $0.5km^2$ each. |
| Mining 50% from Faro (50F) | 50% of the mining demand is satisfied through the selective mining of one reef to a depth of 15m. |
| Secondary wastewater treatment (2WWT) | Sewage collected in a pump driven sewage system and treated through the construction of secondary wastewater treatment plants on each island; subsequent disposal in the near-shore. |
| Septic tanks (SEP) | Sewage is treated through individual septic tanks and excess liquid collected in a gravity run sewage system before being disposed in the near-shore. |
| Sheet piling (SHP) | All coastal construction works are surrounded by sheet piling to restrain sediment flow. |

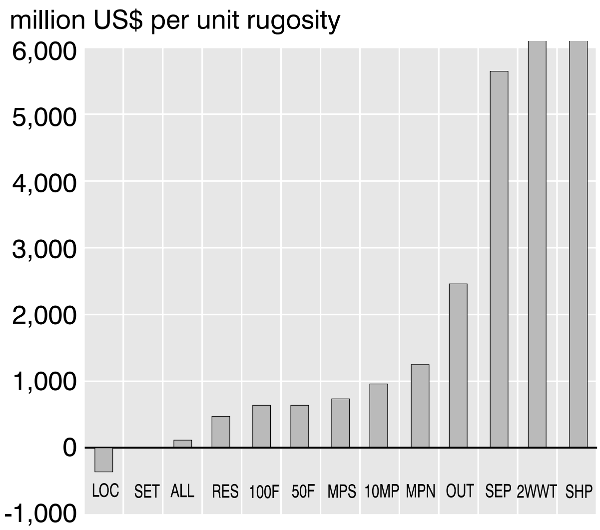


**Figure 4.3.** Cost-effectiveness of environmental protection measures defined in terms of rugosity as an indicator of coral reef health (environmental protection measures defined in Table 4.5).

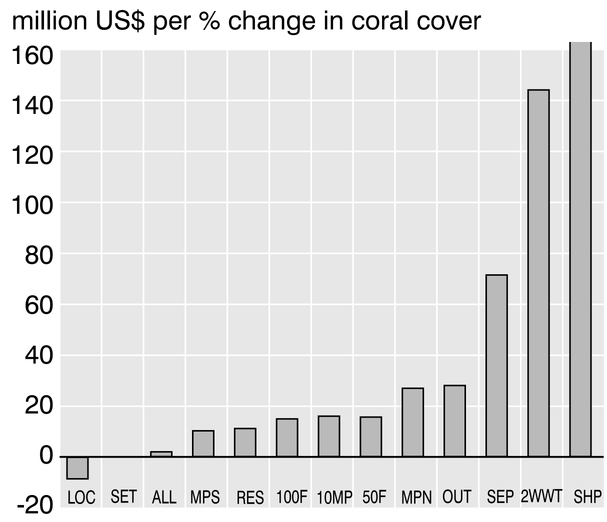


**Figure 4.4.** Cost-effectiveness of environmental protection measures defined in terms of coral cover as an indicator of coral reef health (environmental protection measures defined in Table 4.5).

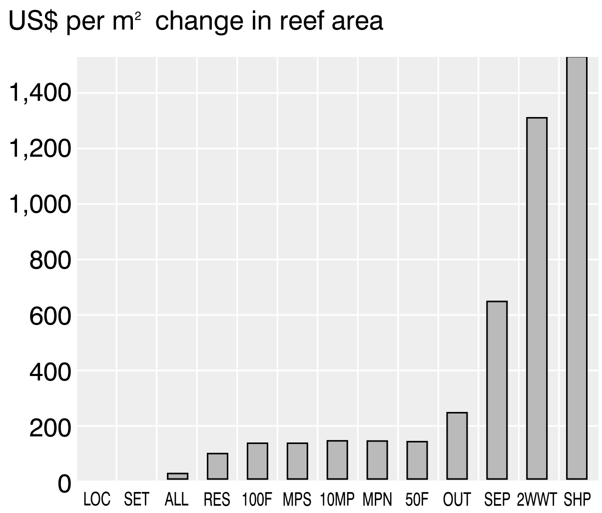


**Figure 4.5.** Cost-effectiveness of environmental protection measures defined in terms of reef area as an indicator of coral reef health (environmental protection measures defined in Table 4.5).

marine parks. In these areas, any impacts are assumed to be reduced to a minimum, resulting in an improvement of the reef in many cases.

Again, one should also consider the public health issue. Although the options of treating sewage are expensive when considering reef health, they should not be ruled out as valuable alternatives in terms of public health. Likewise, the indicators of housing densities are important when considering social issues.

One could also consider indicators of social acceptability through the use of user-defined criteria. For example, the ZERO option does not require any specific actions to be taken and, as such, may be more acceptable. LANDUSE requires people to be retrained, potentially resulting in the loss of jobs. It may also prohibit use of certain areas for traditional activities. In addition, for both of these strategies there is assumed to have been no awareness programs to inform the public as to the need for these strategies. The strategy ALL considers this aspect. The total cost of the proposed awareness program is estimated at less than 1% of the total costs.

**Table 4.6.** Description of environmental protection strategies.

| | *Landuse* | *Sediment* | *Tourist* | *All* |
|---|---|---|---|---|
| Description | Protection of reefs through land use regulations | Reduction of sedimentation reaching the reefs | Restrictions for tourist resorts regarding building regulations and waste disposal | Combination of all measures to improve the environment |
| Sewage treatment | None | Secondary treatment | Disposal through outfalls on tourist islands | Disposal through outfalls |
| Setback policy | On tourist islands | None | Yes | Yes |
| Marine parks | 10 marine parks of 0.5km² each | None | 10 marine parks of 0.5km² each | 10 marine parks of 0.5km² each |
| Mining locations | None | None | | 100% Faro |
| Use of coral rock | Prohibit all | None | Prohibit in tourist industry | None |
| Awareness raising | None | None | None | US$1 million spent on environmental awareness |
| Sheet piling | None | For all construction | On tourist resorts | For all construction |
| Open jetties | None | All | On tourist resorts | All |

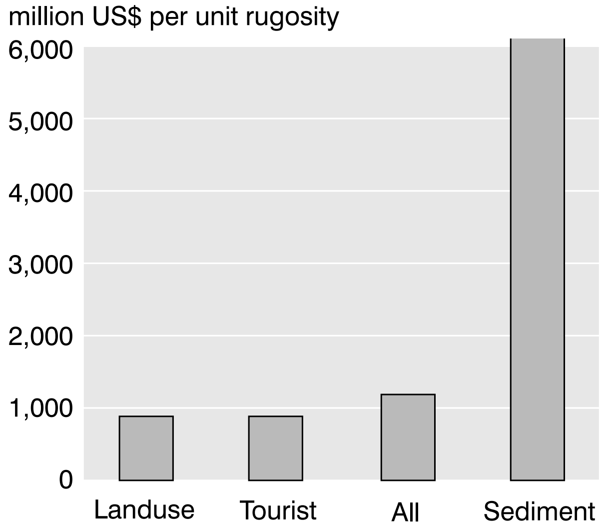


**Figure 4.6.** Cost-effectiveness of environmental protection strategies defined in terms of rugosity as an indicator of coral reef health (environmental protection strategies defined as in Table 4.6).

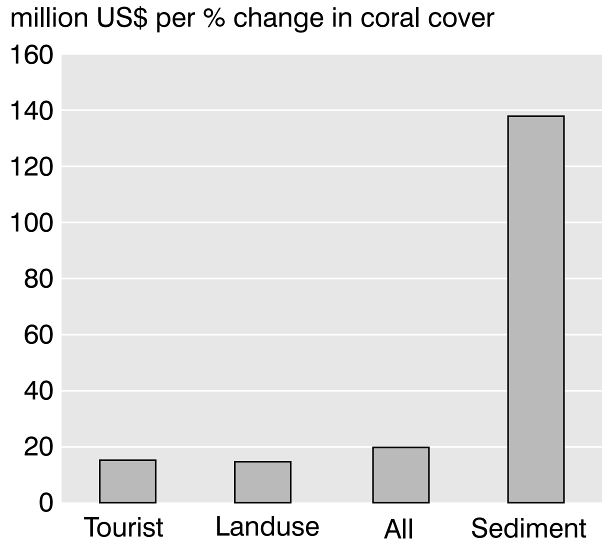


**Figure 4.7.** Cost-effectiveness of environmental protection strategies defined in terms of coral cover as an indicator of coral reef health (environmental protection strategies defined as in Table 4.6).

## Conclusions

The two objectives of the Coral-Maldives model were to test and validate the cost-effectiveness analysis model of coral reef management and protection and to investigate whether the cost-effectiveness analysis model can be a useful tool for decision support for coastal zone management in the Republic of the Maldives. This chapter has described the model and examined different analyses. The model was presented to the decision-makers within the Ministry of Planning, Human Resources and the Environment of the Republic of the Maldives in late 1996. As a result of the work completed up to that time, the following conclusions can be drawn and further recommendations made as to future developments of the model.

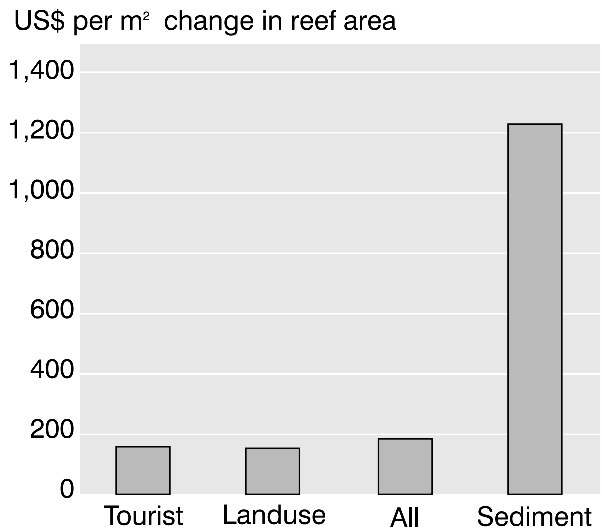


**Figure 4.8.** Cost-effectiveness of environmental protection strategies defined in terms of reef area as an indicator of coral reef health (environmental protection strategies defined as in Table 4.6).

### *Cost-Effectiveness Analysis*

Ranking the interventions in terms of their cost-effectiveness for coral reef management and protection is a useful and potentially valuable tool for reef managers. The results from the Coral-Maldives model should provide reef managers with a clearer picture of the different options available and the likely benefits and costs associated with these management interventions. There are, however, an array of potential indicators describing the success or failure of a coastal zone management strategy. These may be ignored by focusing only on the costs of environmental protection measures and changes in coral reef health. For instance, the issue of public health or coastal erosion and flooding risk may not be taken into account. These are important factors when analyzing options for coastal zone management.

The Maldives case study shows different results from the case studies carried out in Jamaica (Ruitenbeek *et al.* 1999a; Chapter 8) and Curaçao (Rijsberman and Westmacott 1996; Chapter 4). The three case studies take geographically different areas. In the Jamaica case study, the construction of an outfall appears to be a cost-effective measure; however, this is a stand-alone intervention that, in the Maldives, is connected to either a pumped sewage system or a gravity sewage system in combination with septic tanks. The land use zoning programs in the Jamaican case are some of the most cost-effective measures. This pattern is also seen in the Maldives case study.

The Curaçao case study focuses much more on land-based pollutants as these were identified as the major local threats to the reefs. In the Maldives, industrial activity is very small and damage from sewage is low due to the high flushing from the relatively strong water movements; thus, the focus is on minimizing physical damage to the reefs. The Curaçao study primarily examines the different options for treating wastewater flows. Land use regulations are again different. In the Maldives, the protected areas are assumed to be away from sources of pollution and are feasible due to the large area of reefs. It is assumed these areas are able to be protected from physical damage. The situation in Curaçao is different in the sense that the water quality standards that may be imposed for marine parks are entirely dependant on the ability of industries and local government to pay for the interventions to reach these standards. The cost of implementing a marine park can be taken into account; however, the total cost, including wastewater treatment facilities to reach marine park standards, should also be examined.

Cost-effectiveness is a useful indicator to rank the different strategies and start to prioritize individual measures. This could play a substantial role in assisting decision-makers in formulating environmental protection strategies. These, in turn, can be compared as to their effectiveness for coral reef management. Taking the broader view of coastal zone management, the use of such an indicator for the assessment of projects and plans can be complimentary to other coastal zone management indicators. Coral-Maldives demonstrates the use of these additional indicators.

### *Decision Support System for Coastal Zone Management*

The second objective of the model was to develop a decision support system for coastal zone management that could eventually aid the decision-makers in the Maldives in the formulation of their coastal zone management plans. The model was formulated during discussions with various government agencies where the main issues currently of concern and the alternatives available to management were identified. The issues in the decision support system should, therefore, be a fair representation of the current concerns of the Maldives. The model should be able to highlight these issues and show the different impacts alternative strategies may have on a series of coastal zone management indicators. Within these indicators, the user can examine the cost-effectiveness of each strategy as described above.

The decision support system is aimed at decision-makers as well as analysts. The structure is such that analysts can prepare and save case studies that can be later assessed and utilized by the decision-makers. During the comparison of cases, there is a ranking option that can be used to centralize discussions around the selection of cases. These rankings can also be saved and retrieved for later discussions or analyses. The following sections discuss the potential use of the model as a decision-making tool and suggest ways to improve or further develop the model.

The following areas were identified as potential uses of the model:

1. *Coastal zone management workshops and training programs*. Coral-Maldives would be suited to a training workshop for coastal zone management. Participants could include analysts, where model capabilities, data needs, formulation of the scenarios and strategies, and selection of the more successful measures or strategies are discussed. Alternatively, workshops may be held for decision-makers who can examine the alternatives formulated by the analysts and use the decision support system as the discussion forum where specific objectives and indicators, as well as the eventual ranking of alternatives, is the focus.
2. *Preparation of scenarios for environmental reports*. Coral-Maldives can be used to illustrate the impact that different future development scenarios may have on the environment. The decision support system provides a quick method of viewing and comparing different scenarios. These can be used to illustrate environmental reports showing the likely impact of certain development options. The model is not, however, formulated at a level of detail capable of carrying out individual project assessments. Rather, it can indicate trends over the simulation period. The data used has had to be adapted and, in many cases, estimated. For more detailed results, new data sets will be required.
3. *Analysis of different regional development plans*. Similar to the preparation of scenarios for reports, the model can be used to input and examine the impacts of alternative regional development plans. The model

focuses on coastal zone management issues and may, however, miss some social issues such as provision of schools and hospitals, and the provision of fresh drinking water. The spatial extent of the model is also limited to North and South Male in this version and is not able to show the impacts of, for example, decentralization strategies. The model will give graphical information on the likely impacts of the different plans and will allow the decision-makers to compare the results under a series of different indicators.

4. *Identification of areas to protect or develop*. Coral-Maldives can show trends likely to be seen rather than point to specific reefs that should be protected or identify certain islands more suitable for development than others. It will, however, show the differences at the level of the sections defined in the model of the impacts of protection measures or development. Likewise, the model distinguishes between developments on the islands of the inner and outer sections of the atoll and the orientation of developments actually on the island.
5. *Environmental impact assessments*. Environmental impact assessments (EIAs) tend to be carried out for a specific project. As the model stands, the scale is too general for specific project evaluations. However, the concept and much of the techniques used for modeling could be used to create a project-based EIA tool, given further detailing and verification by ground data collection. This could be a useful tool for non-professionals to carry out analysis of environmental impacts. For example, a tool freely available to resort developers may allow certain developments to be redesigned on the basis of more firm environmental evidence.
6. *Indicators for coastal zone management*. Coral-Maldives contains a series of coastal zone management indicators. These can also be added to by user-defined criteria. This allows the user to include recently arising information or issues. The structure of Coral-Maldives also allows the user to focus on the objectives of the management plan through the selection of the indicators. It may also stimulate discussions of gaps missing in the analysis and identify issues that may not otherwise have been discussed.
7. *Establishment of an environmental database*. The Ministry of Planning, Human Resources and the Environment (MPHRE) of the Republic of the Maldives is working towards the establishment of an environmental database. Coral-Maldives contains data that has been collected from a variety of sources. The data used in the model can be either used to add to the database or as a basis for a new database. Updating the data, both in the MPHRE environmental database and in the model database can be achieved through the training of MPHRE staff.

## *Further Developments of the Model*

The model was received well in the Maldives. Several suggestions were made as to how the model could be expanded and improved. One of the first tasks should be to achieve wide acceptance of such a decision-making tool and, through training of different departments, allow the tool to be updated and further developed. The following sections highlight the issues brought to light for use of the model and its further development.

### Cost-Effectiveness Analysis

Studies were continued in the case study sites of Curaçao and Jamaica (see subsequent chapters), including valuation studies and consideration of the benefits and costs associated with changes seen in the reef health as a result of environmental protection measures. These studies provide additional valuable indicators for decision-makers, leading to a clearer understanding than information regarding a change in the physical state of the reef alone may do.

### Spatial Extent of the Model

One main comment received was to expand the model to cover the whole of the Republic of the Maldives. This would allow the user to examine the possibilities of assessing the development of different atolls. At this level of regional planning, users would be able to obtain a clearer picture of alternative development plans. This would require additional data at the same level as is currently in the model. The data would cover population and other socio-economic data, and physical data such as island size, reef conditions, and exposure of the islands. Such a model would allow the user to assess the impacts and explore the alternatives to various regional development plans.

### Inclusion of Additional Issues

In addition to expanding the spatial extent of the model, certain additional issues were also identified as important for coastal zone management in the region:

- *Solid waste*. The issue of solid waste was not included in the current version of the model. It was omitted due to the focus on environmental impacts that were quantified in terms of sediment and physical damage. The issue of solid waste and the impacts of dumping or incineration in selected sites is a current topic of concern for the Maldives. For example, limitations on the amount of land area available has resulted in the infilling of a lagoon close to the capital, Male. The alternatives are limited; however, the full impacts of these actions have not been fully examined.

- *Vulnerability to flooding*. Another issue that is not included in the current version of Coral-Maldives is the increased risk of flooding resulting from reclamation works. Impacts of reclamation are seen in terms of increased coastal erosion that can be mitigated through the construction of coastal protection works. A useful method of including the effects of erosion and the likely risk of flooding is for the user to select a risk level that is acceptable and the costs of achieving this will be computed through the model. To fully implement such a model, data and information would need to be collected on the current erosion patterns on the islands. In addition, if longer time scales were examined, the ability of the reefs to keep pace with sea level rise could be incorporated.

**Database**

The data included in the model will require continued updating and expanding. Certain parts of the database are based on expert judgment, rather than actual field measurements. This may be adequate for the current model; however, this could be improved in subsequent revisions, particularly if more detail was required for more project-orientated analyses. In particular, data on erosion rates, sediment loadings from construction, impact areas surrounding land reclamation works, reef health parameters available on a larger scale, reef areas surrounding islands, and those areas utilized for mining activities are suggested points of focus for data improvements.

**Development of the Decision Support System**

Certain areas of the decision support system could also be improved. Optional ways of defining the environmental protection measures, for instance, could assist the decision-maker. For example, selecting the type of wastewater treatment for each island does not give a clear indication of the level of treatment that will be received. The user could, in theory, also select the public health risk that he or she is willing to accept or the reduction level required and the model could select for each island the least expensive and most effective method for that particular capacity. The user could also be able to spatially define the mining areas and, with more detailed information on reef health, the user could expand these to include defining more specifically the actual reefs targeted for protection.

**GIS Options for Display of Results**

The analysis stage in the decision support system allows the users to examine the result in tabular format as well as more detailed information in charts. Geographic information system (GIS) tools and applications may be able to improve this display of results, linking the datasets to the graphical locations. The feasibility of achieving this should be examined from the perspective of additional data requirements and software availability. Such a development to the current Coral-Maldives model could be carried out as a capacity building exercise.

**Environmental Impact Assessment and Project Evaluation**

The present version of Coral-Maldives is not designed to be used for project evaluation. The level of detail has been generalized and the islands grouped into sections. If such a model were to be available for project evaluation, the level of detail required would need to be far greater. It could be that data is collected for certain project evaluations and that a model is developed for that island or situation only. The detail contained in the model would again be more in-depth and relevant to the specific purpose. The structure of the analysis could, however, follow the same structure as that of the current decision support system.

The current version of the model shows the major trends in the socio-economic conditions and environmental health of one section of the Republic of the Maldives. The model is capable of facilitating discussions and being utilized as a training tool, and is valuable in the identification of areas requiring additional information and data collection. The model can be seen as the basis of an environmental database and, through its further development, could be used in a capacity strengthening exercise for various government ministries within the Maldives. Additional issues and indicators can be added in a similar manner. Updating of the model could be achieved through trained personnel within the country who would be responsible for maintenance and development.

# Chapter 5

# Values Associated with the Local Use of the Montego Bay Marine Park

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Local residents and tourists alike derive direct local use benefits from coral reef ecosystems in the developing tropics, most often associated with recreation and near-shore fisheries. Other marketed benefits may include participation in the aquarium trade, mariculture, crafts, coral sand extraction, and bioprospecting. In addition to these direct benefits, in which components of the marine system input directly and explicitly into the economic activity, there are also local indirect uses. Indirect benefits can be defined as ecosystem functional contributions to economic production value, providing implicit and integral support of economic activities. The most significant of these in terms of the developing tropics is likely the coastal protection that coral reefs afford. Other indirect benefits that may be enjoyed include support of the off-shore fisheries through ecological interactions.

The issue of valuing marine system structural and functional diversity (or biodiversity) can be concerned with the creation of artificial markets (e.g., option, bequest and existence values revealed through contingent valuation, in which estimates of individual or society's utility associated with the system are made), or the creation of new markets (e.g., bioprospecting, in which estimates of system value through a distribution of profits or value-added associated with marine product development are made). Both the creation of new and artificial markets to estimate marine system values help ensure that the total economic value of biodiversity is taken into account when management decisions are being made. While it is indeed important to create or reveal markets to measure the full benefits of marine biodiversity, direct and indirect use values reflected in existing, well established markets are similarly important to consider. Indeed, particularly in developing nations where government accounting systems may be less than adequate, local use values associated with particular marine systems tend to be inaccurately or inadequately represented in resource decision-making and policy development.

This chapter will outline the nature of those direct and indirect local use values as they apply to the Montego Bay Marine Park (the Park), Montego Bay, Jamaica. A methodology is outlined and applied which derives the net present values of those direct and indirect uses for as many base years as reliable and adequate data is available. It is through consideration of the local use values as reported here, in conjunction with subsequent analyses regarding the ecological condition of the reefs and the sustainable level of reef use, that management authorities will be able to obtain more complete information on the extent of the reef-derived economic benefits at risk of being lost if conservation efforts prove inadequate.

## Methodology

### *Theoretical Context: The Production Function Model*

Before the local use values are derived, it is important to place this exercise within the context of a theoretical model. In this case, the marine resources themselves are envisioned as contributing to an economic productive process as traditionally described with a production function. Economic valuation studies of natural systems most often distinguish use from non-use values, and direct use from indirect use values. Rather than maintaining the distinction between direct and indirect use values based on using either a direct or indirect method of estimation, this study will consider both to ultimately be *supply-oriented production function contributions of marine systems to economic value*. In other words, we are concerned with measuring the contributions of marine ecosystems to the value of output in a produced good or service. The isolation of direct from indirect benefits is only useful from the point of view of measurement. Thus, the direct and indirect use value distinction was maintained only so far as we discuss *how* the values were estimated.

The contribution of marine systems to economic value through a production function is most readily envisioned using a Cobb-Douglas model:

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

where $L$ = labor;

$K$ = capital; and,

$R$ = resource base (or biodiversity).

In such a model, the value of marine systems or biodiversity is the marginal change in $Q$ as $R$ changes. Thus, the economic value of the contribution of the coral reefs in Montego Bay associated with one unit of reef of a given quality is the change in the value of the output that is achieved with a one unit increase in reef, holding all other inputs constant. This benefit model, along with separately modeled costs (Chapters 8 and 9), facilitates the examination of economic efficiencies associated with reef management decisions which result in changes in reef quality. This report will not explicitly derive specific production functions, but make the first step by describing the inputs and the values attributed to the use of the resource.

### *Information Sources*

Direct and indirect uses of the Montego Bay Marine Park waters were identified for the purposes of value estimation during a site visit in January and February 1998. The primary means of data collection was document analysis and database search. The types of documents and databases analyzed included government department records and reports, census and survey statistics, non-government organization and academic reports, Montego Bay Marine Park documents, and consultants' reports. This study also benefited from the information made available through a concurrent project—a rapid socio-economic assessment of fishers, water sports and hotel operations—the results of which are reported elsewhere (Bunce and Gustavson 1998a; Chapter 11).

Direct local use values that can be attributed to the benefits achieved through the use of the Park were estimated on an annual basis 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 Park waters were identified as the most significant during the final study site application, as well as being of the highest policy priority. Table 5.1 shows the primary sources of the data used and describes the nature of the information.

The focus of this study on the three primary categories of uses, and thus avoiding detailed examination of other minor local uses, is in keeping with the experience of other investigations into the local use benefits of coral reefs (e.g., Dahuri 1996; Dixon 1992; Pendleton 1995; Sawyer 1992; Tomascik 1993; Weber and Saunders 1996) which demonstrate that analyses should focus on a small number of benefits. Recognizing limitations and constraints on research resources, it is through the detailed documentation and modeling of a small number of local uses that more valuable information can be gained regarding the changes in benefits realized through changes in the quality of the resource. Furthermore, more detailed modeling of a few direct use values will provide a benchmark from which to examine other, less significant local use values for which less detailed information is available. This approach will ultimately lead to a model which provides the maximum amount of information, given practical research limitations, for input into Park management decision-making and the establishment of policy.

### *Net Present Values of Direct and Indirect Local Uses*

To arrive at the annual value of the contribution of the coral reefs of Montego Bay Marine Park to direct and indirect economic activities, the net value of those activities was calculated. The net value is the remainder of the total monetary value of the benefits once all existing economic claims to the production have been deducted. This remainder is the economic production claim which can be attributed to the marine system.

To calculate the net value associated with coral reef use, all variable costs which represent a claim on economic production were first deducted from the gross receipts of the economic activity. This included the costs of utilities, operating services sold to the businesses, repairs and maintenance, goods and materials, government license and registration fees, insurance, and the opportunity costs of labor. It does not include such items as government taxes and subsidies (transfer payments) as these are not payments for activities which involve economic production *per se*. Similarly, any internal financial transactions, such as depreciation, or external financial transactions, such as bank interest payments, are not included.

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

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

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

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

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

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

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

In all instances, conversion from Jamaican to US dollars assumed J$35.5 = US$1 based on the average of the median bid and the median asking price in world markets on the first of the month for the first five months of 1998. Where it was necessary to convert from 1998 values to equivalent 1996 dollar estimates, an average annual domestic inflation rate of 28% was assumed based on a 10 year average of the annual implicit price deflator for total GDP for Jamaica from 1987 through 1996 (source: Statistical Institute of Jamaica).

### *Interpreting Optimal or Sustainable Level of Use*

It must be emphasized that the derivation of NPVs here is not a cost-benefit analysis *per se*. In a cost-benefit

**Table 5.1** Information used for deriving local use values associated with the Montego Bay Marine Park

| *Use value* | *Information source* | *Nature of the information* |
|---|---|---|
| **Tourism** | OAS (1994) | • detailed revenue and expense analysis for the tourism sector in Jamaica as whole for 1992 |
| | Annual Travel Statistics, Jamaica Tourist Board | • annual tourist arrivals, tourist expenditures, and accommodations sales |
| | Jamaica Promotions Corporation | • capital cost models for accommodations |
| **Near-shore fisheries** | Registration of Fishermen Database, Fisheries Division, Jamaican Ministry of Agriculture | • number and type of fishers and number of boats |
| | Bunce and Gustavson (1998a) | • types of fishing activities in Park waters, fishing revenues and costs |
| | Nicholson (1994) | • fishing revenues and costs |
| **Coastal protection** | Jamaica Promotions Corporation | • shoreline land values |
| | Urban Development Corporation | • shoreline land values |
| | various local real estate agencies | • shoreline land values |
| | local land developers | • shoreline land values |

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

The validity of the assumption that the benefits will continue to be received in perpetuity must ultimately be checked against biophysical information regarding the conditions of the reefs in Montego Bay as they have changed over time. Moreover, any future or continuing changes in reef ecological conditions will necessarily have an effect on the current levels of local use. There are two notable documented ecological surveys (Hitchman 1997; Sullivan and Chiappone 1994) which examine reef conditions in the Montego Bay Marine Park. As well, there is additional information available on the reef conditions as perceived by the primary user groups; this latter information is outlined in Chapter 11.

This report will not attempt to make assumptions regarding the sustainable level of local use, but instead will report NPVs for as many base years as there is reliable information. The coral reefs of Montego Bay are part of a highly complex system, involving interactions between ecological components, user groups, and land-based activities. Although there are certainly negative ecological impacts associated with increases in the levels of certain types of local uses, the relationship is not simple, nor can the ecological impacts be easily isolated from other coastal and land-based activities. The high degree of system uncertainty, as well as system links, synergisms and feedbacks, make assumptions regarding the sustainable level of use difficult. Such an exercise is best tackled through a synthesis of these results with other modeling strategies and biophysical information.

## Net Present Values of Local Uses

### *Direct Local Use: Tourism*

Direct economic account information was not available for the tourism sector. For statistical purposes, the Jamaica Tourist Board places tourists who visit Montego Bay into two categories—stop-over (airline arrival) and cruise-ship passengers. Tables 5.2 and 5.3 show the conversion of the average daily visitor expenditures of stop-over and cruise-ship passengers into estimated total annual expenditures in Montego Bay. The total number of stop-over visitors arriving in Montego Bay that remain in the greater Montego Bay area was not available; thus, it was assumed to be equivalent to the average number of bed-nights sold in hotels divided by the average length of a stop-over tourist stay. Cruise-ship passengers arriving in the Montego Bay terminal are assumed to spend their shore time in the greater Montego Bay area and spend an average of one day in port.

Rather than rely on estimates of tourist expenditures from departing-tourist surveys, a study by the OAS (1994) based its economic analysis of the tourism sector in 1992 on a survey of the actual revenues and costs associated with tourism-related businesses. As noted by OAS (1994), using tourist expenditure information is limited mainly due to the fact that expenditures outside of the country for the vacation (e.g., vacation packages) may not coincide with the amount actually received by the domestic businesses involved, and the information itself may be compromised by tourists' abilities to recall expenditures accurately during surveys. The main disadvantage associated with the approach of the OAS (1994) is that some businesses, such as street vendors and miscellaneous retail establishments, were excluded from the analysis as they were not specifically targeted for information collection.

The OAS (1994) study reported results for Jamaica as a whole; thus, the specific revenue and cost profiles cited could not be used in this investigation. It was assumed, however, that the cost structures and net values reported for Jamaica remain *proportionately* the same for the Montego Bay area. Table 5.4 shows net values as a percentage of total revenues for 1992 by the type of business, and the reconciliation of the categories used by the Jamaica Tourist Board (JTB) with those used by the OAS. Where more than one OAS category was placed in the same JTB category (i.e., transportation and entertainment), the net value as a percentage of the total revenue that was assigned to the JTB category was determined by weighting each OAS component according to the OAS category's share of total revenue for all OAS categories within the JTB category. For tourist expenditures registered as "miscellaneous" for which there is no specific cost and revenue structure available in OAS (1994), the weighted average of 20.1% for the whole tourism sector was used.

Table 5.5 shows the annual net values for 1985 through 1996 attributed to stop-over and cruise-ship passenger expenditures, as well as for the tourism sector as a whole. Table 5.6 shows the annual net values broken-down for each tourism sector for 1996 using available information

**Table 5.2** Estimated total annual expenditures by stop-over visitors remaining in Montego Bay

| *Year* | *Total Montego Bay stop-over arrivals*[a] | *Average length of stay (all Jamaican stop-over visitors)*[b] | *Number of bed-nights sold in Montego Bay hotels*[c] | *Proportion of Montego Bay stop-over arrivals remaining in Montego Bay*[d] | *Average individual daily expenditures (current US$)*[e] | *Estimated total annual expenditure (current US$)*[f] |
|---|---|---|---|---|---|---|
| 1985 | 278142 | 9.8 | 1239990 | 0.45 | 73 | $9.1x10^7$ |
| 1986 | 315824 | 10.2 | 1494526 | 0.46 | 78 | $1.2x10^8$ |
| 1987 | 290404 | 10.2 | 1684754 | 0.57 | 77 | $1.3x10^8$ |
| 1988 | 349831 | 10.3 | 1374281 | 0.38 | 76 | $1.0x10^8$ |
| 1989 | 273817 | 10.6 | 1421957 | 0.49 | 78 | $1.1x10^8$ |
| 1990 | 299301 | 10.9 | 1647016 | 0.50 | 80 | $1.3x10^8$ |
| 1991 | 290712 | 10.9 | 1558927 | 0.49 | 79 | $1.2x10^8$ |
| 1992 | 304022 | 11.2 | 1676197 | 0.49 | 84 | $1.4x10^8$ |
| 1993 | 317078 | 11.0 | 1764017 | 0.51 | 85 | $1.5x10^8$ |
| 1994 | 270711 | 10.7 | 1511778 | 0.52 | 84 | $1.3x10^8$ |
| 1995 | 280790 | 10.9 | 1644600 | 0.54 | 87 | $1.4x10^8$ |
| 1996 | 294466 | 11.1 | 1666043 | 0.51 | 85 | $1.4x10^8$ |
| **Average** | **287995** | **10.4** | **1530376** | **0.52** | **n/a** | **n/a** |

[a] Statistics for 1994, 1995 and 1996 from the Jamaica Tourist Board included non-resident Jamaicans. As these numbers were not included prior to 1994, the number of non-resident Jamaicans arriving in Montego Bay for the three latter years was removed. This specific number was not available; thus, it was estimated from national level statistics assuming that the proportion of non-resident stop-over arrivals to total stop-over arrivals was comparable. Source: Annual Travel Statistics, Jamaica Tourist Board.

[b] Source: Annual Travel Statistics, Jamaica Tourist Board.

[c] Source: Annual Travel Statistics, Jamaica Tourist Board.

[d] Estimated by dividing the average number of bed-nights sold by the average length of stay and expressing this number as a proportion of the total number of stop-over arrivals in Montego Bay.

[e] Source: Annual Travel Statistics, Jamaica Tourist Board.

[f] Estimated by multiplying the total number of bed-nights sold in hotels by the average individual daily expenditure of stop-over tourists.

by type of expenditure. Table 5.7 shows the NPVs for the years 1985 through 1996 using the results from Table 5.5.

Due to the unavailability of capital cost information (land, buildings and equipment), the NPVs reported here represent a partial cycle analysis. It should also be noted that the estimated labor costs used in this analysis are the accounting costs of labor and not necessarily the opportunity cost. The extent of the available information did not allow for the reasonable estimation of the accounting labor cost components and the subsequent derivation of the opportunity costs. Given the large size of the tourism sector and the predominant use of relatively low-skilled labor, any discrepancies are not expected to be large.

### *Direct Local Use: Near-shore Fishery*

Historic systematic and reliable information on the size of the near-shore, artisanal fishery in Jamaica is not available (e.g., see survey by Sahney 1982). Regular records of the number of fishers and the method of fishing began when the Fisheries Division of the Government of Jamaica initiated a Registration of Fishermen Database in 1995. Economic information regarding fisheries in Jamaica is even more limited. Espeut (1992) and Espeut and Grant (1990) provide information, yet this information is not directly applicable to the near-shore fisheries in the Montego Bay area. Nicholson (1994) conducted a spring 1994

**Table 5.3** Estimated total annual expenditures by cruise-ship passengers arriving in Montego Bay

| *Year* | *Total Montego Bay cruise-ship arrivals*[a] | *Average length of stay* | *Average individual daily expenditures (current US$)*[b] | *Estimated total annual expenditure (current US$)*[c] |
|---|---|---|---|---|
| 1985 | 72251 | 1.0 | 49 | $3.5x10^6$ |
| 1986 | 93846 | 1.0 | 52 | $4.9x10^6$ |
| 1987 | 77356 | 1.0 | 50 | $3.9x10^6$ |
| 1988 | 92712 | 1.0 | 50 | $4.6x10^6$ |
| 1989 | 97250 | 1.0 | 48 | $4.7x10^6$ |
| 1990 | 70485 | 1.0 | 70 | $4.9x10^6$ |
| 1991 | 136395 | 1.0 | 73 | $1.0x10^7$ |
| 1992 | 221997 | 1.0 | 51 | $1.1x10^7$ |
| 1993 | 181207 | 1.0 | 69 | $1.3x10^7$ |
| 1994 | 154238 | 1.0 | 83 | $1.3x10^7$ |
| 1995 | 193392 | 1.0 | 83 | $1.6x10^7$ |
| 1996 | 200491 | 1.0 | 85 | $1.7x10^7$ |
| **Average** | **119475** | **1.0** | **n/a** | **n/a** |

[a] Non-resident Jamaicans included in statistics from 1989 through 1996. Source: Annual Travel Statistics, Jamaica Tourist Board.

[b] Source: Annual Travel Statistics, Jamaica Tourist Board.

[c] Estimated by multiplying the total number of cruise-ship visitors by the average individual daily expenditure of stop-over tourists.

**Table 5.4** Results of OAS (1994) analysis showing the net values as a percentage of total revenues for the main private sector tourist firms in Jamaica for 1992, and the reconciliation with the Jamaica Tourist Board categories

| *Type of business* | *Net value as a percentage of total revenue* | *Reconciliation with Jamaica Tourist Board categories* | *Net value percentage by Jamaica Tourist Board category* |
|---|---|---|---|
| All-inclusive hotels | 19.0 | — | — |
| Other hotels | 24.8 | — | — |
| Guest houses, villas and apartments | 18.9 | — | — |
| Other accommodations | 17.8 | — | — |
| All accommodations | 20.9 | Accommodations | 20.9 |
| Restaurants and bars | 13.4 | Food and beverage | 13.4 |
| Tour operators | 14.5 | Entertainment | 37.1 |
| Recreation, attraction and sports | 47.9 | Entertainment | 37.1 |
| Taxis | 3.1 | Transportation | 16.7 |
| Car rentals | 36.1 | Transportation | 16.7 |
| Other transportation | 17.7 | Transportation | 16.7 |
| In-bond shopping | 5.3 | Shopping | 5.3 |
| **Weighted average** | **20.1** | | |

socio-economic survey of fishing activities in the Montego Bay Marine Park. This represents the only pre-existing source of economic information for this study. A rapid socio-economic assessment of the primary user groups of the Park also provided valuable information (Bunce and Gustavson 1998a; Chapter 11).

Typical of artisanal fisheries in Jamaica, there is an income share arrangement between the crews, captains, and owners of the boats. Understanding this share arrangement is critical to understanding the distribution of the economic benefits. The arrangement at White House and River Bay, the two largest landing beaches, typically involves 50% of the gross value of the catch or weight of the catch going to the owner of the boat to cover operating expenses, equipment maintenance expenses, and as a return for the capital investment. The remaining 50% is distributed equally among the captain and crew who operated the fishing vessel (the captain is also usually, but not always, the owner of the boat). As there are usually two individuals fishing from one boat, each captain and crew member take 25% of the catch. Where there are more than two fishers, the income is accordingly less (e.g., if there are two crew members and one captain, individuals take one third of 50% of the catch, or approximately 17%). This share arrangement, however, is varied at times. Owners may decrease the percentage share retained for the boat when the catches are low so that the crew receive higher incomes.

Estimates of revenues from fishing based on the number of fishing trips per week, average catches, average price of fish per pound, and the boat sharing arrangements are shown in Table 5.8. Of the methods of fishing for which

**Table 5.5** Annual net values (millions of current US$) for tourism in Montego Bay, 1985-1996

| *Year* | *Annual net value derived from stop-over expenditures* | *Annual net value derived from cruise-ship passenger expenditures* | *Total tourism sector annual net value* |
|---|---|---|---|
| 1985 | 18.3 | 0.704 | 19.0 |
| 1986 | 24.1 | 0.985 | 25.1 |
| 1987 | 26.1 | 0.784 | 26.9 |
| 1988 | 20.1 | 0.925 | 21.0 |
| 1989 | 22.1 | 0.945 | 23.0 |
| 1990 | 26.1 | 0.985 | 27.1 |
| 1991 | 24.1 | 2.010 | 26.1 |
| 1992 | 28.1 | 2.210 | 30.3 |
| 1993 | 30.2 | 2.610 | 32.8 |
| 1994 | 26.1 | 2.610 | 28.7 |
| 1995 | 28.1 | 3.220 | 31.3 |
| 1996 | 28.1 | 3.420 | 31.5 |

**Table 5.6** Annual net values (millions of current US$) by sector category for tourism in Montego Bay for 1996

| | *Accom-modation* | *Food and beverage* | *Enter-tainment* | *Trans-portation* | *Shopping* | *Miscel-laneous* | *Total tourism sector sector annual net value* |
|---|---|---|---|---|---|---|---|
| Stop-over visitors | 17.73 | 0.88 | 5.82 | 1.50 | 0.73 | 2.05 | 28.70 |
| Cruise-ship passengers | 0.00 | 0.02 | 0.75 | 0.08 | 0.65 | 0.41 | 1.91 |
| **Total** | **17.73** | **0.90** | **6.57** | **1.58** | **1.38** | **2.46** | **30.60** |
| **% of total** | **57.9** | **2.9** | **21.5** | **5.2** | **4.5** | **8.0** | **100** |

**Table 5.7** Net present values (millions of current US$) by year for tourism in Montego Bay, 1985-1996

| *Year* | *i = 5%* | *i = 10%* | *i = 15%* |
|---|---|---|---|
| 1985 | 380 | 190 | 127 |
| 1986 | 502 | 251 | 167 |
| 1987 | 538 | 269 | 179 |
| 1988 | 420 | 210 | 140 |
| 1989 | 460 | 230 | 153 |
| 1990 | 542 | 271 | 181 |
| 1991 | 522 | 261 | 174 |
| 1992 | 606 | 303 | 202 |
| 1993 | 656 | 328 | 219 |
| 1994 | 574 | 287 | 191 |
| 1995 | 626 | 313 | 209 |
| 1996 | 630 | 315 | 210 |

there is sufficient economic information, hand line, trap, net and spear fishing occur within Park waters. Using the 1995 statistics for the total number of fishers by fishing method by beach and applying them proportionately to the 1998 estimated total number of boats and fishers by landing beach, we can arrive at an estimate for the number of boats and fishers using Park waters (Table 5.9). We can then use these results to arrive at an estimate for the total number of "owners" (owners of boats for hand line, trap, and net fishing; sole operators for spear fishing).

Nicholson (1994) estimated that total operating costs for fishers (less labor payments) were between 11% and 34% of gross revenues. 25% was assumed here for the calculation of net operating values for all forms of fishing (indications from interviews with fishers during the field portion of the study supported this approximation). In other words, approximately 75% of the gross receipts for net, trap, hand line, and spear fishing can be assumed to be operating surplus less the deduction for the payment to labor.

In 1996, the average hourly wage for large establishments, all sectors for Jamaica as a whole was J$56 in 1996, equivalent to approximately J$92 in 1998 (source: Statistical Institute of Jamaica). Assuming a 40 hour work week (source: Statistical Institute of Jamaica), an average weekly wage in Jamaica is J$3670. To arrive at an estimate for the opportunity cost for labor, this average weekly wage is discounted by 25% to a final figure J$2750 per week per individual to reflect the value of the marginal product of labor. The opportunity cost of labor is then estimated to be J$5500 per boat for net, trap, hand line fishing (assuming an average of one captain and one crew member per boat), and J$2750 per spear fisher. These costs are deducted from gross fishing earnings along with the previously cited estimate of 25% of gross for operating expenses. The derivation of the overall net operating values are shown in Table 5.10.

Nicholson (1994) estimated the average value of the boat capital assets (including vessels and engines) to be on average J$58,000 (current 1994 dollars) per owner. This is approximately equivalent to J$156,000 in current 1998 dollars. The equivalent annual capital costs are thus J$7,800 for $i$ = 0.05, J$15,600 for $i$ = 0.10, and J$23,400 for $i$ = 0.15 for each boat owner. These figures are then deducted from the annual net operating values for net, trap, and hand line fishing owners (but not for spear fishers) as shown in Table 5.10, yielding 1998 net annual values. Total deductions for annual capital cost equivalents are thus J$$5.46 \times 10^5$ for $i$ = 0.05, J$$1.09 \times 10^6$ for $i$ = 0.10, and J$$1.64 \times 10^6$ for $i$ = 0.15. The resulting net annual values are then converted to NPVs (Table 5.11). Note that the negative resource rents arise largely due to the opportunity costs of fishing labor, which can be greater than the actual accounting returns to labor.

### *Other Direct Local Uses*

The other possibly significant direct use values which were explored for this project included the aquarium trade,

**Table 5.8** Estimates of catches, gross incomes per boat, and individual incomes of fishers by method of fishing for early 1998

| *Method of fishing* | *Number of outings per week* | *Approximate catch per outing (lbs)* | *Approximate weekly gross income per boat assuming J$100/lb*[a] (current J$) | *Approximate weekly individual income*[b] (current J$) |
|---|---|---|---|---|
| Troll | 3 to 5 | 10 to 20 | 3000 to 10000 | 750 to 2500 |
| Trap | 1 | 10 to 20 | 1000 to 2000 | 250 to 500 |
| Net | 3 to 5 | 10 to 15 | 3000 to 7500 | 750 to 2250 |
| Hand line | 3 to 5 | 10 to 20 | 3000 to 10000 | 750 to 2500 |
| Spear | 5 to 7 | 10 | 5000 to 7000 | 5000 to 7000[c] |

[a] In general, "table fish" (fish 1.5 lbs each and up) will sell for $J100 per lb, while "frying fish" (fish under 1.5 lbs) will sell for $J50 per lb. Species caught by trolling command specific prices: for example, $J100 per lb for dolphinfish, $J70 per lb for blue marlin, $J60 per lb for tuna (noted as one of the harder fish to sell), and $J100 per lb for kingfish. J$100 per lb was used for calculations assuming that higher value fish are caught.

[b] Weekly individual incomes per fishing activity were estimated as 25% of the approximate weekly gross incomes per boat. This assumes a typical sharing arrangement and an average of one captain and one crew member per boat.

[c] Spear fishing typically has no sharing arrangement, with relatively few expenses or required capital investments; thus, although their net will be less than the gross due to expenses, no adjustments were made to the gross incomes as reported on this table.

**Table 5.9** Total number of fishers and boats by landing beach estimated to be fishing in Park waters in 1998 (Bunce and Gustavson 1998a; Registration of Fishermen Database, Fisheries Division, 1998)

| *Landing beach* | *Number of boats* | *Number of fishers* |
|---|---|---|
| River Bay | 51 | 161 |
| White House | 5 | 15 |
| Bogue | 1 | 8 |
| Reading | 8 | 23 |
| Spring Gardens | 5 | 8 |
| Unregistered spear fishers | — | 150 |
| **Total** | **70** | **365** |

mariculture, coral crafts, other crafts derived from marine materials, and coral sand extraction. In all cases, the benefits associated with these activities were found to be negligible during the final site application. The Natural Resources Conservation (Marine Parks) Regulations of June 5, 1992, proclaimed under the Natural Resources Conservation Authority Act of Jamaica, make it clear that a person shall not "destroy, injure, deface, move, dig, harmfully disturb or remove from a marine park any sand, gravel or minerals, corals, sea fans, shells, starfish or other marine invertebrates, seaweeds, grasses, or any soil, rock, artefacts, stones or other materials" (4.1.a; note that fishing is dealt with separately under the Regulations and is a permitable activity). Thus, the policy direction of the government and the management authorities is to prevent all forms of coral sand extraction or extraction of other

**Table 5.10** Annual net operating values (current J$) by method of fishing for 1998

| *Method of fishing* | *Weekly gross income* | *Total number of owners* | *Weekly net operating value per owner* | *Total annual net operating value (without capital deduction)* |
|---|---|---|---|---|
| Trap | 1000 to 2000 | 13 | -4750 to -4000 | $-3.21 \times 10^6$ to $-2.70 \times 10^6$ |
| Net | 3000 to 7500 | 10 | -3250 to 125 | $-1.69 \times 10^6$ to $6.50 \times 10^4$ |
| Hand line | 3000 to 10000 | 47 | -3250 to 2000 | $-7.94 \times 10^6$ to $4.89 \times 10^6$ |
| Spear | 5000 to 7000 | 154 | 1000 to 2500 | $8.01 \times 10^6$ to $2.00 \times 10^7$ |
| **Total** | **n/a** | **224** | **n/a** | **$-4.83 \times 10^6$ to $2.23 \times 10^7$** |

**Table 5.11** Net annual values and net present values for the fisheries of Montego Bay Marine Park, 1998 (brackets indicate midpoint of estimate)

| | *i = 5%* | *i = 10%* | *i = 15%* |
|---|---|---|---|
| Net annual value (millions of current 1998 J$) | -4.83 to 21.8 [8.5] | -5.92 to 21.2 [7.6] | -6.47 to 20.7 [7.1] |
| Net present value (NPV) (millions of current 1998 J$) | -96.6 to 436 [170] | -59.2 to 212 [76] | -43.1 to 138 [47] |
| Net present value (NPV) (millions of constant 1996 J$) | -59.0 to 266 [104] | -36.1 to 129 [46.5] | -26.3 to 84.2 [29.0] |
| Net present value (NPV) (millions of constant 1996 US$) | -1.66 to 7.49 [2.92] | -1.02 to 3.63 [1.31] | -0.741 to 2.37 [0.815] |

marine materials for use in crafts.

A minor, but ultimately indeterminate, amount of extraction of materials for crafts or direct sale through the informal economy is believed to occur illegally. This is reflected in the contingent valuation results (Chapter 6) in which one individual respondent out of 1,058 noted that one of the benefits derived by the Park was getting shells and stones for natural crafts. The selling of conch shells collected from Park waters is perhaps the most prevalent, yet likely a relatively minor problem. Park rangers actively enforce the "no take" regulations, stopping collectors as they are discovered (Malden Miller, Director of Montego Bay Marine Park, pers. comm. February 1998). Such items are not readily available for purchase in markets, at hotels, or other public areas in the immediate vicinity of the Park, but are readily available from road-side stands outside of Montego Bay.

Coral sand extraction is similarly illegal within the Montego Bay Marine Park boundaries. Sand is extracted from beaches and rivers throughout Jamaica for use in construction materials, primarily as a component of cement. No indications of sand extraction were found during the final site application, but Park authorities noted that there have been signs of some activity near River Bay in the past (Malden Miller, Director of Montego Bay Marine Park, pers. comm. February 1998). Nonetheless, as it is currently the law and policy of the managing authorities to prevent coral sand extraction from occurring, those benefits, believed to be small and unsustainable, may be negated for the purposes of this study.

Mariculture currently does not occur within Park boundaries. Authorities are not pursuing the establishment of mariculture, but would be open to considering the implementation of a program if approached with a serious and viable proposal (Malden Miller, Director of Montego Bay Marine Park, pers. comm. February 1998). The capture of fishes for sale on the aquarium market is also effectively non-existent. No individuals were known or identified during the final site application who participate in this activity. No other direct use activities of potential economic significance, not associated with either fisheries or recreation and tourism, were identified during the final site application.

### *Indirect Local Use: Coastal Protection*

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

The value of coastal protection is estimated from the value of land that is vulnerable to erosion. Investigation into potential sources of information on land values proved that detailed information would not be forthcoming. Information on current land prices was solicited from various sources (Table 5.1). Relying on real estate market information for land value information is limited by the nature of the properties which are available on the market at the time of the survey, and thus for which there is information, and may not yield results representative of the entire region. Moreover, information is not available for many of the prime shoreline areas of the Montego Bay Marine Park.

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

## The Capture of Value from Marine System Contributions to Economic Production

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

As a component of the study, 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 at the time of publication the Park was 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. 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 collectorate and thus are not explicitly available for use in Park management. The extent to which taxes may capture tourism or fisheries rent is not explored further here.

Rent capture instruments are an effective means of aligning private costs with social costs, such that the operators "feel" the true costs associated with using the reefs. The collection of a fee allows management and government authorities to collect funds to pay for the resource management costs that they incur, as well as to help move toward an economically optimal level of use. The capture of rent is most effective if fees are tied to profits or net incomes (before interest and taxes) and, secondarily, to the level of use. The beach fee charges as currently set are minimal and, although they vary roughly according to the type of use, are not linked to varying levels of producer surplus. The current interest of the Montego Bay Marine Park in implementing user fees should be encouraged. An *independent* administration of a program of rent capture that ultimately varies at least according to the level of use and the type of business will help ensure that the funds are accessible by management authorities and don't disappear into the general government collectorate.

### *License Fees*

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.

#### Tourism Related Business License Fees

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

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

The accommodations license fee (the Hotel License Tax) is charged by the Inland Revenue Department of Jamaica and goes into the general collectorate. The fee schedule is based on the category of the accommodation (A, B, C, or D). This system is being phased out, but the premise on which it is based is being maintained—a schedule of fees that varies roughly in relation to the size of the accommodation's revenues. The more deluxe or expensive hotels are currently classified as A or B and are charged an annual fee of J$600 (US$16.90) per room per year. Less expensive forms of accommodation and villas are assessed a fee of J$300 (US$8.45) per room per year, while the least expensive accommodations pay J$150 (US$4.23) per room per year. No information was yet available as to how the fees will be assessed in the future, or how the room rates will translate to a particular accommodation's license fee that is charged.

#### Fisheries License Fee

There is no fishing license fee, although registrants must pay a one-time fee of J$150 (US$4.23) to cover the cost of the required identification card. The fee is collected by the Fisheries Division of the Ministry of Agriculture. As there are no other fishery-related businesses directly tied to the activity in Montego Bay (e.g., processors, packers, transport companies) and all fish sales are directly to the consumer (Bunce and Gustavson 1998a; Chapter 11), there are no other relevant government license fees or charges that may be considered to capture any rent from fishing.

### *Beach Fees*

The Natural Resources Conservation Authority (NRCA) currently charges a "beach fee", which is a license fee charged under the Beach Control Act of Jamaica for use of the foreshore and the seafloor (usually to a point 25m seaward of the high water mark) for either commercial or private purposes. The Beach Control Act of 1956 established all rights of the foreshore and the floor of the sea to the Crown. Rights to the foreshore granted to private individuals before 1956, the date the Act was proclaimed, are maintained, along with rights by prescription granted to fishers (NRCA 1997, p.3 and p.13). The law requires that a license be obtained "...for the use of the foreshore in connection with any commercial enterprise along the coast which involved the use of or encroachment on the foreshore and/or the floor of the sea and the overlying water" (NRCA 1997, p.5). Licenses are renewable on an annual basis and can grant either exclusive or non-exclusive use of the foreshore (the granting of exclusive licenses is no longer practiced, although existing exclusive licenses are renewable). Relevant sections of the fee schedule as stated in the amended Beach Control Authority Regulations (licensing), 1993, are shown in Table 5.12. Those not listed include various fees that are charged for encroachments on the foreshore or floor of the sea (e.g., breakwaters, pipelines, pools, buildings, fences, steps, platforms) and those associated with moorings.

The policy direction of the NRCA is for the use of these fees primarily for the "...rehabilitation of public bathing beaches and the monitoring of beaches generally" (NRCA 1997, p.24). It is also the position of the NRCA that current license fees are "trivial" relative to the profits generated by the use of the public resource. The authority is very conscious of finding ways to raise more revenue, particularly that associated with use of a public resource. The beach fee is a direct mechanism for rent capture; however, none of these funds are explicitly directed to pay

**Table 5.12** Schedule of fees as stated in the amended Beach Control Authority Regulations (licensing), 1993 of Jamaica

| *Category* | *Fee per operator per year (J$)* | *Fee per operator per year (US$)* |
|---|---|---|
| Hotels (100 rooms and over) | 5,000 | 140.85 |
| Hotels (under 100 rooms) | 3,000 | 84.51 |
| Guest houses (30 rooms and over) | 2,000 | 56.34 |
| Guest houses (under 30 rooms) | 1,000 | 28.17 |
| Commercial recreational beaches, public recreational beaches, proprietary and member clubs | 3,000 | 84.51 |
| Beach used exclusively in connection with a dwelling, house or building rented for recreational purposes | 2,000 | 56.34 |
| Commercial or industrial beaches (other than commercial recreational) | 5,000 | 140.85 |
| Fishing beach (10 or more boats or with a fish depot) | 100 | 2.82 |
| Fishing beach (less than 10 boats) | 50 | 1.41 |
| Beach reserved exclusively for the use of owners of lots in a subdivision | 2,500 | 70.42 |
| Beach reserved exclusively for the use of schools, churches, or other bodies or persons for charitable or educational purposes | 100 | 2.82 |

for the management of the Montego Bay Marine Park.

### *Departure Tax*

As of early 1998, all individuals departing Jamaica from either the airport or a cruise ship terminal are charged a departure tax of J$500 or US$15, depending on visitor preferred currency of payment (at the time of publication, this fee had increased to J$750 or US$20). As it relates to the use of the waters of the Montego Bay Marine Park, the departure tax as a charge to tourists captures at least a portion of the consumer surplus. In other words, the collected funds represents a portion of the amount that visitors would be willing to pay for their visit to Montego Bay (and for some visitors, other regions of Jamaica) above the amount that they actually had to pay. Resource rent captured by the tourism industry through the provision of reef-related services is not addressed by this fee mechanism.

## Conclusions

In summary, this study has identified the following net present values associated with the use of the Montego Bay Park waters (for the most recent year that data was available):

- US$210 million (using a 15% discount rate) to US$630 million (using a 5% discount rate) in 1996 associated with tourism;
- –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) in 1998 associated with fishing; and,
- US$65 million (constant 1996 dollars) in 1998 associated with the coastal protection function of the coral reefs.

As stated previously, one of the purposes of focusing on the most significant local use values associated with the coral reefs of the Montego Bay Marine Park is the added usefulness of providing a detailed benchmark to feed into subsequent modeling of the complete set of benefits and costs. This includes consideration of the results from the bioprospecting and contingent valuation components of the larger project to arrive at an overall coral reef benefit model (Chapter 9). The current values of the resources at risk reported here must be placed within the broader context of considering the complete set of true social costs and benefits when examining the economic efficiency of possible coral reef management interventions.

Under the current open access Park management regime, one would predict that all rents would have dissipated—that the profits of operators would be zero. As outlined in this report, this is clearly not the case, although fishing rents are certainly minimal. The two most compelling explanations as to why there are still rents generated through the use of the Montego Bay Marine Park waters are that there are socio-cultural and expertise barriers to entry, and that the rents of the marginal or newer operators are zero due to the high costs associated with entry and lower marginal returns.

Fishing rents are most likely maintained through socio-cultural and expertise barriers. The results of Bunce and Gustavson (1998a; Chapter 11) indicate that fishing activities are associated with a particular socio-economic class and that fishers themselves do not become proficient at fishing until they have gained the necessary experience. Those outside of the fishing communities would likely find it difficult to fish profitably. It was even noted during interviews with Montego Bay fishers (Bunce and Gustavson 1998a; Chapter 11) that wealthier individuals not associated with the fishing communities will at times try fishing, but will soon cease operations due to low catches, being unfamiliar with how or where to fish. The experience gained by the older fishers seems largely to be passed on through persistent involvement in fishing and interaction within the fishing communities themselves.

Spear fishers, who enjoy the largest rents, are less tightly linked to the fishing communities, and thus might be expected to be subject to fewer socio-cultural barriers of entry. However, experience and the unfamiliarity of many Jamaicans with the marine environment would still factor largely into their level of fishing success, and even their willingness to begin fishing in the first place. The overall effectiveness of any barriers of entry into fishing, however, is not absolute. More individuals are fishing (especially spear fishing) as is evidence by the relatively recent and rapid increase in the number of fishers in Montego Bay (Bunce and Gustavson 1998a; Chapter 11). This increase in the number of fishers is expected to continue.

The persistence of rents associated with the tourism sector is most likely due largely to new entrants facing higher costs and receiving lower yields or returns. For example, interviews with water sports operators (Bunce and Gustavson 1998a; Chapter 11) indicated that for some tourist services, such as the independent party cruise and glass-bottom boat operations, the market seems to be saturated or even declining, reducing gross returns. Existing, reportedly more marginal operators even expressed a desire to get out of the business, some unable to do so due to an inability to liquidate their capital investments. In such a market, there would be little opportunity for new entrants as they would likely be faced with even lower marginal yields. Furthermore, for many tourism-related businesses, such as the hotel sector and the water sports operators, there are significant start-up costs and capital outlays necessary, further deterring new entrants.

It must be added that the analysis of NPVs presented here was not able to distinguish between different types of operations within the tourism sector, with the exception of the aggregated sectors of accommodations, food and beverage, entertainment, transportation, and shopping for the year 1996. Although there was an overall positive NPV associated with each, there may be dramatic differences between different types of operators within each category.

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

## Chapter 6

# Lexicographic Preferences and the Contingent Valuation of Coral Reef Biodiversity in Curaçao and Jamaica

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The contingent valuation method (CVM) is a stated preference method that directly surveys individuals to obtain their preferences rather than analyzing their actual behavior as revealed in the market place. In contrast to other methods for cost-benefit analysis (CBA), CVM has received considerable and increasing attention in the literature. The main advantage attracting this attention is the ability of CVM to estimate option, existence and bequest values in addition to direct use values.[1] The travel cost method, production function analysis, and hedonic pricing are all restricted to assessing only the direct use values of the environment (Hanley and Spash 1993).

There are several stages involved in conducting a CVM study—designing and pre-testing the survey, carrying out the main survey, estimating willingness-to-pay (WTP) and/or willingness-to-accept (WTA), bid curve analysis, data aggregation, and final assessment. In making decisions at each stage of the studies' design and conduct, economists impose their implicit value judgments as to what seems appropriate. While the art of survey design may make CVM more controversial, similar judgments are required in the application of any CBA method. What CVM adds is the ability to probe motives and attitudes.

## Issues in Survey Design

Practical CVM survey design must be carefully conducted with awareness of the need to make the trade-off being described both realistic and easy for the general public to understand. This is often a careful balancing act between depth and comprehensibility. Thus, for example, the lengthy technical discussions of ecologists about coral reef degradation have to be simplified to a set of stylised facts. In addition, the length of the survey must be controlled to achieve an administration time that maintains the average interviewee's attention.

### *The Design Process*

The design of a CVM study includes the way information is presented to individuals, the order in which it is presented, the question format, and the amount and type of information presented. There is a wide body of evidence to suggest that survey design can affect responses. Survey design requires framing a realistic decision concerning the environment where the monetary question to be asked is accepted as a possible state of the world in which individual respondents might find themselves. Thus, the analyst must take several decisions, including a reason for the payment, how funds will be raised (i.e., the bid vehicle), and the arrangements for and regularity of payments. For example, Rowe *et al.* (1980) found that WTP to preserve landscape quality was higher when an income tax increase was suggested than when entry fees were used. The technique for bid elicitation may be an open-ended question (with or without a bidding card), a dichotomous choice, or a bidding game. Also, information on physical changes will need to be summarized and the method of their description chosen (e.g., text, graphics, maps).

Due to the sensitivity of responses to the information supplied, the pre-testing of the survey has become of increasing importance. This can be conducted via a small sample test run to see if respondents have problems and special sections can be included to pick out the occurrence of difficulties. A focus group is another method now in use for pre-testing. Generally, the pre-test will enable the identification of problems with regard to the framing of the decision problem, as well as divergence between encoding and decoding of information.

The conduct of the main survey can use several variations. The in-house interview is now most favored in developed country surveys, although the expense of this approach often means surveys are completed in the street, by telephone interviewing, or by mail. In the Caribbean, the difficulty of obtaining a representative sample via in-house interviews and obtaining a tourist sample meant the equivalent of "in-street" surveying was required (i.e., approaching people in the street, at shopping centers and on the beach) in addition to the developed country preference for in-house interviewing. While random samples are recommended, in practice a truly random sample is difficult to obtain. This is especially true in developing countries where large sections of the population may lack telephones or have no postal address. Again, sampling tourists can pose problems in terms of predefining and selecting a random sample. Even in developed countries, the sample is often based on a quota as it is less expensive (although a random element may be included, such as the random walk method).[2] The sample is also often weighted in terms of the local or regional population, whichever is seen as politically more important to the decision and likely to have strong direct economic connections to the outcome.

Responses to the survey may include "protest bids", and these are often omitted from the mean WTP or WTA calculation without adequate reason. Protest bids are zero bids given for reasons other than a zero value being placed on the resource in question. For example, a respondent may refuse any amount of compensation for loss of an environmental asset, which they regard as unique, or a species that they feel should be protected at all costs. Respondents may refuse to state a WTP or WTA amount because they reject the survey as an institutional approach to the problem, or because they have an ethical objection to the trade-off being requested (e.g., a lexicographic preference; Spash and Hanley 1995). Another potential problem is the outlier who bids a very large amount and so has a strong influence on the mean. This should only be regarded as a problem when the bid is unlikely to occur because the individual lacks the income to pay (under WTP) or would actually accept a much lower amount (under WTA). In this case, the respondent would be acting strategically, thus creating a bias.

Analysis of the bid curve is used to test construct validity (i.e., that the socio-economic variables have the expected signs and the regression is statistically significant). Other relationships can also be investigated at this stage. In general, bid curve analysis has tended to be of academic rather than policy interest. However, this analysis can provide useful insights into the behavior of respondents and the determinants of their bids. In this chapter, such analysis is used to investigate the importance of ethical positioning.

Final reflection upon the CVM study can include convergent validity and success of repeatability where there exist other similar studies. The overall success of the exercise will also become apparent as the results are being analyzed (e.g., a high number of protest bids). There are several specific problems that are recognized as possible causes of bias, some of which have been mentioned (e.g., strategic bias, design bias). More problematic are the impacts of the information, as this is, by necessity, restricted but can have serious influence upon the resulting bids and the problem of embedding as raised by Kahneman and Knetsch (1992).

### *Information Provision*

In a hypothetical market, respondents combine information provided to them regarding the good to be valued and how the market will work with information they already hold on that good. Either the hypothetical market or commodity-specific information given to them in the survey may influence their responses. This phenomenon implies that WTP and WTA values are endogenous to the valuation process. Thus, bids to preserve different animal species may vary significantly according to the information provided by researchers (Samples *et al*. 1986). Ajzen *et al.* (1996) concluded from experimental research that the nature of the information provided in CVM surveys can profoundly affect WTP estimates and that subtle contextual cues can seriously bias these estimates under conditions where the good is of low personal relevance. However, Randall (1986) has argued that CVM answers should vary under different information sets, otherwise the technique would be insensitive to significant changes in commodity framing.

Indeed, the effects of information may be inappropriately labelled as bias, depending on the way in which WTP or WTA is changed. Information that improves the knowledge of an individual concerning the characteristics of a good can be regarded as informing a consumption decision. Information that alters the preferences is more problematic in the neo-classical framework and could be regarded as creating a bias. For example, Baron and Maxwell (1996) show that individuals' WTP can be biased by information on the cost of provision of public goods and suggest eliminating information from which costs could be inferred from CVM surveys so that respondents can focus more easily on benefits alone. While such redesign may avoid some types of bias, a more general issue, which remains, is how far individual preferences can be regarded as exogenous to the valuation process and, especially so, when goods are unfamiliar and/or never traded in a market.

### *Part-Whole Bias and Embedding*

This problem arises when the component parts of an individual's valuation are evaluated separately and, when summed, found to exceed the valuation placed upon the whole. CVM studies have found part-whole bias, also termed embedding, and this has been attributed by some to valuation of the moral satisfaction from contributing to a worthy cause ("warm glow") rather than the good itself (Kahneman and Knetsch 1992). The counter reaction has been that CVM surveys finding embedding are flawed in some way that creates the part-whole bias and that this can be corrected by careful survey design (Carson and Mitchell 1993, 1995; Hanemann 1994). However, Bateman *et al*. (1997) have provided experimental evidence for the existence of part-whole bias for private goods outside of the CVM context. They therefore suggest that the problem lies with economic preference theory rather than the CVM approach.

### *Hypothetical Market Error*

Valuations in a hypothetical market could make responses differ systematically from actual payments in actual markets. Random over and under statement would be a non-systematic error term and, therefore, would not represent a hypothetical bias (Mitchell and Carson 1989). In general, CVM studies avoid actual trade-offs, unless they are specifically testing for a hypothetical bias, and so the evidence on the impact of this bias is limited. A CVM study will be different from actual markets because there is no debate over the value of goods, no sequential learning from a series of purchasing decisions, and no enforcement of actual purchases. Thus, the extent to which hypothetical market bias occurs will be dependent upon how realistic the trade-off described is felt to be by respondents. Also relevant is whether the design has considered the type of incentives that might unintentionally be given to respondents.

### *WTP versus WTA*

WTA formats can generate more protest bids and outliers than WTP. Protest bids may occur because people are unwilling, on ethical grounds, to accept monetary compensation for the loss of an environmental asset (an implied loss of property rights). Outliers may be due to a rejection of the notion of compensation resulting in a large request for compensation based upon rejection of the implied trade-off, rather than an amount intended to represent their welfare loss.

Willig (1976) showed that these two welfare measures would be close if the ratio of consumer surplus to income was sufficiently small and if the income elasticity of demand for the good in question was sufficiently low. Where these conditions failed to hold, precise limits on the difference between the two measures could be calculated. While some criticized the applicability of Willig's findings to environmental benefits (Bockstael and McConnell 1980), others extended Willig's theorem to the quantity changes more commonly encountered in environmental valuation (Randall and Stoll 1980).

However, stated WTP has been found to be significantly lower than stated WTA (e.g., Hammack and Brown 1974; Rowe *et al*. 1980). In addition, experimental work has also found that WTA exceeded WTP (Gregory 1986; Knetsch and Sinden 1984). Several reasons have been given as to why WTA may be greater than WTP. First, actual WTA is greater than actual WTP when loss aversion occurs. Individuals value a given reduction in entitlements more highly than an equivalent increase in entitlements (Knetsch 1989). Second, income constrains WTP bids, unless limitless borrowing is possible, whereas WTA bids are unconstrained, making bounded trade-offs hard to enforce. Third, the availability of substitutes provides theoretical evidence for a difference. If private goods are poor substitutes for public goods, then WTA can be greater than WTP (Hanemann 1991). A public good with few private goods as substitutes will be valued differently because under WTP the loss of public good is prevented, while under WTA the private goods are meant to provide compensation and the public good is lost. Fourth, risk-averse consumers find they have only one chance to value the good under the typical CVM and will tend to overstate WTA and understate WTP. They do so due to uncertainty concerning the value of the good and in order to avoid a potential loss (Hoehn and Randall 1987).

On practical grounds, the status quo reference position is preferable in terms of the property rights structure. If an alternative is imposed by the blanket imposition of WTP formats in all CVM surveys, the result can be to create an unrealistic trade-off, hypothetical market bias and protest bids. Thus, rather than follow a generic prescription to always use WTP formats as a conservative estimate of values, the property rights prevalent in a given situation should be used as guidance. This reinforces the theoretical argument for using WTA to measure a loss and WTP for a gain (Knetsch 1994).

### *Dichotomous Choice versus Open-Ended Formats*

The dichotomous choice format has been recommended because those supporting the approach regard a one-off yes or no decision as closer to a free market. This is debatable in itself with the yes or no decision being closer to a political referendum. There should be some concern for the rejection of such an approach in countries where prices are often discussed and argued about rather than given as fixed. Also, to bind the range of choices when conducting dichotomous choice, an open-ended CVM is required as a first step. This means that those advocating dichotomous choice must defend the open-ended CVM. Neither format is clearly superior on *a priori* grounds. However, the dichotomous choice format does suffer problems in practice. The "yea-saying" problem may be evidence of an anchoring bias and has raised questions as to the usefulness of the format. Desvouges *et al*. (1993) found dichotomous choice exceeded the open-ended format and had greater variability. The results are sensitive to the choice of bids by the analyst, and the choice of functional form for mean estimation adds to variability in results.

### *The NOAA Panel: A Comment on Generalized Guidelines*

As the use of CVM has increased, so has the debate between supporters and detractors. Sagoff (1996) has critically attacked CVM and, in particular, what he terms the "Wyoming experiment" of the late 1970s and early 1980s. He sees the technique as economist venturing into the political realm, which he regards as totally separate. Applications to Kakadu National Park in Australia and the assessment of damages arising from the Exxon Valdez oil spill in Alaska created public controversy. In the Exxon case, one result was the suggestion that a specific set of guidelines for conducting a CVM should be followed.

A panel of experts was convened by the National Oceanic and Atmospheric Administration (NOAA) to fight pressure from Exxon coming via the Bush administration. The panel, which included Kenneth Arrow (Exxon consultant) and Robert Solow (State of Alaska consultant), gave qualified support for CVM. They produced guidelines which suggest there is one correct approach to conducting a "good" CVM study (i.e., methodologically similar to Cummings *et al*. 1986). Blind adoption of the NOAA guidelines has become a defense of the validity of specific work, although this ignores the variation in case study circumstances, such as whether property rights prescribe a WTP or WTA approach. In addition, merely quoting the use of NOAA guidelines seems inadequate defense and some regard for independent testing of the validity and applicability of both these guidelines and CVM results is required.

The extent to which CVM can be generalized is easily overstated. According to Cummings *et al*. (1986), CVM works best in only a limited range of circumstances. The most important rules are that respondents understand and be familiar with the commodity to be valued; that respondents have prior valuation and choice experience with respect to the commodity; that uncertainty about the operation of the hypothetical market is low; and that WTP is used in preference to WTA. However, the quantitative results of violating these conditions remain largely unspecified.

The NOAA panel guidelines include the use of WTP; in-house interviews on a random sample; full information on the resource change (including information on substitutes) and checks for understanding; closed-ended referendum formats (dichotomous choice); reinforcing budget restrictions; and careful pre-testing. They have also recommended reducing any resulting valuation, which raises questions over the derivation and credibility of this particular set of rules. In this regard, those using the guidelines should remember that the NOAA panel was politically appointed to adjudicate over the use of CVM in the USA as a result of the Exxon Valdez accident. The procedure for deriving the guidelines, with a Nobel laureate from each of the opposing camps on the panel, would be interesting to discover, along with the underlying justification for some of these rules.

A more general problem is the extent to which any one set of rules can dictate CVM research. The NOAA guidelines have not resolved the debate around CVM because they assume a technical solution regardless of the problem at hand. The rules try to impose a set behavioral model upon individuals (economic rationality) and reject divergent behavior (e.g., see the discussion of part-whole bias in Bateman *et al*. 1997). However, there can be general guidelines as to good practice rather than set formats for an idealised CVM survey that is universally applicable. Regard to bias problems, appropriate testing and conduct of the survey, and learning from past experience are obvious steps to adopt.

## Designing the CVM for the Coral Reef Case Studies

Two separate CMV surveys were designed—one survey for Jamaica and one for Curaçao. The main difference between the surveys, besides geographical and institutional context, arose in the development of the biodiversity improvement scenarios and management options to achieve them. The Jamaican survey was designed and tested first and this informed the Curaçao survey, but feedback on the Curaçao experience was also possible before either of the final surveys. This resulted in some simplification of the information presented and the development of show-cards that could be used in either country.

### *Developing the Information Pack*

The term "information pack" is used to summarize reference to all the descriptive materials included in a CVM survey to convey information about the environmental changes. Maps were sought to show the islands, the reefs by quality, mangroves, endangered or rare species, and main source points of pollution. This was to inform respondents as to the current areas of interest in terms of marine biodiversity, the threats to biodiversity, and the context for the proposed project. In addition, the area covered by the case study needed to be described along with some detail on what it would be protecting.

The final surveys included colour maps, descriptions to be read aloud by the interviewer, and show-cards for the interviewee to study. For each survey area, two maps were used. One showed the whole island and explained the location of the proposed project (i.e., the park) and identified other coral and marine resources (i.e., reefs, seagrass beds and mangroves), and, for Curaçao, the location of the endangered sea turtle. The second map detailed the use zones proposed within the parks themselves (e.g., recreation, fishing, multiple use, and shipping).

### *Institutional and Environmental Setting in Jamaica*

For Montego Bay, Jamaica, background information was gained from available documents which allowed a characterisation of both the environmental quality and the institutional setting. The aim was to find a realistic scenario in which to describe a reason why the general public might need to pay for biodiversity improvement. The choice of an institutional setting was interconnected with the environmental problem that would be selected. There appeared to be several anthropogenic causes of reef damage that could be used in a CVM approach:

1. *Overfishing*. A policy would need to be presented which gave an institutional setting under which overfishing would be reduced. This would need to be combined with knowledge of the system of regulation to assess whether a realistic reason for asking the general public to contribute to such a scheme was feasible. Problems with this approach were the institutional setting, fishing being related to use values creating confusion when separating non-use values, and the difficulty of blaming one cause for marine biodiversity losses.
2. *Mining the reef*. This is an extreme scenario where the entire reef is lost. The difficulty was that the total value, rather than marginal quality change, in the reef in its present state would be estimated. The problems were the hypothetical nature (i.e., the creation of a problem which did not exist), the high probability of protests, and the failure to relate to the current institutional setting. In addition, WTA compensation as the appropriate measure of welfare loss would add another aspect of experimentation to the study.
3. *Waste treatment plant*. The need to improve water quality was the focus here. Problems arose in that many individuals were probably not connected to sewage systems and so would have no obvious payment mechanism. These individuals might resent paying for others' externalities. The institutional setting in terms of who pays and who benefits from wastewater treatment would have needed clarification. In addition, the extent to which the issue would be connected to coral reefs rather than human health was unclear and separating out the effects could be difficult.
4. *Trust fund for restoration*. This was realistic and could be given an institutional setting within the Montego Bay Marine Park. A range of management options for restoration could be outlined and their expected consequences described. Thus, the CVM survey would

outline expected biodiversity benefits related to Park provision. No one issue was needed as a cause to be blamed for reef decline; rather, a range of causes could be identified. There were no obvious problems with this option. However, the credibility of the trust fund was identified as a potential problem because it would be dependent upon whether, for example, the government or a non-government organization (NGO) was seen as most trustworthy to manage such funds. Similar funds in existence in Jamaica (e.g., Portland Environment Protection Association) implied this would be unproblematic.

The Montego Bay Marine Park (MBMP), which had already formed a point of interest in reef management, immediately had the advantages of an actual institution with a record of marine ecosystem management and provided a realistic context within which a WTP scenario could be developed.

### *Institutional and Environmental Setting in Curaçao*

The best options raised for Curaçao were either: i) a trust fund to protect marine biodiversity to be used for the establishment and maintenance of a marine park along the south coast; or, ii) the improvement of the existing underwater park. The present underwater park, at the eastern end of the island, was deemed to be more substantive on paper than in fact. The site borders private property, effectively restricting access. Dive operators in the vicinity and the ecological institute (Carmabi/Stinapa) are the main users of the area. The limits on site access and the proximity of private property raised the following issues:

- The site might be seen as private property rather than a public good;
- Familiarity would be low;
- Use would be restricted, which would limit the survey more to indirect benefits; and,
- The possibilities for biodiversity improvement appeared limited.

At the time this project was being established (early 1997), a plan for a marine park along the whole south coast of Curaçao was developed by the agency responsible for the management of national parks (Stinapa). Thus, the best option was to base the CVM survey on this new plan. A major advantage was adopting an actual project proposal with an expected range of biodiversity improvements.

Information on the current state of Curaçao reef systems was gathered. There are very few mangrove areas and these are mainly surrounding inland lagoons. The main endangered or rare species identified were sea turtles, which have nesting grounds in one area of the islands. The main sources of pollution were industrial, primarily around the Willemstad refinery and the town itself. The main threat of physical damage was through the construction of artificial beaches. In terms of development, new tourist and population centers in the west and east were seen as potential threats.

### *Describing Marine Biodiversity*

Biodiversity is a difficult concept to explain quickly and simply. Previous experience has shown the very term is often poorly understood by the general public and even among sub-groups with high education levels (Spash and Hanley 1995). However, people are quite often familiar with the ideas that lie behind the concept and these need to be brought out before any WTP questioning. The survey downplayed academic wording while portraying the same information.

### *Defining and Describing the Coral Quality Change*

A major concern in designing the CVM survey was the characterisation of the environmental change and its cause and impacts on biodiversity. There was a period of consultation with marine biologists, ecologists and conservationists familiar with the sites and biodiversity degradation of coral reefs in general. Experts advised on the characterisation of the problem for the survey. On this basis, the Jamaican pre-test tried to explain the concept of coral reef abundance. Coral reef abundance was felt to be the best approximation to a measure of coral reef species diversity and health. The description of coral reef degradation and improvement in the WTP preamble and question was in terms of percentages from a maximum (100%). The general public was able to comprehend the idea of percentage changes from a hypothetical maximum without going into the detailed scientific reasoning. The aim was, therefore, limited to describing the environmental trade-off and the benefits from the proposed project.

### *The Benefit Payment Scenario*

In order to design a payment scenario, the project being paid for must be described in enough detail to allow respondents to understand the net benefits. This requires an understanding of the current environmental status quo and the institutional context. The overall aim must be a realistic, if hypothetical, proposal. As explained above, environmental quality within the proposed parks was characterized to give a background picture.

In order to achieve a stated improvement in marine biodiversity, a set of management actions needs to be described. This requires some knowledge of the powers and jurisdictions of institutions so that management options attributed to the manager of the trust fund are realistic. For example, such things as tourist development projects and designation and enforcement of shipping lanes may be regarded as outside park management's jurisdiction.

The reduction of the nutrient and sediment loading onto the reef was seen as the main problem. This could be achieved through sewage treatment and industrial pollution control. However, a marine park is more likely to be involved in monitoring to determine whether such standards are being met and the occurrence of physical damage (e.g., due to anchors from fishing and diving boats). In these cases, the park is unlikely to be actually installing or running mitigating measures. However, the enforcement of the measures and provision of data and information to ensure the measures are enforced could be within park jurisdiction. The management options selected as examples for the survey were, in the end, found to be common to both the South Coast Marine Park in Curaçao and the Montego Bay Marine Park in Jamaica. These were:

- Planting mangroves and coastal plants to reduce impacts from run-off;
- Establishing monitoring of water quality, fish, plant life and mangroves;
- Establishing mooring buoys for fishers;
- Enforcing and patrolling use zones; and,
- Enforcing fishing regulations.

Several other possible management strategies were dropped as being outside of the jurisdiction of the parks:

- Treatment of sewage;
- New drainage systems for storm waters;
- Encouraging proper disposal of chemicals, garbage and other waste to improve water quality;
- Promoting higher industrial effluent treatment; and,
- Limiting inshore dumping by ships.

The current state of the reef system to be included in the park must be given and the expected improvements detailed. Knowledge of the existing situation can be used as the "business as usual" scenario and predictions made about the quality of the environment at some point in the future. This is then compared to the situation at that time with environmental measures in place.

In terms of environmental changes, the "business as usual" scenario is given by the current policy. The CVM survey could use the characterisation of reef quality to imply either stability of the reef system or, more realistically, degradation by a given percentage over a given period of years. The parks would then be described in terms of a "policy on" situation where degradation is avoided or coral abundance is increased. Thus, the management aim could be to either improve reef biodiversity or prevent biodiversity reductions and reef deterioration that would otherwise occur. In the survey, a mixed approach was felt to be most realistic. That is, the current situation of the coral reefs was estimated to be one of deterioration, but in both countries institutions had been identified which were working on reef maintenance. This allowed the current situation to be described as one in which the reef would deteriorate without any action, but that some action was already ongoing. This ongoing management would then allow the reef quality to be maintained at present levels, which had been characterized as degraded. The proposed project for which individuals would be asked to pay would increase the coral abundance from this level. The two scenarios were both for a 25% improvement.

### *Survey Sections and Questions*

The layout for the CVM survey used here has been developed over several years. The design makes use of individual sections to separate a group of issues. In this instance, five main sections were included:

1. *Framing and background information*. The public policy context is described in terms of related issues that are of concern. That is, by a series of questions, the interviewees are made aware of a range of issues among which the environment is but one. They are asked to think about and reflect upon their own priorities. This also helps reinforce the concept of society having limited resources and there being a set of possible public policy issues requiring attention. The idea of framing is to place the problem of coral reef degradation within a broader context. Thus, the questions move from a very general level, with no mention of the environment, to environmental issues and the specific case study sites. Failure to frame the issues may be regarded as promoting one specific issue without any context and has been cited as a cause of embedding problems. Besides being concerned with framing the issue, this first section also gathers background information on the interviewees' knowledge of the site and provides information. The site information is given via maps and a short description. This aims to give all respondents a basic level of knowledge about the area and places it within a geographical context. Such information also acts as another framing device by showing other areas of coral reef and environmental habitat that may be regarded as substitutes. Background information on the interviewees' knowledge and use of the area is also gathered at this

stage. By the end, the context has been set and the interviewee has had to think about the coral reef case study area, their knowledge of the site, the benefits they gain from the coral reef, and their knowledge of biodiversity and, in particular, marine biodiversity.

2. *WTP into the trust fund*. The information forming the background to the WTP question has been described above. The scenario is to improve coral reef biodiversity by 25% given a set of management strategies to be adopted by a marine park. The park will have a trust fund set up explicitly for the purpose. Payment could have been on several bases, but a per annum payment for five years was felt to be reasonably realistic. Beyond five years, people are unlikely to regard actual payment as likely. The main alternative would have been to request a one-time payment and then try to estimate the time period or interest rate over which this might represent a discounted present value. This introduces unnecessary complications and, therefore, the per annum five-year payment mechanism was employed. The bid question was open-ended. Following the bid question, respondents were asked to explain the reason for their response. Tourists claiming no spare income had been noted to be an unusual group in the pre-test for Jamaica and interviewers were directed to probe these respondents. Probing was also requested in the case of those making extremely high bids. A coding table was developed for the zero bidders from the pre-tests. A separate question explores the embedding problem. The approach was to ask respondents whether they would increase their bid if a greater reef area were to be included in the project. Respondents should be prepared to do so unless they place no value on other reef systems. If they state that their bid was to cover all reefs, then a case of embedding has occurred. Subsequent questions probe indirect use values. Respondents are reminded of the uses they make of the area and the expected direct benefits of the project for them. Once the respondents are thinking of the uses they are asked to imagine leaving the island never to return. They are then asked whether this would lead to a reduction in their WTP and, if so, by what percentage. In the pre-test, a few respondents actually increased their bid despite being told their circumstances would be the same. In the final survey, the interviewer was requested to probe such respondents for their reasoning. Next, payment by volunteering hours was requested. This allows the unemployed and those on a low income to contribute to the project. In developing economies, payment by hours may be seen as more practical for many. The respondents were asked to make a commitment over five years, the same period as for the WTP question. The final question in this section was on the impact of information on the individual's preferences. The concern here was to see if the survey was informing the respondent, forming their preferences on coral reef degradation, or both.

3. *Rights and responsibilities*. This section had four questions. The first question splits the sample by the degree to which they attribute the right to be free from harm to five categories of potentially morally considerable groups. The five groups were: i) other humans now living; ii) future generations; iii) marine animals; iv) marine plants; and, v) marine ecosystems. Rights were attributed using a three-point scale with each point being associated with a position. The three positions can be summarized as: i) rights apply absolutely; ii) rights depend upon the circumstances; and, iii) no rights apply. Respondents could also answer "don't know". Those who responded by attributing a right under any category were then probed regarding their readiness to make trade-offs that might occur by the claimed attribution of a right. Thus, within the context of the park, the respondent was asked to agree or disagree with a personal responsibility to prevent harm regardless of the cost. They were then further probed to consider their answer. Those claiming such a responsibility were asked to reconsider if the cost was their current standard of living. Those rejecting the responsibility were asked to reconsider if their current standard of living was maintained. The final question asked how the individual thought the rights they had identified for the park should be protected.

4. *Socio-economics*. The collection of socio-economic data allows population statistics to be calculated and aids bid curve analysis. A set of standard questions was included to cover gender, age, education, and income. In addition, occupation was requested as a check on income and a few experimental variables added, namely dietary preference and religion.

5. *Interviewer response*. The interviewer was asked to give some feedback. The first question was whether others had been listening while the survey was conducted as this can lead to respondents saying what they think others want to hear and being reticent about their own beliefs. Next, the interviewer was asked to rank the difficulty the respondent had in answering each section. Finally, they were requested to note any specific questions that were found to create a problem for the respondent.

## Pre-test Results and Survey Redesign

The survey was designed to derive estimates of non-use biodiversity values and test for the importance of a refusal to make trade-offs of money for environmental quality (i.e., the occurrence of lexicographic preferences). The survey for Curaçao was adapted from the Jamaican case study. This survey was pre-tested and updated prior to the survey being applied in Curaçao. Although the survey had already been pre-tested in Jamaica, the redesign and new cultural and geographic context meant a pre-test was also recommended for the Curaçao case study. Thus, survey pre-tests were conducted in both Jamaica and Curaçao.

The pre-test survey is a crucial stage in the development of a CVM survey and requires sampling the population from which the main test sample will be drawn. Typically, a pre-test is performed on 100 to 150 people with qualitative feedback being the central aim, rather than attempting to gain quantitative results. The aim of pre-testing is to identify any areas where the survey may be misinterpreted, where questions produce unexpected results, and, more generally, to identify areas requiring improvement. For example, misinterpretation can occur due to the use of excessively technical language in the description of environmental quality changes and probing a sample of the general public can make the analyst aware of divergence from the common use of language.

Both the interviewer and interviewee are important sources of feedback during the pre-test. Where survey design requires optional sections, the interviewers must be able to understand the sequencing of questions they are to relay. The CVM surveys used here required the design of questions to probe sub-samples and, therefore, were reasonably complicated and care was taken to re-design the format in light of interviewer comments. The pre-test was also a learning experience for the survey co-ordinators who were responsible for training the interviewers. This allowed the coordinators to revise the method of training and improve on the selection procedure for interviewers. In countries where market research companies, who are practiced in such matters, are unavailable, selection and training of the domestic coordinators takes on specific importance.

The results of the pre-test were used to make several improvements prior to the implementation of the main survey. Among the lessons for survey coordinators, which as mentioned above may be particularly relevant in the context of developing countries, are the following:

- Use older, more mature individuals able to understand the local language and probe the respondent when necessary;
- Increase the level of in-depth individual training of the interviewers;
- Increase the intensity and quantity of feedback given to the interviewers after surveys have been completed;
- Carry out the surveying over a longer period of time to allow quality control after a batch of surveys have been completed;
- Keep a close record of what each interviewer has received and done; and,
- Feedback the survey quota results to the interviewers to keep them informed.

In Curaçao, the survey required re-translation in selected areas. Changes were also made to the original translation in order to maintain direct comparability across different language versions. The administrators in each country selected and trained a set of interviewers (i.e., conducted sessions on familiarisation with the survey and an assessment of the interviewer as a competent but neutral purveyor of the survey information and questions). In addition, close quality control was undertaken to ensure at least 1,000 completed surveys were collected. The outcome was 1,152 surveys in Curaçao and 1,058 in Jamaica.

Detailed results of the main surveys for Jamaica and Curaçao (i.e., population sample statistics and data results for specific sections of the questionnaires) can be found in Spash *et al*. (1998). The remainder of this chapter will be concerned with the analysis of the WTP data and lexicographic preferences.

## Lexicographic Preferences and WTP

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

Monetary valuation of the environment requires the definition of commodities in a way fundamentally identical to marketed goods and services. That is, when an environmental improvement occurs, an individual must give up some consumption of other commodities to maintain a constant utility level. This gives an individual's WTP amount, which can then be summed across all affected individuals to obtain an aggregate WTP figure. Similarly, the minimum quantity of other commodities demanded to accept a reduction in environmental quality is the WTA compensation. In this case, expenditure on other goods must be increased to compensate for the reduction in environmental quality, so maintaining the individual's initial level of welfare. Whether the other commodities are regarded in terms of a single numerate (i.e., money) or remain as a diverse set of goods and services is inconsequential.

The essential message of the normal indifference curve is that individuals are able to swap one bundle for another and can do so for a set of bundles without affecting their welfare level. As mentioned, a problem arises if, for example, an individual believes that aspects of the environment have to be protected without regard to the cost in terms of other commodities. That individual will refuse all money or commodity trade-offs that decrease what is regarded as an environmental commodity in the neo-classical framework. In theory, WTP to prevent the loss would be all the available commodities the individual could command (i.e., their income) and WTA compensation would be infinite. The respondent believes the aspect of the environment in question should remain at or above its current level in terms of either quantity or quality.

Such preferences mean that utility functions, including environmental aspects that are to be protected at all cost, are undefined for an individual (since the axiom of continuity is violated) and that indifference curves collapse to single points (denying the principle of gross substitution). These preferences are termed lexicographic by neo-classical economics because they give absolute priority to one commodity over all others and, therefore, imply a strict ordering as in a lexicon. The position described is, however, best regarded as extreme because its implications for the individual are total sacrifice for the environmental aspect to be protected (e.g., coral reef biodiversity). Economists have tended to regard the denial of continuity and violation of gross substitution as of little relevance because lexicographic preferences are unrealistic and unlikely to occur (Malinvaud 1972, p.20).

The extreme lexicographic position does indeed seem likely to be uncommon because of this overriding ranking of a good above even the individual's own life. The modified lexicographic position might be drawn-up in terms of first attaining a minimum standard of living prior to being prepared to defend the environment. Following Pigou (1920, p.759) this minimum might include, but not be restricted to, a defined quantity and quality of housing, medical care, education, food, leisure, sanitation and safety at work. Sen (1988), appealing back to notions of Adam Smith, goes further and defines functionings (the various living conditions we can achieve) and capabilities (our ability to achieve them) as essential parts of living standards rather than commodities. Such a living standard might be relatively materialistic in societies where being a functional member of society is defined in such terms (e.g., requiring ownership of a car and a television). As Sen (1988, p.17) states: "The same capability of being able to appear in public without shame has variable demands on commodities and wealth, depending on the nature of the society in which one lives". In this formulation, the concept of lexicographic preferences becomes more readily acceptable, but the definition for empirical purposes becomes far more difficult because the minimum living standard is expected to differ among social groupings.

## Rights and Lexicographic Preferences

Lexicographic preferences are signified by a discontinuity in the preference function giving a single point, or bundle of goods, as the indifference set in goods space. The aim of the surveys reported here was first to identify the occurrence of such preferences and then see how far these might be indicative of a refusal to make trade-offs. This was achieved by direct questions on ethical beliefs that signify behavior incompatible with a continuous preference function, follow-up questions and consistency checks. The approach to dealing with lexicographic preferences taken here was based upon previous work (Spash 1993b, 1997, 1998c; Spash and Hanley 1995). The general approach to lexicographic preferences is reviewed next in light of the few key studies previously conducted.

The dominant economic theory of decision-making requires a fundamental philosophical assumption—namely, that individuals believe the net utility from the consequences of an action determines whether that action is right or wrong. Cost-benefit analysis and its tools, such as CVM, assume that individuals are able and willing to consider trade-offs in relation to the quantity and/or quality of public goods. Debates in environmental ethics have raised the issue of individuals refusing to make these judgments and so raised serious problems for the application of economic efficiency arguments (Sagoff 1988; Spash 1993a, 1994). One aspect of refusal can be a basis of belief in inviolable rights so that actions are intrinsically of value or deontological.

Neo-classical economists reject the notion of deontology because there is an assumed rationality attributed to the ability to make trade-offs, whatever the commodity, as long as enough compensation is offered in return. This can be summarized by the old colloquialism that everybody has his or her price. However, some individuals may treat certain aspects of the environment differently from the manner suggested by this theoretical framework. If an individual believes that aspects of the environment, such as wildlife, have an absolute right to be protected, then that individual will refuse all money trade-offs that degrade what is regarded as an environmental commodity in the neo-classical framework. Thus, the prevalence of the deontological position seems likely to be high among those who claim absolute rights to life for humans and other animals, future generations, trees or ecosystems. In contingent valuation, evidence exists in developed countries to suggest individuals express lexicographic preferences for wildlife (Stevens *et al*. 1991) and these relate to rights for animals, plants and ecosystems (Spash and Hanley 1995).

## The Coral Reef Survey Results

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

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

More specifically, respondents were initially asked to use the following categories in attributing or denying rights: an absolute right to be protected from harm applies to this case; a right applies that depends upon the circumstances and may, therefore, be withdrawn under certain conditions; or, no such rights to protection from harm applies to this case. The case where they had to decide which of these categories applied were: i) other humans now living; ii) future human generations; iii) marine animals; iv) marine plants; and, v) marine ecosystems. Respondents could answer that they just did not know, but only 0.2% in Jamaica and 2.1% in Curaçao found this necessary. Table 6.1 shows that almost all the sample are prepared to attribute rights to the first of these categories and that, for Curaçao, this declines moving from i) to v), while, for Jamaica, no decline occurs. More than just attributing rights, the respondents in the majority of cases are attributing an absolute right to protection from harm. Marine animals, plants and ecosystems are attributed these absolute rights by approximately 60% of the Curaçao sample and over 80% of the Jamaican sample.

People may fail to consider whether they are actually prepared to defend this position by making choices in their daily lives. Also, in over 60% of the cases, other people were listening while the interview was being conducted, which might stimulate a social norm. In order to address this issue, those who attributed a right to any of the five categories above were then asked a set of follow-up questions.

The follow-up questions were design to introduce the potential for needing to make trade-offs and to confront the respondent with a reasonably extreme case. The question was also made more specific and related to the marine park in question in order to give the rights-based position a context linked to the WTP questions. The respondents who had attributed any rights to one of the five categories were therefore initially asked whether, in the case of the relevant marine park, they believed the rights they had attributed meant a personal responsibility to prevent harm regardless of the cost. This is equivalent to reflecting that a duty for an individual would result from enforcing a right. The result was approximately 79% of the Jamaican and 68% of the Curaçao respondents answered affirmatively.

Next, respondents were channeled into two separate questions. Those affirming that they have a personal responsibility regardless of the cost were asked whether they would accept harm to the relevant island's marine life and habitat if trying to prevent it would threaten their current living standard. The other group of respondents, who had denied rights in this case, was also asked to reconsider

**Table 6.1.** Rights to protection from harm (% of total survey sample of 1,152 for Curaçao and 1,058 for Jamaica).

| | *Absolute right applies* | | *Right applies depending upon the circumstances* | | *No right applies* | | *Don't know* | |
|---|---|---|---|---|---|---|---|---|
| | Curaçao | Jamaica | Curaçao | Jamaica | Curaçao | Jamaica | Curaçao | Jamaica |
| Other humans now living | 84 | 82 | 9 | 16 | 5 | 2 | 2 | 0 |
| Future human generations | 81 | 82 | 12 | 15 | 4 | 2 | 3 | 1 |
| Marine animals | 57 | 82 | 32 | 13 | 5 | 2 | 6 | 3 |
| Marine plants | 58 | 85 | 29 | 9 | 5 | 3 | 8 | 3 |
| Marine ecosystems | 60 | 84 | 25 | 10 | 4 | 3 | 11 | 3 |

given a more specific scenario. In their case, they were asked whether they would accept a personal duty to avoid harming the relevant island's marine life and habitat if their current standard of living would be unaffected. The outcome of these questions is to enable the sample to be split into four categories (in addition to those denying any rights to any of the five categories described earlier):

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

The results for the two countries are shown for locals and tourists in Table 6.2. The two middle categories, 2 and 3 above, show a willingness to make trade-offs that is consistent with a modified lexicographic position (i.e., once a basic standard of living is obtained, a stronger ethical position for other species is adopted). A readiness to consider the trade-off circumstances and the subjectivity of the relevant standard of living means that individuals in these categories may be regarded as acting as utilitarians and weighing-up the trade-offs. The situation

**Table 6.2.** Personal responsibility to protect life and habitats in the marine park.

| | *No rights in this case* | *No duty* | *Remove duty if cost high* | *Attribute duty if cost low* | *Strong duty* | *Total* |
|---|---|---|---|---|---|---|
| **Curaçao** | | | | | | |
| Number of locals | 2 | 91 | 262 | 120 | 173 | 648 |
| Number of tourists | 8 | 77 | 185 | 75 | 135 | 480 |
| Total number | 10 | 168 | 447 | 195 | 308 | 1128 |
| Total (% of sample) | 0.9 | 14.9 | 39.6 | 17.3 | 27.3 | 100[a] |
| **Jamaica** | | | | | | |
| Number of locals | 10 | 64 | 328 | 74 | 88 | 564 |
| Number of tourists | 0 | 46 | 342 | 34 | 70 | 492 |
| Total number | 10 | 110 | 670 | 108 | 158 | 1056 |
| Total (% of sample) | 0.9 | 10.4 | 63.3 | 10.2 | 14.9 | 100[a] |

[a]Row may not add to 100% due to rounding errors.

for Jamaica shows a dramatic reduction in those attributing absolute or strong rights from 79% down to 14%. Similarly, although slightly less dramatic, for Curaçao the reduction is from 68% to 28%. Despite this large reduction, there is still a sizeable hardcore of individuals taking a position consistent with strong lexicographic preferences. This leaves the question open as to how these individuals expect to protect the rights they hold so strongly and how they would avoid having to make a trade-off decision, for example, where material goods are equated to the discharge of the moral duty being described. In order to try and address these issues, another set of follow-up questions was asked.

## How to Protect Rights?

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

As mentioned earlier, both zero and positive bid strong duty holders are potentially signifying lexicographic preferences. The way in which this entire group, which is prepared to protect the marine environment at personal cost, believes the rights they have identified are to be protected is shown in Table 6.3. The biggest grouping of responses falls upon two methods for protecting the rights identified within the marine park. In Jamaica, 66.4% and, in Curaçao, 48.3% of respondents wanted rights to be protected by either a legal approach or education, or a combination of the two. Some of those holding a strong duty position felt the trust fund was also a good idea and would help in the protection of the rights they had attributed to the marine environment. Others gave responses combining more than one category. The miscellaneous category includes a variety of actions to be taken by various bodies or unspecified groups (e.g., NGO initiatives), unspecified schemes, and restriction of specific activities (e.g., harpooning, anchoring, creation of beaches, diving, allowing technology to prevent pollution, economic development).

The overall picture can be viewed as a proportion of these individuals externalising the cost to other parties or organizations. Alternatively, there may be a genuine failure to consider the cost of the proposed solution. The main category that avoids externalising the cost and maintains a position consistent with a strong lexicographic preference is that of the "lifestyle change". Education may also cover a range of activities that go beyond the

**Table 6.3.** How to protect a strong duty position (code method of protection: 1=legal enforcement, regulation and policing; 2=international community funded initiatives; 3=lifestyle and fundamental behavioral changes; 4=education, formal and informal (e.g., media); 5=user fees; 6=government responsibility and tax funded initiatives; 7=combined education and legal approach; 8=combined various approaches; 9=other miscellaneous approaches; 10=don't know).

| | *Method of protection by code total* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
| **Curaçao** | | | | | | | | | | | |
| Number of locals | 51 | 2 | 12 | 30 | 17 | 14 | 8 | 12 | 8 | 19 | 173 |
| Number of tourists | 28 | 6 | 7 | 28 | 8 | 10 | 4 | 16 | 5 | 23 | 135 |
| Total number | 79 | 8 | 19 | 58 | 25 | 24 | 12 | 28 | 13 | 42 | 308 |
| Total (% of sub-sample) | 25.6 | 2.6 | 6.2 | 18.8 | 8.1 | 7.8 | 3.9 | 9.0 | 4.2 | 13.6 | 100[a] |
| **Jamaica** | | | | | | | | | | | |
| Number of locals | 42 | 2 | 5 | 18 | 1 | 2 | 6 | 5 | 1 | 6 | 88 |
| Number of tourists | 20 | 1 | 5 | 15 | 1 | 4 | 4 | 2 | 10 | 8 | 70 |
| Total number | 62 | 3 | 10 | 33 | 2 | 6 | 10 | 7 | 11 | 14 | 158 |
| Total (% of sub-sample) | 39.2 | 1.9 | 6.3 | 20.9 | 1.3 | 3.8 | 6.3 | 4.4 | 7.0 | 8.9 | 100[a] |

[a] Row may not add to 100% due to rounding errors.

classroom and remain consistent with the ethical position. However, given the limited extent of allowance for open-ended responses on the subject possible in the current survey, little more can be read into this.

The implication for stated WTP is that, in many cases, those holding a strong duty position are prepared to pay for a different institutional framework (e.g., a judicial approach) if required to do so. This, of course, creates a practical problem for a CVM survey that, as part of the design, selects one institutional approach to the problem at hand. In addition, there is the theoretical problem that, where respondents are prepared to pay for an institutional framework, this fails to be a reflection of the resource value, but is rather a contribution to a social construct. An extension to the current research would be to experiment with alternative institutions to see how WTP or WTA varies.

## Internal Consistency of Responses

The characterisation of the change in biodiversity as an improvement also has implications for the trade-off. That is, the expectation of a lexicographic preference is that individuals will bid all their spare income in such a situation for even a small improvement. In fact, individuals may reject the institution that imposes such a condition upon them. This behavior has the advantage for the individual of avoiding acceptance of an institution, which may lead to a potential irreversibility. That is, if the improvement were reversed and the WTP bid had been made, the individual would now have no spare income to give a positive WTP and would then be classified as a zero bidder. The approach taken by Spash and Hanley (1995) was to identify zero bids for non-zero value reasons, identify protest bids and see how many of these were consistent with a lexicographic preference. The hypothesis was then that individuals protest against CVM and bid nothing rather than take part in a process which implicitly buys and sells improvements in what are seen as rights and duties. This approach is followed below and allows the results to be compared with the earlier work.

However, a qualification is necessary. We note that a positive bid by a believer in strong duties can still be consistent with a lexicographic preference. Such individuals are rejecting neo-classical choice theory but are acting in a way consistent with the expectations of mainstream economic theory by giving a WTP amount. If the less extreme modified lexicographic preference position is adopted, positive bids are expected to be the amount above a minimum standard of living. An additional complication is then that while the position seems more reasonable because it is less extreme, that lack of extremity means it is also difficult to identify. That is, positive bids may be given that reduce income to a subjective minimum living standard but this minimum is unknown. One way we try to address the positive bid issue is by using scaling and dummy variables in the bid curve analysis reported later.

First, consider the zero bids, which are taken as a rejection of a trade-off. The only data that is of interest with regard to the lexicographic position is taken to be that defined by the strong duty category. Note that this assumption may be questioned for a modified lexicographic model where a minimum living standard is defended first and, if threatened, takes priority. Positive and zero bids can split this category. The survey allowed for bids by both time and money as shown in Table 6.4. That is, the project gave the scope for including voluntary work to improve marine biodiversity and this was seen as an important alternative in a developing country context where many may be on a low wage or in a non-monetary economy. The impact of this approach is to reduce the zero bid category considered here beyond that of the monetarily defined. Remember, those who show a positive WTP in time and/or money may be indicating that they would be prepared to make a trade-off (indifference) or that they are giving up a substantive part of their current living standard (lexicographic). The zero bidders as a sub-group of strong duty holders are quite small in contrast to previous findings of 3.4% to 7.5%.

Next, the reasons for giving a zero bid are analyzed. These are divided into accepted economic reasons for a zero bid (i.e., income constraint or no value). The remaining reasons, shown in Table 6.5, are taken as indicating non-zero value. The outcome is to reduce the protest zeros, which are consistent with a strong lexicographic preference as defined by the strong duty, to 1.7% for Curaçao and 4.8% for Jamaica.

### *Bid Curve Analysis*

Analysis of the determinants of WTP is particularly relevant to the purposes of the coral reef valuation project. The variables, which are hypothesised to determine variations in WTP, can be specified and studied via econometric analysis. In this section, bid curves are reported for the two case studies. The approach used in this section relies on a "tobit" analysis of the sample. Although many bid curve analyses rely on ordinary least squares (OLS) procedures, such techniques may be flawed when applied to data sets such as those generated by our surveys. The procedure is detailed in standard texts on limited dependent variables (e.g., Maddala 1983) and has been applied

**Table 6.4.** WTP of individuals holding a strong duty position.

| | *Zero bid* | *Positive bid time* | *Positive bid money* | *Positive bid time and money* | *Total* |
|---|---|---|---|---|---|
| **Curaçao** | | | | | |
| Number of locals | 38 | 19 | 82 | 34 | 173 |
| Number of tourists | 46 | 16 | 41 | 32 | 135 |
| Total number | 84 | 35 | 123 | 66 | 308 |
| Total (% of sample) | 7.5 | 3.1 | 10.9 | 5.9 | 27.3 |
| **Jamaica** | | | | | |
| Number of locals | 10 | 8 | 39 | 31 | 88 |
| Number of tourists | 26 | 7 | 29 | 8 | 70 |
| Total number | 36 | 15 | 68 | 39 | 158 |
| Total (% of sample) | 3.4 | 1.4 | 6.4 | 3.7 | 14.9 |

**Table 6.5.** Identifying reasons for non-zero bids by strong duty respondents.

| *Zero bidders by reason* | *Curaçao* | *Jamaica* |
|---|---|---|
| **Zero Economic Value Reason** | | |
| Low income or unemployed | 20 | 13 |
| Reef improvement unimportant | 5 | 0 |
| Non-resident | 25 | 5 |
| Total (% of sub-sample) | 59 | 50 |
| **Non-Zero Value Reason** | | |
| Paying incorrect solution | 6 | 1 |
| Improvement will occur anyway | 2 | 0 |
| Mistrust marine park institution | 3 | 2 |
| Government is responsible | 21 | 3 |
| Could not place a money value | 0 | 3 |
| Other | 2 | 6 |
| Refused to answer or don't know | 0 | 3 |
| Total (% of sub-sample) | 41 | 50 |
| Total number | 84 | 36 |

within the context of environmental economic household and individual choice decision models (e.g., Ruitenbeek 1996). A maximum likelihood estimation (MLE) procedure sets up a likelihood function and through iteration provides an efficient solution to the tobit specification. The procedures are analyzed based on the significance of individual explanatory variables (through t-statistics) and, when comparing models, through a likelihood ratio test based on a chi-square distribution. All tests of significance are reported at a 95% level of confidence.

**WTP Determinants for Curaçao**

A range of variables was available from the survey and those considered most important are shown in Table 6.6. A bid curve analysis, using a semi-log linear form, for Curaçao shows determinants of WTP as a set of standard socio-economic variables, knowledge and the position taken towards rights (i.e., a lexicographic type preference).[3] The socio-economic variables are gender, age and education. Income would be another standard variable expected to determine WTP, but is excluded here.

**Table 6.6.** Variable definitions and basic statistics for Curaçao.

| *Variable* | *Mean* | *Min* | *Max* | *Valid number* | *Label* |
|---|---|---|---|---|---|
| TL | 0.43 | 0 | 1 | 1152 | Tourist (1) or local (0) |
| LANGDUTC | 0.36 | 0 | 1 | 1145 | Language Dutch |
| LANGENG | 0.18 | 0 | 1 | 1145 | Language English |
| LANGPAP | 0.46 | 0 | 1 | 1145 | Language Papiamentu |
| BENUM | 1.41 | 0 | 5 | 1151 | Number of benefit categories |
| VISITF | 0.88 | 0 | 1 | 1152 | Visit site in future |
| KNOWMBD | 4.68 | 1 | 10 | 1152 | Knowledge of marine biodiversity |
| PREFINFO | 0.37 | 0 | 1 | 1152 | Preference change and information effects |
| HARMMA | 1.45 | 1 | 3 | 1078 | Anti-rights to marine animals |
| HARMMP | 1.43 | 1 | 3 | 1060 | Anti-rights to marine plants |
| HARMME | 1.38 | 1 | 3 | 1022 | Anti-rights for marine ecosystems |
| RIGHTSEA | 4.84 | 0 | 6 | 988 | Marine animal/plant/ecosystem rights |
| NODUTY | 0.16 | 0 | 1 | 1128 | No rights/duty to marine environment |
| STRDUTY | 0.27 | 0 | 1 | 1128 | Strong duty |
| SEX | 0.50 | 0 | 1 | 1152 | Gender (male=0; female=1) |
| AGE | 4.24 | 1 | 10 | 1151 | Age by category (1=low; 10=high) |
| EDUC | 2.86 | 1 | 5 | 1139 | Level of educational attainment |
| INCOME | 3.25 | 1 | 10 | 642 | Level of gross income (coded) |
| WTPALL | 49.16 | 0 | 2000 | 971 | WTP (NAF) |
| LNWTP3 | 1.88 | 0 | 7.6 | 971 | Natural log of (WTPALL+1) |
| PROBC | 2.39 | 1 | 10 | 1149 | Ease/difficulty with Section C of survey |

This is because income is correlated with age and education and, therefore, little is added to the explanatory power of the equation if both sets of variables are included. In addition, the income variable only had 642 responses so that its inclusion would severely reduce the number of degrees of freedom in the estimation. Even the responses gained for income were suspected to be suffering from under-reporting, which is especially problematic when others are listening to the interview. The inclusion of a dummy variable for tourists versus locals was strongly insignificant, showing no difference. A set of dummies were also tried to test for the impact of language because the survey was translated into Dutch and Papiamentu, but these were also found to be strongly insignificant by the t-test. The final model results are shown in Table 6.7.[4]

The knowledge and use variables proved significant determinants of WTP. Knowledge of marine biodiversity (KNOWMBD) was derived from a survey question where individuals used a 10 point scale to signify their prior knowledge of the concept after having had a description. Greater knowledge increases WTP. This is also true for the use related variable, giving the number of benefits the individual derives from the marine park (BENUM; e.g., swimming, diving, site seeing, sunbathing).

A set of variables was also included to measure the ethical stance being taken by the respondent. First is the attitude of the individual towards rights. A seven point scale was developed from the questions of the survey covering the attribution of a right to be protected from harm to marine animals, plants and ecosystems (RIGHTSEA). The idea was to create a scale on the basis of the consistent attribution of rights. Respondents who answered "don't know" to any of the three groups were treated as missing data and so no position on the scale was given to these respondents. Those attributing absolute rights to all three aspects of the marine environment were ranked highest, and those denying rights in all three cases ranked lowest, with a graduating scale between these two extremes. As can be seen, rights for the marine environment are positively related to WTP, which means these individuals could be misconstrued as making an implicit trade-off of their rights position and this was implied earlier by the development of the "strong duty" category. Here, the data on personal duties is also incorporated in the equation.

**Table 6.7.** Preferred tobit model for Curaçao. The dependent variable is LNWTP3. Model has 463 limit observations (zero) and 508 non-limit observations. The predicted probability of y > limit given average $x_i$ is 0.5868. The observed frequency of y > limit is 0.5232. At mean values of $x_i$, E(y)=1.5657.

| *Variable* | *Normalised coefficient* | *Standard error* | *Asymptotic t-ratio* |
|---|---|---|---|
| SEX | -0.17322 | 0.073843 | -2.3459 |
| AGE | 0.054646 | 0.018042 | 3.0288 |
| EDUC | 0.18416 | 0.039794 | 4.6278 |
| KNOWMBD | 0.051143 | 0.013414 | 3.8126 |
| BENUM | 0.18653 | 0.039808 | 4.6857 |
| RIGHTSEA | 0.15628 | 0.024749 | 6.3143 |
| NODUTY | -0.31661 | 0.11346 | -2.7904 |
| STRDUTY | 0.16615 | 0.080436 | 2.0656 |
| PROBC | 0.041131 | 0.019463 | 2.1133 |
| PREFINFO | 0.60101 | 0.074180 | 8.1020 |
| CONSTANT | -2.0385 | 0.21111 | -9.6561 |
| LNWTP3 | 0.33092 | 0.011671 | |

The role of ethical positions is confirmed by the significance of the dummy variables on the personal duty to protect the life and habitats of the marine park. The dummy variables represent those respondents taking the strong duty perspective (STRDUTY) and those rejecting any duty (NODUTY). As can be seen, a strong personal duty, regardless of the cost, is positively correlated with WTP, while the rejection of this duty reduces WTP. This shows that WTP for biodiversity improvement is partially related to the ethical concern people show for marine animals, plants and ecosystems. Also, a variable on the difficulty found with these sets of survey questions was included in light of the results for Jamaica. This is also significant and positively correlated, which can be seen as supporting the no duty position in that these individuals care less about marine biodiversity and also find little problem in stating their lack of belief in rights. In contrast, those concerned about biodiversity improvement struggle with their precise ethical position and the extent to which duties are weak (tradable) or strong (lexical).

Thus, the overall results for Curaçao show a model of WTP being dependent upon standard socio-economic variables plus rights and duty-based variables. The RIGHTSEA variable is a recognition at an aggregate level of rights in the marine environment. The STRDUTY and NODUTY variables are specific to the marine park itself and the extent to which individuals are prepared to prevent harm at the risk of a loss in their own living standards.

In addition, a dummy variable called PREFINFO was included to account for whether individuals felt their preferences about marine biodiversity preservation had been changed by the survey. This variable was found to be highly significant and positive.

### WTP Determinants for Jamaica

A similar semi-log linear form of model was developed for Jamaica with a set of socio-economic variables, knowledge and the position taken towards rights (i.e., a lexicographic type preference). The range of variables considered most important, along with some descriptive statistics, are shown in Table 6.8. The socio-economic variables, in this case, are gender and income. Income replaces the age and education variables of the Curaçao model. Income data for Jamaica was far more complete with 839 observations. This time, the inclusion of a dummy variable for tourists versus locals was strongly significant and negatively correlated with tourists. The final model results are shown in Table 6.9.

The knowledge and use variables again proved significant determinants of WTP. Knowledge of marine biodiversity (KNOWMBD) was found to be similar to that concerning reef degradation (KNOWCD) in terms of the equation and, in this case, the latter was used. This is derived from a survey question where individuals used a ten point scale to signify their prior knowledge of the causes of coral reef degradation after having had them

**Table 6.8.** Variable definitions and basic statistics for Jamaica.

| *Variable* | *Mean* | *Min* | *Max* | *Valid number* | *Label* |
|---|---|---|---|---|---|
| TL | 0.47 | 0 | 1 | 1058 | Tourist (1) or local (0) |
| ENVIROAT | 1.53 | 0 | 23 | 1058 | Number of environmental concerns |
| VISITC | 0.47 | 0 | 1 | 1058 | Ever visited marine park |
| VISITF | 0.88 | 0 | 7 | 1056 | Visit site in future |
| KNOWCD | 4.67 | 1 | 10 | 1058 | Knowledge of coral degradation |
| KNOWMBD | 3.29 | 1 | 10 | 1056 | Knowledge of marine biodiversity |
| PREFINFO | 0.19 | 0 | 1 | 1058 | Preferences changed and informed |
| INFO | 0.74 | 0 | 1 | 1058 | Informed only |
| RIGHTSEA | 5.51 | 0 | 6 | 1028 | Marine animal/plant/ecosystem rights |
| NODUTY | 0.11 | 0 | 1 | 1056 | No duty to marine life/habitats |
| STRDUTY | 0.15 | 0 | 1 | 1056 | Strong duty marine life/habitats |
| SEX | 0.56 | 0 | 1 | 1056 | Gender (male=0; female=1) |
| AGE | 3.63 | 1 | 10 | 1058 | Age by category (1=low; 10=high) |
| EDUC | 3.04 | 1 | 5 | 1058 | Level of educational attainment |
| INCOME | 3.47 | 1 | 10 | 839 | Level of gross income (coded) |
| PROBC | 1.83 | 1 | 10 | 1058 | Difficulty with Section C of survey |
| WTPALLX | 26.24 | 0 | 2866 | 833 | WTP (US$) |
| LNWTP3 | 1.54 | 0 | 7.96 | 833 | Natural log of WTPALLX |

**Table 6.9.** Preferred tobit model for Jamaica. The dependent variable is LNWTP3. Model has 317 limit observations (zero) and 516 non-limit observations. The predicted probability of $y >$ limit given average $x_i$ is 0.6544. The observed frequency of $y >$ limit is 0.6194. At mean values of $x_i$, E(y)=1.4304.

| *Variable* | *Normalised coefficient* | *Standard error* | *Asymptotic t-ratio* |
|---|---|---|---|
| TL | -0.19667 | 0.083661 | -2.3508 |
| ENVIROAT | 0.053173 | 0.024215 | 2.1959 |
| INCOME | 0.061696 | 0.015320 | 4.0273 |
| NODUTY | -0.48570 | 0.13237 | -3.6693 |
| VISITC | -0.22942 | 0.076518 | -2.9982 |
| VISITF | 0.47212 | 0.12543 | 3.7641 |
| KNOWCD | 0.038592 | 0.012067 | 3.1980 |
| PREFINFO | 0.36412 | 0.18868 | 1.9298 |
| INFO | 0.49011 | 0.17434 | 2.8112 |
| PROBC | 0.085788 | 0.028718 | 2.9872 |
| CONSTANT | -0.81805 | 0.23137 | -3.5356 |
| LNWTP3 | 0.43953 | 0.014998 | |

described. As with KNOWMBD, greater knowledge increases WTP. This is also true for the positive likelihood of future use of the marine park (VISITF). Also, the relationship between WTP and having visited the park in the past is negative (VISITC). This result is not uncommon for such surveys in that it implies that, once an initial curiosity is satisfied, an individual's utility from subsequent visits will tend to drop off (this is consistent with decreasing marginal utility in individual preference functions).

In Jamaica, the set of variables on ethical stance were less relevant. However, some role for ethical positions is confirmed by the significance of the dummy variable rejecting any duty (NODUTY). This is also negatively correlated to WTP as was the case for Curaçao. The contrast with the results for Curaçao in terms of the role of ethical variables led to the inclusion of survey difficulty variables, and this showed a strong positive correlation with WTP. However, as this was then included in the Curaçao model and a similar result occurred, this alone seems unable to explain the difference in results.

Finally, PREFINFO is a dummy variable for whether individuals felt their preferences about marine biodiversity preservation had been changed by the survey. This was found to be highly significant and positive as in Curaçao. What was different here was the strong positive relationship of a second dummy representing the case of individuals whose preferences had remained unchanged but who felt they had been informed.

Thus, the overall results for Jamaica are in line with those for Curaçao, except in that the model lacks significant rights and strong duty variables.

### Prediction of WTP

The expected WTP will depend on the location of the individual, their individual socio-economic characteristics, and their attitudes towards rights. Simulations using the preferred models were conducted to estimate WTP and the probability that they would return a non-zero bid. Results are shown in Table 6.10.

First, we note that at the sample means, WTP in Curaçao is about US$2.08, while in Jamaica it is US$3.24. This difference is readily explained through the differences in the mix of tourists and locals in the sample. Tourists generally had the same WTP in Curaçao and Jamaica—

**Table 6.10.** Predicted WTP for Curaçao and Jamaica as a function of individual characteristics. Local and tourist statistics taken at population means. For strong duty simulation (Curaçao): RIGHTSEA=6; NODUTY=0; STRDUTY=1. For no duty simulation (Curaçao): RIGHTSEA=0; NODUTY=1; STRDUTY=0. In Jamaica, the simulation turns on and off the NODUTY variable.

| | *Probability of non-zero bid (%)* | *Expected WTP (US$)* |
|---|---|---|
| **Curaçao** | | |
| Sample means—all | 58.33 | 2.08 |
| Sample means—typical local | 56.18 | 1.85 |
| Sample means—typical tourist | 61.15 | 2.46 |
| Locals with strong moral duties/rights | 69.08 | 4.05 |
| Locals with no moral duties/rights | 17.82 | 0.19 |
| Tourists with strong moral duties/rights | 74.18 | 5.82 |
| Tourists with no moral duties/rights | 22.01 | 0.26 |
| **Jamaica** | | |
| Sample means—all | 65.77 | 3.24 |
| Sample means—typical local | 68.49 | 3.75 |
| Sample means—typical tourist | 62.51 | 2.73 |
| Locals with moral duties/rights | 70.72 | 4.26 |
| Locals with no moral duties/rights | 52.37 | 1.66 |
| Tourists with moral duties/rights | 64.22 | 2.98 |
| Tourists with no moral duties/rights | 45.17 | 1.17 |

US$2.46 and US$2.73 respectively. Jamaicans, on the other hand, were willing to pay almost double their counterparts in Curaçao.

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

## Conclusions

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

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

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

Those claiming a strong duty accounted for one third to one sixth of the sample, as shown in Table 6.11. When the data were analyzed for zero bids, in terms of time and money being given for reasons of non-zero value (which also excludes those unable to pay—the low income earners and the unemployed), the sub-sample falls to a few percent. There was no apparent difference between the tourist and local sub-samples as might be expected if the result was due to the developing country context. Another explanation may be that, because the study took the case of an environmental improvement, less controversy arose than if a WTP were asked for preventing an environmental deterioration (i.e., the low percentage of protests among zero bidders consistent with a strong duty). However, as Table 6.11 shows, the process adopted here for confirming respondents' adoption of a strong duty was also effective in reducing the proportion claiming absolute rights. Respondents claiming a strong duty to protect the environment were identified after probing questions confronted the respondent with a hypothetical trade-off in terms of their current living standard. The result contrasts with those attributing general but absolute rights to aspects of the marine environment, being two thirds or more of the sample.

While the finding of only a few percent of respondents in the protest-zero-lexicographic position does conflict with that of earlier studies, some caution should be taken in generalising the result. As mentioned, a positive bid for an environmental improvement can be consistent with a lexicographic position because any increase in the highly ranked good will increase welfare regardless of the loss of those goods ranked as inferior. A second improvement or a reversal of the improvement would both elicit a zero WTP because the individual has no income left (or no spare income under modified lexicographic

**Table 6.11.** Type and consistency of rights and duties for zero bidders.

| | *Curaçao* | | *Jamaica* | | *Total* |
|---|---|---|---|---|---|
| | Locals | Tourists | Locals | Tourists | |
| Sample size | 656 | 496 | 565 | 493 | 2210 |
| Absolute marine rights (number) | 322 | 251 | 385 | 441 | 1399 |
| Absolute marine rights (% of sample) | 58.9 | 56.9 | 71.8 | 89.6 | 63.3 |
| Strong duty (number) | 173 | 135 | 88 | 70 | 466 |
| Strong duty (% of sample) | 26.4 | 27.2 | 15.6 | 15.0 | 21.1 |
| Strong duty and zero bid for reason of non-zero value (number) | 20 | 14 | 6 | 12 | 52 |
| Strong duty and zero bid for reason of non-zero value (% of sample) | 3.0 | 2.8 | 1.0 | 2.4 | 2.4 |

preferences). This raises the interesting possibility that those refusing to bid more for the improvement of other reefs that were classified as showing part-whole bias (see Spash *et al*. 1998) may have lexicographic preferences. In addition, the rights-based position and implied duty does seem to influence bids as shown by the bid curve analysis. This result is very strong for Curaçao, but more limited for Jamaica. This Jamaican result led to consideration of the difficulty respondents may have had in answering the survey. In both countries, the levels of difficulty respondents were observed to have in answering the rights and duties section of the survey has a significant and positive influence on WTP. As this was an unexpected finding, explanations are purely speculative. However, one possibility is that people who dismiss rights and duties for the environment can answer quickly without problems and are also likely to give a low WTP bid. Those who are more concerned, with a higher WTP, struggle when confronted by the idea that they make trade-offs but, when pressed to do so, conform but still regard the language of rights as a more appropriate description of their actual position. Placing a set of right questions prior to the WTP question may, therefore, result in the respondents finding the bid section problematic rather than the ethics section.

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

## Endnotes

1 Option value arises when there is uncertainty about the continued supply of a good or service and an individual is prepared to pay to keep a future option open for use of the good or service. Bequest value refers to the welfare from endowing future generations with goods and services. Existence value is more controversial and varies in definition in the literature, but essentially tries to capture the welfare related to knowing something exists; this welfare is independent of any use which might be made either directly or indirectly (i.e., by future generations).

2 A quota sample is conducted so as to take into account specified population characteristics such as the ratio of male to female respondents, age distribution, and income distribution.

3 Note in the table that to prevent estimation biases and provide a basis for conducting the tobit runs, the dependent variable is specified as LNWTP3, which is the natural logarithm of the WTP plus one. The addition of 1NAF introduces a bias of about +0.1% in the estimates but provides a truncation point on all of the relevant data (i.e., LNWTP=0 if and only if WTPALL=0).

4 Unlike OLS estimates, the estimators in this table cannot be used directly to derive a WTP through simple multiplication. Actual estimation of the WTP requires transformation of this function and application of density function for any given set of characteristics. This is most readily done in a simulation environment, dealt with later in this section.

# Chapter 7

# Montego Bay Pharmaceutical Bioprospecting Valuation

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

For these approaches to be successful, data must be available to translate sampling information (e.g., species types and counts) into final commercial products; these are usually translated through a series of "hit rates." While such hit rates are known for advanced stages of research and development (R&D), most of the literature relates to terrestrial organisms. A preliminary survey of primary marine bioassay data was therefore specifically conducted, with the confidential cooperation of a number of private companies and private research institutes (Putterman 1997; Chapter 12). The exercise demonstrated that data collection of this sort was viable (Table 7.1).

**Table 7.1** Preliminary survey of primary screening hit rates (%) from a collection of 20,000 Caribbean marine organisms

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

Source: Putterman (1997).

Appropriately, a more detailed analysis was pursued to place an economic value on marine pharmaceutical bioprospecting opportunities at Montego Bay, Jamaica. The study consisted of:

- Specific methodology selection and development based on a literature review and analysis;
- Further contracting of firms active in Caribbean bioprospecting to obtain confidential information relating to hit rates;
- Estimation of sales and cost information specific to Montego Bay;
- Development of a hypothetical sampling program for Montego Bay to form the basis for simulation studies; and,
- Economic modeling of values.

## Model Selection and Key Valuation Issues

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

The model specification issues include: i) estimation of gross vs. net economic values; ii) estimation of private vs. social returns; iii) capture of rent shares by local governments; iv) estimation of average vs. marginal returns, and the role of redundancy and substitutability in

**Table 7.2** Comparative summary of pharmaceutical bioprospecting models

| | *Farnsworth and Soejarto (1985); Pearce and Puroshothaman (1992a, 1992b); Principe (1989a, 1989b)* | *Aylward (1993)* | *Mendelsohn and Balick (1995, 1997)* | *Simpson and Craft (1996); Simpson and Sedjo (1996a, 1996b); Simpson et al. (1996)* | *Artuso (1997)* | *Polasky and Solow (1995); Solow et al. (1993)* | *Ruitenbeek and Cartier (1999)* |
|---|---|---|---|---|---|---|---|
| **Model Attributes** | | | | | | | |
| Analytical specification only | | | | | | ✔ | |
| Terrestrial system application | ✔ | ✔ | ✔ | ✔ | ✔ | | |
| Marine system application | | | | | | | ✔ |
| **Policy Applications** | | | | | | | |
| Education and awareness | ✔ | | | | | | |
| National level policies | ✔ | ✔ | ✔ | | ✔ | | ✔ |
| Private profitability analysis | | ✔ | | ✔ | ✔ | | |
| Site specific planning | | | | ✔ | | ✔ | ✔ |
| **General Economic Attributes** | | | | | | | |
| Gross economic value | ✔ | | | | | | |
| Net economic value | | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| Private costs | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| Social costs (including institutional) | | ✔ | | | ✔ | ✔ | ✔ |
| Time delays | | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| Average species value | ✔ | ✔ | ✔ | | ✔ | ✔ | ✔ |
| Marginal species value | | | | ✔ | | ✔ | |
| Average habitat value | | ✔ | ✔ | | ✔ | ✔ | ✔ |
| Marginal habitat value | | | | ✔ | ✔ | ✔ | ✔ |
| **Specific Model Parameters** | | | | | | | |
| Discovery process stages (hit rates) | 1 | 1 | 1 | 1 | 9 | 1 | 3 |
| Discovery process stages (costs) | 1 | 1 | 1 | 1 | 9 | 1 | 1 |
| Revenue sharing treatment | ■ | ■ | | ✔ | ■ | ✔ | ✔ |
| Redundancy/ interdependency | | | | ✔ | ■ | ✔ | |
| Ecosystem yield (species-area relationship) | | | | ✔ | ✔ | ✔ | ✔ |
| "Price function" (once differentiable value) | | | | ✔ | ✔ | ✔ | ✔ |
| Industry structure/ behavior | | | | | | ■ | |
| Risk preference/ aversion behavior | | | | | ■ | | ■ |

✔ explicitly relevant or incorporated
■ treated qualitatively or partially

each of these; and, v) treatment of complexity through interdependence of discoveries and ecosystem yields. The relevance of these issues to Montego Bay, and their treatment within the model selection, is as follows:

- *Gross versus net values*. The primary policy planning issue for Montego Bay is to look at net potential benefits accruing to bioprospecting and to other reef uses (Chapter 5). This requires some ability to deal with site specific costs, realizing, however, that expected sales revenues are likely to be common with any type of drug development, irrespective of product source.
- *Social versus private valuations*. One component of the modeling literature is concerned with the general private profitability and incentive structures associated with drug production and marketing, as well as with R&D. These models typically incorporate taxation provisions within their various analytical stages. For Montego Bay, such analyses are of low priority concern. Of greater consequence is the magnitude of social benefits and the potential for capturing these efficiently. Private profitability is of concern to the extent that any revenue sharing arrangements must not discourage bioprospecting. A related aspect is the potential institutional overhead cost involved in maintaining a structure that oversees bioprospecting contracting. The social costs associated with such activities should be considered in any model that is developed for Montego Bay.
- *Average versus marginal values*. This issue relates to whether the policy problem at hand is concerned with expected average values or marginal values of species and habitats. Much early literature was pre-occupied with average species values, even though site specific planning problems generally require translation of such values into marginal habitat values attributable to an ecosystem (e.g., rainforest or coral reef). Analysts have addressed this problem through various means. Simpson *et al*. (1996) attribute the marginal species value to the value of a collection and translate these to marginal habitat values. Artuso (1997) essentially derives expected (average) values for species or samples and translates them to marginal habitat values using species-area relationships for hypothetical habitats. We will in essence be following this latter approach, with a view to eventually deriving a marginal habitat benefit or "price". Consistent with earlier literature in cost-benefit analysis, we refer to such prices as "planning prices" to the extent that they are the relevant shadow prices to use for land use, investment, and other allocation decisions.
- *Redundancy*. The literature deals with related issues such as "redundancy", "substitutability", and "conditional probabilities" within the R&D process and discovery sequence. There remains, at this stage, debate over the extent to which redundancy of discoveries is an important issue. One perspective is that if new discoveries have redundant attributes with those already discovered, then marginal species values will go down as more drugs are developed. A second perspective is that some bioprospecting in fact relies on looking for product redundancy, with a view to discovering cheaper sources of existing materials. For Montego Bay, we do not explore the redundancy or substitutability issue.
- *Phase-specific costs*. Most of the literature has assumed a single discovery phase and cost for the R&D process when, as noted by Artuso (1997), a more accurate modeling of the process would recognize that many of the success rates are in fact endogenously determined and the cost and success rates are co-determined within a firm's or industry's optimizing behavior. If one recognizes this separation, it implies that there are mechanisms that will tend to maintain the activity at some profitable level. Using a nine stage R&D process, Artuso (1997) shows that this has important implications for genetic resource values and industry behavior, as well as for risk mitigation within the sector. For Montego Bay, we are primarily interested in the ecosystem values, although we acknowledge that some separation of R&D success rates and costs is important. The Montego Bay data are, however, constrained such that optimization studies are not feasible, although we do use a three stage R&D process to incorporate a number of the phase-specific results obtained from industry sources.
- *Revenue sharing*. Many analysts have addressed "capturable value" but our concern here is to pay somewhat greater attention to institutional financial mechanisms such as royalty rates, revenue shares, and sample fees, as well as to show how these mitigate risks in the bioprospecting process. Our model should, therefore, be capable of conducting some simple trade-off analyses to demonstrate the effectiveness in risk mitigation of different mechanisms.

## Model Specification, Assumptions and Information Sources

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

### Model Structure

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

$$ENVN_t = pN_t(1+r)^{-t}\, EVD_{t+\tau}(1+r)^{-\tau} - CN_t(1+r)^{-t}$$

where $p$ = the cumulative probability of developing a commercial drug from a given sample;

$EVD_{t+\tau}$ = expected future value of a commercial drug net of R&D costs;

$\tau$ = length of the R&D period;

$C$ = individual sample costs; and,

$r$ = discount rate (10% real).

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

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

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

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

where $S$ = number of species in an area, defined by the species area relationship parameters $c$ and $z$; and,

$s$ = average number of samples available for any given species.

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

$\alpha$ = contingent royalty on final drug sales expressed as a net profit share;

$f$ = a per sample fee that involves a transfer to local authorities for sample collection (or for multiple sample rentals); and,

$I$ = institutional costs attributable to collection.

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

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

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

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

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

### Revenues and Costs

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

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

### *Institutional Parameters— Costs and Revenue Sharing*

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

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

### *Sampling and Hit Rates*

The model requires estimates of $N_{max}$ and $p$. Sampling rate is perhaps one of the most overlooked parameters in other modeling efforts, yet it plays an important role in establishing ecosystem value. A very slow sampling rate depresses present values, while a very high sampling rate may not be ecologically sustainable; some observers have criticized aggressive marine bioprospecting for endangering some species. To ensure that a reasonable level of sampling occurs, a hypothetical program for Montego Bay was laid out using typical methodologies used by the NCI (Colin 1998). The NCI observes that a team of up to four divers would generate at most 15 samples a day. This is regarded as a sustainable effort for Montego Bay (which has a relatively limited area of about 43ha) and is also consistent with logistical constraints of servicing a collection program. Assuming full-time regular employment of the team over a ten month period (avoiding the hurricane season), the model assumes a maximum annual sampling rate of 3,300 samples. In sensitivity analyses, we subsequently relax this constraint to illustrate the impact of an accelerated sampling program in which all samples are collected in a single year.

Various firms were contracted to provide information relating to marine bioprospecting success rates. Although the detailed information is proprietary, summary statistics adequate for modeling are presented here. The firms' programs generally implied success rates to final product development in the range of 1:25,000 to 1:50,000; these success rates incorporated screening against multiple targets (up to ten). Two specific examples serve to illustrate:

- *FIRM A.* A set of 13,779 samples were analyzed for ten targets. Not all samples were subjected to each target. At the primary screen, 5,137 were isolated and then passed on to subsequent screening and analysis. Through the following stages, six to seven drug leads were eventually identified and were at various stages of preclinical trials and licensing prior to clinical trials. This implies a cumulative hit rate to the preclinical trial stage of 1:2,120. We use Artuso's (1997) estimates for subsequent success rates for typical testing programs (0.4 for preclinical; cumulative 0.25 for three clinical stages; 0.9 for new drug approval) to arrive at a cumulative probability of 1:23,600 from that set of samples.
- *FIRM B.* A set of 5,400 samples was analyzed against

multiple targets. Through two stages of screening and further analyses, four leads were isolated and dereplicated. This implies a cumulative hit rate to the synthesis/modification stage of 1:1,350. Using Artuso's (1997) estimates of success beyond this stage (same as above, and 0.5 for successful synthesis/modification), a cumulative probability of 1:30,075 is estimated for that set of samples.

In the base case, we use a cumulative success rate of 1:30,000. This is higher than most terrestrial estimates, which are typically of the order of 1:100,000, and also higher than reported programs for shallow water marine invertebrates from the Pacific Ocean analyzed by the NCI (Newman 1995). The latter were estimated to generate commercial products at a rate of 1:80,000 at best. We utilize this poorer hit rate as a sensitivity case in our analyses.

### *Role of Coral Abundance*

The amount of intact and live coral reef available in Montego Bay is the subject of some controversy, and the causes and extent of degradation remain the subject of open debate (Chapters 1 and 8). Literature has placed coral abundance as high as 74% and as low as 5% (Table 7.3). No systematic comprehensive surveys have been undertaken over the entire zone, and the nature of the estimates often differ methodologically. Moreover, there is significant local concern that overstating the amount of degradation may inadvertently deter tourists, even though most divers and tourists feel that the reef quality is quite good. For our purposes, we primarily rely on two results.

First, total coral area was analyzed based on GIS interpretation of polygons as presented in the Coastal Atlas of Jamaica (Natural Resources Conservation Authority of

**Table 7.3** Selected live coral estimates for Montego Bay

| *Source* | *Coral abundance (%)* | *Basis* |
|---|---|---|
| Discovery Bay Marine Laboratory | 10 to 74 | 1982 baseline estimate of 9 transects |
| Hughes (1994) | 5 to 12 | shallow water surveys of 2 sites |
| Sullivan and Chiappone (1994) | 15 to 25 | rapid ecological assessment |
| Hitchman (1997) | <13 | 14 sample sites in high impact area of Montego Bay and Bogue Lagoon |
| Hong Kong University of Science and Technology, Reef Check 1997 | 22 [1997]<br><22 [preliminary 1998] | Caribbean wide, the 1997 Reef Check survey noted that low levels were "possibly reflecting losses due to bleaching and disease" |
| Kent Gustavson, pers. comm. 1998 | 25 of substrate | personal estimate |
| Stephen Jameson, pers. comm. 1998 | 15 of substrate | personal estimate |
| Jill Williams, pers. comm. 1998 | 25 to 50+ of substrate | reports from local fishers, divers, and other resource users; many good sites "at depth" |
| Ruitenbeek *et al*. (1999a; see also Chapter 8) | 24 to 38 of substrate | model equilibrium predictions for low stress and high stress conditions, excluding fishery sector reforms |
| Ruitenbeek *et al*. (1999a; see also Chapter 8) | 29 to 43 of substrate | model equilibrium predictions for low stress and high stress conditions, including fishery sector reforms |

Jamaica). This shows a total area of coral substrate of approximately 42.65ha. Second, long-term coral cover was based on fuzzy logic model calculations of the ecosystem under various stress assumptions (Chapter 8). At current levels of fishing pressure, the equilibrium abundance level was predicted to be 39.8%. With expected reforms to the fishery, it is expected that damage will decrease and abundance would increase to 42.7%. We note that under sustained economic growth as forecast by local authorities, the model predicted that coral quality would decline to the region of 20% to 25% abundance. For the purposes of simulation, therefore, we take a 43% abundance level as a status quo scenario and a 25% abundance level as a degradation scenario. In terms of reef areas, these levels correspond to 18.34ha and 10.66ha respectively.

### *Ecosystem Yield and the Species-Area Relationship*

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

## Valuation Results and Discussion

Using typical cost estimates for Jamaica and using typical hit rates and end-use values, scenario analyses were conducted using the parametric model. The reference

**Table 7.4** Estimated coral reef species and sample numbers based on species-area relationships

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

Note: The benchmark global value from which these are derived is from Reaka-Kudla (1997) using 93,000 total described coral reef species from an area of 588,960km$^2$. This implies by solution $c$=2,750 in the reference case, where $z$=0.265. A ratio of 10.2:1 expected species to currently described species is also based on Reaka-Kudla (1997, p. 93f), who suggests this as a most likely ratio based on assessments of rainforest and coral reef species-area dynamics. Survey length is based on a maximum of 3,300 samples annually.

case places marine bioprospecting values at just under US$2,600 per sample or US$7,775 per species. The per species values are somewhat higher than the typical estimates for terrestrial species, primarily because of the higher demonstrated success rates in terms of product development.

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

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

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

The relatively low "price" and the apparently small drop in benefits from significant coral reef degradation underlines the importance of the ecosystem yield. In effect, two factors contribute to this result. First, because of the non-linear relationship between species and area, a decrease in coral abundance does not translate one to one into a decrease in species or available samples. Second, the loss in available samples is not experienced immediately; annual sampling constraints under a sustainable program using the NCI standards at Montego Bay would yield approximately 3,300 samples annually. The economic effect of these "lost samples" is therefore discounted substantially and would consequently have less of an impact on current management decisions.

Detailed sensitivity results are shown in Table 7.5. The analysis confirms that the impacts of the incremental institutional costs for operating a national program consistent with the recommendations by Putterman (1998; Chapter 12) are minimal. It would appear, therefore, that such institutional investments are warranted.

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

Second, the results show a number of important potential risk mitigation strategies. In the base case of a 10% net profit share, the expected value of the sampling generates a marginal benefit to Jamaica of US$22,600/% coral abundance. Conversion of this share to a US$250 sample collection fee, or to rentals equivalent to this fee, would generate a similar price of US$21,800/% coral abundance. This price is maintained, of course, even if hit rates are lower or R&D costs go up as the value is linked only to the sampling program. It is probable that, in general, an appropriate risk mitigation strategy for Jamaica would likely involve some combination of royalty or profit share payment ($\alpha > 0$) and modest sample fee. Such a strategy would guarantee captured values of the same order as those expected in the reference case, but would reduce exposure to hit rate uncertainties, product marketing uncertainties, and ecosystem dynamics.

In addition, we note that even with this sampling program there is, of course, no guarantee of a hit. One can, in fact, calculate the expected number of samples that must be collected to generate at least one hit. When the hit rate is 1:30,000, this corresponds to 21,000 samples, and when it is 1:80,000 the expected number of samples is 55,000. This higher number is almost identical to the base case expectation that the system will yield 53,660 samples. In the mineral prospecting literature, the situation of not achieving a "hit" is referred to as "gambler's ruin" and, while venture capital markets act to take on risks like this, governments are often reluctant to enter into such arrangements. In this case, therefore, a public body would

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

| *Case* | *z* | $\alpha$ (%) | *f* (US$ per sample) | *N* | *T* (yrs) | $NPV_G$ (million US$) | $NPV_J$ (million US$) | $P_G$ (US$/%) | $P_J$ (US$/%) |
|---|---|---|---|---|---|---|---|---|---|
| **Base Case Scenario at 43% Coral Abundance** | | | | | | | | | |
| Reference[a] | 0.265 | 10 | 0 | 53,660 | 16.3 | 70.09 | 7.01 | 225,614 | 22,561 |
| High *z* | 0.3 | 10 | 0 | 31,763 | 9.6 | 54.46 | 5.45 | 297,516 | 29,752 |
| Low *z* | 0.2 | 10 | 0 | 142,099 | 43.1 | 84.61 | 8.46 | 30,901 | 3,090 |
| Fee only | 0.265 | 0 | 250 | 53,660 | 16.3 | 70.09 | 6.76 | 225,614 | 21,763 |
| High *z* | 0.3 | 0 | 250 | 31,763 | 9.6 | 54.46 | 5.25 | 297,516 | 28,699 |
| Low *z* | 0.2 | 0 | 250 | 142,099 | 43.1 | 84.61 | 8.16 | 30,901 | 2,981 |
| Blended revenue shares | 0.265 | 8 | 50 | 53,660 | 16.3 | 70.09 | 6.96 | 225,614 | 22,402 |
| High *z* | 0.3 | 8 | 50 | 31,763 | 9.6 | 54.46 | 5.41 | 297,516 | 29,541 |
| Low *z* | 0.2 | 8 | 50 | 142,099 | 43.1 | 84.61 | 8.40 | 30,901 | 3,068 |
| High R&D cost | 0.265 | 10 | 0 | 53,660 | 16.3 | 17.64 | 1.76 | 56,783 | 5,678 |
| [R/C ratio=1.1:1] | 0.265 | 0 | 250 | 53,660 | 16.3 | 17.64 | 6.76 | 56,783 | 21,763 |
| | 0.265 | 8 | 50 | 53,660 | 16.3 | 17.64 | 2.76 | 56,783 | 8,895 |
| Low hit rate | 0.265 | 10 | 0 | 53,660 | 16.3 | 25.02 | 2.50 | 80,525 | 8,052 |
| [1:80,000] | 0.265 | 0 | 250 | 53,660 | 16.3 | 25.02 | 6.76 | 80,525 | 21,763 |
| | 0.265 | 8 | 50 | 53,660 | 16.3 | 25.02 | 3.35 | 80,525 | 10,795 |
| Unconstrained[b] | 0.265 | 10 | 0 | 53,660 | 1.0 | 139.07 | 13.91 | 1,054,202 | 105,420 |
| High *z* | 0.3 | 10 | 0 | 31,763 | 1.0 | 82.32 | 8.23 | 699,475 | 69,948 |
| Low *z* | 0.2 | 10 | 0 | 142,099 | 1.0 | 368.27 | 36.83 | 2,145,937 | 214,594 |
| Institutional[c] | 0.265 | 10 | 0 | 53,660 | 16.3 | 70.09 | 6.96 | 225,614 | 22,561 |
| **Degradation Scenario at 25% Coral Abundance** | | | | | | | | | |
| reference *z* | 0.265 | 10 | 0 | 46,477 | 14.1 | 66.12 | 6.61 | | |
| high *z* | 0.3 | 10 | 0 | 26,994 | 8.2 | 49.37 | 4.94 | | |
| low *z* | 0.2 | 10 | 0 | 127,492 | 38.6 | 84.06 | 8.41 | | |

[a] Uses study result hit rate of 1:30,000 and sales:R&D cost ratio of 1.5:1. $P_G$ and $P_J$ may be converted to US$/ha basis by dividing by 0.4265.

[b] Assumes all samples are collected and subjected to preliminary screening within 1 year.

[c] Includes institutional overheads of central government agencies.

likely prefer some guaranteed income, even if it means giving up some future royalty position.

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

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

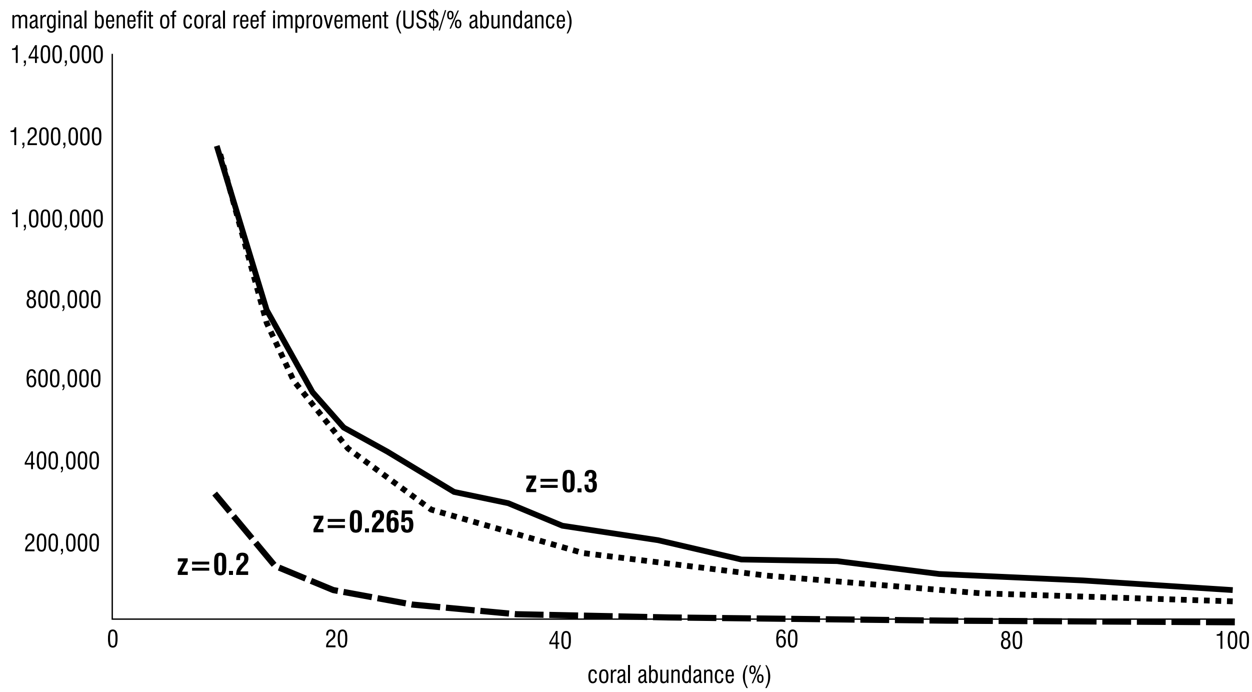


**Figure 7.1** Marginal benefit function for Montego Bay bioprospecting values