Coral Reefs: Their Functions, Threats and Economic Value

Herman S. J. Cesar

ABSTRACT

Coral reef ecosystems provide many functions, services and goods to coastal populations, especially in the developing world. A variety of anthropogenic practices threatens reef health and therefore jeopardises the benefits flowing from these services and goods. These threats range from local pollution, sedimentation, destructive fishing practices and coral mining to global issues like coral bleaching. Economic valuation can help to shed light to the importance of the services and goods by 'getting some of the numbers on the table'. Valuation techniques are discussed and a summary of economic studies on coral reefs is presented. The concepts of Total Economic Value and Cost Benefit Analysis are used to illustrate the valuation of marine protected areas (national parks, etc.) and of threats.

1. INTRODUCTION

Coral reefs are the flowers of the sea, surrounded by fascinatingly coloured fish with remarkable diversity. Reefs are also rather productive shallow water marine ecosystems (Odum and Odum, 1955) that are based on rigid lime skeletons 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 requirement of corals.

Different structural types of coral reefs are distinguished:

(i) fringing reefs;
(ii) patch reefs;
(iii) barrier reefs; and
(iv) atolls.

Fringing reefs are the most common type of coral reefs. They develop adjacent to the shore usually along rocky coasts of uplifted islands or along the shores of exposed limestone islands.

Patch reefs are isolated and discontinuous patches of fringing reefs.

Barrier reefs develop sometimes rather far away from coastlines in areas where coral growth has kept up with gradual drop of the sea-bed.

Finally, *atolls* are circular reefs that arise from deep-sea platforms such as submerged volcanic seamounts.

Coral reefs have important ecosystem functions, which provide crucial goods and services to hundreds of millions of people. The goods and services form an important source of income to the local population (fishery, mariculture, etc.), often living at subsistence levels. Also, they are a potential tourist attraction, thereby contributing to local income generation and foreign exchange. Besides, they form a unique natural ecosystem, with important biodiversity value as well as scientific and educational value. And coral reefs form a natural protection against wave erosion.

Currently, however, coral reefs are being depleted rapidly in many locations in the world due to destructive fishing practices (poison fishing, blast fishing, muro-ami, etc.), coral mining, marine pollution and sedimentation among others. Besides, at the global level, coral bleaching has recently become an additional major threat. Often, these threats are the result of externalities: people causing the threat benefit from unsustainable economic activities, but the costs are borne by others depending in some way or another on coral reefs.

Hodgson and Dixon (1988) describe a clear externality situation where logging causes sedimentation resulting in reef degradation (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 shows the importance of obtaining economic values for the various reef goods and services, e.g. a fishery value and a coastal protection value. These goods and services can deal with 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. The values of all these goods and services together forms the Total Economic Value (TEV) (e.g. Spurgeon, 1992). This TEV can be calculated for a specific area or for alternative uses (e.g. preservation area, tourism area, multiple use area, etc.). We can also use economic valuation to calculate the economic losses due to destruction of reef functions, as in blast fishing (Pet-Soede et al. 1999)

In this overview chapter, the functions, goods and services of coral reefs are described first in Section 2. The threats to coral reefs and their impacts on the various reef functions will be discussed in Section 3. In Section 4, economic valuation of coral reefs is described in detail, followed by an enumeration of valuation techniques in Section 5. The paper ends with a discussion.

2. FUNCTIONS, GOODS AND SERVICES OF CORAL REEFS AND ASSOCIATED ECOSYSTEMS

Ecosystems provide a great many functions, services and goods. The terms 'functions', 'goods' and 'services' have, in this context, slightly different meanings, though these terms are used interchangeably by many in the environmental economics literature. Costanza et al. (1997, p. 253) 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 provides the function of storage and retention of water, with the associated service of water supply. Table 1 (next page) summarises the functions and their corresponding goods and services that Costanza et al. (1997) investigated for coral reefs. The description of the examples is taken from Moberg and Folke (1999).

In a recent paper by Moberg and Folke (1999), the most important goods and services of coral reef ecosystems are systematically presented (see Table 2 on next page). The authors distinguish goods into renewable resources (fish, seaweed, etc.) and mining of reefs (sand, coral, etc.). The services of coral reefs are categorised into:

(i) physical 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);
(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.

Table 1. Ecosystem functions and corresponding goods and services of coral reefs

Ecosystem functions	Corresponding Goods and Services	Examples for coral reefs
Capacitance, damping and integrity of ecosystem response to environmental fluctuations	Disturbance regulation	Coastal protection and sediment retention
Recovery of mobile nutrients and removal or breakdown excess or xenic nutrients and compounds	Waste treatment	Nitrogen fixation, waste of assimilation and CO_2 and Ca budget control
Trophic-dynamic regulations of populations	Biological control	Feeding places both within ecosystem and between ecosystems
Habitat for resident and transient populations	Refugia	Nurseries and habitats
That portion of gross primary production extractable as food	Food production	Fish and other seafood products
That portion of gross primary production extractable as raw materials	Raw materials	Seaweed, materials for medicine curio, jewellery, coral blocks, sand
Providing opportunities for recreational activities	Recreation	Tourism, recreation, game-fishing
Providing opportunities for non-commercial use	Cultural	Aestetic, cultural, religious and spiritual values

Source: adapted from Costanza et al. (1997) and Moberg and Folke (1999)

Table 2. Goods and ecological services of coral reef ecosystems identified in Moberg & Folke (1999)

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

Source: adapted from Moberg and Folke (1999)

Note that this categorisation is slightly different than that of Costanza et al. (1997). Besides, Moberg and Folke additionally identify information services, such as climate and pollution records.

In the next two sections, the threats to reefs and the economic value of reefs will be discussed. In each of these, the goods and services presented above will be the building blocks of the discussion.

3. THREATS TO CORAL REEFS

Threats or over-uses can be divided into human-induced threats and natural threats. The latter, including hurricane damage, will not be discussed here further[1]. There are several categories of anthropogenic threats. Many of the threats to coral reefs are extensively discussed in the edited volume by Salvat (1987). In the Appendix, a concise summary of the recent literature on threats is given through an annotated bibliography. Threats can be divided into local and global threats. The main threats at the local level are:

(i) destructive and non-sustainable fishery practices, such as poison fishing, blast fishing, muro-ami fishing among others;
(ii) sedimentation, pollution, and waste;
(iii) mining and dredging activities; and
(iv) non-sustainable tourism practices.

Currently, the main global threat is coral bleaching (Wilkinson et al. 1999). Below, seven major threats will be discussed[2]. In subsequent chapters, a number of these and other threats will be presented in detail.

Poison Fishing

With Hong Kong restaurant prices as high as US$ 60–180 per kilo for certain types of groupers and Napoleon wrasse, the wild-caught live-fish trade has a gold rush-like character. Both in the restaurant retail business and in the older aquarium fishery, cyanide is nearly exclusively used as the 'cost-effective' way of harvesting live fish. Large-scale poison fishing vessels operate in remote and unpopulated areas of Indonesia and elsewhere, leaving behind a mosaic of coral destruction. Besides, the use of cyanide and other poisons for the aquarium fish has a long tradition, that is still continuing, notwithstanding attempts to curb this activity, for instance in the Philippines through the International Marinelife Alliance (IMA).

In this monograph, the chapter by Mous et al. points out that the habitat destruction through poison fishing is not as large as earlier anticipated. However, the overfishing aspects of poison fishing and the live reef fish trade in general are very large. In another chapter, Cesar et al. describe how the currently unsustainable and destructive live reef fish trade could be transformed into one that is sustainable and non-destructive, through well-managed introduction and expansion of grouper aquaculture and of regulated sustainable fishery of live fish (both juveniles and adults).

Blast Fishing

Though forbidden nearly in all countries in the world, and despite the inherent dangers, home-made bombs are still a very popular fishing 'gear' used to catch schools of reef fish and small pelagics and thereby 'earning money the easy way'. In the past, the explosive charge came from World War II bombs, though fertilisers and illegally purchased dynamite, often from civil engineering projects, are currently used. The explosion shatters the stony corals and kills fish and invertebrates in a large surrounding area. Over time, blast fishing damages the whole reef and thereby destroys the resource base of many subsistence fishers. The chapter by Pet-Soede et al. in this edited volume describes in detail the economics of this destructive activity both from the perspective of the blast fisher and of society.

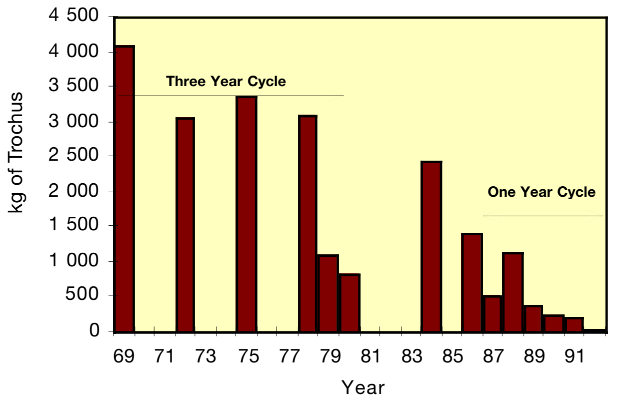
Overfishing

Though not necessarily as destructive as the other threats described above, overfishing does damage coral

[1] Sometimes, what appears like a natural threat is really the result of anthropogenic threats. The sand erosion in a reef area is natural but may be the result of coral mining, anchoring, and blast fishing. Also various coral diseases can be seen as natural even though they may be exacerbated by human induced stress to the corals.

[2] Some of the descriptions of the threats come from Cesar et al. (1997).

Figure 1. Yield of Trochus Shells in Noloth (Central Maluku) in 1969-1992.



Source: Cesar (1996)

reefs, mainly through a reduction in fish diversity. It also decreases the value to recreational divers, who are eager to see both large predators and abundance of small colourful fish. In general, the necessary reduction in effort to avoid overfishing and achieve optimal sustainable yields is in roughly estimated at in the order of 60 percent (McManus et al, 1992). Alternative income generation, for instance in eco-tourism, could be one potential way of bringing about this reduction in effort. Besides lowering the total effort, fisheries management efforts should also focus on the creation of sanctuaries and establishment of closed seasons. A number of papers on overfishing are described in the annotated bibliography on threats in the Appendix. In figure 1, a typical case of overharvesting or a reef resource is illustrated. In the past, mother-of-pearl shells were collected in a three-year cycle following a traditional *sasi*-system. Since that system collapsed, total yields over time have been significantly lower (see Cesar, 1996).

Coral Mining

Corals have long been used for building material and for the production of lime, as well as in the ornamental coral trade. The lime is often used as plaster or mixed with cement to reduce costs for private dwellings and local administrative offices. Coral mining not only destroys reef flats, and thereby its coastal protection function, but leads indirectly to logging of secondary forests, which is used for lime burning. Notwithstanding the negative impacts of coral mining on the coastal protection service of reefs, as well as on other ecosystem services, coral mining is still extensive practised in many parts of the world. Two examples of coral mining are worked out in the paper by Öhman and Cesar in this volume.

Sedimentation

Sedimentation, both from urban areas and from logging activities, smothers corals as it prevents the symbiotic algae and the coral polyps from capturing sun light and plankton respectively — their primary sources of energy and nutrition. These problems are particularly acute close to estuaries of rivers and urban centres. The chapter by Hodgson and Dixon in this volume describe the economic impact of logging-induced sedimentation on tourism and fisheries. These estimates show that gross revenues associated with logging in the Philippines are 2.8 lower than those of tourism and fisheries. For urban-induced sedimentation, economic costs are much more difficult to calculate. The reason is that such discharges have many sources, and the reduction of these discharges often has many other economic benefits (such as water treatment benefits, etc.) making the costs to corals probably minor.

Urban Pollution and Waste

Pollution, both from agro-chemicals and industrial discharges, can also kill corals. An economic analysis of pollution in urban areas is presented by Russell (1992). This paper describes the costs and benefits of coastal waste management in urban areas. As stated above, human and industrial waste are responsible for much of the sedimentation in urban coastal areas. Russell takes tourism (diving and other coastal recreation), fishery and health (decreased incidence of dysentery and other water-borne diseases) as prime benefits of coastal waste management. Annual costs presented of additional waste management (sewage and solid waste) for urban centres in Indonesia are US$ 987 million. The benefits are: tourism (US$ 101 million), fishery (US$ 221), and health (US$ 4.8). Hence total annual benefits are US$ 327 million, or one-third of the costs.

Coral Bleaching

During the period February to June 1998, a significant rise in the surface water temperature in the Indian Ocean and elsewhere was observed. Especially alarming about the 1998 bleaching event was the scope of the event and the fact that many reefs previously regarded as near pristine were seriously affected. The bleaching and subsequent mortality may result in serious socio-economic impacts, particularly for those nations whose economies are heavily dependent on the revenues generated by reef-based tourism, and reef-based fisheries. Hard hit were large areas of coral reef from Sri Lanka and the Maldives in South Asia to the East African coastal line. The chapter by Westmacott et al. in this volume deals extensively with these socio-economic impacts.

Compatible Uses

Many of the goods and services that coral reefs provide to humans can lead to incompatibilities: the concurrent use of the all goods and services is not possible. This is because certain ecosystem functions exclude the use of other ecosystem resources at the same time and in the same place, e.g. biodiversity research and resource extraction. This becomes even more obvious once the resource use becomes a threat. In fact, a threat could be seen as the over-use of a specific service: water pollution in a coastal zone is basically an over-use of the natural purification function of wetlands. And coastal zones, which are more and more devoid of fish, have fallen victim to the threat of overfishing.

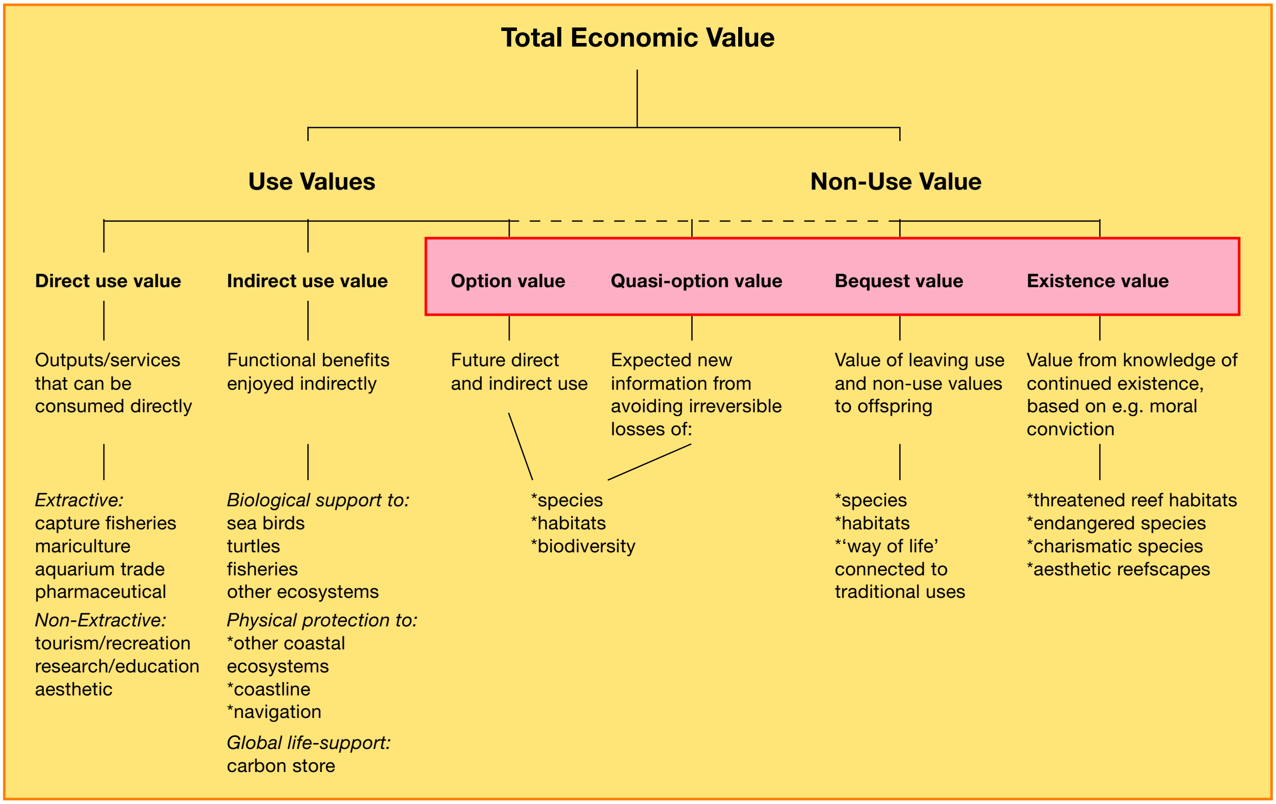
This compatibility issue has been worked out by Spurgeon (1992) and is demonstrated in the Chapter by Cesar et al. in this volume on Jamaica's Portland Bight Protected Area. This Park is a combined marine and terrestrial (coastal) park on the south coast of Jamaica, just west of the capital, Kingston. Many of the services are not necessarily compatible. Especially the extractive uses, such as charcoal burning, tend to be incompatible with other services, such as tourism and biodiversity preservation. On the other hand, fisheries and tourism can well go together, especially if some zoning is applied. The challenge of managing a protected area is to allow multiple uses while conserving nature at the same time. Successful area management includes zoning as well as threat regulation.

4. ECONOMIC VALUE OF CORAL REEFS

The economic value of an ecosystem is often defined as the total value of its instruments, that is the goods and ecological services that an ecosystem provides. For coral reefs, we therefore need to know its major goods and services as well as their interactions with other ecosystems. Next, these goods and services need to be quantified and monetised. For goods sold in the market place, this is straightforward by looking at their market price, but for ecological services, this is not the case. Therefore, complex valuation techniques are used to arrive at an economic value of these services. These techniques are presented in the next section. The concept of Total Economic Value and the valuation of a specific area and threat are discussed here. For a discussion on the economic valuation of coral reefs, see Spurgeon (1992) and Dixon (1998).

The value of all the compatible goods and services combined gives the Total Economic Value (TEV) for an ecosystem. The neo-classical foundations of economic value and its relationship with willingness to pay and consumer surplus are not discussed here (see Pearce and Turner, 1990 for a general discussion and Barton, 1994 and Pendleton, 1995 for a specific discussion on the economic value of coral reefs). Each of the goods and services of coral reefs presented in table 2 above generate economic value. Fishery resources can be harvested and sold, creating value added and likewise, the coastal marine area enables sea transportation that creates profits. Similarly, preservation and eco-tourism create value. The mapping between the goods and services on the one

Figure 2. Total Economic Value and Attributes of Economic Values for Coral Reefs



Source: Barton (1994).

hand and their values on the other hand is straightforward, as is shown in figure 2.

As indicated in figure 2, there are six categories of values:

(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 non-extractive uses. Indirect use values are, for example, the biological support in the form of nutrients and fish habitat and coastline protection. The concept of option value can be seen as the value now 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 NGOs in wills are an example of the importance of the bequest concept. The existence value reflects the idea that there is a value of an ecosystem to humans irrespective of whether it is used or not.

These values all are quite abstract and theoretical. In the next section, valuation methods are discussed to see how the economic value of these uses can be measured in practice. Measuring these values in monetary ways is not straightforward, and in some cases (nearly) impossible. Yet, it is important to take these into account. As Dixon (1989) states: "Whether a coastal resource is a good or service, marketed or nonmarketed, is not important in terms of its function in the coastal ecosystem. The extent, to which coastal resources represent easily marketed goods, however, heavily influences resource management decisions. Nonmarketed goods and environmental or ecosystem services are frequently overlooked or their importance played down. This is one of the factors leading to resource management conflicts and poor decisions".

One purpose of obtaining the TEV of coral reefs and using Cost-Benefit Analysis (CBA) is to get some numbers on the table for policy discussions. For instance, a government might consider proclaiming a specific bay a Marine Protected Area (MPA) or a Multiple-Use Coastal Area (MUCA). There are significant management costs involved in the management of MPAs and MUCAs and the government may want to know in economic terms whether the management costs are economically justified. Or a government might get complaints from NGOs about certain unsustainable coastal activities. These activities form a threat but they generate quite some cash at the same time, and the government needs to be convinced that it is worthwhile to curb the threat. Both these issues will be briefly discussed.

Economic Value of an MPA

Establishing an MPA is a costly affair and a government needs to be well informed about the pros and cons of an additional MPA (McClanahan, 1999). Many MPAs in developing countries are basically unprotected. Such areas are referred to as 'paper parks'. Cyanide fishers in Indonesia allegedly know exactly where the parks are, as these areas have relatively abundant fishery resources while enforcement is so weak that this does not form a threat to them. Determining the economic value for an MPA involves three important steps.

First, the compatible uses and/or the zoning of the areas has to be determined, as discussed above. See also Barton (1994). Secondly, the additional contribution of park protection to the goods and services of the ecosystem(s) need to be determined. And thirdly, a CBA is carried out by comparing the net benefits in step 2 with the costs of management. The actual value of the park is then 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".

In this monograph, three papers discuss the valuation of a coastal area. White et al. discuss the net benefits of coral reef and wetland management on Olango Island in the Philippines. Dixon et al. discuss a valuation of the Bonaire Marine Park in the Netherlands Antilles. Finally, Cesar et al. give an economic valuation of an integrated terrestrial and marine protected area in Jamaica. In each of these three valuation studies, the costs of managing the park sustainably are economically justified.

Economic Value of a Threat

Since the economic benefits from reef destruction are often used to justify continuation of this threat, quantifying the costs associated with coral reef degradation is important to make a balanced assessment of the ben-efits and costs of various threats. To do this, a CBA is carried out where the net benefits of the harmful activity to the people causing the threat are compared with the net societal costs plus the enforcement costs of actually eliminating the threat. To illustrate the costs and benefits of a threat, table 3 on next page presents a CBA where the societal costs are calculated per ecosystem service of the reef[3].

[3]Note that some of the numbers presented in table 3 are outdated and more recent data on blast fishing and coral mining are presented in the chapters by Pet Soede et al. and Öhman and Cesar in this volume.

Table 3. Total Net Benefits and Losses due to Threats of Coral Reefs in Indonesia
(present value; 10% discount rate; 25 y. time-span; in 1000 US$; per km^2)

	Net Benefits to Individuals	Net Losses to Society				
Function:	Total Net Benefits	Fishery Protection	Coastal	Tourism	Others	Total Net Losses (quantifiable)
Threat						
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	2-260	3–482	>67.0	176–903
Sedimentation from logging	98	81	–	192	n.q.	273
Overfishing	39	109	–	n.q.	n.q.	109

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

Table 4. Net Benefits to Individuals: Amount per km^2 and per Stakeholder
Benefits per stakeholder in parentheses; present value; 10% discount rate; 25 y. time-span; in 1000 US$; per km^2)

Individuals:	Fishermen	Miners, Loggers	Others (payments)	Total per km^2
Threat:				
Poison Fishing	29 (468.6 per boat) (23.4 per diver)	–	4 (317-1585 per person)	33
Blast Fishing	15 (7.3 per fisherman)	–	?	15
Mining	– (1.4 per mining family)	67 (18 - 54 per person)	54	121
Sedimentation due to logging	–	98 (1990 per log. family)	?	98
Overfishing	39 (0.2 per fisher)	–	–	39

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

Note that the analysis focuses on only three ecosystem services, leaving out a number of other services. Total costs should thus be interpreted as rough estimates of the lower range of true costs associated with reef destruction. However, this lower boundary already proves the point that reef destruction is not economically justified for each of the threats.

In this volume, four examples of economic analyses of threats are given: Hodgson and Dixon describe the trade-off between logging on the one hand and tourism and fisheries on the other hand. Mous et al. discuss the economics of cyanide fishing. Pet-Soede et al. discuss the costs and benefits associated with blast fishing. Finally, Öhman and Cesar compare two case studies on the economics of coral mining. A recent overview of valuation studies for coral reefs is given in Ruitenbeek and

Cartier (1999), see also the chapter by Gustavson and Huber in this book.

Stakeholder Analysis

Though it is useful to know the societal cost and the profits (benefits) of a threat, it is often — from a management perspective — even more important to know the economic forces that are driving destructive practices. A stakeholder analysis is therefore called for. This type of analysis aims at getting insight into the following two questions:

(a) who is gaining and who is losing from the current situation and a prescribed future scenario;

(b) what is the size of the stake in actual dollar terms for each stakeholder.

To illustrate this point, table 4 shows the private benefits that accrue to the various groups of stakeholders involved in causing the threat as well as to each of the persons/families/boats/companies involved.[4] The aggregated numbers (last column of table 4) correspond with the total benefits presented in table 3 (second column). Interestingly, net benefits per square kilometre to individuals appear to be highest for coral mining. Yet, private benefits per stakeholder (person/boat/company/ etc.), poison fishing and logging-induced sedimentation have by far the highest private incentives, 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 (in present value terms). Side-payments are also particularly high, very roughly estimated at some US$ 0.3–1.5 million for some receivers of large payments. On the other extreme, coral mining is a rather marginal activity for the mining families involved (for a discussion, see Cesar et al. 1997).

Benefit Transfer

It is often quite costly to carry out studies to determine the precise Total Economic Value 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. The values calculated in those studies might, if carefully done, sometimes be used for another area. If an extensive study has been carried out for the fisheries and tourism potential in one marine reserve in the Philippines, than it is not unlikely that these values can form a proxy for another marine reserve elsewhere in the Philippines. Put differently, because of human or financial resource constraints, values can sometimes be taken out of previous studies which focus on a different region or time period. This practice of transferring of monetary values is called as 'benefit transfer'. An example is given in the article by White et al. in this monograph.

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

5. VALUATION TECHNIQUES

In the environmental economics literature, a host of valuation techniques have been developed over the last decades. Standard techniques in microeconomics and welfare economics rely on market information to estimate value. However, the externalities inherent to environmental issues prevent these techniques from being used most of the time. For an elaboration of this issue that is accessable to non-economists, see Dixon (1998). Specifically for tropical coastal ecosystems, Barton (1994) gives a detailed overview of 15 different techniques. Spurgeon (1992) gives an interesting summary of this topic with many actual numbers. Table 5 gives a listing of the most common techniques used for valuing the goods and services of coral reef ecosystems. Three general categories are distinguished:

(i) directly to obtain information about the value of the affected goods and services or of direct expenditures;

(ii) potentially applicable techniques, which use the market indirectly to obtain information about values and expenditures;

(iii) survey based methods, which use hypothetical markets and situations through, for instance, questionnaire surveys such as the contingent valuation method (CVM).

Table 5. Valuation Techniques used for Valuing Goods and Services of Coral Reef Ecosystems

Generally Applicable Techniques	Using conventional market value of goods and services directly affected ● Change in Productivity / Effect of production (EoP); ● Stock (houses, infrastructure, land) at Risk (SaR) ● Loss of earnings / Human capital approach (HC); ● Opportunity cost approach (OC); Using the value of direct expenditures (cost based) ● Preventive expenditures (PE); ● Compensation payments (CP)
Potentially Applicable Techniques	Using implicit or surrogate market values – indirect approaches ● Property-value and other land-value approaches (PV); ● Travel-cost approaches (YC); Using the magnitude of potential expenditures (cost based) ● Replacement costs (RP); ● Shadow-project costs (SPC)
Survey-Based Methods	Survey-Based Methods ● Contingent valuation meth. (CVM) — hypothetical markets and situations

Source: Adapted and shortened from Dixon (1988), Barton (1994).

Table 6. 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)
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)

These 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. We will here specifically discuss five methods, which are also used in many of the chapters that follow. These techniques are:

(i) Effect on Production (EoP);
(ii) Replacement Costs (RC);
(iii) Damage Costs (DC);
(iv) Travel Costs (TC); and
(v) the Contingent Valuation Method (CVM).

These techniques correspond to the various types of values, as shown in table 6. 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 6 shows.

Effect on Production (EoP)

This technique, also referred to as the 'change in productivity' method, looks at the difference in output (production) as the basis of valuing reef services. The technique mainly applies here to fisheries and tourism (producer surplus) to estimate 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 example of the EoP method is 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 breakdown of protective management. McAllister (1998) gives estimates of reef productivity for reefs in excellent condition (18 $mt/km^2/yr$) as well as good condition (13 $mt/km^2/yr$), and 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 health coral reef. Hence, the cost of replacing the coral reef with protective constructions, such as revetments and underwater wave breakers are 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^{-1} 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 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 per km of reef per year. Cesar (1996) uses a combination of the value of agricultural land, costs of coastal infrastructure and houses to arrive at a range of US$ 90 up to US$ 110,000 per km of reef per year.

Travel Costs (TC)

This approach is often used to estimate the welfare associated with the recreational use of a National Park, where the travel time or travel costs are used as an indicator of the total 'entry fee', and therefore, a person's willingness to pay for visiting a Park. The further away people live from the Park, the higher the costs are to visit the Park. Because of the variation in these costs among visitors, the demand for different prices can be determined and 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). Both the Travel Cost method as well as the Contingent Valuation method below have a number of drawbacks that will be discussed later in this section.

An example of TC is Pendleton (1995) who uses 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 * travel costs). Based on this estimated demand curve, the travel costs from each region and assuming annual visits to the marine park to be 20,000, 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), with a value of A$ 144 million per year for tourists visiting the Great Barrier Reef.

Contingent Valuation Method (CVM)

In the absence of people's preferences as revealed in markets, the contingent valuation method tries to obtain information on consumers' preferences by posing direct questions about willingness to pay and/or willingness to accept. 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. Sought are personal valuations of the respondent for increases or decreases in the quantity of some goods, contingent upon a hypothetical market.

An example of CVM is the chapter by Spash in this monograph. Visitors to Montigo Bay (Jamaica) and Curaçao (Netherlands Antilles) were surveyed 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 for an increase in coral cover in the Park. Expected WTP for coral reef improvement was US$ 3.24 per person in a sample of 1058 respondents for Montigo Bay. For Curaçao, the number was US$ 2.08 per person. But this value was heavily dependent on whether respondents believed that marine systems possessed inherent rights, or that humans had inherent duties to protect marine systems. Such preferences would increase WTP by up to a factor of three. Another example is Dixon et al.'s paper in this monograph. They arrive at an average Willingness to Pay for a consumer surplus of US$ 325,000 for Bonaire Marine Park.

There are a number of biases associated with CVM that are important to note. These biases have given CVM in the eyes of some a bad name. The careful use of CVM is therefore necessary. Barton (1994) summarises 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 when 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, involving several aspects. *Design bias* refers to how the questions are structured. *Instrument bias* will result if the respondent reacts either way 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.

Table 7. System of Classifying Marine Biodiversity Valuation Methodologies

	Biodiversity Production Valuation Method	Biodiversity Utility Valuation Methods	Biodiversity Rent Capture Valuation Methods
Economic Basis	'Supply-Oriented'	'Demand Oriented'	'Profit-Oriented'
Description	Values biodiversity within an economic production function	Values biodiversity within an economic utility function	Values biodiversity as a distribution of profits or value-added
Valuation Target	Measures the contribution of biodiversity to the value of output in a produced good or service. Can estimate and isolate direct or indirect Use Values, including ecological functions or embedded information	Measures the contribution of biodiversity to the utility of an individual or society. Can estimate aggregated Use and Non-Use Values, including consumer's surplus	Measures one or more components of the distribution of Use Values, focusing on captured rents, profits or value added. Can isolate value of embedded information
Examples of Methods	Cobb-Douglas production function Linear Transforms Non-linear Transforms	Contingent Valuation Hedonic Pricing 'Value of life' measures	Royalty evaluations Patent system evaluations Joint venture evaluations

Source: adapted from Ruitenbeek and Cartier (1999).

Table 5 above gave a classification of valuation techniques, using three categories:

(i) generally applicable techniques using direct market information on values and expenditures;
(ii) potentially applicable techniques, which use the market indirectly, such as the TC-method; and
(iii) survey based methods, such as the contingent valuation method (CVM).

Ruitenbeek and Cartier (1999) give an interesting new classification of valuation methodologies, specifically for marine biodiversity. This classification, shown in table 7, is also summarised in the article by Gustavson and Huber in this book. This classification can be directly applied for coral reefs.

6. 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, we see many coastal populations who are unaware of the goods and services that coral reef ecosystems provide and who are unable to see through the complex linkages of the natural world. We see people using coral reefs unsustainably and even destructively. And we see politicians unwilling to look beyond their short-sighted lenses, and consequently we see a lack of funds for coral reef management, even though the long-term costs of inaction are typically much higher than the funds needed.

Dixon (1998) gives a beautiful illustration of what could happen if we would all look beyond our short-sighted own interests: "In Hawaii, for example, the traditional land management unit was called the *ahupua'a*, which was a slice of land that went from the top of the mountain down to the edge of the coral reef. Thus, the individual or group who owned the *ahupua'a* owned an entire functioning ecosystem, a self-contained economic and environmental unit. Any externalities were thereby internalised, and the land managers realised that actions taken in the upper watershed (such as agricultural production or logging) would have an effect both on the water quality on the taro fields in the lower watershed as well as in the coral reef and the coastal fish ponds. Since all impacts were contained within the system (with clearly defined integrated property rights), decisions were being made taking these impacts into account and thereby balancing any tradeoffs involved. The Hawaiian *ahupua'a* system is the ideal world; it very rarely exists today. Usually externalities are present, and they lead to the results that we observe: mismanagement, overuse, needless destruction of precious resources".

One important issue in economic valuation studies is to whom the benefits will accrue and whether these are real or virtual. Travel costs for National Parks form the key welfare measure for the tourism function of coral reef ecosystems. Some of these costs are actually paid and accrue to local or foreign business operators. Most costs are, however, virtual. They describe 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 associated. It is also important, for the economic analysis of a specific country, to distinguish between local and foreign tourists and between actual expenditures on travel costs and virtual figures. For the economic value of a National Park for a specific country, only the consumer surplus of local tourists should be used. And of the actual expenditures, only those accruing to the host country. . With CVM, if the economic valuation is done with respect to the value to a specific country, only the contingent valuation for the inhabitants of that country should be considered.

A second and last important issue is the fact that valuing all the benefits of coral reefs is often frustrating and nearly impossible. Often, however, this is not needed. Assume we show that the net benefits to blast fishers is lower than the societal losses in sustainable fishing income and tourism revenues combined (see Pet-Soede et al. in this monograph). Then, no complicated techniques, such as TC and CVM are needed and no major data collection on the value of bio-prospecting, biotic services and physical structure services are necessary: two services that can be monetised easily already suffice to show the costs of inaction. Hopefully, economic valuation can help and raise the awareness to all those involved in order that we may enjoy the beauty of coral reefs forever.

REFERENCES

Ablong, W. E., Murphy, J. M., & White, A. T., (1998) "Integrated Coastal Management in Negros Oriental, Philippines: Participation in Coastal Habitat Assessment and Management". Paper Presented at the International Tropical Marine Systems Management Symposium, 23–26 November, Townsville, Australia, 16 pp.

Alcala, A. C., (1988) "Effects of Marine Reserves on Coral Fish Abundances and Yields of Philippine Coral Reefs". *AMBIO*, Vol. 17, No. 3, pp. 194–199.

Alcala, A. C., & Russ, G. R., (1990) "A Direct Test of the Effects of Protective Management on Abundance and Yield of Tropical Marine Resources". *J. Cons. int. Explor. Mer.*, Vol. 46, pp. 40–47.

Alder, J., Sloan, N. A., & Uktolseya, H., (1994) "A Comparison of Management Planning and Implementation in Three Indonesian Marine Protected Areas", *Ocean and Coastal Management*, Vol. 24, No. 3, pp. 179–198.

Alvarez, A. A. (1995) "Dead Corals in Exchange for Live Fish Exports?". *Marinelife*, Vol. 2, No. 1, pp. 9–10.

Andersson, J. E. C., & Ngazi, Z., (1995) "Marine Resource Use and the Establishment of a Marine Park: Mafia Island, Tanzania". *AMBIO*, Vol. 24, Nos. 7–8, pp. 475–481.

Andrews, G., (1998) "Mafia Island Marine Park, Tanzania: Implications of Applying a Marine Park Paradigm in a Developing Country". *ITMEMS*, November, 15 pp.

Barton, D. N., (1994) "Economic Factors and Valuation of Tropical Coastal Resources". *SMR-Report* 14/94, Bergen, Norway, 128 pp.

Bakus, G. J. (1982) "The Selection and Management of Coral Reef Preserves". *Ocean Management*, Vol. 8, pp. 305–316.

Bell, J. D., & Galzin, R., (1984) "Influence of Live Coral Cover on Coral Reef Fish Communities". *Marine Ecology – Progress Series*, Vol. 15, pp. 265–274.

Berg, H., Öhman, M. C., Troeng, S., & Lindén, O., (1998) "Environmental Economics of Coral Reef Destruction in Sri Lanka". *AMBIO*, Vol. 27, No. 8, pp. 627–634.

Bjork, M., Mohammed, S. M., Bjorklund, M., & Semesi, A., (1995) "Coralline Algae, Important Coral-reef Builders Threatened by Pollution". *AMBIO*, Vol. 24, Nos. 7–8, pp. 502–505.

Bohnsack, J. A., & Ault, J. S., (1996) "Management Strategies to Conserve Marine Biodiversity". *Oceanography*, Vol. 9, No. 1, pp. 73–82.

Brown, B. E., (1997) "Coral bleaching: Causes and Consequences". *Coral Reefs*, Vol. 16, pp. S129–S138.

Brown, B. E., & Dunne, R. P., (1988) "The Environmental Impact of Coral Mining on Coral Reefs in the Maldives". *Environmental Conservation*, Vol. 15, No. 2, pp. 159–166.

Brown, B. E., Le Tissier, M. D. A., Scoffin, T. P., & Tudhope, A. W. (1990) "Evaluation of the Environmental Impact of Dredging on Intertidal Coral Reefs at Ko Phuket, Thailand, Using Ecological and Physiological Parameters". *Marine Ecology : Progress Series*, Vol. 65, No. 3, pp. 273–281.

Bunce, L., Gustavson, K., Williams, J., & Miller, M., (1999) "Report: The human side of reef management: a case study analysis of the socioeconomic framework of Montego Bay Marine Park". *Coral Reefs*, Vol.18, No. 4, pp. 369–380.

Butler, J. N., Burnett-Herkes, J., Barnes, J. A., & Ward, J., (1993) "The Bermuda Fisheries: A Tragedy of the Commons Averted?". *Environment*, Vol. 35, No. 1, pp. 7–15, 25–33.

Cesar, H. S. J., (1996) *Economic analysis of Indonesian coral reefs*. Working Paper Series "Work in Progress", World Bank, Washington DC. 97 pp.

Cesar, H., Lundin, C. G., Bettencourt, S., & Dixon, J., (1997) "Indonesian Coral Reefs — An Economic Analysis of a Precious but Threatened Resource". *AMBIO*, Vol. 26, No. 6, pp. 345–360.

Campos, W. L., Del Norte-Campos, A. G. C., & McManus, J. W., (1994) "Yield Estimates, Catch, Effort and Fishery Potential of the Reef Flat in Cape Bolinao, Philippines". *UP Marine Science Institute Contribution* No. 221, University of Philippines, Manila, pp. 82–95.

Christie, P., White, A. T., & Buhat, D., (1994) "Community-Based Coral Reef Management on San Salvador Island, the Philippines". *Society and Natural Resources*, Vol. 7, pp. 103–117.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., & Sutton, P., (1997) "The value of the world's ecosystem services and natural capital". *Nature*, 387: 253–260.

Davis, D., & Tisdell, C. (1995) "Recreational Scuba-Diving and Carrying Capacity in Marine Protected Areas". *Ocean & Coastal Management*, Vol. 26, No. 1, pp. 19–40.

Davis, D., & Tisdell, C. (1996) "Economic Management of Recreational Scuba Diving and the Environment". *Journal Of Environmental Management*, Vol. 48, No. 3, pp. 229–248.

Dennis, G. D., & Bright, T. J., (1988) "The Impact of a Ship Grounding on the Reef Fish Assemblage at Molasses Reef, Key Largo National Marine Sanctuary, Florida". *Proceedings of the 6th International Coral Reef Symposium Australia*, Vol. 2, pp. 213–218.

Dixon J. A., Fallon Scura, L., Carpenter, R. A., & Sherman, P. B., (1988) *Economic analysis of environmental impacts*. 3rd ed., Earthscan, London.

Dixon J. A. (1989) "Coastal resources in Kosrae: an undeveloped economic resource". *Kosrae Island Management Plan*, Vol. II, background paper, East-West Center.

Dixon, J. A., (1998) "Economic values of coral reef: what are the issues?" in Hatziolos, M. E., et al. (eds.) *Coral reefs: challenges and opportunities for sustainable management*. World Bank, Washington, pp. 157–162.

Dixon, J. A., Scura, L. F., & van't Hof, T., (1993) "Meeting Ecological and Economic Goals: Marine Parks in the Caribbean". *AMBIO*, Vol. 22, pp. 117–125.

Dixon, J. A., Scura, L. F., & van't Hof, T., (1995) "Ecology and Microeconomics as 'Joint Products': The Bonaire Marine Park in the Caribbean" in Perrings, C. A., et al. (eds.) *Biodiversity Conservation*. Kluwer Academic Publishers, Dordrecht, pp. 127–145.

Dulvy, N. K., Stanwell-Smith, D., Darwall, R. T., & Horrill, C. J., (1995) "Coral Mining at Mafia Island, Tanzania: A Management Dilemma". *AMBIO*, Vol. 24, No. 6, pp. 358–365.

Fiske, S. J., (1992) "Sociocultural Aspects of Establishing Marine Protected Areas". *Ocean and Coastal Management*, Vol. 18, pp. 25–46.

Gabrié, C., Planes, S., Baldwin, J., Bonvallot, J., Chauvet, C., Vernaudon, Y., Payri, C., & Galzin, R., (1994) "Study of the Coral Reefs of Bora-Bora for the Development of a Conservation and Management Plan". *Ocean and Coastal Management*, Vol. 25, No. 3, pp. 189–216.

Galvez, R., Hingco, T. G., Bautista, C., & Tungpalan, M. T., (1989) "Sociocultural Dynamics of Blast Fishing and Sodium Cyanide Fishing in Two Fishing Villages in the Lingayen Gulf Area" in Silvestre, G., et al. (eds.) *Towards Sustainable Development of the Coastal Resources of Lingayen Gulf, Philippines*. ICLARM Conference Proceedings 17, pp. 43–62.

Gittings, S. R., Bright, T. J., Choi, A., & Barnett, R. R., (1988) "The Recovery Process in a Mechanically Damaged Coral Reef Community: Recruitment and Growth". *Proceedings of the 6th International Coral Reef Symposium Australia*, Vol. 2, pp. 225–229.

Harriott, V. J., Davis, D., & Banks, S. A., (1997) "Recreational Diving and its Impact in Marine Protected Areas in Eastern Australia". *AMBIO*, Vol. 26, No. 3, pp. 173–179.

Hatcher, A. L., Wright, G. D., & Hatcher, B. G., (1990) "Resolving the Conflict Between Conservation Values and Extractive Use of the Abrolhos Coral Reefs". *Proc. Ecol. Soc. Aust.*, Vol. 16, pp. 55–70.

Hatcher, B. G., Johannes, R. E., & Robertson, A. I., (1989) "Review of Research Relevant to the Conservation of Shallow Tropical Marine Ecosystems". *Oceanogr. Mar. Biol. Annu. Rev.*, Vol. 27, pp. 337–414.

Hawker, D. W., & Connell, D. W., (1992) "Standards and Criteria for Pollution Control in Coral Reef Areas" in Connell, D. W., & Hawker, D. W., (eds.) *Pollution in Tropical Aquatic Systems*. CRC Press, Boca Raton, FL, pp. 170–191.

Hawkins, J. P., & Roberts, C. M. (1993) "Effects of Recreational Scuba Diving on Coral Reefs: Trampling on Reef-Flat Communities". *The Journal of Applied Ecology*, Vol. 30, No. 1, pp. 25–30.

Hawkins, J. P., & Roberts, C. M., (1994) "The Growth of Coastal Tourism in the Red Sea: Present and Future Effects on Coral Reefs". *AMBIO*, Vol. 23, No. 8, pp. 503–508.

Hingco, T. G., & Rivera, R., (1991) "Aquarium Fish Industry in the Philippines: Toward Development or Destruction" in Chou, L. M., et al., (eds.) *Towards and Integrated Management of Tropical Coastal Resources*. ICLARM Conference Proceedings 22, pp. 249–253.

Hodgson, G., & Dixon, J. A., (1988) "Logging Versus Fisheries and Tourism in Palawan: An Environmental and Economic Analysis". *Occasional Paper* No. 7, Environmental and Policy Institute, East-West Centre, Honolulu, , 95 pp.

Hundloe, T., Vanclay, F., & Carter, M., (1987) *Economic and socio economic impacts of crown of thorns starfish on the Great Barrier Reef*. Institute of Applied Environmental Research, Grifftih University, Report to the Great Barrier Reef Marine Park Authority, Townsville.

Hughes (1994) "Catastrophies, Phase Shifts, and Large-Scale Degradation of a Caribbean Coral Reef". *Science*, Vol. 265, pp. 1547–1551.

Jennings, S., & Polunin, N. V. C., (1995), "Relationships Between Catch and Effort in Fijian Multispecies Reef Fisheries Subject to Different Levels of Exploitation". *Fisheries Management and Ecology*, Vol. 2, pp. 89–101.

Jennings, S., & Polunin, N. V. C., (1997) "Impacts of Predator Depletion by Fishing on the Biomass and Diversity of Non-Target Reef Fish Communities". *Coral Reefs*, Vol. 16, No. 2, pp. 71–82.

Johannes, R. E., & Riepen, M., (1995) "Environmental, Economic and Social Implications of the Live Reef Fish Trade in the Asia and the Western Pacific". *Nature Conservancy*, Jakarta, 81 pp.

McAllister, D. E., (1988) "Environmental, Economic and Social Costs of Coral Reef Destruction in the Philippines". *Galaxea*, Vol. 7, pp. 161–178.

McClanahan, T. R., (1995) "A Coral Reef Ecosystem-Fisheries Model: Impacts of Fishing Intensity and Catch Selection on Reef Structure and Processes". *Ecological Modelling*, Vol. 80, pp. 1–19.

McClanahan, T. R., & Kaunda-Arara, B., (1996) "Fish Recovery in a Coral-reef Marine Park and its Effect on the Adjacent Fishery". *Conservation Biology*, Vol. 10, No. 4, pp. 1187–1199.

McClanahan, T. R., & Obura, D., (1997) "Sedimentation Effects on Shallow Coral Communities in Kenya". *Journal Of Experimental Marine Biology And Ecology*, Vol. 209, Nos. 1–2, pp. 103–122.

McClanahan, T. R., Muthiga, N. A., Kamukuru, A. T., Machano, H., & Kiambo, R. W., (1999) "The Effects of Marine Parks and Fishing on Coral Reefs of Northern Tanzania". *Biological Conservation*, Vol. 89, No. 2, pp. 161–182.

McClanahan, T. R. (1999) "Perspective: Is there a future for coral reef parks in poor tropical countries?". *Coral Reefs*, Vol. 18, No. 4, pp. 321–325.

McManus, J. W. , (1994) "The Spratly Islands: A Marine Park?". *AMBIO*, Vol. 23, No. 3, pp. 181–186.

McManus, J. W., (1996) "Social and Economic Aspects of Reef Fisheries and their Management" in Polunin, N. V. C., & Roberts, C. M., (eds.) *Reef Fisheries*. Chapman and Hall, London, pp. 1–36.

McManus, J. W., Nanola, C. L., Reyes, R. B., & Kesner, K. N., (1992) "Resource Ecology of the Bolinao Coral Reef System". *ICLARM Stud. Rev.*, 22, Manila, Philippines, 117 pp.

McManus, J. W., Reyes, R. B., & Nanola, C. L., (1997) "Effects of Some Destructive Fishing Methods on Coral Cover and Potential Rates of Recovery". *Environmental Management*, Vol. 21, No. 1, pp. 69–78.

Moberg, F., & Folke, C., (1999) "Ecological goods and services of coral reef ecosystems". *Ecological Economics*, Vol. 29, pp. 215–233.

Nowlis, J., Sladek, Roberts, C. M., Smith, A. H., & Siirila, E., (1997) "Human-enhanced Impacts of a Tropical Storm on Nearshore Coral Reefs". *AMBIO*, Vol. 26, No. 8, pp. 515–521.

Nzali, N. L., Johnstone, R. W., and Mgaya, Y. D., (1998) "Factors Affecting Coral Recruitment on a Nearshore Reef in Tanzania". *AMBIO*, Vol. 27, No. 8, pp. 717–722.

Odum H. T., & Odum, E. P., (1955) "Trophic structure and productivity of a windward coral reef community on Eniwetok". *Atoll. Ecol. Monogr.*, pp. 291–320.

Öhman, M. C., Rajasuriya, A., & Lindén, O., (1993), "Human Disturbances on Coral Reefs in Sri Lanka: A Case Study". *AMBIO*, Vol. 22, No. 7, pp. 474–480.

Öhman, M. C., Rajasuriya, A., & Olafsson, E., (1997) "Reef Fish Assemblages in North-Western Sri Lanka: Distribution Patterns and Influences of Fishing Practices". *Environmental Biology of Fishes*, Vol. 49, pp. 45–61.

Pauly, D., & Chua, T.-E. (1988) "The Overfishing of Marine Resources: Socioeconomic Background in Southeast Asia". *AMBIO*, Vol. 17, No. 3, pp. 200–206.

Pauly, D., Silvestre, G., & Smith, I. R., (1989) "On Development, Fisheries and Dynamite: A Brief Review of Tropical Fisheries Management". *Natural Resources Modelling*, Vol. 3, No. 3, pp. 307–329.

Pearce, D. W., & Turner, K. R., (1990) *Economics of natural resource and the environment*. 1 ed., London: Harvester Wheatsheaf.

Pendleton, L. H., (1995) "Valuing Coral Reef Protection". *Ocean & Coastal Management*, Vol. 26, No. 2, pp. 119–131.

Pet-Soede, C., Cesar, H. S. J., & Pet, J. S. (1999) "An Economic Analysis of Blast Fishing on Indonesian Coral Reefs". *Environmental Conservation* (in press), 26 (1).

Polunin, N. V. C., & Roberts, C. M., (1993) "Greater Biomass and Value of Target Coral Reef Fishes in Two Small Caribbean Marine Reserves". *Marine Ecology: Progress Series*, Vol. 100, Nos. 1-2, pp. 167–176.

Rakitin, A., & Kramer, D. L., (1996) "Effect of a Marine Reserve on the Distribution of Coral Reef Fishes in Barbados". *Marine Ecology: Progress Series*, Vol. 131, Nos.1–3, pp. 97–113.

Rajasuriya, A., Ranjith, M. W., De Silva, N., & Öhman, M. C., (1995) "Coral Reefs in Sri Lanka: Human Disturbance and Management Issues". *AMBIO*, Vol. 24, Nos. 7–8, pp. 428–437.

Raymakers, C. (1998) "Imports of Indonesian Marine Products into the European Union 1990-1995". *Traffic, Europe*, Brussels, 91 pp.

Renard, Y., (1996) "Sharing the Benefits of Coastal Conservation". *World Conservation*, Vol. 27, No. 2, pp. 21–23.

Richmond, R. H., (1993) "Coral Reefs: Present Problems and Future Concerns Resulting from Anthropogenic Disturbance". *Amer. Zool.*, Vol. 33, pp. 524–536.

Riopelle, J. M., (1995) "The Economic Valuation of Coral Reefs: A Case Study of West Lombok, Indonesia". Thesis, Dalhousie University, Halifax, NS, 74 pp.

Roberts, C. M., (1994) "Marine Reserves: A Brief Guide for Decision Makers and Users". Presented at the Workshop on Coastal and Ocean Resource Management, NGO Islands Forum, UN Global Conference on the Sustainable Development of Small Island Developing States, Barbados, April 25–May 6, 12 pp.

Roberts, C. M., (1995a) "Effects of Fishing on the Ecosystem Structure of Coral Reefs". *Conservation Biology*, Vol. 9, No. 5, pp. 988–995.

Roberts, C. M., (1995b) "Rapid Build-up of Fish Biomass in a Caribbean Marine Reserve". *Conservation Biology*, Vol. 9, No. 4, pp. 815–826.

Roberts, C. M., & Polunin, N. V. C., (1991) "Are Marine Reserves Effective in Management of Reef Fisheries?", *Reviews in Fish Biology and Fisheries*, Vol. 1, pp. 65–91.

Roberts, C. M., & Polunin, N. V. C., (1993) "Marine Reserves: Simple Solutions to Managing Complex Fisheries?". *AMBIO*, Vol. 22, No. 6, pp. 363–368.

Rogers, C. S., (1990) "Responses of Coral Reefs and Reef Organisms to Sedimentation". *Marine Ecology Progress Series*, Vol. 62, pp. 185–202.

Rogers, C. S., McLain, L., & Zullo, E., (1988) "Damage to Coral Reefs in Virgin Islands National Park and Biosphere Reserve From Recreational Activities". *Proceedings of the 6th International Coral Reef Symposium, Australia*, Vol. 2, pp. 405–410.

Ruitenbeek, H. J., & Cartier, C. M., (1999) "Review of the biodiversity valuation literature" in Ruitenbeek, H. J., & Cartier, C. M., *Issues in applied coral reef biodiversity valuation: results for Montego Bay, Jamaica*, World Bank Research Committee Project RPO#682-22 Final Report, World Bank, Washington, Chapter 3.

Ruitenbeek, J., Ridgley, M., Dollar, S., & Huber, R., (1999) "Optimization of economic policies and investment projects using a fuzzy logic based cost-effectiveness model of coral reef quality: empirical results for Montego Bay, Jamaica". *Coral Reefs*, Vol. 18, No. 4, pp.381–392.

Russ, G. R., & Alcala, A. C., (1996) "Marine Reserves: Rates and Patterns of Recovery and Decline of Large Predatory Fish". *Ecological Applications*, Vol. 6, pp. 947–961.

Russell, K. D., (1992) "The Economics of Coastal Waste Management" in Chua, T.-E., and Garces, L. R., (eds.) *Waste Management in the Coastal Areas of the ASEAN Region: Roles of Governments, Banking Institutions, Donor Agencies, Private Sector and Communities*. ICLARM Conference Proceedings 33, pp. 149-163.

Saila, S. B., Kocic, V. Lj., & McManus. J. W., (1993) "Modelling the Effects of Destructive Fishing Practices on Tropical Coral Reefs". *Marine Ecology Progress Series*, Vol. 94, pp. 51–60.

Salvat, B., (ed.) (1987) *Human Impacts on Coral Reefs: Facts and Recommendations*. Antenne Muséum E.P.H.E., French Polynesia.

Savina, G. C., & White, A. T., (1986) "A Tale of Two Islands: Some Lessons for Marine Resource Management". *Environmental Conservation*, Vol. 13, No. 2, pp. 107–113.

Smith, M. P. L., Bell, J. D., & Mapstone, B. D., (1988) "Testing the Use of a Marine Protected Area to Restore and Manage Invertebrate Fisheries at the Arnavon Islands, Solomon Islands: Choice of Methods and Preliminary Results" in *Proceedings of the 6th International Coral Reef Symposium, Australia*, Vol. 2.

Spurgeon, J. P. G., (1992) "The Economic Valuation of Coral Reefs". *Marine Pollution Bulletin*, Vol. 24, No. 11, pp. 529–536.

Sybesma, J., (1988) "Marine Resource Protection versus Marine Tourism in Curacao: a Management Problem" in *Proceedings of the International Coral Reef Symposium Australia*, Vol. 2, pp. 411–414.

Thorhaug, A., (1992) "Oil Spills in the Tropics and Sub-Tropics" in Connell, D. W., & Hawker D. W., (eds.) *Pollution in Tropical Aquatic Systems*. CRC Press, Boca Raton, FL, pp. 101–127.

Wantiez, L., Thollot, P., & Kulbicki, M., (1997) "Effects of Marine Reserves on Coral Reef Fish Communities from Five Islands in New Caledonia". *Coral Reefs*, Vol. 16, No. 4, pp. 215–224.

White, A. T., (1979) "Sumilon Island: Philippine Marine Park Pilot Site Enjoys Early Success". *ICLARM Newsletter*, Vol. 2, No. 4, pp. 10–12.

White, A. T., (1989) "Two Community-Based Marine Reserves: Lessons for Coastal Management" in Chua, T.-E., and Pauly, D., (eds.) *Coastal Area Management in Southeast Asia: Policies, Management Strategies and Case Studies*. ICLARM Conference Proceedings 19, pp. 85–96.

White, A. T., Barker, V., & Tantrigama, G., (1997) "Using Integrated Coastal Management and Economics to Conserve Coastal Tourism Resources in Sri Lanka". *AMBIO*, Vol. 26, No. 6, pp. 335–344.

Wilkinson, C. R., Lindén, O., Cesar, H., Hodgson, G., Rubens, J., & Strong, A. E., (1999) "Ecological and Socioeconomic Impacts of 1998 Coral Mortality in the Indian Ocean: An ENSO Impact and a Warning of Future Change?". *AMBIO*, Vol. 28, No. 2, pp. 188–196.

Appendix. Bibliography of Human-Induced Coral Reef Threats and Management Issues

Authors	Threats	Mgt. Issues	Description
Ablong et al. (1998)	All	Yes	Description of the Coastal Resource Management Project (CRMP) to establish a sustainable resource along 2,000 km of the Philippine coast, using participatory methods.
Alcala (1988)	Overfishing	No	Assessment of coral fish abundance and yields at four islands in the Philippines to compare marine reserves with non-reserve and control sites; significant differences in catch per unit effort were found.
Alcala & Russ (1990)	Overfishing	No	Test of the effects of removal of protective marine management at Sumilon Island, Philippines, 1984; found a 54% decline in total yield of reef fishes in a 2 year period that also affected areas adjacent to the reserve.
Alder et al. (1994)	Overfishing, coral mining, blasting, poison, pollution, tourism	Yes	Compares management of 3 Indonesian marine reserves: Kepulauan Seribu, Bunaken Manado Tua and Taka Bone Rate; discusses common issues facing the reserves and stresses the need for education, community development programmes, and attention to the socio-economic needs of the residents.
Alvarez (1995)	Poison	No	Short description of the live fish trade in the Philippines and its effects on coral reef systems.
Andersson & Ngazi (1995)	Overfishing, blasting, coral mining	No	Examines the socio-economic relationship between indigenous resource users and their coastal environment; concludes that participation from local resource-users can greatly benefit planning and management decision-making.
Andrews (1998)	All	Yes	Assesses the process and motives for establishment of the Park, with critical reference to the transposition of developed country conservation and management paradigms to a developing country.

Authors	Threats	Mgt. Issues	Description
Bakus (1982)	General	Yes	Provides criteria by which to select coral reef reserves, and identifies mechanisms through which multiple-user conflicts can be resolved.
Bell & Galzin (1984)	General	No	Empirical study in French Polynesia on the effect of differences in percentage live cover on the number of fish species and individuals.
Berg et al. (1998)	Coral mining	No	Analysis of the ecological services provided by reefs in Sri Lanka in terms of their potential long-term economic benefits; over a 20 year period, reefs were found to value US$ 140,000-7.5 m. km^{-2}, and the costs of coral mining were found to exceed net benefits by US$ 6 m.
Bjork et al. (1995)	Pollution	No	Study examining the levels of coralline algae on coral skeletons at four reefs in Tanzania, in order to assess the impact of wastewater exposure on algae distribution; calcification rate decreased with proximity to wastewater outlet, as well as with increased exposure to phosphates, but not ammonia or nitrates.
Bohnsack & Ault (1996)	All	Yes	Evaluates management strategies to protect marine biodiversity and promote the sustainable use of resources; propose new management tools based upon marine reserves, with reference to application to Florida Keys National Marine Sanctuary.
Brown (1997)	Temperature	No	Review of recent data related to the physical and biological factors associated with coral bleaching, including environmental triggers, the biological responses of corals, and their scope for adaptation.
Brown & Dunne (1988)	Coral mining	No	Describes mining activities on coral reefs around North Male Atoll (Maldives) and environmental impacts; suggests alterna tives for the construction industry to protect the reefs.
Brown et al. (1990)	Dredging	No	Assesses the impact on coral cover of increased sedimentation caused by a 9 month dredging operation in 1986-1987, Phuket, Thailand; at Ko Phuket, a measurable decrease in coral cover and species diversity was noted, although corals recovered rapidly, with complete restoration noted 22 months after the onset of the dredging.
Bunce et al. (1999)	—	Yes	The article describes the socio-economics of reef management through a case study of the Montego Bay Marine Park
Butler et al. (1993)	Overfishing	Yes	Describes the fishery on the Bermuda platform and the government's historical efforts to manage the fishery, including the 1990 ban on pot fishing and its results.
Campos et al. (1994)	Overfishing	No	Estimates catch, fishing effort and yield of the fishery at Cape Bolinao specific to different types of gear (spear, traps, corrals, gill nets); compares data with other fisheries in the region to conclude that current rates of extraction should not be increased.
Christie et al. (1994)	Blasting, poison, fish collecting	Yes	Overview of community-based Marine Conservation Project for San Salvador Island (IMCPSS) including means of implementation and results; shows that community-based protection and management is a feasible solution.

Authors	Threats	Mgt. Issues	Description
Davis & Tisdell (1995)	Tourism	Yes	Examines the critical thresholds of marine protected areas for recreational scuba diving in view of the potential impact of divers on the reef systems.
Davis & Tisdell (1996)	Tourism	Yes	Uses economic instruments to assess the most effective allocation of scuba divers between recreational dive sites; suggests management strategies to allocate divers amongst multiple sites.
Dennis & Bright (1988)	Grounding	No	Results of a two-year study examining re-colonisation of coral communities following a ship grounding; found significant differences in species composition, community structure and biomass.
Dixon et al. (1993)	Tourism	Yes	Discusses the trade-offs between the economic and protection benefits of marine parks in the context of the need for the integrated management of coastal areas; economic analysis of the benefits and costs of protecting Bonaire Marine Park to isolate its maximum sustainable use level and draw lessons for park management.
Dixon et al. (1995)	Tourism	Yes	Examines the feasibility of achieving joint ecological and economic benefits in marine protected areas through the case study of Bonaire Marine Park in the Caribbean; assesses ecological sustainability and compares tourism revenue with protection costs; draws lessons for park management.
Dulvy et al. (1995)	Coral mining	Yes	Results of a study showing impact of coral mining on reef communities at Mafia Island, Tanzania; live coral cover and fish abundance and diversity were substantially lower than at the unmined site; assesses management issues surrounding the mining of coral.
Fiske (1992)	General	Yes	Results of a study comparing the establishment of two marine sanctuaries: La Parguera, Puerto Rico and Fagatele Bay, American Samoa, in light of sociocultural variables influencing the process; identifies key sociocultural variables and argues in favour of planned social change.
Gabrié et al. (1994)	Overfishing, tourism, urbanisation	Yes	Assesses the state of the coral reefs of Bora-Bora (French Polynesia) and analyses the conflicting multiple uses of the reef to enable the design of a sustainable management plan; management recommendations are provided.
Galvez et al. (1989)	Blasting, poison	Yes	Results of ethnographic studies of two villages in the Lingayen Gulf, Philippines to assess how and due to what factors cyanide and blast fishing continue to take place despite legal restrictions; describes villager perceptions of the practices and provides recommendations for management of the reef resource.
Gittings et al. (1988)	Grounding	No	Results of a 27-month study detailing the recruitment and recovery of Molasses Reef, Key Largo National Marine Sanctuary, following a freighter grounding; results point to specific measures that can be taken to expedite coral recovery.

Authors	Threats	Mgt. Issues	Description
Harriott et al. (1997)	Tourism	No	Results of a study assessing the potential impacts of divers at four dive sites in Eastern Australia via. comparing diver contacts with corals with diver training and experience levels; suggests management strategies to limit the damage caused by diving.
Hatcher et al. (1989)	General	Yes	Review of recent research related to anthropogenic impacts on coral reef systems, including management issues.
Hatcher et al. (1990)	Lobster fishing	Yes	Combines ecological and anthropological approaches to describe the patterns of usage and resources at the Houtman Abrolhos reefs of Western Australia; aims to identify areas of conflict between the user groups in order to contribute to a sustainable management strategy for the area.
Hawker & Connell (1992)	Pollution	No	Discusses pollution threats to coral reef systems and describes studies pointing to tolerance levels for each type of pollution.
Hawkins & Roberts (1993)	Tourism	No	Study examining the impact of reef trampling by scuba divers and snorkellers near Sharm-el-Sheikh, Egypt; found that coral communities were significantly altered in size, species composition, and abundance in locations of heavy diver trampling.
Hawkins & Roberts (1994)	Tourism	No	Examines the impact of tourism on coral reefs through a case study on the Red Sea; evaluates present and planned development and potential growth in impact; proposes sustainable development strategies.
Hingco & Rivera (1991)	Poison, fish collecting	No	Overview of the fish collecting industry in Bolinao, Philippines with a focus on the use of cyanide, including local attitudes toward its use and mechanisms that support the practice; policy recommendations are made.
Hughes (1994)	Overfishing, hurricanes, disease	No	Analysis of phase-shift in Jamaican coral reef community structures due to anthropogenic and natural causes, including implications and future prospects.
Jennings & Polunin (1995)	Overfishing	No	Study of six Fijian fisheries to compare catch-per-unit-effort (CPUE) and value-of-catch-per-unit-effort (VPUE); results suggest that the fisheries are sustainable since fishermen frequently fail to maximise their efficiency.
Jennings & Polunin (1997)	Overfishing	No	Study of ten Fijian fisheries to measure the indirect effects of fishing on the biomass and diversity of reef fish; a negative relationship was found between the biomass of piscivorous fishes and fishing intensity, but increases in the biomass of their potential prey species were not noted.
Johannes & Riepen (1995)	Poison, overfishing	No	Overview of all aspects of the live fish trade in Asia and the Western Pacific including impacts on fishing communities and coral reef systems; provides policy recommendations.
McAllister (1988)	Sedimentation, poison, blasting, overfishing, pollution, coral mining	No	Details the economic, social and environmental costs of coral reef destruction in the Philippines.

Authors	Threats	Mgt. Issues	Description
McClanahan (1995)	Overfishing	Yes	Presents a coral reef simulation model which calculates the effect of fishing various species at different levels of intensity on the coral reef ecology; results in the design of a management strategy based upon the highest and most stable yield of fishery.
McClanahan & Kanda-Arara (1996)	Overfishing	Yes	Study analysing fish numbers and weights at two older marine protected areas in comparison with a newly created marine park (with an adjacent marine reserve) in Kenya; total fish landing in the reserve decreased by 35% due (in part) to a flawed park design with low edge-to-area ratio.
McClanahan & Obura (1997)	Sedimentation	No	Results of a study testing the effects of sedimentation on coral reef communities in the Watamu and Malindi National Marine Parks, Kenya; the biological diversity and ecological health of the sediment-affected reefs remained stable throughout the study.
McClanahan et al. (1999)	—	Yes	Paper discusses the proliferation of MPAs in Kenya and elsewhere in the world where management is relatively poor. The article argues that there is an economic rationale to have fewer, but better managed MPAs.
McClanahan (1999)	Overfishing	Yes	Tests a previously-designed overfishing model at protected reef sites in Kenya and Zanzibar in comparison with unprotected sites; found that fishing led to a reduction in the abundance of certain fish species and an increase in the sea urchin population.
McManus (1994)	Military, oil drilling	Yes	Argues in favour of the establishment of an international marine park at the Spratly Islands as a strategy to resolve conflicting claims over the region by China, Taiwan, the Philippines, Malaysia and Vietnam.
McManus (1996)	General	Yes	Overview of social scientific issues and research approaches related to the management of coral reef systems; discusses reefs as common property, Malthusian overfishing, and includes management options.
McManus et al. (1992)	Blasting, poison, anchoring	Yes	Describes four-year programme of monitoring the ecology and harvest patterns of a coral reef system in Bolinao, Philippines, to assess the effects of harvest on fish diversity; includes recom mendations for management of the reef.
McManus et al. (1997)	Blasting, poison, anchoring	No	Assess the effects of blasting, cyanide and anchor damage on a coral reef in Bolinao, Philippines, between 1987 and 1990.
Nowlis et al. (1997)	Sedimentation	No	Studies the impact of sediment on coral reefs in St. Lucia following a tropical storm; sediment resulting from intensive land-use practices and road construction was found to have a considerably damaging effect on nearshore reefs.
Nzali et al. (1998)	Blasting	No	Results of a study comparing coral recruitment patterns at two sites at Taa Reef, Tanzania, one of which had been severely damaged by blasting; findings suggest that recolonisation is negatively affected by a reduction in viable seed populations, as reflected in coral cover levels.

Authors	Threats	Mgt. Issues	Description
Öhman et al. (1993)	Mining, blasting, poison, pollution, tourism, fish collecting, anchoring, nylon nets	No	Study comparing three adjacent coral reefs in Sri Lanka: Bar Reef, Talawila Reef, and Kandakuliya Reef, in terms of the diversity and abundance of fish and coral, and anthropogenic impacts.
Öhman et al. (1997)	Blasting, poison, nylon nets	No	Assesses the distribution and abundance of reef fish within Bar Reef Marine Sanctuary, Sri Lanka in comparison with an adjacent, unprotected reef; the organisation of fish assemblages was related to habitat type, indicating that habitat destruction has a significant impact upon reef fish communities.
Pauly & Chua (1988)	Overfishing	No	Provides a historical and socio-economic background to the marine fishery in Southeast Asia; analyses current problems including stagnating catches, environmental problems, and population growth.
Pauly et al. (1989)	Overfishing, blasting	Yes	Assesses fishery management in the Third World in relation to rural poverty in these regions; contends that Malthusian overfishing describes the third world fishery, which is qualitatively different from overfishing in the developed world; suggests management strategies.
Polunin & Roberts (1993)	Overfishing	Yes	Assesses the result of protective fishery management through a comparison of Saba Marine Park (Netherlands Antilles) and Hol Chan Marine Reserve (Belize) with adjacent unprotected fisheries; analysis of abundance, size and biomass of common target species.
Rakitin and Kramer (1996)	Overfishing	Yes	Examines the distribution of sedentary vs. mobile and catchable vs. less-catchable species of fish in reserve and nearby non-reserve areas in Barbados; the marine reserve was found to protect the fish community, but evidence for the emigration of fish from the reserve was insufficient and inconsistent.
Richmond (1993)	Sedimentation, pollution, temperature, blasting, poison	No	Comparison of natural and anthropogenic disturbances to coral reef communities; describes key anthropogenic impacts.
Roberts (1994)	Overfishing	Yes	Describes the benefits of establishing marine reserves for the protection of fish stocks, sustenance of adjacent fisheries, protection of biodiversity; addresses several questions related to reserve set-up and effective management.
Roberts (1995a)	Overfishing	No	Assesses the effects of overfishing on reef community structure and reef processes, including a discussion of losses in species diversity, keystone species, predator species, and functional groups of species.

Authors	Threats	Mgt. Issues	Description
Roberts (1995b)	Overfishing	Yes	Study assessing the response of fish populations to the creation of a marine reserve in the Caribbean; abundance, size and biomass was greater in comparison with neighbouring areas; it was concluded that reserves play an important role in the protection of fish stocks.
Roberts & Polunin (1991)	Overfishing	Yes	Examines available evidence to assess whether marine reserves protect nearby fisheries, and/or supplement these fisheries through the emigration of fish from the reserve; concludes that although fish abundance and sizes increase within protected reserves, little evidence supports the theory of fishery recruitment and immigration.
Roberts & Polunin (1993)	Overfishing	Yes	Argues in favour of marine reserves as a low-cost alternative to conventional methods of fisheries management; assesses recent studies of reserve function in replenishing fish stocks.
Rogers (1990)	Sedimentation	No	Examines the effect of sedimentation (due to dredging, runoff, sewage) on coral reef communities at the ecosystem and organism level, including a discussion of interactions between fishes and their habitat.
Rogers et al. (1988)	Tourism	Yes	Results of a study assessing the damage caused to coral reefs as a result of recreational activities in Virgin Islands National Park and Biosphere Reserve; concludes with recommendations for monitoring and management of tourist activity.
Ruitenbeek et al. (1999)	General Impacts	Yes	The paper discusses cost-effective mitigation options for coral reef degradation using fuzzy logic procedures with empirical results from Montego Bay, Jamaica.
Russ & Alcala (1996)	Overfishing	Yes	Results of a study assessing the rates and patterns of increase in density and biomass of large predatory marine fish following the creation of marine reserves at Sumilon and Apo Islands, Philippines; over time, significant, positive linear correlations were found between fish density with years of protection in reserves.
Saila et al. (1993)	Blasting, anchoring, poison	No	Modelling of reef system in Lingayen Gulf, Philippines, assessing fish diversity and coral re-growth over time and under certain conditions; found that a 30% reduction in current destructive fishing practices (through halting use of poison) would enable slow reef recovery.
Savina & White (1986)	All	Yes	Assessment of two communities in the Philippines in which marine resource management projects were implemented; describes and discusses differences between the communities and presents implications for resource management.
Smith et al. (1988)	Overfishing	Yes	Results of a study testing whether the abundance and mean size of three species of invertebrate coral organisms increased as a result of the creation of a marine protected area at the Arnavon Islands, Solomon Islands.
Sybesma (1988)	Tourism	Yes	Assesses the management of Curaçao Underwater Park, Netherlands Antilles as a model for the sustainable use of resources in marine systems.

Authors	Threats	Mgt. Issues	Description
Thorhaug (1992)	Pollution	No	Discusses major impacts of oil spill on tropical systems and currently used clean-up methods; policy recommendations are made.
Wantiez et al. (1996)	Overfishing	No	Results of a study assessing the effect of marine reserve protection on the species richness, density, and biomass of coral reef fish communities in New Caledonia; statistically significant results confirm the efficacy of marine reserves.
White (1979)	All	Yes	Assessment of the implementation and management of Sumilon Marine Park, Philippines as a model for marine resource management.
White (1989)	All	Yes	Results of a study comparing two community-based marine resource management projects in the Philippines; includes assessment of implementation, economic benefits accrued, and lessons for the management of coastal marine resources.
White et al. (1997)	General	Yes	Proposes an integrated coastal management approach to resolve tourism development/coastal protection conflicts in Hikkaduwa, Sri Lanka; provides an economic evaluation of the proposed management plan.
Wilkinson et al. (1999)	Temperature	No	Discusses and assesses the extent and impact of bleaching damage caused by the warming event of 1998 to coral reef systems in the Indian Ocean; discusses the potential for recovery in various locales and includes socio-economic impacts on reef-dependent communities.