Economic Valuation and Socioeconomics of Coral Reefs: Methodological Issues and Three Case Studies[1]

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Abstract

In most tropical countries, coral reef ecosystems provide coastal populations with a number of goods and services. However, a variety of anthropogenic practices threatens reef health and therefore jeopardizes the benefits flowing from these goods and services. These threats range from local pollution, sedimentation, destructive fishing practices and coral mining, to global issues such as coral bleaching.

By "getting some of the numbers on the table", economic valuation can help shed light on the importance of the goods and services and show the costs of inaction in the face of threats. Creating markets for sustainable resource use can highlight the value of these goods and services to local populations.

This paper gives an overview of economic valuation (total economic value, cost benefit analysis) and the techniques supporting it (contingent valuation, travel cost, effect on production, etc.) as they are applied to coral reef ecosystems.

The paper also highlights some of the socioeconomic issues of reef degradation and conservation and shows the importance of economic issues involved in stakeholder analysis. Stakeholder analysis helps to show who gains and who loses from threats to the coral reef and from conservation measures. Together with economic valuation, it thereby helps to determine what drives unsustainable practices and how such practices can best be mediated given the local social situation.

Three case study examples are explored. The first examines the total economic value of a specific area, namely Jamaica, and the costs and benefits of this area when coastal management is introduced. The second demonstrates cost benefit and stakeholder analysis of a threat to coral reefs. The third estimates the economic costs of climate change (coral bleaching, erosion, etc.).

The paper concludes with an up-to-date summary of economic valuation studies on coral reefs.

Introduction

Coral reefs form a unique ecosystem, richer in biodiversity than any other ecosystem in the world. Reefs are productive, shallow water, marine ecosystems that are based on rigid lime skeletons; themselves formed through successive growth, deposition and consolidation of the remains of reef-building corals and coralline algae. The basic units of reef growth are the coral polyps and the associated symbiotic algae that live in the coral tissues. This symbiotic relationship is the key factor explaining both the productivity of reefs and the rather strict environmental requirements of corals.

Coral reefs have important ecosystem functions that provide crucial goods and services to hundreds of millions of people. These goods and services often form an important source of income for local populations (through fishing, mariculture, etc.), and sustenance to those living at subsistence levels. They are also a tourist attraction, contributing to local income and foreign exchange. In addition, they form a unique natural ecosystem, with important biodiversity

[1] WorldFish Center Contribution No. 1721

value as well as scientific and educational values. In addition, coral reefs form a natural protection against wave erosion.

Currently, however, coral reefs are rapidly being depleted in many locations around the world as a result of, amongst other things, destructive fishing practices (poison fishing, blast fishing, muro-ami, etc.), coral mining, marine pollution, sedimentation and coral bleaching. Often, these destructive impacts are the result of externalities – the people who cause the damage benefit from unsustainable economic activities, but the costs are borne by others who depend in some way or other on coral reefs. Economists argue that this is often due to the absence of a well-functioning market for environmental goods and services. Hodgson and Dixon (1988) describe an externality situation in which logging causes sedimentation that results in reef degradation (affecting tourism) and fishery losses. For the logging company, these tourism and fishery losses are not part of their profit calculation. In the absence of government policy and/or public outcry, logging would continue even if the external costs to society were much higher than the net profits of the logging industry, as was the case in the example of Hodgson and Dixon.

This example indicates two things. First, it shows the importance of a stakeholder analysis of who is gaining and who is losing from a situation and the potential for a possible intervention; and, second, it shows the importance of obtaining economic values for the various reef goods and services, e.g. a fishery value and a coastal protection value. Some of these goods and services involve concrete marketable products, such as shellfish, for which the value can be determined based on the demand, supply, price and costs. Other services depend on the possible future uses of yet unknown biodiversity on reefs for which, sometimes, markets can be created. The values of all these goods and services together form the total economic value (TEV) of reef ecosystems (e.g. Spurgeon 1992). This TEV can be calculated for a specific area or for other uses (e.g. preservation area, tourism area, multiple use area, etc.). Economic valuation can also be used to calculate the economic losses due to destruction of reef functions, as in blast fishing (Pet-Soede et al. 1999), coral mining (Berg et al. 1998) or bleaching (Westmacott et al. 2000c). The three case studies in this paper discuss each of these points. These case studies are briefly summarized here.

Case study 1 The TEV of the Portland Bight area (Jamaica) and a cost benefit analysis (CBA) of establishing a marine protected area (MPA)

Establishing a marine protected area (MPA) is a costly affair and a government needs to be well informed about the pros and cons of an additional MPA (McClanahan 1999). Evaluating the costs and benefits of establishing and running an MPA is a crucial step for an economist involved in MPAs. The net benefits of establishing a park are defined as the net increase in the value of the ecosystem due to the establishment and management of the park minus the costs of managing the park. Pendleton (1995, p.119) states: "Past valuations of tropical marine parks inaccurately measure their economic value because they value the resource protected and not the protection provided". For the Portland Bight Protected Area (Jamaica), a combined marine and terrestrial multiple use area, the cost-benefit analysis (CBA) of establishing the protected area was carried out as part of attempts to obtain international donor money to run the protected area.

Case study 2 Benefit cost and stakeholder analysis of coral mining in Lombok (Indonesia)

Coral mining for lime production is a source of income and subsistence in many developing countries. The associated damage to the reef is, however, significant, both in physical and monetary terms. The economic benefits from reef destruction are often used to justify continuation of this damage. Accordingly, it is important to quantify the costs associated with coral reef degradation if a balanced assessment of the benefits and costs of various practices is to be made. To do this, a CBA is carried out where the net benefits of coral mining to the people causing the damage are compared with the net societal costs plus the enforcement costs of eliminating coral mining in a specific location. In this case study the CBA relates to Lombok, Indonesia.

Case study 3 Economic losses due to coral bleaching in the Indian Ocean

Climate change may, in the long run, be the most important threat to coral reefs. The massive 1998 coral bleaching event was only one of recent hints of what may happen in the future. Bleaching can have severe impacts on both fisheries and tourism. In the longer run, if the balance between reef growth and bio-erosion shifts as a result of coral die-off, it can also lead to reduced levels of coastal protection. For this threat, a cost-benefit framework is not appropriate at the local level as there are no local gains from bleaching. Hence, the focus is on the economic costs of reef destruction alone.

This paper combines a background on the valuation and socioeconomics of coral reefs with these three case studies. The goods and services of coral reefs are described in Section 2. The basic concepts of economic valuation and their techniques are discussed in Sections 3 and 4, respectively. Section 5 focuses on the socio-economics of coral reefs, which is discussed with specific reference to stakeholder analysis. The next three sections (6-8) describe case studies on the TEV and the costs and benefits of marine parks, the CBA and stakeholder analysis of a threat, and an estimation of the economic costs of climate change (coral bleaching, erosion, etc.). The paper concludes with a discussion of the issues raised. The Annex brings together the most well-known valuation studies on coral reefs.

Goods and services of reefs[2]

Ecosystems provide a great many functions, goods and services. The terms "functions", "goods" and "services" have, in this context, slightly different meanings, although many authors use these terms interchangeably in the environmental economics literature. Costanza et al. (1997) define functions, services and goods in the following way: "Ecosystem functions refer variously to the habitat, biological or system properties or processes of ecosystems. Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly, from ecosystem services". For example, a forest on steep slopes provides the function of water retention and an associated service of water supply. Upland deforestation leads to dry season water shortages in the lowlands and deterioration in the eco-system service of water supply.

Moberg and Folke (1999) systematically presented the most important goods and services of coral reef ecosystems (see Table 1). The authors categorized goods as renewable resources (fish, seaweed, etc.) and materials obtained from the mining of reefs (sand, coral, etc.). The services of coral reefs are categorized into: (i) physical

Table 1. Goods and ecological services of coral reef ecosystems identified in Moberg and Folke (1999)

Goods		Ecological services					
Renewable resources	Mining of reefs	Physical structure services	Biotic services (within ecosystem)	Biotic services (between ecosystems)	Bio-geochemical services	Information services	Social and cultural services
Sea food products	Coral blocks, rubble/sand for building	Shoreline protection	Maintenance of habitats				
Raw materials and medicines	Raw materials for lime and cement production	Build up of land	Maintenance of biodiversity and a genetic library	Biological support through "mobile links"	Nitrogen fixation	Monitoring and pollution record	Support of recreation
Other raw materials (e.g. seaweed)	Mineral oil and gas	Promoting growth of mangroves and seagrass beds	Regulation of ecosystem processes and functions	Export of organic production, etc., to pelagic food webs	CO_2/Ca budget control	Climate control	Aesthetic value and artistic inspiration
Curios and jewelery		Generation of coral sand	Biological maintenance of resilience		Waste assimilation		Sustaining the livelihood of communities
Live fish and coral collected for the aquarium trade							Support of cultural, religious and spiritual values

Source: Adapted from Moberg and Folke (1999).

[2] This section is an abbreviated version of Cesar (2000).

structure services, such as coastal protection; (ii) biotic services, both within ecosystems (e.g. habitat maintenance) and between ecosystems (e.g. biological support through mobile links, such as fish that move from mangroves in their juvenile stages to coral reefs in their adult life); (iii) biogeochemical services, such as nitrogen fixation; (iv) information services (e.g. climate record); and (v) social and cultural services, such as aesthetic values, recreation and gaming. Note that this categorization differs slightly from that of Costanza et al. (1997).

Economic valuation of coral reefs[3]

The economic value of a reef ecosystem is often defined as the total value of its instruments, that is, the goods and ecological services that it provides. We, therefore, need to know what these major goods and services of reef ecosystems are, as well as how they interact with other ecosystems. Next, these goods and services need to be quantified and evaluated in dollar terms. For goods sold in the market place, this is simply achieved by looking at their market price, but for ecological services, this is not possible. Instead, complex valuation techniques are used to determine the economic value of these services. Note that, in principle, markets could be established for each of the goods and ecological services where no markets currently exist, although this might be very costly and impractical.

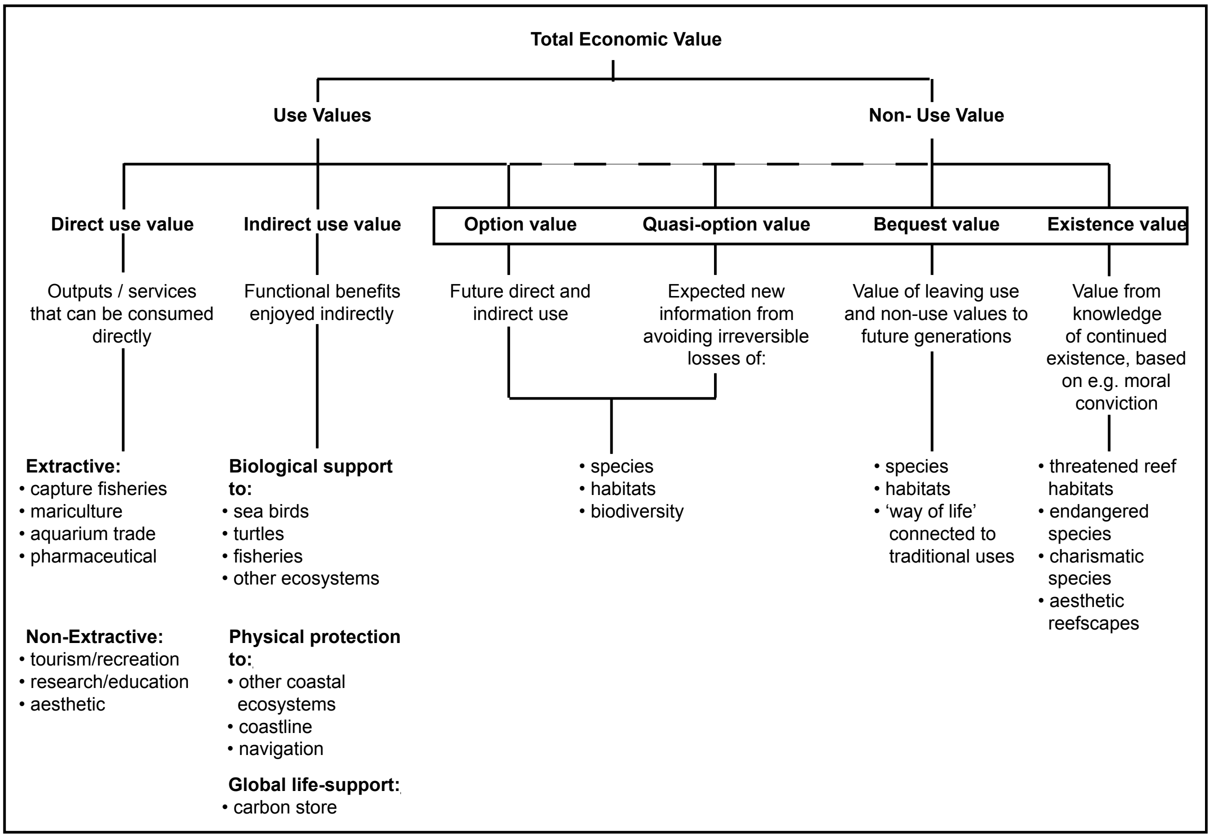
The value of all the compatible goods and services combined gives the TEV for an ecosystem.[4] Each of the goods and services of coral reefs presented in Table 1 above generate economic value. For example, fishery resources can be harvested and sold, and the coastal marine area enables sea transportation that creates profits. Similarly, preservation and ecotourism create value. The mapping between the goods and services on the one hand and their values on the other hand is straightforward, as is shown in Figure 1.

As indicated in Figure 1, there are six categories of values. These are (i) direct use value; (ii) indirect use value; (iii) option value; (iv) quasi-option value; (v) bequest value; and (vi) existence value. Direct use values come from both extractive uses (fisheries, pharmaceuticals, etc.) and from non-extractive uses. Indirect use values are, for example, the biological support provided in the form of nutrients and fish habitat and coastline protection. The concept of option value can be seen as the current value of potential future direct and indirect uses of the coral reef ecosystem. An example is the potential of deriving a cure for cancer from biological substances found on reefs. Bio-prospecting is a way of deriving money from this option value. The quasi-option value is related to the option value and captures the fact that avoiding irreversible destruction of a potential future use gives value today. The bequest value is related to preserving the natural heritage for generations to come where the value today is derived from knowing that the coral reef ecosystem exists and can be used by future generations. The large donations that are given to environmental non-government organizations (NGOs) in wills are an example of the importance of the bequest concept. The existence value reflects the idea that an ecosystem has value to humans irrespective of whether or not it is used. In the Annex, examples of the different values in the literature are presented.

One purpose of obtaining the TEV of coral reefs and using CBA is to get some numbers on the table for policy discussions. For instance, a government might consider proclaiming a specific bay an MPA. The management costs of running MPAs are significant and the government may want to know in economic terms whether the management costs are justified. Or a government might get complaints from NGOs about certain unsustainable coastal activities; these activities constitute a threat but, at the same time, they generate quite some cash, and so the government needs to be convinced that it is worthwhile to curb the threat. Indeed, powerful economic forces are often driving destructive patterns of coral reef use, rendering short-term economic profits, sometimes very large, to selected individuals.

Coral reef protection is presumed to conflict with economic development, and to require a sacrifice of economic growth. However, this perception stems mainly from a failure to recognize the magnitude of costs to the present and future economy resulting from reef degradation. To illustrate this point, Table 2 shows estimates of the benefits to individuals and losses to society

[3] This section is an abbreviated version of Cesar (2000).
[4] The neo-classical foundations of economic value and its relationship with willingness to pay and consumer surplus are not discussed here (however, see Pearce and Turner (1990) for a general discussion and Barton (1994) and Pendleton (1995) for a specific discussion on the neo-classical economic value of coral reefs).



Source: Barton (1994).

Figure 1. Total economic value and attributes of economic values for coral reefs

from each square kilometer of coral reef destruction, and thus provides a basis for an economic rationale for preventative or remedial efforts. For coastal protection and tourism losses, there are both "high" and a "low" scenario estimates (shown as extremes of a range), depending on the types of coastal construction and tourism potential. "High" cost scenarios are indicative of sites with high tourism potential and high coastal protection value. The opposite holds for "low" cost scenarios.

Valuation techniques[5]

A host of valuation techniques have been developed in recent decades. Standard techniques in micro-economics and welfare economics rely on market information to estimate value. However, most of the time, the externalities inherent in environmental issues prevent these techniques from being used. For an elaboration of this issue for non-economists, see Dixon (1998). Specifically for tropical coastal ecosystems, Barton (1994) gives a detailed overview of 15

Table 2. Total net benefits and losses due to threats to coral reefs in Indonesia (Net present value; 10% discount rate; 25 year time-span; in US$'000; per km²)

	Net return to beneficiaries	Net losses to society				
Function / Threat	Total net benefits	Fishery	Coastal protection	Tourism	Others	Total net losses (quantifiable)
Poison fishing	33	40	0	3-436	n.q.	43-476
Blast fishing	15	86	9-193	3-482	n.q.	98-761
Coral mining	121	94	12-260	3-482	> 67.0	176-903
Sedimentation from logging	98	81	–	192	n.q.	273
Over-fishing	39	109	–	n.q.	n.q.	109

Source: Adapted from Cesar et al. (1997) n.q. = not quantified

[5] This section is an abbreviated version of Cesar (2000).

different valuation techniques. Spurgeon (1992) gives an interesting summary of this topic with many actual numbers. Table 3 gives a listing of the most common techniques used for valuing the goods and services of coral reef ecosystems. Three general categories are distinguished. The first includes generally applicable techniques that use the market directly to obtain information about the value of the affected goods and services or of direct expenditures. The second includes a number of potentially applicable techniques, which use the market indirectly to obtain information about values and expenditures. The third general category involves survey-based methods that use hypothetical markets and situations.

Valuation techniques enable us to estimate in money terms the direct and indirect use value, as well as the option, quasi-option, bequest and existence values. Specifically discussed here are five methods, which are also used in many of the chapters that follow. These techniques are: (i) Effect on Production (EoP); Replacement Costs (RC); Damage Costs (DC); Travel Costs (TC); and the Contingent Valuation Method (CVM). These techniques correspond to the various types of values, as shown in Table 3. For details on other techniques, see Barton (1994). Note that both TC and CVM have many shortcomings, including problems of designing, implementing and interpreting questionnaires. However, in the cases where they are used, they are typically the only techniques available, as Table 3 shows.

Effect on Production (EoP): This technique, also referred to as the "change in productivity" method, uses the difference in output (production) as the basis for valuing reef services. The technique mainly applies here to fisheries and tourism (producer surplus) and estimates the difference in value of productive output before and after the impact of a threat or a management intervention. Coral bleaching may, for instance, lead to fewer dive tourists and, therefore, lower tourism revenues. Hence, the change in net profit (i.e. effect on production) can be calculated, and this can be used as a proxy for the loss in tourism value. For fisheries, the technique is used to calculate the loss in the fisheries value from a specific threat, such as coral mining, or the gain in the fisheries value from a management intervention, such as the introduction of a marine reserve. The main challenge is the calculation of the changes in productivity in physical terms between the "with" and "without" scenario.

An examples of the EoP method is provided in Alcala and Russ (1990), who report on a decline of US$54 000 in the total yield of reef fishes off Sumilon Island (Philippines) after the breakdown of protective management. McAllister (1998) gives estimates of reef productivity for reefs in excellent condition (18 mt/km^2/yr), in good condition (13 mt/km^2/yr) and in fair condition (8 mt/km^2/yr). Based on changes in condition over time and estimates of net profits associated with these yields, McAllister estimates the fisheries loss in the Philippines at US$80 million per year.

Replacement Costs (RC): The replacement cost approach is used to value the ecosystem service of coastal protection. Data on investments to control coastal erosion are used as a proxy for the coastal protection service of a healthy coral reef. The cost of replacing the coral reef with protective

Table 3. Correspondence between the types of value and the valuation methods

Type of Value	Valuation Method
Direct Use Values	
tourism (consumer surplus)	Travel Cost (TC)
tourism (producer surplus)	Effect on Production (EoP)
fisheries	Effect on Production (EoP)
Indirect Use Values coastal protection	Replacement Costs (RC); Damage Costs (DC)
Non-use values	
Option Values	Contingent Valuation Method (CVM)
Quasi-option Values	Contingent Valuation Method (CVM)
Bequest Values	Contingent Valuation Method (CVM)
Existence Values	Contingent Valuation Method (CVM)

constructions, such as revetments and underwater wave breakers, is used.

A study quoted in Spurgeon (1992) indicates that on Tarawa Atoll in Kiribati, coastal defences costing US$90 720 had to be built to prevent coastal erosion. Berg et al. (1998) give a detailed analysis of the replacement costs following years of coral mining in Sri Lanka. The average cost varies between US$246 000 and US$836 000/km of protected coastline. Cesar (1996) quotes a case in Bali, Indonesia, where coastal protection expenditures of US$1 million were spent over several years for 500 m of coastline protection. Finally, Riopelle (1995) cites information on a hotel in West Lombok which has spent US$880 000 over a seven-year period to restore their beach stretch of around 250 m, allegedly damaged by past coral mining.

Damage Costs (DC): In the absence of coastal protection, the monetary damage to property and infrastructure from surge and storms can be enormous. Hence, the damage cost approach uses the value of the expected loss of the "stock at risk" as a straightforward proxy for the value of the coastal protection service.

Berg et al. (1998) use the cost of land loss as a proxy for the annual cost of coastal erosion due to coral mining in Sri Lanka. Depending on land price and use, these costs are between US$160 and US$172 000/km of reef per year. Cesar (1996) uses a combination of the value of agricultural land and the costs of coastal infrastructure and houses to arrive at a range of US$90 up to US$110 000/km of reef per year for the value of coastal protection afforded by the reef.

Travel Costs (TC): This approach is often used to estimate the welfare associated with the recreational use of a national park. With this technique, the travel time or travel costs are used as an indicator of the total "entry fee" and, therefore, a person's willingness to pay to visit a park. The further away people live from the park, the higher the costs are to visit it. Because of the variation in these costs among visitors, the demand for different prices can be determined, a "demand curve" for the park can be constructed, and the associated consumers' surplus can be determined. This surplus represents an estimate of the value of the environmental good in question (e.g. the National Park).

Pendleton (1995) provided an example of TC. He used this method to estimate the value of the Bonaire Marine Park. To obtain the welfare estimate, Pendleton divides the number of visitors from each state/country by the population of the corresponding origin. This visitation rate is then regressed upon travel costs, giving the demand curve for reef-oriented vacations to Bonaire (visitation rate = [0.0725 – 0.0000373] x travel costs). Based on this estimated demand curve, on the travel costs from each region and on an assumption of 20 000 annual visits to the marine park, the total consumer surplus of visitors to the Bonaire Marine Park is approximately US$19.2 million annually. Another example is a TC study reported in Hundloe et al. (1987), which attributes a value of AU$144 million per year for tourists visiting the Great Barrier Reef.

Contingent Valuation Method (CVM): Where people's preferences are not revealed by markets, CVM uses direct questions about willingness to pay (and/or willingness to accept as compensation) to estimate consumers' preferences. It basically asks people what they are willing to pay for a benefit, or what they are willing to accept by way of compensation to tolerate a loss. This process of obtaining information may be carried out either through a direct questionnaire/survey or by experimental techniques in which subjects respond to different stimuli in "laboratory" conditions. CVM seeks to obtain the respondent's personal valuations of increases or decreases in the quantity of some goods, contingent upon a hypothetical market. Spash (2000) gave an example of CVM from a survey in Montego Bay (Jamaica) and Curaçao (Netherlands Antilles) to investigate the consumer surplus, or individual utility, of coral reef improvement. The survey instrument was designed to capture the "non-use" benefits of marine biodiversity, for both local residents and for visitors. The question to respondents dealt with their willingness to pay (WTP) for more coral cover in the park. Expected WTP for coral reef improvement was US$3.24 per person in a sample of 1 058 respondents for Montego Bay. For Curaçao, the number was US$2.08 per person. But this value was heavily dependent on whether or not respondents believed that marine systems possessed inherent rights, and that humans had inherent duties to protect marine systems.

There are a number of biases associated with CVM that are important to note. These biases have given CVM a bad name in the eyes of some. Careful use of CVM is therefore necessary. Barton (1994) summarizes the following biases, described in the literature:

- Hypothetical bias: This refers to the potential error inherent in the process that is not an actual situation. Respondents may not take the interview seriously enough to give bids reflecting their true preferences.
- Strategic bias: People may answer strategically if they feel that their reply will influence real events, i.e. if they feel that their willingness-to-pay bid may entail actual payment, their values will be lower than otherwise.
- Information bias: The way in which the hypothetical situation is described can have a powerful effect on the reply, and involve several aspects. Design bias refers to how the questions are structured. Instrument bias will result if the respondent reacts (positively or negatively) to the hypothetical instrument or vehicle of payment that is suggested (e.g. entry fee). Starting-point bias refers to the observation that the starting bid may affect the final outcome in a converging bidding process.

An important issue in economic valuation of natural resources is the concept of benefit transfer. It is often quite costly to carry out studies to determine the precise TEV of coral reefs in each location, e.g. a specific marine park. However, it is sometimes possible to use a meta-analysis of studies carried out in other, comparable, areas. For example, if an extensive study has been carried out for the fisheries and tourism potential in one marine reserve in the Philippines, then it is not unlikely that these values can form a proxy for another marine reserve elsewhere in the Philippines. This practice of transferring monetary values is referred to as "benefit transfer".

The TEV gives the economic value of an area at a certain moment. Often, we would like instead to know the costs and benefits of coral reef protection. In such situations, the costs of government interventions need to be compared with the net benefits of such interventions. Economists tend to use extended cost benefit analysis (extended CBA) to evaluate the interventions. For a background to extended CBA, see Belli et al. (2001).

Review of literature

The literature related to the economic valuation of coral reefs shows that past research has focused very much on direct use values of coral reefs and, to a lesser extent, on indirect use and non-use values. Research on the TEV of coral reefs is limited. It is not surprising that most of the past studies focused on use values of coral reefs as these are the easiest to measure and also are probably of most interest to stakeholders, in particular, policy decision-makers.

The literature review indicates that most of the studies on direct use values of coral reefs focus on the values generated from fish production, recreation or tourism, and research and education. Most of these studies used the productivity change (EoP) method to estimate the use value (in terms of revenue) generated. The other method that is commonly used to estimate the use values of coral reefs generated from recreational or tourism activities is the TC method. The third method being used to estimate the use value generated from coral reef ecosystems is CBA.

The productivity change (EoP) method is also used to estimate indirect use values provided by coral reefs, e.g. their coastal protection value. Most studies using EoP estimate the net present value (NPV) of the stock at risk (e.g. infrastructure) linked to a loss in coastal protection. This net present value is used as an approximation of the coastal protection value of the reef. The other method commonly used to estimate indirect use values generated from coral reef ecosystems is the RC method. For example, Cesar (1996) used RC to estimate that the reef's loss of protective capability is linked linearly to its protective value.

In contrast, Ruitenbeek and Cartier (1999) estimated the value of Montego Bay coral reef using a model incorporating drug values, local bio-prospecting costs, institutional costs, discovery success rates for marine extracts, and a hypothetical bio-prospecting program for the area using National Cancer Institute sampling protocols. De Groot (1992) used shadow pricing to estimate the cost of biodiversity maintenance for the Galapagos National Park.

Of all the valuation techniques developed to estimate the non-use value of coral reefs, the CVM is the most commonly used. De Groot (1992) also used sales of books and films to estimate the cultural/artistic inspirational use value of coral reefs. In the same study, he also considered the level of donations to estimate the spiritual use value of Galapagos National Park in Ecuador.

De Groot (1992) also provided an estimate of the TEV based on the total annual monetary returns from direct and indirect use of Galapagos National Park. In the same study, benefit transfer was used to estimate the annual value of the reefs based on the similarities between the Dutch Wadden Sea and Galapagos estuarine areas, with the assumption that 10 per cent of fishery in Galapagos depend on the nursery function provided by inlets and mangrove lagoons.

Socioeconomics of coral reefs

Economic analysis of coral reefs goes considerably beyond pure monetary valuation (Cesar, 2000). It includes consideration of at least the following four issues:

- **The extent of poverty and income deterioration due to coral reef degradation;**
- **The degree to which local populations rely on reef fisheries for subsistence purposes;**
- **The existence (or otherwise) of other income generating activities in reef areas; and**
- **Stakeholder analysis of which social group wins and which loses from various threats and management actions.**

In this paper the focus is on stakeholder analysis and other income generating activities. To illustrate the stakeholder analysis, Table 4 shows the private benefits that accrue to the various groups of stakeholders involved in causing threats to the coral reefs of Indonesia as well as to each of the persons/families/boats/companies involved.[6] The aggregated numbers (last column of Table 4) correspond with the total benefits presented in Table 2 (second column).

Interestingly, at US$0.121 million, net benefits per square kilometer to stakeholder groups are highest for coral mining. Yet, private benefits per stakeholder (person/boat/company/etc.) are highest to those involved in poison fishing and logging-induced sedimentation, ranging from US$2 million per company in the case of logging to over US$0.4 million per boat in the case of poison fishing. Side-payments are also particularly high, very roughly estimated at some US$0.3 to 1.5 million for some receivers. At the other extreme, coral mining is a rather marginal activity for the mining families involved (for a discussion, see Cesar et al. 1997).

Case study one: Total economic value of a coastal area (Jamaica's Portland Bight)

Introduction and study area

On 2 April (Earth Day) 1999, the Jamaican government declared its largest environmental conservation area, the Portland Bight Protected Area (PBPA). The PBPA is situated along Jamaica's southern coast, just west of Kingston (Jamaica's capital). Its marine region runs due south into the Caribbean Sea along the 200-meter depth contour. The area has a number of valuable ecological resources, including coral reefs, wetland systems, dry limestone forests, and a number of endangered species. Some of these resources are currently under threat of over-fishing, dynamite fishing, pollutants (such as industrial waste, oil and sewage), charcoal burning, wood cutting and marijuana cultivation. The PBPA is classified as a

Table 4. Net benefits to stakeholder groups: (NPV at 10% discount rate over 25 years in US$'000; per km². Benefits per stakeholder in parentheses)

Threat \ Individuals	Fishers	Miners, Loggers	Others (payments)	Total per km²
Poison fishing	29 *(468.6 per boat)* *(23.4 per diver)*	-	4 *(317-1 585 per person)*	33
Blast fishing	15 *(7.3 per fisher)*	-	?	15
Mining	-	67 *(1.4 per mining family)*	54 *(18-54 per person)*	121
Sedimentation due to logging	-	98 *(1 990 per logging family)*	?	98
Over-fishing	39 *(0.2 per fisher)*	-	-	39

Source: Adapted from Cesar (1996) and Cesar et al. (1997).

[6] The column "Others" presents the payments to third persons, sometimes referred to as "political rents".

"multi-use conservation area", combining private and public lands and activities such as agriculture and industry alongside residential and wilderness areas. The goal of the Portland Bight Management Plan is to ensure the sustainable use of natural resources and the conservation of threatened species and ecosystems, while at the same time meeting the needs of the current generation in terms of physical and social infrastructure, services, and income generation (CCAM, 1999).

The PBPA covers 520 km^2 of land (which includes 82 km^2 of wetlands and 210 km^2 of forests), and a marine area of 1 356 km^2. The land area of the PBPA is 4.7 per cent of Jamaica's total land mass, an area larger than the entire island of Barbados. Coral cays and reefs occur sporadically throughout the marine area of Portland Bight, notably at the edge of the island shelf. Mangrove wetlands predominate along much of the coastline. Shoreward, benthic regions of the Bight are dominated by mudflats. The Bight functions as habitat for a number of marine organisms, including the endangered West Indian Manatee (*Trichecus manatus*). The PBPA also contains four prominent examples of tropical dry limestone forest, containing a unique evergreen forest as well as cactus scrubs. The approximately 60 km^2 Hellshire Hills area is the largest remaining pristine dry limestone forest in Central America and the Caribbean. The Hills are home to the last of the remaining Jamaican Iguana (*Cyclura collei*), which is an endangered species endemic to the island.

Resources, services and functions

The various ecosystems in the PBPA support a host of different resources, services and functions (RSFs). The most important ones are discussed below.

Direct uses: These include <u>fisheries,</u> harvesting pelagic and demersal fish that feed along the coral reefs and the rest of the island shelf of Portland Bight. The fishing grounds of South Jamaica cover an area of almost 2 586 km^2. Lobster, shrimp and conch stocks, although severely depleted, are an economically valuable resource. A second direct use is <u>forestry;</u> products from the limestone woods of the PBPA satisfy local demand for <u>timber products</u> such as fuel wood and charcoal. Mangrove wood is also valued as a source of poles for fences, stakes, scaffolds, and yamsticks, and is used in housing construction. In addition, the mangroves and dry limestone forests provide a host of <u>non-timber products</u>, such as honey, orchids and medicinal plants.

Indirect uses: The <u>tourism and recreation</u> sector is a fundamental component of the Jamaican economy, in 1997 attracting 1.8 million visitors and over US$1.3 billion. In comparison with the north coast, tourism along Jamaica's south coast is very undeveloped. The Portland Bight region, like the rest of Jamaica, appeals to tourists interested in relaxation, touring, swimming and sunbathing, and enjoying natural surroundings (Halcrow 1998). Other indirect uses relate to the PBPA's <u>navigation function</u>. Two major ports located within the Bight are major alumina storage and shipping complexes and are also used for the export of goods and the import of oil, grain, etc. The wetlands allow for natural <u>waste treatment</u>, <u>sediment retention</u> and <u>coastal protection</u>. The latter is important to prevent coastal erosion. The mangrove and limestone forests fix carbon dioxide, a process referred to as <u>carbon sequestration</u>. This is increasingly recognized as an important ecosystem service whereby mangroves offset CO_2 emissions, thus helping to slow down the greenhouse effect (Sathirathai 1998).

Non-uses: Some ecosystem functions are remote and not accounted for as either direct or indirect use. The many unique ecosystems contained within the PBPA make an important contribution to the <u>biological diversity</u> of the island, and provide habitat or nesting areas for endangered species, several of which are endemic to Jamaica. This non-use function is related to use-functions. Tourists come to enjoy the biodiversity and culture, but the idea of "non-use value" is the intrinsic existence of these functions independent of human use.

The PBPA management plan and its associated costs

The management plan for the Portland Bight Protected Area (PBPA) prepared by the (CCAM) Caribbean Coastal Area Management was published in May 1999 and approved by the Natural Resources Conservation Authority (NRCA). The plan delineates the boundaries, defines the management objectives, and outlines specific management plans for almost every natural resource in the PBPA. The management plan describes the 28 different zones, and explains the plans for community environmental education, enforcement and tourism development within the PBPA. It contains a preliminary assessment of the resources needed to manage the PBPA, as well as suggestions as to how the PBPA might be sustainably financed. CCAM intends to take a co-management approach, promoting the management of the resources in the project area as a joint effort of the stakeholders, including the government. In the model being pursued, co-management takes place through resource management councils, made up of representatives of the stakeholders in the resource – including government agencies, resource users, the private sector and NGOs.

Operational expenses of the PBPA will be financed from government subvention, user fees, income from a trust fund and profits from tourism activities and merchandizing. Grant funds will play a large part in financing the necessary capital expenditures. The recurrent costs of the PBPA Management Plan are estimated at US$1.496 million per year, while the capital investments are estimated at US$2.422 million. The capital budget consists of many items (computers, GPS equipment, vehicles) that are typically written off in a five-year period. Using this five-year write-off period, the combined recurrent and capital costs of managing the PBPA are roughly US$19.2 million over 25 years in net present value terms (10 per cent discount rate). This information is used in the following comparison of the costs and benefits of the PBPA.

Economic valuation

Each of the resources, services and functions (RSFs) for the three categories of ecosystems (marine; wetland; terrestrial) has an economic value. The main problem with the valuation of these RSFs is that their measurement in monetary terms is time-consuming, and in some cases impossible. Table 5 suggests a very rough first guesstimate of the most relevant values for the

Table 5. Categories of ecosystems in PBPA and their perceived economic values*

	Values	← Direct economic value →						← Indirect economic value →				← Non-use →		
Services & Functions / Eco-systems	Area (km²)	Fishery (habitat; catch)	Forestry (charcoal, etc.)	Forestry (non-timber)	Tourism	Recreation (Game, etc.)	Navigation	Waste treatment	Sediment retention	Coastal protection	Carbon fixation	Biodiversity	Cultural heritage	Etc.
Marine	1356	xxx	-	-	xxx	xx	xxx	xx	xx	xxx	-	xxx	x	
Seagrass	?	xxx	-	-	-	-	-	xx	xx	x	-	xxx	-	
Coral reefs	?	xxx	-	-	xx	xx	-	x	x	xx	-	xx	-	
Islets	1	-	-	-	xxx	-	-	-	-	xxx	-	-	xx	
Rest of the shelf	?	x	-	-	x	xx	xxx	x	x	x	-	-	-	
Wetlands	82	xx	x	x	xx	xx	-	xxx	xxx	xx	xx	xxx	-	
Mangroves	55	xxx	x	x	xx	xx	-	xxx	xxx	xxx	xx	xxx	-	
Tidal marsh	12	xx	-	-	x	-	-	xxx	xxx	x	-	x	-	
Saline pools	15	x	-	-	x	-	-	x	x	x	-	x	-	
Terrestrial	438	-	x	x	xxx	xx	-	x	xx	x	x	xxx	xx	
Forest	210	-	x	x	xxx	xx	-	x	xx	x	x	xxx	x	
Shrubs, etc.	20	-	x	x	x	-	-	-	-	x	x	-	-	
Agriculture	168	-	-	-	-	-	-	-	-		-	-	x	
Human/ Industry	40	-	-	-	-	-	-	-	-		-	-	xx	
Total	1876	xxx	x	x	xxx	x	xxx	x	xx	xxx	x	xxx	xx	

* The higher the guesstimated value of the function, the larger the number of stars (x) – from 0 to 3 stars. The circles around a set of stars indicate that the specific value for a function/resource can only be calculated for a set of ecosystems combined. The circles in the "Total" row indicate the functions and resources for which a monetary valuation is given in the text.

various ecosystems in the PBPA. This is achieved by giving every value for each of the ecosystems a number of stars (0, 1, 2, or 3) depending on the likely contribution of the ecosystem to the RSFs. Not only is measurement of RSFs difficult, but also certain values can only be calculated for a set of ecosystems combined. In Table 5, this is indicated by a circle around a set of ecosystems. For instance, it is very hard to discuss the fisheries for mangroves, reefs, sea-grass and tidal marshes separately given the complex interrelationships between these ecosystems. For the tourism and recreation function, a somewhat similar situation exists; most tourists are interested in a package of cultural and natural experiences, rather than in individual elements of the package.

Fisheries: The total yield of the Portland Bight fishery in 1997 was 1 088.4 t. This corresponds to 0.8 mt/km^2/yr. Haughton (1988) suggested that the maximum sustainable yield (MSY) for the south Jamaican fishery is 2.2 t/km^2 (Cesar et al. 2000). Given the relatively low capital intensity, this is close to the maximum economic yield (MEY). At low levels of capital, MEY and MSY are close, while at high levels of capital, the MEY can be much smaller than the MSY. The discrepancy between actual yields and the MEY (or MSY) shows the enormous level of over-fishing. Given the open access nature of Jamaican coastal fisheries, it is assumed that current yields equal the open access equilibrium (OAE), where all economic rents are squeezed out of the market. Espeut and Grant (1990) show reasonable profit margins for south-shelf fishers of 50 per cent (pot fishers) and 54 per cent (net fishers). With growing piracy, fish pot stealing and over-fishing, we assume that profits have declined to zero over the last decade. This shows that the actual economic value added has been squeezed out of the fisheries over the last 10 years. Cesar et al. (2000) estimated that MSY profits are US$5000/ km^2 /yr or US$6.78 million for the PBPA at an average fish price of US$2.8/kg. In the OAE, the fishery value would be zero.

Forestry: In the mangrove and limestone forests, trees are cut for construction material, fuel wood and charcoal production. Though some level of mangrove thinning is sustainable if regulated properly, wood extraction in the dry limestone forests is unsustainable due to the absence of topsoil. In the Hellshire Hills, some 60 people are involved in charcoal production[7], creating a total gross value per year of US$100 000. Harvesting of non-timber products takes place at such a small-scale that, here, the value of these non-timber resources is put at zero.

Tourism and recreation: With the exception of Hellshire Bay, a popular beach day-trip destination for local Kingston residents, the number of tourists currently visiting the PBPA is very small.[8] Eco-tourism development possibilities in the PBPA are suggested in Halcrow (1998). The extent to which tourism develops depends on expansion of facilities, marketing, and on reduction of possible violence and tourism harassment (Halcrow 1998). Two scenarios are identified in this case study. In the first, these constraints are not adequately dealt with, while, in the second, gradual and sustainable expansion of eco-tourism is realized. In the latter scenario, the value of tourism and recreation is taken to be US$0.75/ km^2/yr based on benefit transfers (Costanza et al. 1997)[9] of US$4.7 million for the whole PBPA (assuming that one third of the area is of interest to tourists). In the former scenario, we assume (tentatively) that tourism profits are one tenth of this amount (US$470 000), the same as in the future "without PBPA" case. We further assume that, currently, the value added from tourism is zero.

Carbon fixation: Growing forests can sequester carbon. The net growth of dry limestone forests is very limited and net carbon fixation is assumed to be zero. Mangroves have a much larger potential. Sathirathai (1998) estimates a value of US$8 200/ km^2/yr based on US$5.67 per tonne of carbon and a primary productivity for mangroves in Thailand's Kanjanadit district of 1 510 t of carbon/ km^2/yr. Using this value as a benefit transfer, the 55 km^2 of mangroves in Portland Bight have an annual value of US$45 million. It is assumed that the net area of mangroves remains stable in the PBPA, but that it would decline by 1 per cent annually in the absence of good management.

Coastal protection: Mangroves and other wetlands as well as coral reefs contribute to coastal protection, as such ecosystems are able to dissipate wave energy. In recent years, mangrove destruction has resulted in damage to the coastal

7 Data are scarce given the illegality of this activity (see Cesar et al. 2000).
8 This is a very different picture from areas along Jamaica's northern coast. For example, Gustavson (1998) calculated tourism values for Montego Bay had a net present value associated with the hundreds of thousands of tourists ranging from US$210 million to US$630 million.
9 Costanza et al. (1997) give an annual value for coastal ecosystems of US$0.82/km^2 and for forests of US$0.66/km^2. This would give a weighted average of roughly US$0.75/km^2 for the relevant parts of the PBPA.

road going into the Portland Ridge. For the Portland Bight, Cesar et al. (2000) estimated that the total coastal protection value was around US$3.55 million in NPV terms or nearly US$400 000 per year (with 10 per cent discount rate). It is assumed, following Pet-Soede et al. (1999), that a 1 per cent loss in coastal ecosystems leads to a 1 per cent loss in the coastal protection function, and this in turn leads to a loss of 1 per cent of the value of the coastline. With a 1 per cent decline in mangrove stands in the absence of park management (but no decline with park management), the benefits of the PBPA in terms of coastal protection are US$4 000 per year.

Biodiversity: To estimate biodiversity in a developing country, Ruitenbeek (1992) suggests taking the value of foreign support likely to be available to protect the biodiverse resource through NGOs, through the Global Environment Fund and other means. A recent study for Indonesia has shown that two marine parks were able to capitalize on their global value of biological diversity, by obtaining an average of US$10 000/km^2/year (Cesar et al. 2000). In the PBPA, the areas of most interest in terms of biodiversity are the Hellshire Hills, the Portland Ridge, the wetlands, and the rest of the strip along the coast. These areas, totalling about 200 km^2, could be eligible for global grant funding of around US$10 000/km^2/year, or a total annual cash revenue of US$ 2 million.

Total benefits of PBPA: The values of the ecosystems' services can be combined to calculate the total benefits of the PBPA (Pendleton 1995). To do so, the difference in value between a "with PBPA" scenario and a "without PBPA" scenario needs to be calculated. However, as discussed, the aggregation of economic values would still need to take into account the compatibility of the different functions for a specific use (Spurgeon 1992; Barton 1994). Of all the services discussed above, the only one not compatible with sustainable use is charcoal. Therefore, in the "with PBPA" scenario, charcoal production will stop. It is assumed that the changes are complete in 25 years, so that fisheries will be back at its maximum sustainable yield in 2025.

Comparison of costs and benefits: Table 6 pulls together all the values of the ecosystem. The total (incremental) benefits of the PBPA are estimated at US$52.6 million in present value terms (at a 10 per cent discount rate) in the optimistic tourism scenario and US$40.8 million in the pessimistic tourism case. Hence, the US$19.2 million costs over the next 25 years (see above) are well justified on economic grounds.

Case study two: Costs and benefits of coral mining in Lombok, Indonesia[10]

Introduction

One of the key threats to coral reefs is the extraction of corals for lime production and construction materials. This is carried out in many areas around the world, including East Africa (Dulvy et al. 1995; Andersson and Ngazy 1995), South Asia (Brown and Dunne 1988; Rajasuriya et al. 1995; Berg et al. 1998), Southeast Asia (Cesar et al. 1997) and in the Pacific (Salvat 1987). Extraction of corals has a detrimental effect on the reef ecosystem. For instance, a study carried out by Dulvy et al. (1995) in Tanzania showed that live coral cover in mined areas was one third of that in the unmined sites. In addition

Table 6. Values for ecosystem services in the Portland Bight (US$'000)

	"Without PBPA"		"With PBPA"		Accumulated difference 2000-2025[11] (in NPV)
Year	*2000*	*2025*	*2000*	*2025*	
Fisheries	0	0	0	6 780	18 928
Forestry	100	100	0	0	-916
Tourism (high)	0	470	0	4 700	11 809
Tourism (low)	0	470	0	470	0
Carbon fixation*	0	0	450	450	4 122
Coastal protection*	0	0	40	40	366
Biodiversity	0	0	2 000	2 000	18 322
Total (high tourism)	100	570	2 490	13 970	52 631
Total (low tourism)	100	570	2 490	9 740	40 822

*These are calculated in net terms. This means that the "with" scenario gives the net gains relative to the "without" scenario.

[10] This section is based on Cesar (1996) and Ohman and Cesar (2000).
[11] Note that the numbers in this column are not equal to the difference in the numbers of the previous two columns; they are the net present value of the accumulated difference over the 25-year period.

to these direct effects, loss of land and increased sedimentation have also been reported (e.g. Salvat 1987; Dulvy et al. 1995). If corals are collected from a reef, recovery appears to be slow. Dulvy et al. (1995) stated that recovery of the reefs to the pre-disturbance live coral cover could take up to 50 years.

Although coral extraction is destructive, it is a source of income and subsistence for many people in the developing world. Yet, by adversely affecting the foundation of the reef, coral mining is likely to result in longer term costs to society. In this case study we analyze the cost and benefits of coral mining in Lombok, Indonesia. In a financial analysis we describe the mining business and estimate its net profits. In the economic analysis, we also consider the societal costs of coral mining in terms of associated losses to reef functions, specifically fishery, tourism and coastal protection functions. The case study shows that the societal costs far outweigh the private gains accruing to a handful of individuals, even though these individuals themselves have a clear interest to continue, partly because of a lack of other income-generating activities in the area.

Financial analysis: The coral mining business

Lombok is an island situated in the south central Indonesian archipelago between Bali and Sumbawa. Its population of 2.4 million people depends to a large extent on the island's coastal resources. Tourism is an important industry that is growing rapidly. Other activities include fishing and mangrove forestry (Subani and Wahyono 1987; Cesar 1996). Coral mining for lime production is a small-scale, but widespread, industry around the island, with recently 500 to 1 000 families involved in the business. A case study by Cesar (1996) described a small area in West Lombok where 60 families have practised mining on a 2 km long stretch of reef over a 10-year period. The corals were collected, burnt and sold as lime.

A crucial input for the mining process is locally harvested fuel wood. The study found that each family used roughly 20 m^3 of fuel wood taken from a secondary forest. Another interesting expense in the production of lime for each family was the side-payments for "protection", as coral mining is illegal in Indonesia. This is important to consider in the financial analysis as it is a real cost to the business. Finally, there were no labor costs, as coral mining in Lombok is a family business; fathers and sons do the mining and the women break up the corals and are involved in the burning and sieving processes.

Economic analysis: Societal costs of coral mining

Extraction of corals for lime production affects many essential reef functions. Here, three such functions are discussed: fisheries, tourism and coastal protection. These three were selected as they were considered to be quite important and relatively easy to quantify. The sum of the quantifiable damage can be interpreted as a lower-boundary of the total mining losses. As a result of mining activities the functions of coral reefs will decrease gradually. Figure 2 gives the assumed paths over time, as elaborated in Cesar (1996). Fringing coral reefs act as natural wave breakers and protect against coastal erosion. In the Lombok study it was assumed that coastal protection would start breaking down after five years of mining. Tourism on the other hand, would be affected immediately. As divers are sensitive to the aesthetic appearance, other diving destinations would become relatively more popular. Therefore, it was assumed that after two years, tourism would have vanished. It was further suggested that no substantial recovery of the corals would take place within the time frame of the analysis. For fisheries, it was assumed that reef fisheries would disappear and be replaced by a less valuable pelagic fishery.

For the economic valuation of the losses of these functions, the case study presents two scenarios, one in which there is limited tourism potential and little coastal construction (the "low" scenario) and one in which there is high tourism potential and considerable coastal infrastructure (the "high" scenario). All costs are calculated in NPV terms for a 30-year time horizon. The NPV expresses the discounted sum of annual costs over the 30 years. The net loss of the fishery function was valued at US$74 900 in both scenarios. For the "low" scenario, the loss of the tourism function was estimated at US$2 900 and that of the coastal protection function at US$12 000. In the "high" scenario, loss of tourism is estimated at US$481 900 and erosion costs are estimated at US$260 000 (see Figure 3 and Table 7).

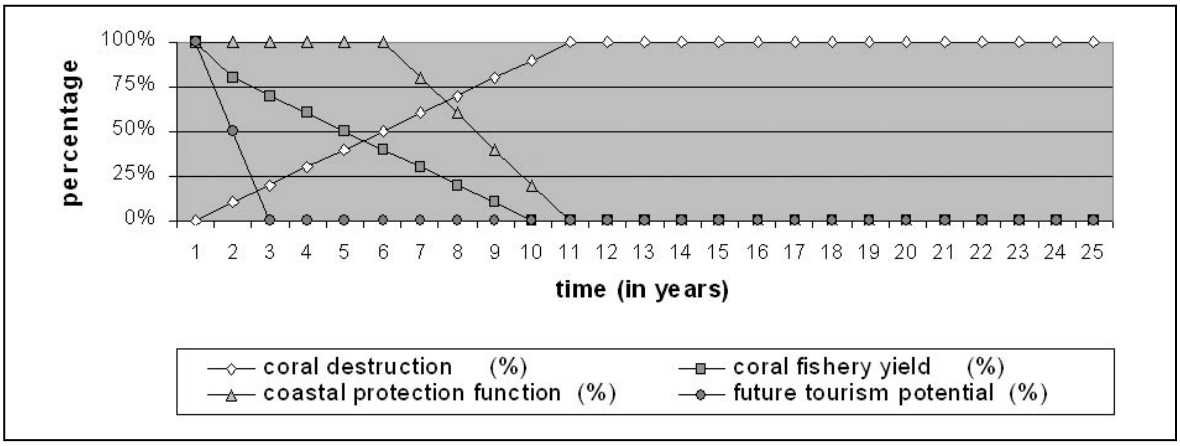


Figure 2. Destruction of coral reefs over time in the Lombok case study

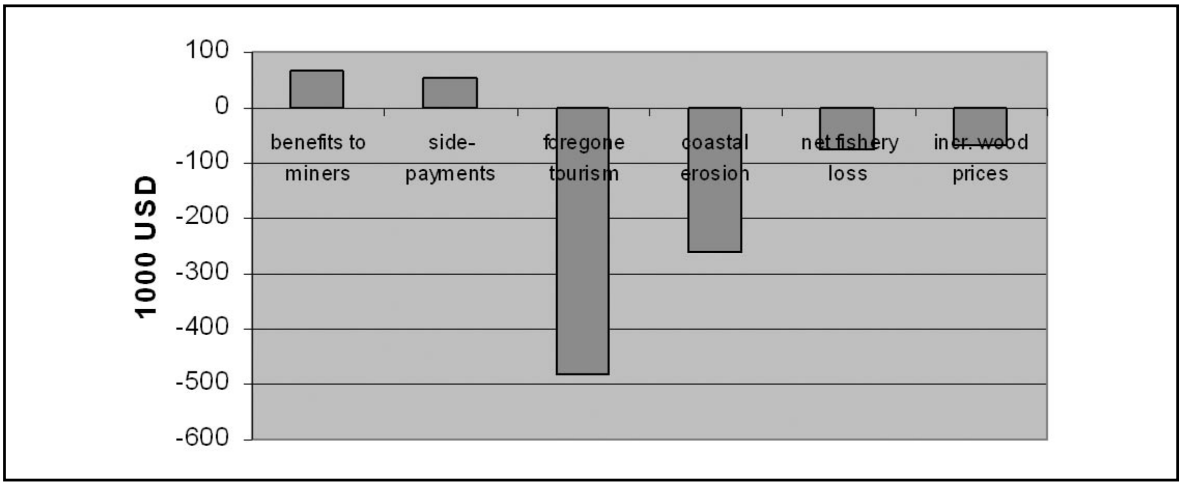


Figure 3. Costs and benefits of coral mining in a "high" scenario case

Table 7. Costs and benefits of coral mining per square kilometer in NPV terms

"Low" scenario (US$'000)				*"High" scenario (US$'000)*			
Costs Direct costs		Benefits Direct benefits		Costs Direct costs		Benefits Direct benefits	
Labor	0	Sales of lime	302	Labor	0	Sales of lime	302
Wood	67			Wood	67		
Side-payments	54			Side-payments	54		
Other costs	13			Other costs	13		
		Side-payments	54			Side-payments	54
Indirect costs		Indirect benefits		Indirect costs		Indirect benefits	
Coastal erosion	12			Coastal erosion	260		
Increase in wood prices	67			Increase in wood prices	67		
Other functions	n/a			Other functions	n/a		
Opportunity costs				Opportunity costs			
Foregone tourism	3			Foregone tourism	482		
Net fishery loss	75			Net fishery loss	75		
Labor costs	101			Labor costs	101		
Total costs	392	Total benefits	356	Total costs	1 119	Total benefits	356
Costs to miners	235	Benefits to miners	302	Costs to miners	235	Benefits to miners	302
Net present value (economic)			-33	Net present value (economic)			-762
Net present value (financial)			67	Net present value (financial)			67

Table 7 also shows that there are three additional items in the economic analysis. First, when calculating mining profits in the financial analysis, labor costs were set to zero because only family labor was involved. For the economic analysis, however, these costs need to be imputed in some way, as the mining family could have been employed elsewhere ("opportunity costs"). These costs were estimated at US$101 000 in NPV terms. Secondly, the true costs of fuelwood were assumed to be larger than the price paid by the families, because of the unsustainable way in which the logging was carried out. The economic costs were assumed to be double the price paid. Thirdly, the side payment paid by the mining family for protection is a true cost to that family. However, from an economic point of view, it is merely a transfer of resources from one group in society (the miner) to another (the protector), so these costs were not incorporated.

Combining the net profits from mining with the societal costs, Table 7 shows that the economic cost imposed on society by mining is US$36 000/ km^2 for a "low" value scenario (costs are US$392 000 in NPV terms and benefits are US$356 000). For the "high" scenario, the contrast between costs and benefits is even more pronounced: US$1 119 million versus US$0.356 million. This means that the NPV of mining is US$-763 000 in the "high" scenario. For both scenarios, therefore, coral mining constitutes a significant, long-term loss to society.

Case study three: The economic cost of coral bleaching in the Indian Ocean

Introduction

The 1998 massive worldwide episode of coral bleaching and subsequent damage to coral reefs is likely to result in serious socioeconomic impacts. With 135 persons per km^2, the Indian Ocean region is the most densely populated coastal region in the world (WRI 1998). The majority of the population is poor and the dependence on fisheries for income and animal protein intake is high. Over-fishing is already a major threat and coral bleaching could worsen this. In other areas, coastal tourism and diving are the main income-generating activities; in the Maldives 45 per cent of the GNP stems directly or indirectly from tourism revenues. Furthermore, the land area around the Indian Ocean is prone to seasonal cyclones; coral reefs form natural barriers to protect the coastline from erosion. In Sri Lanka, severe coastline erosion has already occurred in areas where the reef substrate has been heavily mined. Countermeasures to prevent further erosion are already costing the Sri Lankan government around US$30 million (Berg et al. 1998).

This case study aims to provide a plausible range of expected damage estimates in monetary terms. It is based on studies carried out under the "Coral Reef Degradation in the Indian Ocean" program (CORDIO). Specifically, this case study summarizes the tourism and fisheries studies carried out in 1999-2000 under this umbrella program in the Maldives, Sri Lanka, Tanzania and Kenya. The data are generalized to arrive at an overall estimate for the Indian Ocean. Monetary values do not express the true losses to coastal populations dependent on reefs and to others enjoying these ecosystems. Yet, these values can hint at the extent of the problem. And this can assist in raising awareness of the bleaching problem.

Uncertainty and scenarios

The uncertainty surrounding many of the relationships between coral bleaching and coral mortality on the one hand and ecosystem services on the other is enormous. In addition to that, the recovery rate of reef areas after widespread mortality is difficult to predict. In order to consider possible future outcomes, two scenarios are explored. In the first, damage to the reef is not too bad and recovery is relatively quick; in the second, damage is great and there is very slow or no recovery, with the result that long-term impacts are severe. These two scenarios were postulated in Wilkinson et al. (1999) and further specified as described below.

The optimistic first scenario

- A slight decrease in tourism-generated income and employment, as some divers stay home or go elsewhere, and few tourists alter their behavior.
- Some change in the fish species composition. (Initially, fish productivity increases with larger numbers of herbivores; catch reductions for ornamental fish, etc.).
- No major change in the coastal protection function, as bio-erosion of dead reefs and coral growth of new recruits even each other out.

The pessimistic second scenario

- Major direct losses in tourism income and employment, especially when charismatic marine fauna disappear as a result of bleaching and resulting mortality.
- Fish productivity drops considerably as the reef structure disintegrates, resulting in less protein in the diet, particularly for coastal communities.
- The reef ceases to function as a protective barrier, resulting in increased coastal erosion.

Valuation of economic damage

Given the mainly long-term impacts of coral bleaching and the only limited time that has elapsed since the bleaching episode of 1998, it is very difficult to translate the current results from the CORDIO socioeconomic studies into a long-term valuation estimate. With this caveat, estimates of the cost of coral bleaching on tourism, fisheries and other reef services are presented.

Tourism: Financial and economic costs for the Maldives and Sri Lanka in 1998-99 are shown in Table 8. Financial costs are actual costs to the economy from tourism losses. The economic costs express the welfare loss to all concerned individuals transpose in the world due to coral bleaching in a specific country. This expresses a global value but not a figure from which a national government can directly benefit. The description for these two countries and the costs for 1998-99 closely matches those derived in the "optimistic scenario". Although the long-term impacts are uncertain, it is assumed that they will follow the optimistic scenario. It is assumed that, after the second year, tourism growth rates return to normal, and hence the losses are the accumulated losses over time due to a two-year dip in growth rates. Estimates of total coastal tourism around the Indian Ocean could not be obtained, but, based on general data in Westmacott et al. (2000c) and on guesstimates by the author, it is assumed that relevant affected tourism in the Indian Ocean is approximately three times the losses in the Maldives plus ten times the losses in Sri Lanka. This gives a total tourism loss of US$389 million for the whole Indian Ocean in present value terms over a 20-year time horizon and with a 10 per cent discount rate.

For the pessimistic scenario, if we assume long-lasting impacts, the data from Kenya and Tanzania seem to be relatively close to the scenario description. These estimates come from a hypothetical willingness-to-pay (WTP) study, where tourists were surveyed in relation to a severe bleaching and associated mortality event. The *financial* cost of coral bleaching in Zanzibar in 1998-99 was estimated at a mid-point of US$3.8 million. In Mombasa, this was calculated at a mid-point of US$16.7 million. The total *economic* cost[12] of the coral bleaching in Zanzibar was estimated at a mid-point of US$6.2 million and for Mombasa US$29.2 million. To arrive at an estimate for the rest of the Indian Ocean, the Zanzibar and Mombasa estimates were extra-polated based on available information.

Fisheries: The fisheries losses are even more uncertain than those of tourism. In a recent case study by McClanahan and Pet-Soede (see Westmacott et al. 2000a), no significant impacts of coral bleaching in Kenya were found. This follows quite closely the optimistic scenario described above. If we assume that in the future this observation will remain, there are zero financial losses in fisheries. The case of a pessimistic scenario is problematic as no hard fishery data are available on which to estimate the losses. On this issue, we follow Wilkinson et al. (1999) by assuming that the bleaching and

Table 8. Optimistic scenario: Financial and economic costs for the Maldives, Sri Lanka, and the rest of the Indian Ocean for 1998-99 and net present value (NPV) over 20 years

	Financial costs (US$M)		Economic costs (US$M)	
	1998-99	*NPV*	*1998-99*	*NPV*
Maldives	3.0	14.8	19.0	93.6
Sri Lanka	0.2	1.0	2.2	10.8
Rest of the Indian Ocean	11.0	54.4	79.0	389.0

Table 9. Pessimistic scenario: Financial and economic costs for Zanzibar, Mombasa and the rest of the Indian Ocean for 1998 and net present value (NPV) over 20 years

	Financial costs (US$M)		Economic costs (US$M)	
	1998-99	*NPV*	*1998-99*	*NPV*
Zanzibar	3.8	32.6	6.2	52.6
Mombasa	16.7	1 41.9	29.2	248.6
Rest of the Indian Ocean	205.0	1 744.9	354.0	3 011.4

[12] Here, we take total economic costs as the sum of the financial and economic costs as presented in Westmacott et al. 2000b.

mortality witnessed in the Indian Ocean leads to a loss of 25 per cent of reef-related fisheries from year 5 until year 20. In the first five years, this percentage grows linearly from 0 per cent to 25 per cent. Following Costanza et al. (1997), the value of fishery production is assumed to be US$220/ha/yr.

Other reef services: Other services provided by reefs include coastal protection, research, etc. For coastal protection, we assume a value of US$174/ha/yr (Wilkinson et al. 1999). Other reef services are valued at US$97/ha/yr, based on Costanza et al. (1997). The calculations for coastal protection were based on the assumption that, in the Indian Ocean, around 25 per cent of reef areas protect medium to high value infrastructure and 75 per cent protect low value infrastructure. It was also assumed that around 50 per cent of the reef areas have high tourism potential and 50 per cent have low tourism potential. For this calculation, the present value data of Cesar (1996) were annualized. In the pessimistic scenario, bleaching in the Indian Ocean is assumed to lead to a decline in reef services of 50 per cent, starting from year 5, with a lineal growth from 0 per cent to 50 per cent in the first 5 years. These percentage losses in services are multiplied by the annual value of the services, and summed across the services to give total annual losses per hectare per year. This number is multiplied by the 36 100 km^2 of reefs in the Indian Ocean. Finally, the net present value over a 20-year period is taken, using a 10 per cent discount rate.

Summary: Table 10 summarizes the information above. In the pessimistic scenario, total damages over a 20-year time period are valued at over US$8 billion, and arise primarily from coastal erosion (US$2.2 billion), tourism loss (US$3.3 billion), and fishery loss (US$1.4 billion). In the optimistic scenario described above, the losses are still considerable, but are of the order of magnitude less than the damage in the pessimistic scenario, and stem mainly from a US$0.5 billion loss of tourism revenue.

Table 10. Estimates of the overall economic valuation of the socioeconomic impacts of the 1998 coral bleaching event in the Indian Ocean ***(Net present value in US$M over a 20-year time horizon with a 10% discount rate)***

Scenarios Coral reef ecosystem services	Optimistic scenario	Pessimistic scenario
Food production (e.g. fisheries)	0	1 361
Tourism and recreation	494	3 313
Disturbance regulation (coastal protection)	0	2 152
Other services	114	1 200
Total	608	8 026

Discussion

Why do economists want to value something as invaluable as coral reefs? The answer could well be, "because coral reefs are so beautiful that we want to make sure that our grandchildren can enjoy them as well."

Yet, there are many coastal populations who are unaware of the goods and services that coral reef ecosystems provide and who do not appreciate the complex linkages of the natural world. Creation or transformation of markets for environmental goods might help overcome these problems. Markets could also assist in cases where people use coral reefs unsustainably and even destructively, and where politicians with short-term views fail to provide funds for coral reef management, even though the long-term costs of inaction are typically much higher than the funds needed initially.

One important challenge in economic valuation studies is to identify to whom the benefits (real or virtual) accrue. In TC studies, some of the costs are paid and accrue to local or foreign business operators. Most costs are, however, virtual. They describe, for example, a potential willingness-to-pay for a specific improvement in reef quality in a national park. In the case of CVM, all values are virtual in the sense that there are no actual cash transactions involved.

A second important challenge is the fact that valuing all the benefits of coral reefs is often frustrating, and sometimes nearly impossible. The good news is, however, that not all benefits have to be valued. Assume it can be shown that net benefits to blast fishers is lower than societal losses from the loss of sustainable fishing income and tourism revenues combined. In that case, no complicated techniques are needed and no major data collection on the value of bio-prospecting, biotic services and physical structure services are required; two services that can be measured in monetary terms suffice to show the costs of inaction.

When valuing reef-destructive activities such as coral mining, the type of valuation presented above provides information that is useful for designing reef management plans. Comparing mining profits with the associated societal costs can significantly raise awareness of the long-term detrimental impacts of coral mining. Furthermore, an understanding of the financial returns to coral miners will increase the appreciation of the driving forces behind each miner's behavior and so improve the design of management plans.

As has been shown in this paper, economic valuation can be used to raise the awareness of all those involved in the use and management of coral reefs, with the result that the beauty of the coral reefs may be enjoyed forever.

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Annex I: Economic values for marine systems – a compilation from the literature[13]

Summary table

Study	Direct Use	Indirect use	Non-use	Total economic value	Benefit/ opportunity cost ratio
1 Cahuita National Park, Costa Rica; *Marcondes (1981)*	√				√
2 Virgin Islands National Park, St. Johns; *Posner et al. (1981)*	√				√
3 Great Barrier Reef; *Carter et al. (1987)*	√				
4 Great Barrier Reef 'Region'; *Hundloe et al. (1987)*	√		√		
5 Bacuit Bay, Philippines; *Hodgson and Dixon (1988)*	√				
6 Philippines; *McAllister (1988)*	√				
7 Galapagos National Park, Ecuador; *Edwards (1991)*	√				
8 Philippines Coral Reefs; *McAllister (1991)*		√			
9 Galapagos National Park; *de Groot (1992)*	√	√	√	√	√
10 John Pennekamp/Key Largo; *Leeworthy (1991)*				√	
11 Panama Coral Reefs; *Spurgeon (1992)*	√				
12 Valdez Oil Spill, Alaska; *Hausman et al. (1992)*	√				
13 Valdez Oil Spill; *Carson et al. (1992)*			√		
14 Bonaire Marine Park; *Dixon et al. (1993)*				√	
15 Taka Bone Rate Coral Reef Atoll, Indonesia; *Sawyer (1992)*	√				
16 Bonaire Marine Park; *Pendleton (1995)*				√	
17 Coral Reefs at Negril, Jamaica; *Wright (1994)*				√	
18 Indonesia Coral Reefs; *Cesar (1996)*	√	√			
19 Montego Bay Coral Reefs; *Spash et al. (1998)*			√		
20 Montego Bay Coral Reefs; *Gustavson (1998)*	√	√			
21 Great Barrier Reef; *Driml (1999)*	√				
22 Montego Bay Coral Reefs; *Ruitenbeek and Cartier (1999)*		√			
23. Eastbourne, English Channel; *King (1995)*	√				
24 John Pennekamp Coral Reef State Park & adjoining Key Largo National Marine Sanctuary; *Mattson and DeFoor (1985)*	√				
25. Pulau Payar Marine Park, Malaysia: Non-Use Value; *Ayob et al. (2001)*			√		
26. Recreational coral bleaching and the demand for coral reefs: A case study; *Ngazy et al. (2004)*	√			√	
27. An economic analysis of coral reefs in the Andaman Sea of Thailand; *Seenprachawong (2004)*	√			√	
28. Valuation of recreational benefits: An application of the travel cost model to the Bolinao coral reefs in the Philippines; *Ahmed, et al. (2004)*	√				
29. Analysis of the recreational value of the coral-surrounded Hon Mun Islands in Vietnam; *Pham and Tran (2004)*	√				
30. Recreational benefits of coral reefs: A case study of Pulau Payar Marine Park, Kedah, Malaysia; *Yeo (2004)*	√				

[13] Reproduced from Cesar (2000), Pearce and Moran (1994), Cartier and Ruitenbeek (1999) and other articles.

1 Cahuita National Park, Costa Rica; *Marcondes* (1981)

Direct use:
A form of TC appraisal of the recreational value of the Cahuita National Park, Costa Rica. Consumer surplus estimates were derived from observed wage equivalent travel time net of transport costs multiplied by visitor population. The resulting benefit-cost ratio demonstrated that the park is economically beneficial.

Benefit/opportunity cost ratio:
Cahuita National Park ratio 9.54. (A conventionally assessed ratio rather than one based on opportunity cost.)

2 Virgin Islands National Park, St. Johns; *Posner et al.* (1981)

Direct use:
Conventional benefit-cost analysis of the Virgin Islands National Park, St. Johns, identified significant direct and indirect benefits associated with the park, particularly tourist expenditure and the positive effect on land values in proximity to the designated area. Little information is available on the environmental effects of alternative land uses or the extent of visitors' consumer surplus. Total benefit (1980) approximated US$8 295/ha over about 2 820 ha of National Park on St Johns.

Benefit/opportunity cost ratio:
Ratio of total (direct and indirect) benefits to total cost 11.5 (A conventionally assessed ratio rather than one based on opportunity cost.)

3 Great Barrier Reef; *Carter et al* (1987)

Direct use:
Estimating the socioeconomic effect of the Crown of Thorns starfish on the Great Barrier Reef. This TC study provided estimates of consumer surplus of AU$117.5 million/year for Australian visitors and AU$26.7 million/year for international visitors. The study showed that tourism to the reef is valued (in NPV terms) over and above current expenditure levels by more than AU$1billion.

4 Great Barrier Reef 'Region'; *Hundloe et al.* (1987)

Direct use:
A TC study of the Great Barrier Reef estimated AU$144 million/year consumer surplus for domestic tourists and international tourists, based on travel cost expenditure by visitors to the 'Reef Region'.

The same study estimated consumer surplus from visits to coral sites and the 'Reef Region' of the Great Barrier Reef at AU$106 million/year, based on TC to coral sites by domestic and international tourists, and includes all attributes of the 'Reef Region'.

A CVM study on the Great Barrier Reef also provides an estimate of AU$6 million/year consumer surplus, or over AU$8/adult visitor WTP to see coral sites in their present (1986-87) condition; based on a survey of visitors to reef sites only, thereby excluding all other attributes of the Great Barrier Reef 'Reef Region'.

Non-use:
Based on a 1986 mail survey of Australian citizens older than 15 years, the CVM study estimated AU$45 million/year consumer surplus or AU$4/visit WTP to ensure that Great Barrier Reef is maintained in its current state. Estimate excludes respondents who had visited the Reef.

5 Bacuit Bay, Philippines; *Hodgson and Dixon* (1988)

Direct use:
Using (EoP) productive change method, the study at Bacuit Bay, Philippines, concluded that the PV gross revenue for recreation and tourism of the location is US$6 280 with logging, versus US$13 334 with logging ban. Computation was based on mean hotel capacity, occupancy, and daily rates; and an assumed 10 per cent annual decline in tourism revenue due to degradation of seawater quality from sedimentation.

The study also estimated the PV gross revenue for fisheries to be US$9 108 with logging versus US$17 248 with logging ban, based on assumed constant returns to scale of natural systems; and on regression analysis of sediment loading, coral cover and species, and fish biomass relationships.

CBA study evaluates management options: (i) continuation of logging as usual; (ii) logging ban in Bacuit Bay drainage basin.

6 Philippines; *McAllister* (1988)

Direct use:
Using productivity change, the study estimated US$80 million/year of loss in fish production in Philippines caused by dynamiting, muro-ami, and poisoning of coral reefs; based on estimates of current and potential production. Production levels were calculated for varying levels of reef quality.

Productivity Change was also used to estimate the aquarium trade in the Philippines. Global aquarium trade attributable to the Philippine Coral Reefs (US$10 million in 1988) could be increased by 50 per cent with sustainable production practices. The price of Philippine aquarium species is discounted internationally due to method of capture.

7 Galapagos National Park, Ecuador; *Edwards* (1991)

Direct use:
Using Hedonic Demand Analysis, based on a non-linear regression using cost, duration, and itinerary data from travel brochures, as well as cost and duration survey data, this study estimated vacation value of Galapagos National Park, Ecuador at US$312/day/person in 1986.

8 Philippines Coral Reefs; *McAllister* (1991)

Indirect use:
A Replacement Cost study of coastal protection afforded by the Philippines coral reefs. The study estimated US$22 billion, based on construction costs of concrete tetrapod breakwaters to replace 22 000 km^2 of reef protection. As reported by Spurgeon (1992).

9 Galapagos National Park; *de Groot* (1992)

Direct use:
Using productivity change method on Galapagos National Park, de Groot estimated US$0.40/ha/yr (permitted) ornamental product sales; US$0.70/ha/yr local fish and crustacean harvest; and US$5.20 /ha/yr construction materials as having productive use value within the "production function" category of environmental functions.

The study also estimated US$45/ha/yr for recreational value for the total protected area, based on maximum carrying capacity of 40 000 visitors/year, and average expenditure per visit of US$1 300.

US$2.73/ha/yr was estimated for education and research of marine areas, based on research expenditures, and expenditures on field courses, fellowships, training courses, education facilities and materials.

Indirect use:
A Replacement Cost study for organic waste treatment at Galapagos National Park estimated US$58/ha/yr based on the costs of artificial purification technology (applies to marine area only).

Shadow Price was used to estimate the cost for biodiversity maintenance. Estimate of US$4.9/ha/yr, equal to 10 per cent of the market value of any activity reliant on biodiversity maintenance. Classified as a conservation value of the Galapagos National Park, in the category of 'regulation functions'.

The same study also estimated US$0.55/ha/year for nature protection; based on the park budget and the idea that money invested in conservation management should be seen as productive capital because of the environmental functions and socioeconomic benefits provided by conservation of Galapagos National Park.

Non-use:
Based on sales of books and films, de Groot estimates US$0.20/ha/yr for cultural/artistic inspirational use; based on donation, de Groot estimates US$0.52/ha/yr for spiritual use for Galapagos National Park.

An option value of US$120/ha/yr was also estimated, which is equal to the total value of all the park's conservation and productive use values combined. Conservation values include *inter alia* habitat/refugia value and recreation, while productive uses include food, construction materials, etc.

Total economic value:
Total annual monetary returns from direct and indirect use of Galapagos National Park approximate US$120/ha/yr. In present value terms this represents US$2 400/ha (at 5 per cent discount rate) or almost US$2.8 billion for the entire study area.

Benefit/opportunity cost ratio:
Benefit Transfer was used by de Groot on Galapagos National Park: US$7/ha/yr was estimated based on the similarities of the Dutch Wadden Sea and Galapagos estuarine areas. It was assumed that 10 per cent of fishery in Galapagos depends on the nursery function provided by inlets and mangrove lagoons.

10 John Pennekamp/Key Largo; *Leeworthy* (1991)

Total economic value:
TCM estimates a consumer surplus for recreation and tourism of US$285 to US$426/person/day, based on a survey of some 350 park users in 1990 at John Pennekamp/Key Largo, Florida. Nine models were estimated, final range was taken from the two models which best fitted the data. The inclusion of an 'opportunity cost of time' variable was found to increase significantly consumer surplus estimates.

11 Panama Coral Reefs; *Spurgeon* (1992)

Direct use:
Based on a percentage of the Smithsonian Research Institute's budget for work in Panama, the education and research value of Panama coral reefs is estimated at US$2.5 million in 1991. One-sixth of the 1991 US$15 million budget is considered attributable to coral reefs in Panama.

On the other hand, the education and research value of the Belize coral reefs value was estimated at US$150 000/year, based on annual expenditures by UK Coral Cay Conservation to maintain 25 researchers on reefs in Belize.

12 Valdez Oil Spill, Alaska; *Hausman et al.* (1992)

Direct use:
A Recreation Demand study estimated the value of recreation use losses caused by the Valdez oil spill in Alaska at US$3.8 million (1989).

13 Valdez Oil Spill; *Carson et al.* (1992)

Non-use:
A CVM study of oil spill by the *Exxon Valdez* estimated median per household WTP of US$31 as a one-off amount to prevent future oil spills. Aggregating over affected households derives an estimate of US$2.8 billion as the total lost passive-use values as a result of the *Exxon Valdez* oil spill.

14 Bonaire Marine Park; *Dixon et al.* (1993)

Total economic value:
A CVM study on recreation and tourism at the Bonaire Marine Park reports a mean annual WTP estimate of US$27.4 for diving. At visitation rates of 18 700 divers (1992) paying US$10/diver/year fee, estimated consumer surplus is US$325 000.

Using productivity change, gross tourist revenue estimated at US$23.2 million (1991). The study also estimated the revenues and costs of dive tourism, and the carrying capacity of dive sites (4 000–6 000/site/year, for a total of 190 000–200 000).

15 Taka Bone Rate Coral Reef Atoll, Indonesia; *Sawyer* (1992)

Direct use:
A productivity change study on Taka Bone Rate Coral Reef Atoll in Indonesia estimates PV gross revenues (in billion Rp): -2 to 103 without management vs 47 to 777 with management; based on fishing activity surveys; and sensitivity analyses wherein fish catch declines are 0-15 per cent and the discount rates are 5 to 15 per cent. CBA study evaluates management options: (i) no management; (ii) establishment of marine park with regulated fishing.

16 Bonaire Marine Park; *Pendleton* (1995)

Total economic value:
Economic valuation for dive at Bonaire Marine Park, using productivity change method, net tourism revenue estimated to be US$7.9 to 8.8 million (1991); based on ownership and profit data.

TCM study yields consumer surplus of US$19.2 million.

Park NPV study based on 20 year period discounted at 10 per cent estimates local benefits at US$74.21 million and consumer surplus as US$1 79.7 million.

17 Coral Reefs at Negril, Jamaica; *Wright* (1994)

Total economic value:
Based on CVM survey data and 162 000 visitors/year on Negril, Jamaica, the study elicits WTP of US$31/person/year for a consumer surplus of US$5 million/year to maintain coral reef in current condition; and US$49/person/year for a surplus of US$8 million/year to restore reefs to "excellent" condition.

TCM was also used to estimate a demand curve for vacations; the coral reef consumer surplus was netted out of vacation consumer surplus to examine the resultant shift in demand and reduction in tourist volume if reef quality should decline.

18 Indonesia Coral Reefs; *Cesar* (1996)

Direct use:
Using productivity change method on Indonesian coral reefs, NPV of fisheries loss/sq km estimated at: US$40 000 (poison fishing); US$86 000 (blast fishing); US$94 000 (coral mining); US$81 000 (sedimentation); and US$109 000 (over-fishing); based on assumptions about the reef and fishery impacts of these practices. The study uses CBA to compare the private and social net benefits of a sustainably managed reef fishery, with those of a fishery subjected to detrimental fishing practices, coral mining, or sedimentation.

The same method was used to estimate the NPV of tourism loss/km^2 of reef in Indonesia. It was found to be: US$3 000 to US$436 000 (from poison fishing); US$3 000 to US$482 000 (blast fishing and coral mining); and US$192 000 (sedimentation) based on assumptions regarding the rate of reef degradation associated with each practice. CBAs for each activity (inc. reef-destroying activity) estimate the value of tourism loss. For each activity, reef degradation causes a decrease in potential tourism revenue. All rates of change are based on assumptions.

Indirect use:
Using productivity change method, NPV of coastal protection/km^2 of reef was estimated at US$9 000 to US$193 000 (blast fishing); US$12 000 to US$260 000 (coral mining); based on replacement costs, the rate of reef destruction by each activity, and the rate of decline in the reef's ability to protect. CBAs for each reef-destroying activity include the cost of protective function losses. For each activity, reef destruction reduces the protective capability of the reef. The reef's loss of protective capability is linked linearly to its protective value.

19 Montego Bay Coral Reefs; *Spash et al.* (1998)

Non-use:
Using CVM on Montego Bay coral reefs, with survey design specifically targeted to dealing with lexicographic preferences through probing of zero bids and analysis of zero bids using Tobit estimation. Expected WTP for non-use value of tourists ranged from US$1.17 to US$2.98 for 25 per cent coral reef improvement; for locals range was US$1.66 to US$4.26. Upper values were for respondents perceiving strong moral duties and rights; lower were for no such duties/rights. Based on population characteristics, non-use NPV of Montego Bay reefs estimated to be US$19.6 million.

A similar CVM survey with similar design as Montego Bay study was conducted at Curacao coral reefs. Expected WTP for non-use value of tourists ranged from US$0.26 to US$5.82, for locals, range was US$0.19 to US$4.05. Based on population characteristics, non-use NPV of Curacao reefs estimated to be US$4.5 million.

20 Montego Bay Coral Reefs; *Gustavson* (1998)

Direct use:
Using productivity change method, NPV of US$1.31 million was estimated for artisanal fisheries at Montego Bay Coral Reefs (1996); including trap, net, handline and spear-fishing by local fishers. Cost of inputs is deducted from gross values to arrive at net values. Base case assumes shadow price of labour of 75 per cent market rate; 100 per cent market valuation leads to negative NPVs for fishing.

Recreational NPV of coral reefs at Montego Bay was estimated at US$315 million (1996) in the study. Calculation included tourist-related accommodation, food and beverage, entertainment, transportation, retail and miscellaneous services. Cost of service provision is deducted from gross values to arrive at net values.

Indirect use:
Using productivity change method, the NPV of coastal production at Montego Bay coral reefs was estimated at US$65 million (1996); based on

value of land at risk or vulnerable to coastal erosion along foreshore. Author notes this is upper value and is dependent on erosion incidence assumptions in absence of reef, which are highly speculative.

21 Great Barrier Reef; *Driml* (1999)

Direct use:
Using productivity change method, gross revenues of fisheries on Great Barrier Reef is estimated at AU$143 million (1996), based on 1995/6 catch data for major commercial species, and a survey of current fish prices. Study updates Driml (1994), estimates presented in Driml (1997) and Driml et al. (1997).

The study also estimated the gross recreational value for the Great Barrier Reef at AU$769 million (1996) using productivity change method. This includes AU$647 million for commercial tourism and AU$123 million for recreational fishing and boating; based on volume and price data for hotel stays and reef trips, and survey data for private recreational boat use. This study also updates Driml (1994).

22 Montego Bay Coral Reefs; *Ruitenbeek and Cartier* (1999)

Indirect use:
Value of Montego Bay coral reef based on model incorporating drug values, local bio-prospecting costs, institutional costs, discovery success rates for marine extracts, and a hypothetical bio-prospecting program for the area using National Cancer Institute sampling protocols. Model highlights role of revenue-sharing arrangements and ecosystem yield in deriving total benefits and marginal benefits. Average net social value of species in base case is estimated to be US$7 775. Based on base case sampling program, total social NPV of Montego Bay reef area is US$70.09 million. First differential of the benefit function yields US$225 000/% or US$530 000/ha coral abundance.

23. Eastbourne, English Channel; *King* (1995)

Direct use:
Using CVM, based on 179 randomly selected individuals, with 167 responses, the mean WTP for recreational beach use and reduction in the frequency of oil spill were estimated at £1.78 and £1.41 respectively. 80 per cent of the zero WTP were protest votes. The aggregated annual recreational use value of the beach was estimated at £4.5 million. It was estimated as a product of mean WTP and the total number of beach days (2.6 million based on the Eastbourne Tourism Survey conducted in 1990). King considers this as the lower bound of the value as non-use and option values are not included in the calculation.

24 John Pennekamp Coral Reef State Park & adjoining Key Largo National Marine Sanctuary; *Mattson and DeFoor* (1985)

Direct use:
Using TC, the study estimated revenue for the beach use from recreational diving, sightseeing and snorkelling at US$47.6 million for 1984-1985, or US$85 per square metre for John Pennekamp Coral Reef State Park and adjoining Key Largo National Marine Sanctuary.

Number of visitors was estimated from the visitors going through the park gate (644 628 people) and those going into the water (467 370 people) from 1 July 1984 to 30 June 1985. About 64 per cent of the total estimated water visitors go to the reef in dive boats. Travel costs include expenses on transportation, meals, lodging, dive trip costs, air tank fills and a portion of diving gear costs.

25. Pulau Payar Marine Park, Malaysia: Non-Use Value; *Ayob et al.* (2001)

Non-use:
Using CVM (referendum) method, the study aims to elicit the WTP from non-users of Pulau Payar Marine Park for non-use values. The WTP for non-use values computed averaged RM31.02 (US$8.16) and dropped to RM30.14 (US$7.93) with revision. Respondents agreed to contribute to the fund for bequest value (52 per cent), existence value (22 per cent) and option value (17 per cent).

26. Recreational coral bleaching and the demand for coral reefs: A case study; *Ngazy et al.* (2003)

Direct use/Total economic value:
Based on a CVM questionnaire survey with 157 divers, the study elicited an average WTP of US$84.7 extra per person per year to dive in more pristine reef sites. Based on the WTP, the authors estimated the economic loss due to bleaching ranged between US$1.6 and US$4.8 million

depending on whether 25 per cent or 75 per cent of visitors to Zanzibar dived. The financial revenue from diving ranged between US$2.5 and US$7.4 million on the same assumption.

27. An economic analysis of coral reefs in the Andaman Sea of Thailand; *Seenprachawong* (2003)

Direct use:
Using TCM, the study estimated the annual benefit from the recreational services of Phi Phi at US$205.41 million. That is, the value of Phi Phi is about US$6 243 per ha per year.

Total economic value:
CVM was used to estimate utility values associated with coral reef biodiversity at Phi Phi. The mean willingness to pay (WTP) per visit was estimated at US$7.17 for domestic visitors and at US$7.15 for international visitors. The total value of Phi Phi's coral reefs was estimated to be US$147 000 a year for domestic visitors and US$1.24 million a year for international visitors. The CVM study also estimated the total value (use and non-use) of the reefs to be US$497.38 million a year, averaging US$15 118 per ha per year.

28. Valuation of recreational benefits: An application of the travel cost model to the Bolinao coral reefs in the Philippines; *Ahmed, et al. (2003)*

Direct use:
Using TCM, the study estimated an average consumer surplus of US$223 per person, equivalent to US$1.3 million based on the crude estimate of 5 845 visitors to the reef at Bolinao in the peak season during March to May in 2000.

29. Analysis of the recreational value of the coral-surrounded Hon Mun Islands in Vietnam; *Pham and Tran (2003)*

Direct use:
Using the zonal TCM, the study estimated the recreational value of the coral-surrounded Hon Mun Islands to be US$17.9 million a year. The annual recreational value estimated for the islands using the individual TCM was approximately US$8.7 million.

CVM was used to elicit WTP to a MPA trust fund, with total WTP from domestic tourists estimated at US$241 239 and WTP from foreign tourists estimated at US$175 450.

30. Recreational benefits of coral reefs: A case study of Pulau Payar Marine Park, Kedah, Malaysia; *Yeo* (2003)

Direct use:
91 per cent of visitors interviewed were willing to pay an entrance fee to Pulau Payar Marine Park, estimated at an average WTP of slightly more than US$4. Using CVM, the annual recreational value was estimated to be US$390 000.