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The Economic Value of Ecosystems: 4 - Coral Reefs

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THE ECONOMIC VALUE OF ECOSYSTEMS:

4 - CORAL REEFS

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I. INTRODUCTION

Coral reef ecosystems provide a variety of valuable economic benefits to individuals and to society. Coral reefs are responsible for the formation and maintenance of thousands of islands and beaches worldwide. Potential harvests of fish from all coral reefs are estimated to be almost an eighth of the current world fish harvest (Munro 1984). The variety of life forms that inhabit coral reefs are a significant tourist attraction and may even have value for those who are unable to visit the reefs in person. Perhaps more importantly, reef ecosystems provide sustenance to rural populations throughout the tropics, by providing food, shelter and environmental protection - as well as being an integral component of indigenous cultures.

Despite their economic value, coral reefs are threatened - both directly and indirectly - by human activity. Direct damage to coral reefs stems from the use of destructive resource extraction techniques, such as the use of dynamite and poisons, as well as from unsustainable fish harvest levels and ecologically insensitive tourism activities. Indirect impacts may be just as severe, most commonly arising from pollution in the form of sewage, oil, thermal effluent and heavy metals, and from sedimentation caused by dredging, landfill and inland forest clearance. In addition, the specter of global warming and rising sea levels poses an additional threat to coral reef communities sensitive to changes in temperature and light.

This paper suggests that a proper understanding and accounting of the economic benefits provided by coral reefs will lead to improved management of reef ecosystems. Maintenance of reef integrity under a range of 'sustainable' use options is the key to maximizing the social benefits obtained from coral reefs. 'Development' options for coral reefs - or for adjacent terrestial or marine ecosystems - often result in significant foregone economic benefits. If these negative impacts are held up to public scrutiny, the case for 'development' will pale and the chances of putting the management of coral reefs on to a 'sustainable' footing will be increased.

II. THE ECONOMIC VALUE OF ECOSYSTEMS

As in the case of many other important biological resources, the full range of economic goods and services produced by coral reef ecosystems is rarely reflected in the design and implementation of management schemes for the reefs. Decision-makers in the private - and even public - sectors often make management decisions based on the perceived financial value of coral reefs instead of their economic value. Financial values are essentially monetary benefits as viewed from the perspective of the individual or firm. However, many of the goods and services produced by biological resources either do not pass through markets or have diffuse benefits that are difficult to capture by any one individual or firm. As a result of these ***market failures*** the private sector often takes into account only a narrow slice of the benefits of biological resources in conducting business as usual.

Economic values represent the benefits derived by society as a whole. Where financial and economic values diverge significantly, government intervention - whether at a local, national or international level - is often called for in order to ensure that private incentives reflect social values. Unfortunately, actions taken by the public sector often fail to redress market failure. Instead public policies are often designed with personal or political gain in mind, or in simple ignorance of their effects, creating ***policy failures***. By distorting existing markets for biological resources, or for related goods and services, policy failures create additional obstacles to efficient and equitable resource allocation.[1]

If substantial market or policy failures are present, the financial impacts of management strategies will be poor indicators of their economic impacts. One way of combatting such failures is to insist on generating the information necessary to make more prudent investment decisions. This can be done by requiring more detailed environmental and economic analysis of proposed management plans for coral reefs and their associated marine and terrestrial environments. A key element in such environmental cost-benefit analyses is to identify the range and likely value of the benefits provided by the reef under a variety of management options. If the management plan under evaluation is a 'development' option, a number of the reef benefits are likely to be sacrificed and must be acknowledged as costs to the project. On the other hand, the benefits realized under a 'sustainable' use option will provide the justification for maintaining the integrity of the reef.

Likewise, it is just as important to consider impacts on coral reefs arising from activities in adjacent marine and terrestrial environments. Coral reefs are often degraded as a result of activities that occur at a distance from the reef itself. For instance, degradation of reefs due to the accumulation of sedimentation is often linked to logging of coastal forests. Hodgson and Dixon (1988) examined the impacts of coastal logging on the tourism and fishing industry in Bacuit Bay, Philippines, and found that the benefits of logging activities were outweighed by the loss in value resulting from degradation of off-shore reefs. Thus, whether the focus of the study is the management of the reef or its surrounding ecosystems, the provision of information on the economic values generated by coral reefs is an essential input to the process of making environmentally and economically sound decisions.

Resource and environmental economics provides a means of analysing the interface between the economic system and the environment through the economic valuation of environmental goods, services and attributes. The economic value of an ecosystem - or its subcomponents - is derived from estimating monetary values for its direct use, indirect use, option and non-use values.

The direct use of ecosystem outputs in non-consumptive, consumptive or productive activities are the values most commonly measured in valuation exercises. ***Direct use values*** are derived from goods and services that are used in consumption or production. They describe the benefits of goods that enter directly into the human economy, such as commercial or subsistence reef fishing. In addition, the direct consumption of services such as tourism, recreation and research often generate considerable economic value. The estimation of these values, particularly those derived from the depletion and consumption of resource stocks, is a long-established area in resource economics.

A second category of use value - ***indirect use values*** - can be distinguished from direct use values. Indirect use values originate from the environmental functions that support and

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[1]See Bishop, Aylward and Barbier (1991) for an overview of market and policy failures.

protect economic activity. As these functions are not directly consumed or used in productive activity, they often go unmarketed and financially unrewarded. Nonetheless, for their supportive or protective role these functions are of economic value - even if this value is difficult to measure. Aylward and Barbier (1992) point out that methodological advancements in the measurement of indirect use values increasingly allows economists to value environmental functions.

In addition to use values, economists have suggested that environmental resources may have ***option and existence values***. Option values are associated with the future use of a resource and future flows of information regarding the use of resources. Since society is generally considered to be risk averse there may be a positive option value to assuring future direct or indirect uses of the resource. Finally, there may be non-use or existence values associated with a resource. These are benefits derived by an individual from the mere knowledge that the resource continues to exist.

Thus the ***total economic value*** of an ecosystem is made up of its direct use, indirect use, option and existence values. An illustration is provided in Table 1, in which a variety of the economic values generated by coral reefs are classified according to whether they are direct, indirect or existence values. These values are discussed further in Section III.

The objective of economic valuation is to measure society's willingness-to-pay (WTP) for the resource in question. In a perfectly competitive market WTP would be reflected by market prices. World prices, for example, often provide a benchmark for valuing goods and services that are internationally traded. For other non-tradeable goods, value is reflected in local market prices. However, market imperfections and distortions in agricultural and commodity markets in many developing countries mean that market prices do not properly reflect the marginal opportunity cost to society of using the resource. In such cases, shadow prices - which make adjustments to market prices to account for market distortions - provide a better indication of economic value.

An even greater challenge is the valuation of environmental resources that are not marketed. Valuation of such goods and services necessitates exploring alternative methods of valuation. A number of sophisticated techniques - such as contingent valuation, hedonic pricing, the travel cost method, and the production function approach - exist for estimating the WTP for non-marketed environmental resources. Alternative, second- and third-best methods for valuing direct use values include approaches based on replacement costs, indirect opportunity costs, damage costs, preventive expenditures and relatocation costs.[2]

Methods for valuing the regulatory functions of ecosystems will differ depending on whether economic activity or property is being supported or protected (Aylward and Barbier 1992). If economic activity is being supported, the indirect use value of environmental functions is related to the change in the value of production or consumption produced by any alteration of the existing function. If such activity is being protected, the implicit suggestion is that changes to the function may result in a decrease, but not an increase, in the value derived

[2]See Braden and Kolstad (1991) for a theoretical and technical review of the more sophisticated methods, and Dixon et al. (1988) for a more general overview of valuation methods.

Table 1. Total Economic Value of Coral Reefs

TOTAL ECONOMIC VALUE		
USE VALUES*		**NON-USE VALUES**
Direct Uses	**Indirect Uses**	**Existence Values**
Extractive:	**Biological Support to:**	Endangered Species
Capture Fisheries	Other ecosystems	Charismatic Species
Mariculture	Fisheries	Threatened Reef Habitats
Aquarium Trade	Sea Birds	Cherished 'Reefscapes'
Curio Trade	Turtles	
Pharmaceutical		
Other Industrial	**Physical Protection to:**	
Construction	Ecosystems	
Genetic Material	Land forms	
	Navigation	
Non-Extractive:	Coastal extension (EEZs)	
Tourism		
Recreation	**Global Life Support:**	
Research	Calcium Store	
Education	Carbon Store	
Aesthetic		

*Use values also include option values that reflect a premium or discount on direct and indirect use values in the presence of uncertainty.

from the function. In either case, if the application of more sophisticated techniques is not possible due to time and resource limitations, second-best approaches (such as those indicated earlier) must be employed. In the case of environmental functions, extra caution must be used to avoid double-counting of economic benefits and neglecting trade-offs between different values.

Techniques for directly eliciting willingness to pay - in particular the contingent valuation method - are the only way to measure option and existence values. Because such survey techniques are complex, time-consuming and data-intensive, most research along these lines has taken place in developed countries. In evaluating option and existence values of coral reef ecosystems in developing countries, analysts must often resort to the use of qualitative assessment.

III. THE ECONOMIC VALUE OF CORAL REEF ECOSYSTEMS

A. Direct Use Values: Extractive

A single reef can harbor many thousands of organisms and several thousand different species, many of which are directly used by people for food, the aquarium and curio trade, construction material, medicinal applications and as a source of genetic material. The economic value attributable to coral reefs for their role in producing these commodities primarily depends on the demand for these products and the quantity extracted. However, much of the research conducted to date on direct use values is based on world or local market prices. As a result there are two caveats that pertain to the financial figures cited below.

First, market prices indicate the actual amount consumers pay to obtain goods and services. If consumers are willing to pay more than the market price, then they receive something of value at no extra cost by making their purchase at the going price. If a considerable amount of this ***consumer surplus*** exists then the financial figures cited will understate the economic value of the good. Second, the figures may be overstatements of economic value if the quantity harvested or extracted is excessive or if significant off-site effects are produced. Nevertheless, in the absence of applications of more sophisticated techniques, market prices give some indication of the range of values and their economic significance.

Reef organisms, including fish, crustaceans, mollusks, echinoderms, worms and seaweed have long been used by humans as ***sources of dietary protein, vitamins and minerals***. While some species are primarily of importance only for subsistence use, others are harvested commercially or even traded internationally. The protein from reef species is of particular importance to subsistence communities that have little ready access to alternative sources. On Yap, a small island in Micronesia, 76% of daily household meat consumption comes from fish, three quarters of which are from reefs (Kay and Smalley 1989).

Munro (1984) estimated that fish species harvested from coral reefs could potentially supply nine million tonnes of fish per year - one-eighth of the world's supply of fish in 1984. The productivity of fisheries will tend to vary from site to site according to local conditions.

However, a study by McAllister (1988) suggested that losses in fish production caused by dynamiting, *muro-ami* and poisoning of reefs in the Philippines came to $80 million per year.[3]

The largest crustacean, the spiny lobster, is a delicacy well-known to tourists in the West Atlantic, as well as being of subsistence value and a foreign exchange earner in Papua New Guinea (Wells, in press). Numerous species of mollusks are collected from coral reefs for food including giant clams, conches, ark shells, lucina clams and octopuses (Salm 1984; Lewis 1988; Kay and Smalley 1989). Echinoderms, such as sea cucumbers which are boiled, sun-dried or smoked to produce the Asian delicacy *trepang* are also of local or regional value. Exports of sea cucumber from Fiji rose from 20 metric tonnes in 1979-80 to over 700 metric tonnes in 1988 (McElroy, 1990). Perhaps a more unusual delicacy in Western terms is the Palalo Worm, much prized in Western Samoa and other Pacific Islands (Wells et al. 1983). Finally, seaweed consumed raw or in cooked form provides an important dietary source of vitamins and minerals throughout the Pacific.

Aquaculture on reefs or of reef-dwelling organisms is not yet widely practiced, but it is expected that the cultivation of many heretofore wild species may be worth pursuing in the future. In Thailand, *Serranid* fish species are cultured in cages, whilst efforts to culture the Giant Clam on reefs in the Pacific have proved successful at producing large quantities of clam meat and shell per hectare. Pearl oysters are also cultured for their shell and pearls. In the Caribbean sponges are farmed and in Asia seaweeds are also grown in reef environments (Wells in press; Munro and Williams 1985)

Reefs - as rich, biodiverse communities - are also an important ***source of genetic material*** which may be increasingly important in breeding species for aquaculture, as well as of potential use in crop breeding. Progress in genetic engineering promises the ability to perform transgenic manipulations - in this case transferring genetic material from marine to terrestrial species. Potential uses of the reservoir of genetic diversity harbored by coral reefs include designing genetic resistance to disease and pests in both marine and agricultural environments.

Of the several hundred marine ***fish traded for use in marine aquariums***, reef species predominate. In addition to reef fish, various reef invertebrates are also traded such as shrimps, sea stars and corals. The market for marine species for use in aquaria has expanded rapidly over the past two decades, particularly in the US, Europe and Japan. While some species fetch as much as $500 per fish, wholesale prices are usually in the range of $0.20 to $30. The import value of world trade in marine aquarium fish in 1985 was estimated to be $24-40 million (Wood 1985). McAllister (1988) suggests that the Philippines brought in $10 million from the aquarium trade in 1988. Collection of reef species is occasionally excessive - usually for high value species - but if the reef remains intact, replenishment appears to occur rapidly and species are not usually endangered by the trade (Randall 1987).

[3]Muro-ami is a fishing technique in which swimmers scare fish into a net by raising and dropping scarelines (fishing lines with stones on the end) onto the reef.

Trade in curio items originating from coral reefs comes primarily from mollusc and coral species. Mollusc shells have been used for centuries by humans as religious symbols, currency, receptacles, tools and ornaments. The trade in shells and derivative products plays an important economic role in the economy of the Philippines, Papua New Guinea and other Pacific Islands where it provides employment for large numbers of people. Many corals - in particular coloured and branching species - are also collected and sold for use as decorations or jewellery. Unfortunately, little information is available on domestic trade in coral species for such uses. In countries where excessive extraction has led to deleterious effects on reefs, trade restrictions have occasionally been implemented - the Philippines banned trade in stony coral in 1977. Unfortunately, a corresponding rise in illegal and, therefore, undocumented trade is often the end result.

As with tropical forests, the use of reef species as a source of novel ***medical and industrial applications*** is receiving increased attention. The fact that reef species are usually less endemic and more ubiquitous than rainforest species may mean that successful applications could provide more widespread benefits for reef areas. A number of useful applications have been found and more remain under development. *Gorgonian* species have yielded compounds active against cancer and prostoglandins useful in the treatment of heart disease asthma and gastric ulcers. Coral skeletons of some *Porites* species have been used as bone graft substitute - the graft is eventually absorbed and replaced by true bone (Patat and Guillemin 1989). A prospective application with potentially large market value is the commercial use of pigments which protect corals from harmful ultra-violet rays. Imperial Chemicals Industries (ICI) has already acquired the rights to develop a number of these pigments for use as sunscreens for humans, as well as for use in plastics and paints. Finally, in 1992 the Coral Reef Foundation entered into a five-year contract worth $2.9 million for the supply of reef samples to the U.S. National Cancer Institute for use in its cancer and AIDS screening program.

Dead coral rock and living coral colonies are often mined from reefs for use in ***building, road and harbour construction***, as well as a source of calcium carbide and lime. Stony coral has been extracted for hundreds of years in this fashion in many tropical countries, especially small islands, where alternative building materials of terrestrial origin are rarely available or comparatively much more expensive. Since more compact slow growing massive corals such as *Porites* and *Faviids* are preferred, recovery and regeneration after mining is very slow. Little or no recovery was recorded ten to sixteen years after mining had taken place on Maldivian reefs (Brown and Dunne 1988). Where no substitute building material exists, the best option might be to sacrifice particular reefs and mine these to a much greater depth. As all the benefits of a reef would be lost by such an approach such decisions require a careful estimation of reef benefits and comparison with the costs of alternative sources of supply.

B. Direct Use Values: Non-extractive

Coastal tourism is a large and rapidly expanding business in the tropics. In 1987, the Pacific had 33 million visitors with an annual growth of 7%. In the same year, the Caribbean had 9.6 million visitors, 13% up over the year before, with tourist expenditure of $6.6 billion

(Miller and Auyong 1991). Unfortunately, it is difficult to isolate what proportion of tropical coastal tourism is due to tourist activities directly associated with coral reefs. The spectacular diversity and colours present in reef ecosystems provide ideal conditions for SCUBA diving, snorkeling, reef-walking, fishing and just visiting park areas. In addition it is difficult to assess the value of expenditures only indirectly related to coral reef activities such as travel and hotel expenditures. Furthermore, it is difficult to calculate what proportion of these expenditures remains in the local economy and to what extent they have a multiplier effect generating additional benefits above and beyond the initial expenditure level. Finally, as with all financial data, expenditure levels are not necessarily indicative of what people would have been willing to pay for the experience - consumer surplus is not reflected in such data.

Despite these difficulties in measuring the economic value of tourism, it is clear that many small islands, countries and coastal communities derive a large portion of their income from reef-based tourism. Dive-based tourism in Bonaire, Netherland Antilles was responsible for $23 million in gross revenues from hotels, airfares, diving and other expenses in 1991 (Dixon, Scura and van't Hoft, 1991). In 1985 - the latest year such figures were calculated - Bonaire's GDP was approximately $44 million. Florida's John Pennekamp Coral Reef State Park and the adjoining Key Largo National Marine Sanctuary were visited by 1 million people in 1986, generating an income of $47 million (DeFoor and Mattson 1986). According to Kelleher (1991) the Great Barrier Reef generates an annual income of $80 million. In the Maldives, where tourism accounts for 18% of GDP, tourist receipts rose from $15 million in 1981 to $63 million in 1988 (Binnie and Partners, 1990). Estimates of annual expenditures on diving abound: $80-90 million in the Bahamas in 1985, $53 million in the Cayman Islands marine protected area (Dixon and Sherman 1990) and $7 in Hawaii (Van Poollen 1983). Hundloe (1990) found that people were willing to pay $5 million above and beyond what they already pay (i.e. their consumer surplus) for reef activities on Australia's Great Barrier Reef.

Research and educational activities undertaken in coral reef ecosystems are, at first glance, difficult to differentiate from tourism. Researchers and students pay for food and lodging, hire boats and fishing or diving gear just as tourists do. Over 250 marine research institutions exist in the Caribbean, South Pacific and Indian Ocean areas. Spurgeon (1991) calculates that at least $2.5 million of the Smithsonian Institute's 1991 budget for work in Panama can be said to be attributable to Panama's coral reefs. In addition, there are numerous expeditions to reef zones each year. Coral Cay Conservation estimates their annual expenditures to maintain a team of 25 researchers on reefs in Belize at roughly $150,000. Such figures convey only the financial expenditures on goods and services due to these activities. Economic benefits that are more difficult to value include the information generated by research or the increased environmental awareness and attendant changes in attitudes that result from educational trips. For instance, growth rings and compounds contained within coral skeletons indicate and record past climatic and environmental changes. Such information is valuable in environmental monitoring and forecasting, but attributing a value to such information would be extremely difficult.

Perhaps the major difference between research and educational activities and tourism is in the scale of the activity. Research and educational trips to coral reefs are of a smaller scale and thus less likely than mass coastal tourism to have the potential for detrimental impacts on reefs. Hawkins (1991) indicated that excessive recreational diving caused significant damage to reef communities in the Red Sea. In the case of Bonaire Marine Park in the Netherland Antilles, Dixon, Scura and van't Hoft (1992) suggest 5,000 dives per site per year as a theoretical carrying capacity for the local reefs. Above this threshold the impact of further dives only 'wears' on the reef, while intermediate use levels below the threshold may actually tend to increase diversity indices. In Florida, Tilmant (1987) observed no major impacts on reefs when they were used by less than 1,500 visitors per reef per year. While these studies are only a first step towards more detailed analyses, they demonstrate the importance of understanding the 'tourist' carrying capacity of reefs.

It must also be recognized that research is itself not a purely non-extractive activity. Medicinal, industrial and taxonomic research efforts are likely to involve only a limited extraction of the original source material. However, the discovery of an important medicinal or industrial use for a coral reef species may require sustained extraction in order to support consumer demand. This may lead to questions regarding the sustainability of such extraction and its impact on the remainder of the reef. When reefs yield information useful in medicinal or industrial applications, or are viewed in museums or aquarium it may also be important to design mechanisms for returning an appropriate share of the economic benefits of these uses to the conservation of the reef. These may include simple up-front payments for organisms extracted or involve future claims on benefits as in the case of royalties for pharmaceutical products.

Local communities living near coral reefs receive a variety of additional, cultural benefits from reefs. ***Cultural and heritage values*** represent the benefits of traditions and customs which have arisen within communities based on their association with coral reefs. Spiritual and aesthetic values reflect the contribution of coral reefs to the quality of life of those people living and working in such a natural and scenic environment.

C. Indirect Use Values

Coral reefs provide a wide range of indirect use values including biological support to other ecosystems and organisms; physical protection to other productive marine ecosystems, valuable terrestrial habitats and coastal shipping; and global life support through the role of reefs as a calcium and carbon store.

By providing ***biological support to other ecosystems and organisms*** coral reefs play a key ecological role in the generation of direct use values garnered from these systems and organisms. Coral reefs replenish other reefs with organisms and support productive fisheries in nearby seagrass beds and mangroves. The pelagic juvenile stages produced by many reef organisms often drift across to other ecosystems due to currents and can act as a food source for other species. The juveniles of other species actually settle and mature in their new environment until harvested by fishermen. Mature individuals of some species also migrate daily between reefs and other ecosystems to feed. Coastal fisheries are supported by reefs which can provide pelagic fish with a major part of their diet. In the Maldives, the tuna fishery is dependent on shoals of reef fish which are used as live bait for the pole-and-line fishing technique. Other recipients of biological support from coral reefs include sea birds which feed on reefs and Hawksbill turtles which feed, sleep and breed on reefs and reef islands.

Coral reefs act as natural, self-repairing breakwaters which dissipate wave energy thereby creating low energy environments. Seagrass beds, lagoons and mangroves all develop and flourish in these environments. Without the ***physical protection*** of the reefs, such environments could not continue to generate valuable goods and services. Protection afforded by reefs also reduces coastal erosion which may otherwise cause the disappearance of land, islands and beaches. Without such protection, coastal defences would need to be constructed as a replacement, and economic activities relocated or even sacrificed. In the tropics, many beaches and sometimes islands themselves are created naturally from coral reef material.

Provisions in the third United Nations Convention on the Law of the Sea (UNCLOS III, 1982) state that coastal zones and their associated legal rights can be extended further out to sea by the presence of offshore rocks, islands and coral reefs. Therefore, where reef extensions occur, and when rocks and islands exist solely due to reef protection, any additional benefit accruing to a coastal state is in part attributable to the coral reef responsible. For example, it is alleged that two reefs extend the coastal sovereignty of the Philippines by 22,800 square nautical miles in an area where oil reserves are found. Finally, reefs protect near-shore waters from wave disturbance, creating calm and safe conditions for navigation and recreational uses.

Reefs also play a role in ***global life support***. Calcification is a major biochemical process on coral reefs. As a result reefs play a significant role in the world calcium balance. Smith (1978) calculated that at least half of the 1.2×10^{13} mol of $CaCO_3$ delivered to the sea each year is precipitated by corals. The economic significance of this role has yet to be determined.

In the case of carbon storage some approximate indicators of economic value have been developed - largely with the intention of promoting the function of tropical forests as a carbon store. For example, in a review of the literature on the value of carbon storage, van Kooten, Thompson and Vertinsky (1992) reveal that researchers have valued carbon at from $2 to $250 per ton. By their very nature, coral reefs store substantial quantities of carbon in the form of carbonate rock. In addition, Whittaker (1975) has indicated that coral reefs fix more carbon per annum than rainforests. The net primary productivity of coral reefs is roughly 2,500 grams/m^2/year of carbon per year as opposed to 2,200 grams/m^2/year for tropical forest. As atmospheric CO^2 is in equilibrium with oceans a carbon storage value should be attributable to coral reefs as well as rainforests.

D. Option and Existence Values

At present little is known about the option and existence value of coral reefs. A survey by Hundloe, Vanclay and Carter (1987) reveals that Australians are willing to pay $36 million annually for maintaining the Great Barrier Reef in its current state. Unfortunately the study does not distinguish between the use, option and existence values that make up this figure.

sDue to the lack of empirical research regarding the option and existence values of coral reefs, a qualitative assessment may be called for when the economic value of a reef is evaluated. Although it is increasingly possible to quantify the use benefits provided by reefs there often remains a large degree of uncertainty over the level of future benefits. Thus, an additional premium - or option value - may be warranted in the case of management plans that conserve future options for the use of coral reefs. Similarly, existence values may be difficult to measure in monetary terms. However, if it is thought that people derive satisfaction from the mere knowledge that a particular reef will be maintained in its current state then such values should not be overlooked in economic analyses.

Research into option and existence values will require analysis of local and national values. In the case of natural assets of international importance - such as the Great Barrier Reef - significant 'global' option or existence values may also be worthy of attention. In such cases, the assessment of existence and option values must extend beyond the domestic level. Hundloe, Vanclay and Carter (1987) indicate that the $36 million figure must be taken as a lower bound since many people in other countries value the existence of the Great Barrier Reef, as well as the option to visit it someday.

IV. INCORPORATING ECONOMIC VALUES INTO CORAL REEF MANAGEMENT

Using the example of tropical forests, Barbier (1991) has indicated that there is no single management alternative that will capitalize on all the potential values of a natural resource system. Trade-offs between different values will exist between products and services that are mutually, or at least partially, exclusive. For example, it is difficult to reap the benefits of extracting reef material for construction and simultaneously harvest the full potential of the reef fishery. In evaluating different management plans it is important to understand which values will be realized and which will be foregone.

Reef management is often characterized by an attempt to fulfill particular objectives or to capitalize on particular values of reefs. While the list presented in Box 1 is by no means exhaustive it covers the major uses to which reefs or particular zones within a larger reef area are typically dedicated. According to this typology of reef zonation the major uses of reefs may comprise zones for preservation, tourism, multiple use, sustainable extraction, mariculture and non-sustainable use.

As a broad guide to understanding the trade-offs between differing strategies for managing reefs, Table 2 explores which economic values are likely to accrue to each economic use zone. It is not necessarily the case that a zonation that capitalizes on a larger range of values is better than one with a smaller range of benefits. In any evaluation of different zonation strategies for a particular reef area it would be necessary to determine the relative magnitude of the various values. However, uses that capitalize on a wider range of benefits would tend to be less prone to the risk of sudden changes in demand for particular products or services. In addition, strategies that maintain the integrity of the reef and, therefore, its capability to generate the full range of values clearly keep more options open for the future.

Box 1 Coral Reef Economic Use Zones

Preservation: With the exception of research, and possibly some low volume, high-priced tourism, no other activities would take place.

Tourism: The reef would be devoted to non-extractive tourism, minimizing impacts.

Multiple Use: A combination of extractive uses and tourism would take place, requiring management to ensure sustainability.

Sustainable Extraction: The reef would be used primarily for extractive uses, with a minimum of tourism activity.

Mariculture: The reef would be devoted to the intensive but sustainable farming of reef organisms, e.g. Giant Clams.

Non-Sustainable Extractive Use: The unsustainable use of a reef - e.g. for extensive coral mining - would destroy the reef's integrity thereby forfeiting virtually all other reef benefits.

In the case of large reefs falling under a single management authority, a number of reef zones might be demarcated with each zone dedicated to a different economic use. In such cases, it may be possible to capitalize on a broader range of values for the reef as a whole. Clearly, the optimal management plan is to zone reefs with reference to the natural characteristics of the reef and the demand for reef products and services. A tourism zone might be located offshore from an area developed for coastal tourism in order to minimize disturbance to other zones and to minimize access costs. A sustainable extraction zone located near a port area would provide ease of access to fishermen and other users, whilst maintaining the indirect benefits of biological support and physical protection to the urban population. A preservation area for research purposes, meanwhile, might be situated on a more remote section of the reef.

Subdividing reefs into economic use zones diversifies the economic values gained from the reef. Ideally, the boundaries of such zones would be flexible allowing use to respond to changes in demand and fluctuations in reef populations. However, such a flexible approach to zonation would require limiting any non-sustainable zones that irreversibly degrade the integrity of the reef.

V. *CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH*

This paper has demonstrated that coral reefs can provide a number of important use and non-use values under a range of different management regimes. While most of the studies of reef values to date have relied on trade or market data there are a number of innovative studies that have begun to apply more advanced economic valuation techniques. While an overview of efforts to date yields a rough impression of the value of coral reef ecosystems, further

Table 2. Economic Value of Coral Reefs Under Different Zonation Strategies

Economic Values	Preservation	Tourism	Multiple Use	Sustainable Extraction	Mariculture	Non-Sustainable Extraction
	Economic Use Zones					
Direct Uses						
Extractive:						
Fisheries	0	0	x	1	*1	0
Aquarium Trade	0	0	x	1	x	0
Curio Trade	0	0	x	1	x	0
Pharmaceutical	0	0	x	1	x	0
Other Industrial	0	0	x	1	x	0
Genetic Material	0	0	x	1	x	0
Construction	0	0	x	1	x	1
Non-Extractive:						
Tourism	x	1	x	x	x	0
Recreation	x	1	x	x	x	0
Research	1	x	x	x	x	0
Education	1	x	x	x	x	0
Aesthetic	0	x	1	1	x	0
Indirect Uses						
Biological Support	1	x	x	x	x	0
Physical Protection	1	1	1	1	1	0
Global Life Support	1	1	1	1	1	0
Option Values	1	x	x	x	x	0
Existence Values	1	x	x	x	x	0

Key: O = no value
1 = full potential value
x = only a portion of the full potential value
*1 = greater than the normally accessible value

Source: Based on Spurgeon (1991), also see Spurgeon (in press) for more details.

basic and applied research - into both natural science and economic issues - is needed if coral reefs are to be managed in a sustainable fashion.

In the natural sciences there is a need for more quantitative information on sustainable levels of extraction of reef organisms, and on reef carrying capacities for tourist activities. However, these can only be achieved if there is a greater understanding of the fundamental biological processes such as reproduction, growth and recolonization, and the processes of interactions between ecosystems. Of particular importance is the need to further understand the relationship between these processes and the many, variable environmental parameters, such as temperature and light.

Applied economics research would enable the transformation of the outputs of basic and applied scientific research into economic arguments for sustainable approaches to reef management. Economic field work carried out in close conjunction with ecological research and directed towards the application of promising valuation techniques (e.g. the production function approach and contingent valuation method) would greatly assist in clarifying the likely magnitude and importance of the indirect use values of coral reefs. In addition, applied research into option and existence values should seek to elicit the premium people are willing to pay above and beyond use and indirect use values for the maintenance of coral reefs. Theoretical issues regarding the techniques used in the measurement of the value of biological resources and environmental quality are well-established. What remains is their application to real allocation decisions.

Applied research efforts should involve interdisciplinary teams and be of such a scale - in both space and time - to be relevant to ongoing project or policy decision processes. This entails both project appraisal work and longer-term applied research. Only by undertaking the necessary research will the economic consequences of changes in reef management or the prospective impacts of changes in land or marine resource use in associated ecosystems be established and conveyed to private and public decision-makers.

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Economics, Natural-Resource Scarcity and Development: Conventional and Alternative Views, Earthscan, London, 1989 (paperback £15.00)

The history of environmental and resource economics is reviewed; then using insights from environmentalism, ecology and thermodynamics, Barbier begins the construction of a new economic approach to the use of natural resources and particularly to the problem of environmental degradation. With examples from the global greenhouse effect, Amazonian deforestation and upland degradation on Java, Barbier develops a major theoretical advance and shows how it can be applied. This book breaks new ground in the search for an economics of sustainable development.

David W. Pearce, Anil Markandya and Edward B. Barbier

Blueprint for a Green Economy, Earthscan, London, 1989 (paperback £8.95)

This book was initially prepared as a report to the Department of Environment, as part of the response by the government of the United Kingdom to the Brundtland Report, *Our Common Future*. The government stated that: '...the UK fully intends to continue building on this approach (environmental improvement) and further to develop policies consistent with the concept of sustainable development.' The book attempts to assist that process.

Edward B. Barbier, Joanne C. Burgess, Timothy M. Swanson and David W. Pearce

Elephants, Economics and Ivory, Earthscan, London, 1990 (paperback £10.95)

The dramatic decline in elephant numbers in most of Africa has been largely attributed to the illegal harvesting of ivory. The recent decision to ban all trade in ivory is intended to save the elephant. This book examines the ivory trade, its regulation and its implications for elephant management from an economic perspective. The authors' preferred option is for a very limited trade in ivory, designed to maintain the incentive for sustainable management in the southern African countries and to encourage other countries to follow suit.

Gordon R. Conway and Edward B. Barbier

After the Green Revolution: Sustainable Agriculture for Development, Earthscan Pub. Ltd., London, 1990 (paperback £10.95)

The Green Revolution has successfully improved agricultural productivity in many parts of the developing world. But these successes may be limited to specific favourable agro-ecological and economic conditions. This book discusses how more sustainable and equitable forms of agricultural development need to be promoted. The key is developing appropriate techniques and participatory approaches at the local level, advocating complementary policy reforms at the national level and working within the constraints imposed by the international economic system.

David W. Pearce, Edward B. Barbier and Anil Markandya

Sustainable Development: Economics and Environment in the Third World, London and Earthscan Pub. Ltd., London, 1990 (paperback £11.95)

The authors elaborate on the concept of sustainable development and illustrate how environmental economics can be applied to the developing world. Beginning with an overview of the concept of sustainable development, the authors indicate its implications for discounting and economic appraisal. Case studies on natural resource economics and management issues are drawn from Indonesia, Sudan, Botswana, Nepal and the Amazon.

David W. Pearce and R. Kerry Turner

** *Economics of Natural Resources and the Environment*, Harvester-Wheatsheaf, London, 1990.

This textbook covers the elements of environmental economics in theory and in application. It is aimed at undergraduates and includes chapters on sustainable development, environmental ethics, pollution taxes and permits, environmental policy in the West and East, recycling, and optimal resource use.

David W. Pearce, Edward B. Barbier, Anil Markandya, Scott Barrett, R. Kerry Turner and Timothy M. Swanson

Blueprint 2: Greening the World Economy, Earthscan Pub. Ltd., London, 1991 (paperback £8.95)

Following the success of *Blueprint for a Green Economy*, LEEC has turned its attention to global environmental threats. The book reviews the role of economics in analyzing global resources such as climate, ozone and biodiversity, and considers economic policy options to address such problems as global climate change, ozone depletion and tropical deforestation.

E.B. Barbier and T.M Swanson (eds.)
Economics for the Wilds: Wildlife Wildlands, Diversity and Development, Earthscan Pub. Ltd., London, 1992 (paperback £12.95).

This collection of essays address the key issues of the economic role of natural habitat and wildlife utilization in development. The book argues that this role is significant, and composes such benefits as wildlife and wildland products, ecotourism, community-based wildlife development, environmental services and the conservation of biodiversity.

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