existing indigenous species and alter the balance of the ecosystem.

The growing international recognition of the problem has led to maritime agencies such as the International Maritime Organization and Australian Quarantine and Inspection Service introducing special ballast water guidelines.

There have already been attempts to kill the organisms using chlorine or hydrogen peroxide. However, such treatment would be too expensive on a large scale. Heat treatment has been used successfully in Canada to kill off mussel infestation in a pipe line. In this case, the water was heated to 36–38°C for two 6 h periods. Current research shows that short (30–90 sec) periods of heat treatment of dinoflagellate cysts at temperatures as low as 40–45°C may well prove effective.

Whether such treatment would be presently feasible in practical terms is open to question since for a 45 000 t ship, heat generation power of 45 MW would be needed to do this, on top of the 20 MW of waste heat from the ship's main engines.

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VIEWPOINT

The Economic Valuation of Coral Reefs

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Coral reefs are highly productive, diverse, and attractive ecosystems which provide a valuable range of benefits for mankind. Despite this, reefs all around the world are being damaged through over-exploitation and indirect human impacts. Part of the problem stems from the fact that the full economic value of coral reefs is rarely appreciated. If governments, decision-makers, and individuals were more aware of their true value when used sustainably, then perhaps the future for coral reefs would not look so bleak.

In this article I mention the main advantages and problems of putting monetary values on the environment. Then, using coral reefs as an example. I explain how natural habitats, or ecosystems, can be valued using a 'Total Economic Value' approach. Direct and indirect uses as well as non-use values are described and brief details given of appropriate economic valuation techniques (see Hufschmidt *et al.*, 1983). Finally, I suggest a framework suitable for resource accounting which should help overcome the problem of summing the value of different benefits, some of which are mutually exclusive. Although some benefits described here are unique to coral reefs, the concepts and valuation techniques explained are equally applicable to most natural habitats.

Why Value the Environment?

The natural environment provides a variety of uses or benefits of value to mankind which can be separated into three main types. *Direct uses*, which include tourism and harvesting of natural resources or 'goods'; *indirect uses*, where benefit is gained indirectly from natural habitats, usually through support and protection of other economic activities and are often referred to as natural functions or environmental 'services'; and *non-uses*, such as option and existence values, whereby value can be derived without any current human use. The Total Economic Value of a habitat is thus derived by valuing all of these (Barbier, 1989).

Decisions are constantly being taken over whether activities and developments in the coastal environment should be carried out. Before implementation, analyses are generally conducted to assess their financial and/or economic viability. Private enterprises (individuals and firms) base their decisions on analyses using financial values, i.e. actual market prices, to determine whether or not a project will be profitable. Meanwhile, for public developments, government decision-makers use economic analyses with economic values to determine the overall net economic benefit (social benefit) to society as a whole, thereby ensuring the optimum allocative use of resources. Economic values include shadow prices, i.e. market prices adjusted for taxes and subsidies, and opportunity costs, i.e. costs measured in terms of their value in their next best alternative use. Cost-Benefit Analysis (CBA) is one such economic analysis technique commonly used for assessing development alternatives where the objective is to identify and value all economic benefits and costs associated with a particular development.

However, there are two main reasons why development decisions may not result in the optimum allocation of resources. Firstly, environmental benefits may include many non-marketed goods and services which have no readily acknowledgable monetary value. Secondly, natural habitats, especially marine habitats, have off-site benefits which occur away from the habitat. Loss of non-marketed and off-site benefits are by definition omitted from financial analyses, and although supposedly accounted for in economic analyses, they are unfortunately predominantly only mentioned qualitatively, if at all. The same applies for off-site negative environmental impacts resulting from large-scale developments such as chemical industries and coastal logging. Due to the sensitivity of coral reefs and the interrelated nature of coastal environments, off-site development impacts present a serious yet commonly neglected threat to reefs.

So that optimum allocation decisions can be made, loss of non-marketed goods and services and off-site benefits must be fully accounted for, as should off-site development impacts. Recent advances in valuation techniques mean that more of these can now be quantified in monetary terms, providing more meaningful and influential information for decision-makers. Although requiring more effort, time and money to undertake, better informed development decisions should pay off in the long term. For example, Hodgson & Dixon (1988) assessed different development alternatives in Bacuit Bay, Philippines, using cost-benefit analysis and accounting for environmental effects. They determined that over a 10 year period reef fisheries and tourism would generate US$ 41 million more than logging the adjacent forests.

The Brundtland Commission defined sustainable development as development which "meets the needs of the present without compromising the ability of future generations to meet their needs". To fully concur with this, some form of accounting for national and international natural resources is required. Establishing the amount and availability of natural resources and habitats is a necessary step forward but would be more meaningful if their current and potential values were known. Progress towards this has been made by some European countries, but the approach needs substantial further research (see Pearce *et al.*, 1989).

Valuing the environment for resource accounting requires techniques capable of valuing direct, indirect and non-use benefits accruing from resources and habitats in their benefit maximizing use. Their economic value is essentially the difference in current and/or potential net economic benefit to society in situations with and without the resource or habitat in question. Appreciating the full value of the environment is also required to provide a more secure basis for policies designed to safeguard the environment.

Practical applications are widespread. Claims for environmental damages are now reaching phenomenal levels. A compensation claim of US$ 30 million was recently made by the Egyptian Government for damages to 340 m^2 of coral reef in the Strait of Tiran caused by the grounding of an empty cargo ship. An independent assessment put the value at close to US$ 250 000, and an out-of-court settlement of US$ 600 000 was eventually agreed upon. A universally acceptable methodology for placing realistic values on such damages is thus needed. Valuing the environment should also enable the best management strategy of natural resources and habitats to be determined, one which provides the maximum net social benefit to society (see Spurgeon & Aylward, 1992).

Problems of Valuing the Environment

Despite recent advances in the use of environmental valuation techniques and the obvious advantages gained through using them, it is still rarely carried out. To value some benefits needs much detailed economic and biological information. Even with this, some techniques have problems, which include inconsistency and bias (see Pearce & Turner, 1990). These factors can thus be a major hurdle, particularly in developing countries.

Inaccuracies will always exist because of incomplete understanding of complex environmental processes and inherent biological uncertainties. However, determining the relative value of the environment is a valuable first step.

Ethical concerns probably create the biggest problem when valuing the environment. Many people simply believe it is immoral, especially to price individual organisms. Such pricing occurs in some States in the USA in an attempt to simplify and speed Natural Resource Damage Assessments (NRDAs) (US Dept of Commerce, 1984). However, I prefer to advocate an approach whereby the Total Economic Value (TEV) of habitats is measured. The objective is to determine the aggregated sum of all economic benefits derived from a habitat. Once determined, the economic implications of environmental impacts can be assessed in terms of the overall change in TEV.

Whether we like it or not, environmental valuations are being made implicitly all the time. Every time a development goes ahead which damages a habitat, that habitat has in effect been valued at less than the worth of the developments' net benefit. Because some benefits cannot be quantified, determining the TEV of a habitat only provides a minimum value, and is thus not a price tag. If this is made clear then environmental valuation can be seen for what it is; a valuable tool providing a useful lower limit to the value of the environment.

Whilst undervaluation may lead to overexploitation of resources, overvaluation can result in other serious inefficiencies in the market. For industries and services operating near sensitive environments, it may be justifiable to subject them to large liabilities where unique and irreplaceable natural habitats are at risk from damage. Conversely the danger must be avoided that over-valuation does not adversely affect important services which pose a slight environment risk due to excessive insurance premiums or threat of accident payouts.

Finally, developers may view environmental valuation as an attempt to prevent further development. However, the aim of environmental valuation is to enable better development decisions to ensue by leaving less room for subjective decision making.

The Values of Coral Reefs and How They Are Measured

Direct Use Values—Extractive

Fisheries, Aquarium, and Curio Trades. A single reef can harbour many thousands of organisms and species, many of which can be harvested sustainably. Many are edible and regularly harvested for consumption. Potential harvests of reef fish are estimated at 9 million t y^{-1}, an eighth of the current world fish harvest (Munro, 1984). An average maximum sustainable yield (MSY) of 15 mt km^{-2} yr^{-1} of all reef organisms is suggested by Munro & Williams (1985) although total MSYs calculated for reef fish range from 0.5–36 mt km^{-2} yr^{-1}. Reef fish, molluscs and corals are also extensively used in the aquarium and curio trades, for which individual specimens may realize high prices. The world import value for the expanding marine aquarium trade was estimated to be US\$ 24–40 million y^{-1} in 1985 (Wood, 1985). Because these are on the whole marketable commodities, determining appropriate economic values should be relatively straightforward.

However, contrary to popular belief, the economic value of these uses is not necessarily the MSY but is the profit maximizing yield (PMY). Because all costs and revenues involved in collecting and selling the products should be accounted for, the greatest overall benefit is achieved when profits are maximized. Due to natural fluctuations in fish catches, variable market prices and staggered capital outlay, the PMY is best calculated using cost-benefit analysis over a long period of time. The resulting value for each extractive use is the economic *productivity value*. When assessing environmental damages, a monetary value can be determined for the *change in productivity* of that habitat. This is essentially the difference in value of productive output before and after the impact.

Unfortunately, CBA costs and revenues are rarely simple to determine. Only when market prices reflect the true worth of a product can that price be used. Market prices distorted by taxes or subsidies should be adjusted to a 'shadow price', giving their true economic value. Market prices of similar of 'substitute' commodities can be used for non-marketed products. Finally, costs should be measured in terms of their opportunity cost, defined as what they would earn in their next best alternative use.

Collection of the necessary information and calculations to determine the maximum profit is thus a complex and time consuming process. Inherent biological uncertainties also mean that accurate valuations are impossible. There are thus good reasons for adopting a quicker and more simple valuation technique using MSYs. Although commonly sought in fisheries biology, MSYs are sensitive to assumptions. However, by multiplying MSY by appropriate market or substitute prices this method can provide adequate estimates of reef productivity values.

Harvesting reef products usually generates both financial and social benefits. The price consumers pay for a product is the financial value, whilst the extra amount they would be willing to pay is additional social benefit. Known as consumer surplus, this is essentially the additional satisfaction gained in excess of payment. Products used on a subsistence level without going through a market will therefore provide social benefit but no financial value.

A valuation technique which enables consumer surplus to be valued is the *Contingent Valuation Method* (CVM). This analytic survey technique uses hypothetical situations to place monetary values on goods and services for which no market system exists. It does this by eliciting information on peoples' willingness to pay, or willingness to accept compensation, for increases or decreases in the quantity of some good or service, contingent on some hypothetical market. In this case, locals can be asked how much they would be willing to pay for certain reef products assuming they could not be obtained elsewhere. Where money is not perceived in the same way as in the Western world, the *Costless Choice Method* can be used (Dixon & Sherman, 1990). In this instance, the hypothetical bidding uses commonly exchanged goods. This is a highly useful and flexible valuation technique which can be adapted to measure virtually all types of environmental benefit or damages.

Pharmaceutical and Other Industrial Uses. It is often noted that coral reef organisms have excellent potential for pharmaceutical and industrial applications. Corals, gorgonians and sponges contain many biologically active compounds of considerable potential value. Some uses have already been successful, for example of coral skeletons in bone grafts. In these cases, productivity values can be measured. Unfortunately, however, valuing uses which are not yet commercially viable is difficult because it is impossible to predict the likely success of such applications. Comparison with work relating to the value of potential rainforest products is interesting but disheartening. To make such applications commercially viable usually requires lengthy research at exhorbitant costs. Also, with recent advances in biotechnology, pharmaceutical companies find it cheaper and more profitable to patent synthetically formulated drugs. In a study on Korup National rainforest, it was estimated that Cameroon itself would only benefit by US\$ 5000 per patent for drugs derived from indigenous plants (Ruitenbeck, 1989), much less than the profit derived from end users. As is the case in agriculture, a further extractive use of coral reefs is as a source of genetic material, though once again, predicting potential economic values is difficult.

Construction. Coral is used extensively as building blocks, aggregate and for production of lime. However, because usually the more compact, slow growing corals are used, and because mining is destructive, it is generally considered a non-sustainable use. Its immediate market value may be high, but this fails to account for the considerable loss of other reef benefits. Any economic analysis of coral mining operations must therefore fully consider the forfeited benefits.

Direct Use Values—Non-extractive

Tourism. There is little doubt that tourism yields the greatest direct financial benefit of all reef uses. Many small island nations, such as the Maldives, depend heavily on reef-based tourism for economic development. All revenues directly generated from reef-related tourism are attributable to reefs, from SCUBA diving and fishing to Marine Park entrance fees. In addition, indirect tourism revenues, such as accommodation, food and travel costs, are also attributable to reefs where their expenditure is directly related to reef activities.

Using the above assumptions, Mattson & DeFoor (1985) estimated that in 1984–85, coral reefs in two marine parks in Florida generated an income of US$ 47.6 million. These parks, John Pennecamp Coral Reef State Park and Key Largo National Marine Sanctuary, attract 1 million visitors each year. By dividing revenues generated by the area of reef used, the authors determined coral reef values of US$ 15.75 m^{-2} yr^{-1} from direct revenues, and US$ 85 m^{-2} yr^{-1} from gross revenues.

However, in addition to financial benefits, the real tourist value of reefs also includes a significant degree of tourist consumer surplus (TCS) value. This is the additional satisfaction gained by tourists visiting reef sites in excess of payment. In many instances, tourists visit reef sites for free, and any admission or hire charges are often below what people would be willing to pay. It could, however, be argued that this additional benefit is actually realized indirectly by tourists paying inflated prices for accommodation, food and souvenirs because they believe they are getting good value from the reefs.

Two methods exist for determing the extent of this additional economic value. The contingent valuation method can be used to survey willingness to pay for certain reef activities. Using this method, Hundloe (1990) estimated a TCS for coral reef activities on the Great Barrier Reef (GBR) of AUS$ 6 million per year, or over AUS$ 8 per adult.

An alternative is to use the *Travel Cost Method* (TCM). This is based on the assumption that the number of people visiting a site is inversely related to the distance they come from. If the number of people visiting the site and their travel costs are known, then regression analysis estimates the value of that site to visitors. Using this method, Hundloe (1990) estimated that the TCS for people visiting coral reef sites on the GBR was AUS$ 105.6 million per year.

Research. Like tourism, scientific research can generate significant quantifiable revenues for local economies. Many economic benefits may ensue from research findings, but immediate financial benefits can be determined through analysis of annual expenditures or budgets of marine research centres operating on coral reefs. For example, since one sixth of research at the Smithsonian Research Institute in Panama is reef-related, US$ 2.5 million of their 1991 US$ 15 million budget could be said to be due to coral reefs. The same applies to expeditions to reefs. For example, all the money spent by the UK 'Coral Cay Conservation' expedition surveying coral reefs in Belize can be attributed to reefs there. Their annual expenditure in Belize in 1991 came to BZ$ 300 000 (J. Ridley, pers comm, 1991).

However, of far greater overall significance are benefits relating to the findings of reef research. Although difficult to value the benefits of gaining academic knowledge, much of this value can be considered as part of that derived from applied research. Unfortunately, this too is difficult to value, but the benefits are easier to envisage. Biomedical research can increase the range of commercial products available and helps in combating disease, and research on corals can be used for environmental and climate change monitoring. No attempts have been made to quantify the value of reefs in these terms.

Education. Financial benefits arise through education programme expenditures and present little problem in valuation. Such expenditures are, however, likely to be accounted for when valuing tourism and research revenues, so differentiation is possibly not worth the effort. As for research, possibly the greatest value arises in the form of social benefit. This includes the first hand experience and knowledge gained, together with the increased sense of environmental awareness acquired. To determine the extent of this benefit, an adapted form of CVM survey could be carried out, assessing people's opinions before and after visiting reef sites.

Social Value. Local communities living nearby and utilizing coral reefs gain additional esoteric benefit similar to that of tourism consumer surplus. This 'social value' is referred to in the literature under a variety of guises all of which are very much interrelated. It includes cultural and heritage values which represent the benefit to communities of traditions and customs which have evolved based on associations with coral reefs. It also includes spiritual and aesthetic benefits.

Since the different attributes making up this social value for coral reefs are inextricably linked, there seems little point in attempting to value them individually. No quantifications seem to exist for this social value of reefs, but attempts could be made using an adapted CVM. Local people could be surveyed to assess their willingness to pay to maintain the reefs as they are, and adjustments made to exclude their perceived value of the reef's other direct benefits.

Indirect Use Values

Biological support. Coral reefs interact in a variety of ways with other ecosystems having indirect economic implications. They support fisheries both offshore and in nearby seagrass beds, lagoons and mangroves. Pelagic juvenile stages produced by many reef organisms drift across to other ecosystems due to currents and either act as a food source for commercial fish, or settle and mature until harvested by fishermen. Mature individuals of some species also migrate daily between reefs and other ecosystems. Colonies of seabirds feed heavily on reef fish, and turtles feed and breed on reefs and reef islands. The recreational value of these is increasing as eco-tourism grows.

Precise valuation of such benefits is difficult, but estimating a rough value may be feasible. The biological support value can be determined using the *Change in Productivity* approach, essentially being the difference in value of the biologically supported economic activity in situations 'with' and 'without' the reef. An alternative way of measuring this is to use what I refer to as the *Percentage Dependence Technique.* The biological support value is effectively the value of the supported activity multiplied by an estimated percentage dependence of that activity on the reefs' presence.

Coastal Zone Extensions. The third United Nations Convention on the Law of the Sea (UNCLOS III, 1982) gives rise to a new, previously undocumented yet potentially massive value for some coral reefs. The law specifies several different types of coastal zone, including Exclusive Economic Zones, Territorial Waters and Archipelagic Waters, over which coastal states have certain rights concerning resource use. These zones extend a certain distance seawards measured from baselines which are usually the low water mark of coastlines. However, provisions within the law mean that baselines may be drawn from fringing reefs around islands and from reefs exposed at low tide within 12 nm of land. By increasing the extent of coastal zones, these reefs can be responsible for significant economic benefits.

Although UNCLOS III is not yet fully ratified, its provisions are highly persuasive in international legal proceedings. An example of reefs extending coastal zones is provided by Alicia Annie and Commodore Reefs off the coast of the Philippines. According to UNCLOS III, these two reefs extend the Archipelagic Waters of the Philippines, giving them ownership rights to several of the Spratley islands which in turn gives the Philippines an additional 22 800 nm^2 of Archipelagic Waters. The presence of large oil reserves in these waters means that these reefs potentially provide a most valuable asset. The value attributable to such reefs is the difference in value to the coastal state of coastal resources measured with and without the reef extension.

Physical Protection. One of the more significant but perhaps least obvious benefits of coral reefs is the physical protection they afford to coastlines. Coral reef organisms actively produce calcium carbonate skeletons which form an effective regenerating barrier that dissipates wave energy. This protection provides measurable benefits.

In regions prone to severe storms and strong prevailing currents, reefs can significantly reduce coastal erosion. Many beaches, stretches of coastal land and indeed whole islands owe their existence to coral reefs. This is not only due to physical protection, but also because reefs produce vast quantities of beach material. The land protected often has considerable value due to the many profitable economic activities, notably tourism. Rocks and islands may also have associated coastal zones which would be forfeited if they are eroded away as a result of reduced reef protection.

Highly productive low energy environments are also created as a result of reef protection. Many seagrass beds, lagoons and mangroves only exist because of the calm conditions experienced behind reefs. Such habitats can be of great economic value, especially from commercial fisheries. The calming effect of reefs can also create safe waters for navigation.

The true economic value of reef protection is the difference in value of supported economic activities occuring with and without reef protection. For fully intact reefs, this value can be estimated using the Percentage Dependence Technique, being the total value of supported economic activities multiplied by their estimated dependence on reef protection. Although difficult to calculate precisely, the relative magnitude of reef protection value could be determined by taking into account factors such as the degree of exposure, frequency of storms, depth and structure of the reef. Alternatively, when damage to a reef and its protective function occurs, then the *Change in Productivity* valuation technique is applicable.

An alternative method for valuation is the *Replacement Cost* technique. Here the reef's protective value is assumed to be equivalent to the cost of installing artificial coastal defences to replace the reefs protective function. For example, on Tarawa Atoll in Kiribati, to prevent coastal erosion following the mining of coral reefs, coastal defences costing US$ 90 720 had to be built (Howarth, 1982).

Valuing the reef protection function in this way usually gives a minimum value because the response may be restrained by ability to pay, the benefits of measures taken may be far greater than the costs involved and, unlike reef protection, artificial replacements will need renewing. However, excessive values can also be given. McAllister (1991) suggested that since the construction costs of using concrete tetrapod breakwaters is US$ 1 million/km^2, then the 22 000 km of fringing reef along the Philippine coastline is worth at least US$ 22 billion. This, however, ignores the fact that erosional sensitivity and economic activities vary along coastlines and that other cheaper forms of coastal defence may suffice.

Global Life Support. On a global scale, biochemical processes occurring on coral reefs can play an important role. Due to calcification, coral reefs play a significant role in the world calcium and carbon balances. According to Smith (1976), 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.

It has been estimated that coral reefs act as a sink for 111 million t of carbon per year, the equivalent of 2% of present output of anthropogenic CO_2. In the event of global warming and predicted increases in reef production this figure may even rise to 4% of the present CO_2 output within 100 years (Kinsey & Hopley, 1991). In light of the potential economic costs of global warming (estimated by Nordhaus to be US$ 13 m^{-3} of carbon released) this carbon storage function of coral reefs may be of significant economic value. However, Kinsey and Hopley do point out that reef calcification might lead to initially increased concentrations of atmospheric CO_2 and hence exacerbate global warming.

Social services

If a large coral reef is destroyed, then in addition to losing direct benefits from extractive uses, communities which relied on that reef for their livelihoods may suffer other economic losses. Damages to reefs in the Philippines may have resulted in the loss of over 127 000 fishermen's jobs and could also cause malnutrition because seafood provides the Philippines with 50% of its animal protein (McAllister, 1988). If there are insufficient alternative employment opportunities then economic costs could result from ensuing unemployment, related crime and the setting up of compensationary welfare services. If there are no immediate substitute sources of protein, malnutrition could lead to costs from associated medical treatment and loss of earnings. Thus for a healthy reef, these potential costs could be looked upon as benefit in the form of savings on otherwise incurred social welfare expenditure.

Non-Use Values

Existence Values. Existence value can be defined as the utility that people gain simply from knowing that something exists and will continue to exist in the future. Part of the satisfaction comes from the fact that people can be sure that future generations will be able to enjoy this existence, and as such is referred to as bequest value. Evidence that such a value exists is the fact that people donate money to environmental organizations such as 'Save the Whale Fund', even though they may never actually see a whale themselves.

Existence values have not been determined for coral reefs, but have been measured for individual species (see Pearce, 1990) and for ecosystems (Bennett, 1984). The only method of valuation is to use the CVM, whereby people's willingness to pay for an area to be preserved is sought. A rough calculation by Pearce (1990) gives an existence value for the Amazonia rainforest of at least US$ 3.2 billion. It was assumed that each adult from the richest nations would pay US$ 8 to stop deforestation, this figure being derived from average existence values for certain endangered wild species in the USA. If, however, the adverse effects associated with rainforest removal, such as global warming, were highlighted, then the existence value would be expected to shoot up.

Measurement of the existence value of a coral reef would require an extensive CVM survey. Information is needed on people's willingness to pay for a reef to be preserved, with no future uses allowed. These data are needed from three main population sources: people living near the reef (where existence value should be differentiated from social value), people living in the rest of the country and people from all other countries. Obviously many complications exist, but an attempt using a well structured sampling strategy would be interesting.

Common sense suggests that several easily identifiable factors will dictate the magnitude of existence value for coral reefs. The greater the quality, condition and uniqueness of the reef on a national and global scale, the greater its likely existence value. The size of population, level of income, standard of education and the environmental perception of people in the country owning the reef will also greatly influence the value.

Option values. Option value is the benefit received by retaining the option of using a resource in the future by protection or preserving it today. It is not the expected value from future use, but what people are willing to pay now to maintain their option to use the resource later. In effect, it is equivalent to an insurance premium guaranteeing the supply of something in the future which may otherwise become unavailable.

The 'option price' (option value plus expected consumer surplus) has been calculated for certain animal species (see Pearce & Turner, 1990), but the option value for habitats has not. In theory this value is measurable, but once again only by using the CVM. However, since reefs are unique and irreplaceable natural environments with dwindling supplies and growing demands, it can be assumed that their option value will be large. Factors such as reef size, quality and uniqueness, and the perceived threat of destruction will all affect option value.

A combined non-use or 'vicarious' value (existence plus option value) has been estimated for the Great Barrier Reef by means of a CVM mail survey (Hundloe, 1987). A value of AUS$ 45 million/year was calculated by ascertaining the amount that average Australian citizens would be willing to pay to ensure that the Great Barrier Reef is maintained in its current state. Because the underlying motives for this value were not distinguished, it would therefore incorporate option and existence values (including preservation and bequest motives). However, as Hundloe pointed out, it is a gross underestimation due to the exclusion of foreign opinions.

The ability to capture monetarily some of these non-use values is evolving, particularly in developed countries, through various wildlife contribution funds. Motives for donations would include existence and option value, both of which should grow in size as people become more environmentally aware and as the opportunity to experience wild habitats at first hand increases.

Intrinsic Value. In addition to all the above reef benefits, it can be argued that an intrinsic value also exists for all reefs and their organisms. There is a small but growing concensus that other organisms have rights regardless of whether they have any utility. Unlike an anthropocentric existence value, intrinsic value is impossible to measure monetarily. The magnitude of intrinsic value will, however, be in proportion to the diversity or richness of reefs, and a degree of subjectivity will always remain.

Cost of Reefs

To correctly reflect the Total Economic Value of coral reefs, their costs to society should also be considered. These, however, rarely exist and are usually insignificant compared to the economic benefits of the same reef. Certain reefs, or parts of them, are navigational hazards, making it necessary for ships to detour around them, causing shipwrecks and preventing access to land and islands. Many islands have channels blasted through reefs which permits safe and cheap access. The fuel and time costs of detours could be measured, as could the opportunity cost of forfeited economic activity.

Aggregation of Economic Values

The problem we are now presented with is how to sum the different benefits making up the TEV of a coral reef. To enable reefs to be fully valued for resource accounting purposes, a valuation framework should be used. Ideally, current financial and social benefits would be recorded in monetary values per unit area per year. Where this proves difficult, estimations for a possible range of values would have to suffice. As well as assessing the current value of each use and non-use, potential value of each direct use should be determined.

However, the simple aggregation of benefits is impossible because there are trade-offs between different use options, with some use and non-use values being mutually exclusive. Therefore, reefs, or parts of them, would need to be categorized according to their main economic uses. Table 1 describes six possible types of 'economic use zones'. Table 2 then shows the valuation framework mentioned above and also indicates the relative proportion of each value that can theoretically be summed in each zone. By valuing the different benefits for each relevant economic use zone the Total Economic Value for any reef system could then be determined simply by summing the values for each zone.

This approach can also be adopted to determine an optimum management strategy for coral reefs (Spurgeon & Aylward, 1992). Coral reef uses could be planned and controlled so that society gains maximum benefit by optimizing the various use and non-use trade-offs.

The figures shown in Table 2 represent the proportions of each value that can be summed together and are

TABLE 1

Economic use zones.

This describes six categories of reef use zones which could be used for resource accounting purposes. These use zones also relate to possible alternative reef management strategies.

Preservation: With the exception of research, and possibly some exclusive 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, but some tourism may occur.
Mariculture: The reef would be devoted to the intensive but sustainable farming of reef organisms, e.g. Giant Clams.
Non-Sustainable Use: The unsustainable use of a reef would destroy the reef integrity thereby forfeiting virtually all other reef benefits e.g. coral mining.

TABLE 2

Aggregation of Economic Values.

This illustrates the different proportions of each use and non-use value which could be added together in different reef use zones to give the Total Economic Value of a reef system. The relevant proportions for each value are indicated here as multipliers which are further explained in the text.

	Economic use zones					
	Preservation	Tourism	Multi use	Sust. Extr.	Mariculture	Non. Sust.
Financial benefits						
Direct Uses						
Fisheries	0	0	m	1	>1	0
Aquarium trade	0	0	m	1	s	0
Curio trade	0	0	m	1	s	0
Pharmaceutical	0	0	m	1	s	0
Other Industrial	0	0	m	1	s	0
Genetic material	0	0	m	1	s	0
Construction	0	0	s	1	s	>1
Tourism	s	1	m	s	s	0
Research	1	m	m	m	m	s
Social benefits						
Indirect Uses						
Biological support	1	m	m	m	s	0
Coastal zone ext.	1	1	1	1	1	0
Physical protection	1	1	1	1	1	0
Global life support	1	1	1	1	1	0
Social services	0	0	m	1	s	0
Indirect costs						
Navigational	−1	−1	−1	−1	−1	0
Other Economic Value						
Uses						
Product consumer surplus	0	0	m	1	s	0
Tourism consumer surplus	s	1	m	s	s	0
Social Value	0	s	1	1	s	0
Research Value	1	m	m	m	m	s
Educational Value	s	1	m	s	s	0
Non-uses						
Option Value	1	m	s	s	s	0
Existence Value	1	s	s	s	s	0
Intrinsic Value	1	1	m	m	m	0

Proportion of value which can be summed for each zone: s=some of the value (0.01–0.50) 0=none of the value.
1=full sustainable value. >1=increased value. m=most of the value (0.51–0.99) −1=negative value.

a form of multiplier. A multiplier of '*1*' represents the *standard value*, or the expected value for any reef use or non-use which is exploited to its maximum sustainable natural limit. Where a use is unsustainable, or intensively cultured, a multiplier of '>1' may be applicable. However, if unsustainable, the value will not last long and will no doubt destroy the reef integrity thereby losing virtually all other reef benefits. For those values which are completely incompatible, such as the existence value of an unsustainably used reef, there is a multiplier of '*0*'. Reef costs appear as '-1', as a negative value.

Because many reef uses and non-uses are only partially compatible, in many instances only part of their values can be summed. Multipliers for these can be divided into those where only some '*s*' of the value can be claimed (apply multiplier of 0.01–0.50, i.e. 1–50% of standard value), and those where most '*m*' of the value can be claimed (multiplier of 0.51–0.99, i.e. 51–99% of standard value). In practice, actual multipliers used would have to be determined subjectively and may vary in different locations under different circumstances.

In theory, by fully accounting for all benefits using the TEV approach, all intangible attributes, such as biodiversity and aesthetic value should be accounted for. Looked at on their own, it is impossible to put monetary values on these attributes. Essentially, the greater the biodiversity and aesthetic beauty, the greater the magnitude of all use and non-use values.

Environmental valuation is still in its infancy and is certainly not without its problems. Despite not solving all the problems, it is hoped that this paper will stimulate interest in the subject, especially in people previously critical of the suggestion that economic valuations have a place in marine conservation or in assessing damage from marine pollution.

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