BULLETIN OF MARINE SCIENCE, 69(2): 1031–1045, 2001

IMPROVING THE ECONOMIC EFFECTIVENESS OF CORAL REEF RESTORATION

James P. G. Spurgeon

ABSTRACT

This paper provides a brief overview of the economic costs and benefits of coral reef restoration and considers the potential application of benefit-cost analysis. Three coral restoration case studies indicate that restoration costs can vary enormously, from around US\$10,000 ha^{-1} to US\$5 million ha^{-1}. A brief review of the economic benefits of coral reefs based on a 'total economic value' approach (i.e., accounting for direct and indirect uses, and 'non-uses'), reveals that potentially many thousands of US\$ per hectare could accrue from reef restoration. Various parameters are identified which dictate the value of coral benefits, and those factors that can be manipulated through restoration to enhance coral benefits are highlighted. The paper concludes with a number of recommendations. There is scope for greater application of a 'benefit-cost analysis' framework to assess the justification for restoring coral reefs and to improve the overall effectiveness of such initiatives.

Coral reefs throughout the world are being degraded (Jameson et al., 1995; Birkeland, 1997). As a result, there is an increasing interest in, and perceived need for, coral reef restoration. Numerous attempts at restoring coral reefs are currently being undertaken (NCRI, 1999). There are some useful guidelines (Miller et al., 1993) and reviews of the literature (Edwards and Clark, 1998) available.

As outlined by Edwards and Clark (1998), reasons for undertaking the restoration, rehabilitation, and relocation of corals include:

- Accelerating reef recovery from direct human impacts (ship-groundings, thermal effluents, dredging, coral mining, etc.) and natural/indirect impacts (El Niño, dinoflagellate blooms, crown-of-thorns starfish, etc.)
- Saving coral communities from potential damage (e.g., relocating corals prior to dredging)
- Enhancing the attractiveness of reefs for tourism

Thus, although part of the above restoration work is experimental, much is conducted for good practical purposes. The costs incurred can be many thousands or even millions of US dollars. In the USA, coral restoration has become a mandatory and generally accepted part of the damage assessment and compensation claim process for addressing coral-related ship-grounding incidents. However, are coral restoration activities an appropriate use of funds to help in the struggle to maintain and conserve coral reefs?

This paper forms a continuation of a wider review of the economic costs and benefits of the restoration and rehabilitation of a range of coastal habitats (Spurgeon, 1998). The paper is not intended to be a comprehensive review of the subject, rather an overview of some key issues. The main aims of the paper are to:

- Review the general economic costs and benefits of coral reef restoration
- Draw upon three reef restoration case studies
- Assess the potential application of benefit-cost analysis to reef restoration
- Highlight ways of enhancing the economic efficiency of reef restoration
- Comment on the economic justification for coral restoration

- Make recommendations for the future

It is worth noting two limitations to the paper. First, it is an attempt to cover a complex subject in a brief and relatively simplistic manner. Second, there is a lack of available information on the subject.

Benefit-Cost Analysis

Resources and funds available for coral reef conservation are without doubt limited. Economics should in theory be able to help prioritize use of any such resources and funds available since economics can be defined as 'the study of the efficient allocation of resources'. One tool that can help to make best use of resources and to maximize the economic returns from using a country's resources (i.e., labor, capital, and natural resources) is benefit-cost analysis (BCA; see Little and Mirlees, 1974; Hufschmidt et al., 1983; Dixon et al., 1988). The technique involves assessing all the economic costs and benefits relating to a particular use of resources (e.g., a restoration scheme) so that they can be weighed and compared to the economic viability of alternative uses for those resources.

In this way, BCA, or even just the thought processes associated with BCA can be used to:

- Help select the most efficient use of available funds (e.g., decide whether or not to restore a reef)
- Help maximize benefits to society from the selected option by fine-tuning the scheme details

The main stages involved in the BCA process are to:

- Define the details for each feasible scheme option (including the 'with' and 'without scheme' option)
- Determine the most appropriate spatial and temporal study limits
- Identify all scheme costs and all scheme benefits
- Place an economic (monetary) value, where possible, on all costs and benefits
- Calculate 'present-day' costs and benefits through 'discounting'
- Compare present-day costs to present-day benefits

The process of discounting is effectively the opposite of adding interest and means that costs and benefits arising at future dates are worth less than those arising at the present time (see Little and Mirlees, 1974; Dixon et al., 1988). Those schemes with a benefit-to-cost ratio (BCR) greater than 1 are economically justified. Generally, the higher the BCR, the more efficient the use of resources. The formula for calculating the BCR is:

$$BCR = \frac{\sum_{t=0}^{T} B_t/(1+r)^t}{\sum_{t=0}^{T} C_t/(1+r)^t}$$

where $\sum$ = Sum of values, B_t = Benefit at time t, C_t = Cost at time t, T = Timescale of project, t=0 = Start time of project, and r = Discount rate.

There are, however, limitations to the use of BCA. A major hurdle is the difficulty in valuing some of the many associated environmental benefits. Despite this, significant methodological advances are being made with respect to valuation techniques. The key to it is to ensure that all benefits and costs are identified through understanding how all the stakeholders will be affected. Then, appropriate valuation techniques should be applied.

There are other decision-making tools available to help decide on appropriate use of funds in related circumstances. For example, cost-effectiveness analysis (CEA) can assist in identifying the least cost or most cost-effective way of achieving certain environmental objectives (Dixon et al., 1988; Ruitenbeek et al., 1999). The technique certainly has its advantages when scheme objectives are obvious and agreed to by all.

Likewise, multi-criteria analysis (MCA) can help select a preferred scheme option without the need for estimating monetary values (Korhonen et al., 1992; Fernandes et al., 1999). A thorough understanding of stakeholder views is also required, as well as the views of appropriate experts. The preferred option is selected through scoring, weighting, and prioritizing a series of different objective criteria.

The U.S. government has increasingly been relying on an alternative method of assessing the appropriate extent to which damaged habitats should be restored or compensated for, known as habitat-equivalency analysis (HEA; Unsworth and Bishop, 1994; Milon and Dodge, this volume). This approach combines biological and economic information, particularly relating to the timing of lost biological functions, to determine the scale of a suitable compensatory habitat replacement project. A major limitation with this approach is that the ecological, social, and economic beneficiaries of replacement habitats are not necessarily the same as those suffering losses from the damaged habitat. There are numerous other associated problems as highlighted by Milon and Dodge (this volume).

Although CEA, MCA, and HEA are all valid option appraisal techniques, they are all incapable of addressing whether or not coral restoration schemes are money well spent.

The Economic Costs of Reef Restoration

The main economic cost components associated with reef restoration schemes can generally be broken down into 'capital' and 'operational' costs as detailed in Table 1. In addition, it is important to note two other types of cost that should be accounted for, notably the opportunity cost of using the site and any off-site impacts that the restoration may have, particularly to any donor site involved. When comparing alternative options, whole-life costs should be considered, using an appropriate time period.

Economic costs are measured in terms of the 'opportunity cost' of using each particular resource. The opportunity cost of a resource is the value of that resource in its next best alternative use, as measured by its social value less the social value of any inputs (labor, material, etc.) which could be used elsewhere. Market prices can generally be used as a basis for opportunity costs, although they often need adjusting to allow for market distortions (e.g., government subsidies and taxes).

There is a distinct lack of readily available information on the economic cost of coral reef restoration. Furthermore, information that does exist is neither generally comprehensive nor particularly comparable. However, a few examples of potential costs are given in the text below, and are summarized in Figure 1 to indicate the potential magnitude and range of costs.

Case Study 1: Florida.—Over the past decade there have been a number of coral reef restoration schemes in the United States. The majority of these have come about due to ships running aground on reefs. One such example is the reef restoration following the

Table 1. Costs typically incurred in reef restoration initiatives.

A. Capital costs
Pre-construction—studies to ensure most appropriate restoration scheme is selected (e.g., site surveys, objective setting, assessment of alternatives and design)
Construction—actual costs to carry out the scheme (e.g., substrate preparation, equipment, labor, materials, stock, and transport)

B. Operational costs
Management—to control and enhance the development of the site (e.g., prevent disturbance)
Monitoring—to assess the success of the restoration (e.g., check health of transplants)
Maintenance—to maintain structures (e.g., re-install boulders or corals after a storm)

C. Other associated cost
Opportunity cost of the site—(i.e., value of using the site in its next-best alternative use — for reefs the options are generally limited)
Damage to donor site—(i.e., loss of value to the site-donating organisms)

MV ELPIS, a 143 m cargo freighter, foundering on a reef in the Florida Keys National Marine Sanctuary in 1989. Under the National Marine Sanctuaries Act, the National Oceanic and Atmospheric Administration (NOAA) was authorized to recover costs and damages to pay for restoration of the site. Restoration funds of US$1.66 million (1991 prices) were awarded to restore 2605 m^2 of totally destroyed reef and 468 m^2 of partially destroyed reef. The rehabilitation involved removing debris, stabilizing the reef substrate, importing new substrate, transplanting corals and sponges, and monitoring (NOAA, 1997a). A simple extrapolation of costs based on 0.3 ha damage gives an overall cost of US$5.5 million ha^{-1}. This value is calculated merely as a means of indicative comparison.

CASE STUDY 2: MALDIVES.—A study comparing the effectiveness of different coral reef rehabilitation techniques was carried out in the Maldives by the Centre for Tropical Coastal Management Studies on behalf of the U.K. Department for International Development (Edwards et al., 1994). Estimated costs (in 1994 prices) for the installation of three different artificial reef options were as follows:

One-cubic-meter concrete blocks cost US$320 m^{-2} (US$1.6 million ha^{-1} using a recommended maximum of 50% coverage for larger areas).

Concrete armourflex mattresses cost US$100 m^{-2} (US$1 million ha^{-1}).

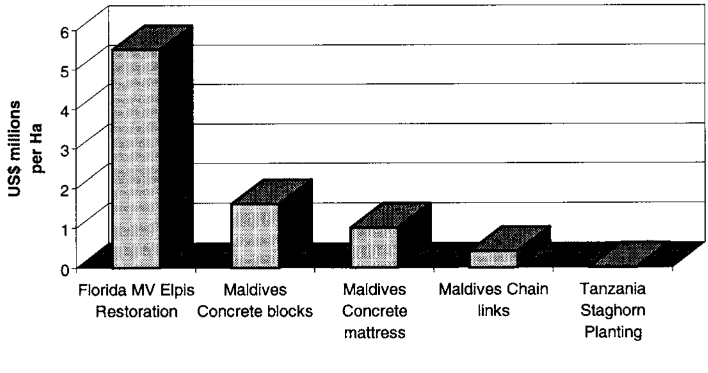

Figure 1. Comparison of reef restoration costs.

Table 2. Factors affecting magnitude of restoration costs

1. Location of the site
Developing/developed country
Site remoteness and accessibility
2. The operation
Scale and complexity of operation
Experience of designer and contractors
Means of fixing substrate and transplant
Density of transplanting/fixing corals
Source of substrate and corals
Cost of local labor and materials, etc.
Weather conditions during the operation
3. Conditions at the site
Depth of the reef
General exposure (e.g., to wind, tides, waves)
State of existing topography and substrate
Existing habitat/species present
Presence of contamination/water quality, etc.
Nature of adjacent areas
4. Availability of funds
Perceived need for the scheme
Actual availability of money for the scheme

Anchored chain-link fencing cost US\$40 m^{-2} (US\$0.4 million ha^{-1}).

The costs are only for the creation and installation of artificial structures on top of a dead reef structure, completely destroyed by coral mining. The costs do not therefore include transplantation and subsequent monitoring. These activities required considerable effort (330 man-hours to transplant 500 coral colonies onto 50 m^2 of armourflex and 114 man-hours for each monitoring of the same). Within 2.5 yrs of the transplants, 40–60% had died or been broken off by wave action. On the other hand, natural coral recruits were relatively successful (Edwards et al., 1994).

CASE STUDY 3: TANZANIA.—At the other end of the scale, low-tech reef rehabilitation initiatives in low-energy environments need only cost in the order of US\$10,000 ha^{-1} (Lindahl, pers. comm., 1999). A study involving the rehabilitation of coral reefs through transplanting staghorn corals (*Acropora formosa*) in the Mafia Island Marine Reserve, Tanzania, shows that simple methods for transplanting can be effective yet relatively inexpensive (Lindahl, 1998). This obviously has important implications for reef restoration in developing countries. The study is based on placing loose and tied pieces of staghorn coral onto natural substrate in low-energy sites. Estimated costs of US\$10,000 ha^{-1} assume that the collection, transportation, and placing of coral pieces is undertaken by trained locals under the supervision of an experienced biologist. Monitoring costs are excluded.

As clearly highlighted above, potential costs for reef restoration efforts vary enormously. Many factors affect the magnitude of likely costs, of which a few are detailed in Table 2. A key influential factor is obviously the type of restoration technique selected. Some methods require significant use of labor and a complex approach to construction and substrate preparation, while others do not. Factors such as cost of labor and whether it is

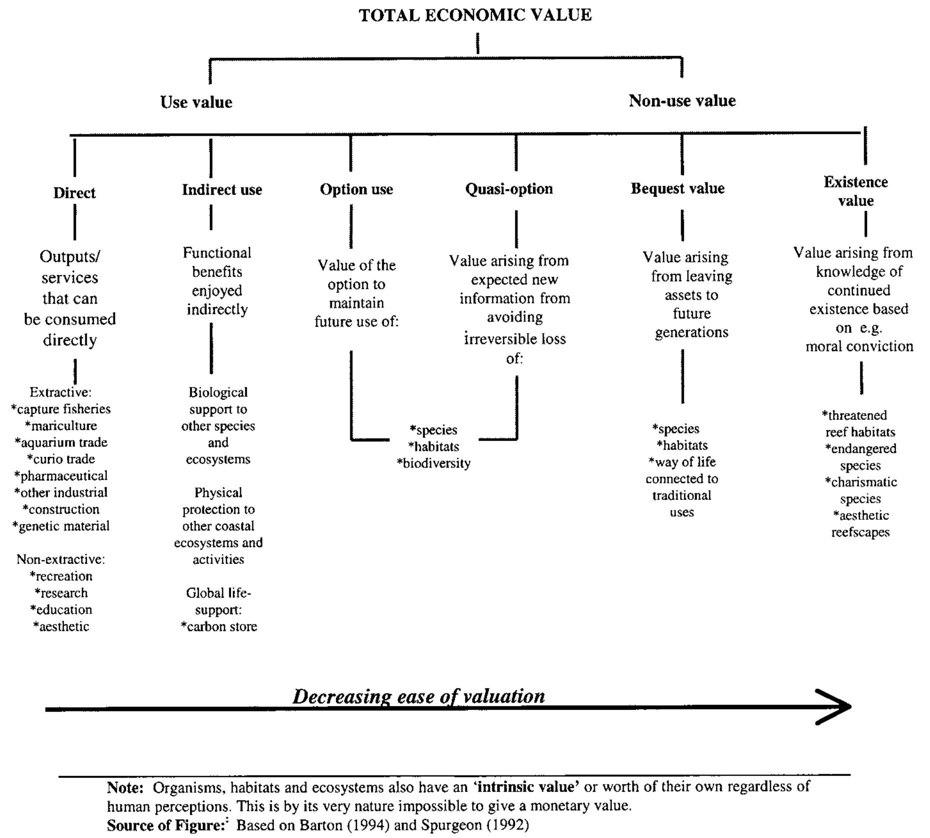

Figure 2. Total economic value of coral reefs.

in a developed or developing country can make a big difference. Accessibility and coral depth will dictate the time taken for the operations. Perhaps the greatest influencing factor in the level of costs incurred in the above examples is the amount of funds available to carry out the restoration.

The Economic Benefits of Coral Reefs

Coral reefs provide a vast array of benefits to mankind in the form of goods (products) and services (functions) (Spurgeon, 1992; Birkeland, 1997). Since few of the goods and services are traded in the market-place, they rarely have a readily observable monetary or financial value. However, they can have a considerable economic value, particularly when utilized on a sustainable basis. Coral restoration schemes may in theory be able to reintroduce many, if not all, of the benefits associated with them.

There are several ways of categorizing the full range of benefits attributable to coral reefs (Barton, 1994; Pearce and Turner, 1990). Possibly the most comprehensive and appropriate is based on the notion of 'total economic value,' which comprises 'direct' and 'indirect use values' and 'non-use values,' as outlined in Figure 2.

In addition to the 'current' habitat values shown in Figure 2, there will also be a range of 'potential' values. For example, a coral reef may not currently be used for tourism, but it may be in the future. Similarly, a particular coral reef species may have no current use, but it may prove to be a valuable product in the future (e.g., for medicinal purposes). 'Option value' may capture humankind's willingness to pay now to preserve a reef in case these uses arise in the future, but it does not represent the full extent of future-related earnings and economic benefits that may be huge. 'Quasi-option value' may also in part help capture some of the 'potential' value.

Since economists tend to determine values based on observing market behavior, the value of non-traded environmental goods and services needs to be measured in some other way. Over the past few decades, various economic techniques have been adopted which now enable the value of all habitat uses and non-uses (but exclude intrinsic value) to be estimated (Hufschmidt et al., 1983; Dixon et al., 1988; Pearce and Turner, 1990). The methodologies are by no means problem-free, but they are constantly being refined and improved through further use and subsequent critical review. They should only ever be used when their limitations are fully acknowledged and minimized accordingly. Some of the main techniques can be briefly summarized as follows:

- Change in Productivity/Production Function: A technique based on 'cause and effect' which assesses direct and indirect relationships between the loss of an environmental resource and associated changes in economic output.
- Substitute Prices: Where a product has no market value, a price can be placed on it based on the market price of similar or 'substitute' products.
- Replacement/Relocation Cost: The value of a habitat is assumed to be at least equivalent to the cost of replacing it, or relocating it elsewhere.
- Avertive/Preventative Cost: The value of a habitat is assumed to be at least equivalent to previous expenditure used to avert/prevent damage to that habitat type.
- Hedonic Pricing: A statistical technique based on extracting the environmental value of a marketed product by disaggregating the effect each attribute has on the overall market price.
- Travel Cost Method (TCM): Travel times and costs of a sample of visitors to a site are used to determine a demand curve and hence the recreational value for that site.
- Contingent Valuation Method (CVM): A questionnaire survey technique whereby a representative sample of individuals are asked their 'willingness to pay' to ensure or prevent a specific environmental change. The responses are interpreted and aggregated to produce an overall value, potentially including option and existence value.

No study appears to have been conducted yet that assesses the 'total economic value' of benefits associated with coral reef restoration. A study was recently carried out in Florida using CVM to value the benefits of coral reef restoration, but the results were not available for this review. This Section thus simply identifies some key values of coral reefs estimated in non-restoration benefit assessment studies.

The benefit values outlined below are total or 'average' estimated values per hectare of coral reef from different locations around the world. The appropriate value for restoration benefits to use in a BCA would actually be 'marginal' values. Marginal benefits relate to the additional benefit gained per change in unit provided. With respect to coral restoration benefits, the benefit gained should equate to the difference in benefits occurring in situations both 'with' and 'without' the restoration scheme.

As with restoration costs, the extent of value for each type of coral reef benefit also depends on a number of different parameters. The text below reveals the main factors affecting the level of benefits accruing from coral reefs. By understanding which factors are most influential, and which can readily be manipulated by the type of restoration scheme adopted, it is possible to enhance coral restoration benefits. The 'manipulative' factors are highlighted with an asterisk (*).

FISHERIES.—Coral reefs provide economic benefits in terms of fishery output from directly and indirectly supporting finfish, shellfish, and a range of other organisms. The benefits can be measured using the 'change-in-productivity' method, based on market prices or 'substitute' prices. The latter is effectively the price of alternative products in the region which provide the same function but do have a market price. The actual economic benefit is the market/substitute price less costs incurred in catching them.

In Sri Lanka, an estimate for the 'net' value (i.e., revenues less costs) of reef fish was calculated to be between US$80 and 100 ha^{-1} yr^{-1} (Berg et al., 1998). As pointed out by the authors, this figure represents a low value since it excludes the potential revenues from ornamental reef fish exports.

Cesar (1996) estimated a net benefit of US$120 ha^{-1} yr^{-1} for coral reef fisheries in Indonesia. This is based on a maximum sustainable yield of finfish and invertebrates from reefs in excellent condition up to a depth of 30 m, assuming a range of productivity of 10–20 metric tonnes per year and a value of US$1 per kg of fish.

A much higher net benefit value, US$3000 ha^{-1} yr^{-1}, has been estimated for fisheries associated with the Montego Bay coral reefs in Jamaica (Gustavson, 1998). However, the assumption used that all fish caught within Montego Bay are attributable to the coral reef there gives an inflated value.

It is worth pointing out that the above figures are annual values, potentially accruing for many years if gathered on a sustainable basis. Furthermore, reef fisheries, particularly in developing countries, provide an important livelihood and a substantial component of the nutrition to many communities. On the other hand, it is worth noting that these values relate to relatively high-quality reefs. Such a high rate of productivity is unlikely to be generated for some years following reef restoration.

The fishery value of a coral reef will depend on many factors, which include, among others, the following (the 'manipulative' factors are highlighted with an asterisk [*]): Market value of reef fish; *Percentage live coral cover; Balance of fish species; Nutrient input; Algal growth; *Surface area of substrate; *Void space and its complexity.

Coral restoration is unlikely to rapidly or significantly increase the fishery value of a reef area. However, by providing structures for corals to attach to which have a large surface area and a complex wealth of different sized voids and crevices, enhanced fishery benefits may be gained. The actual extent of benefits will depend on the 'limiting' factors for further development of fish communities.

OTHER REEF PRODUCTS.—Coral reefs provide an excellent potential source of other valuable products, including chemical and genetic products, often without terrestrial counterparts. Research companies are beginning to, and may increasingly, capitalize on this, and use corals and reef-associated organisms as the basis for producing valuable commercial products. Harvesting certain corals for the aquarium industry is another potentially lucrative possibility.

Based on potential net revenues and probabilities of finding and using coral products in such a way, the coral reefs in Montego Bay, Jamaica were estimated to be worth around US$530,000 ha^{-1} (Ruitenbeek and Cartier, 1999).

Factors affecting the likely pharmaceutical value of a coral reef include: Intensity of pharmaceutical research on the reef; *Diversity of organisms; *Abundance of commercially useful organisms

Pharmaceutical use of corals and reef-related organisms is very much in its early stages. As yet, coral restoration has not really focused on this aspect, although this could change in the future. There may thus one day be scope for enhancing the value of reefs by selectively increasing the diversity and abundance of commercially useful organisms through strategic restoration or transplantation.

RECREATION.—Reefs also provide significant benefits from recreation (e.g., snorkeling and diving), both for local residents and visitors to the area. Several valuation techniques are capable of measuring this benefit, including change in productivity, TCM, and CVM. It is even possible with the latter two methods to calculate consumer surplus values. Consumer surplus is the additional enjoyment gained by individuals using a resource over and above the amount they pay for using it. As such, it is an important economic value associated with environmental resources that are not fully priced in the market place.

Mattson and DeFoor (1985) estimated values for the recreational benefit provided by coral reefs in Florida. Based on direct recreational expenditure, the reefs can be argued to generate US$235,000 ha^{-1} yr^{-1}, and when related indirect expenditure is included, US$1.27 million ha^{-1} yr^{-1}. These values are adjusted to 1997 values and do not reflect 'net economic value', but rather gross expenditures.

In Sri Lanka an approximation was made for the recreational value of coral reefs both from an expenditure point of view and in terms of consumer surplus. Based on net financial profits from the tourism industry (hotels, restaurants, dive operators, etc.) alone, a value of US$1500 ha^{-1} yr^{-1} was determined for the reefs near a popular tourist destination. Using the contingent valuation approach, a willingness-to-pay value (including consumer surplus) of US$2140 ha^{-1} yr^{-1} was calculated for the same area. The different valuation approaches measure quite different types of value. Great care must be used in interpreting these values since their accuracy and reliability is uncertain.

In Indonesia, the order of magnitude of the recreational benefits of coral reefs have been valued at between US$30 and 5000 ha^{-1} yr^{-1} (Cesar, 1996). However, it must be noted that these calculations were crude, being based on simple assumptions relating to estimated net benefits accruing from diving, snorkeling, and accommodation expenditure in areas of both low and relatively high tourism.

A significantly higher recreation value was estimated for the coral reefs of Montego Bay. Gustavson (1998) estimated a recreation net value equivalent to US$740,000 ha^{-1} yr^{-1} based on tourist-related expenditures less the costs of the services provided. However, the assumption made that all tourism revenues in Montego Bay are attributable to the coral reefs clearly gives an overestimate.

Factors affecting the recreational value of coral reefs include, among others: Numbers, wealth and expenditure of visitors and residents; Environmental awareness of visitors and residents; Individuals' appreciation of diving, reef life, and recreational fishing; Facilities available; Access; *Species diversity and abundance; *Attractiveness and interest of the site; *Publicity of the site.

The recreational value of a coral reef can without doubt be high. There is certainly potential for coral restoration schemes to help maintain the integrity of well-used coral reef areas (e.g., Van Treeck and Schumacher, 1999). However, the aesthetic nature of the restoration scheme is critical. On the one hand, an unattractive, poorly designed scheme could easily detract from the value of a site, while on the other hand, a well-designed scheme could enhance the attractiveness, interest, and hence value of a site.

COAST PROTECTION.—Coral reefs provide a valuable coastal protection service or function. The value can be estimated based on the damages that would be incurred through erosion and flooding if the protection function was lost. Damages would generally relate to loss of land, properties, and infrastructure, which can be valued using change-in-productivity and/or replacement costs. An alternative approach to valuing the coast-protection function is to use the theoretical cost of replacing the reef function with man-made coast-protection structures (i.e., preventative expenditure or the replacement cost technique).

In Sri Lanka, the value attached to reefs in performing the coast protection function is argued to be between US$1.6 and US$1700 ha^{-1} yr^{-1} based on potentially lost land values, and between US$12,300 and US$42,000 ha^{-1} yr^{-1} based on the preventative expenditure approach (Berg et al, 1998).

In Indonesia, coast protection has been estimated to be in the order of between US$90 ha^{-1} yr^{-1} for remotely populated areas and US$110,000 ha^{-1} yr^{-1} for areas with major infrastructure (Cesar, 1996). Again these valuations are crude, based on the replacement cost of losing land, infrastructure, and properties through increased erosion, with 1 km^2 of reef assumed to protect 1 km^2 of land.

Gustavson (1998) estimated a net coast protection value equivalent to around US$150,000 ha^{-1} yr^{-1} for the coral reefs of Montego Bay. As with the previous coast protection value estimates, the relationship between the coral reefs' presence and the assumed erosion rates appears to be somewhat speculative.

Factors affecting coast protection value include, among others: Use (properties/land use) and hence value of the shoreline; Sensitivity of the shoreline to erosion and flooding; Frequency and magnitude of storms in the area; Distance between the reef and the shore; Underlying coastal processes; *The wave absorbing capacity of reefs (i.e., reef structure, rugosity, depth, etc.).

Unless coral restoration schemes are in shallow waters close to sensitive and valuable shorelines, associated coast-protection benefits from coral restoration will be relatively low. Enhanced coral growth and presence from restoration schemes will only increase coast protection benefits very slowly over time. However, the provision of artificial reef structures raised up off the substrate could generate significant coast protection benefits immediately.

NON-USE VALUES.—Coral reefs are an extremely interesting and attractive habitat of great value to humans throughout the world. As a result, many reefs may have significant option and existence values. The contingent valuation method (CVM) is the only technique capable of revealing the extent of such values, although few such studies have been undertaken for coral reefs. There are also many complex theoretical issues involved in carrying out such studies (Mitchell and Carson, 1989).

In Australia, a value of US$79 million yr^{-1} (updated to 1997 prices) was estimated using CVM for the combined non-use value of the Great Barrier Reef (Hundloe, 1990). As mentioned in the study, the non-use value was calculated only for people living within

Australia, thus representing a minimum value, since many other people would value maintaining the Barrier Reef.

A CVM study was used to estimate a non-use value (or pure conservation value) of US$20 million associated with the coral reefs in Montego Bay, Jamaica (Spash et al., 1998). The value is based on conservative estimates of the willingness to pay of locals and tourists, but again, not other people internationally.

Non-use value will again depend on many factors, some of which may include: Extent of the population – local, regional, national, and international; Socio-economic characteristics of the populations (e.g., income, employment, interests); Level of environmental awareness; Uniqueness of the site; Alternative sites in the region and country; *Species diversity and abundance; *Naturalness and integrity of site; *Potential for future use.

Non-use values are only likely to be a significant component of coral restoration benefits if the integrity of a large coral reef area is at risk, and the reefs are regionally or nationally important. For this to be the case, restoration must also be an appropriate solution to the problem of reef degradation, and the restoration scheme must not detract too much from the naturalness of the reef site.

Benefits Associated with the Case Studies.—The potential significance of the main benefits that accrue from coral reefs and that may be generated by the three restoration schemes discussed earlier is highlighted in Figure 3. In the absence of an economic benefit assessment for each scheme itself, it at least indicates the potential degree of benefits that could arise from the restoration schemes relative to the overall magnitude of possible coral reef benefits from a healthy reef. This approach is fairly subjective and is based on the author's understanding of the sites and restoration schemes.

The following observations can be made with respect to economic benefits relating to the three case studies mentioned above. Recreation benefits will be highest in Florida due to the popularity of the site, the extensive nature of the restoration scheme and the general wealth of visitors. Fishery benefits will generally be greater where structures provide additional voids and surface area for organisms to utilize. The potential benefits from pharmaceutical uses in such circumstances are currently limited, although one day they could be enormous. There is potentially considerable benefit from most coral restoration schemes in terms of research and education.

Installation of artificial structures will speed the process of the coral area forming a wave-absorbing structure, thus providing improved coastal protection. As is the case for fisheries, the extent of biological support is likely to be related to the provision of voids, surface area, and coral cover. Finally, non-use values and intrinsic values are even more complex to evaluate. The magnitude of non-use value is likely to be related to factors such as the extent to which the sites' overall coral reef integrity is maintained by the restoration and the uniqueness of the site. Similar factors will apply for intrinsic values, although it can be argued that the more a site's naturalness is interfered with, the less the intrinsic value.

Conclusions and Recommendations

The costs involved in reef restoration projects are rarely fully assessed and reported. Few sources of information exist and even those that do exist do not generally identify all the relevant costs. There is therefore a need for a comprehensive costing framework that

Benefits	Coral reefs in general	Florida MV Elpis restoration	Maldives rehabilitation	Tanzania Mafia
Direct Uses				
Fisheries	✓✓	✓✓	✓	✓
Pharmaceutical	✓✓✓	✓	✓	✓
Ornamental	✓✓	-	✓	✓
Recreation	✓✓✓	✓✓✓	✓✓	✓✓
Research	✓✓	✓✓	✓✓	✓✓
Education	✓✓	✓✓	✓✓	✓✓
Indirect Uses				
Biological support	✓✓	✓✓	✓✓	✓✓
Coast protection	✓✓✓	✓✓	✓✓	✓
Global life support	✓	✓	✓	✓
Option Value	✓✓	✓	✓	✓
Quasi-Option Value	✓✓	✓	✓	✓
Existence Value	✓✓✓	✓	✓	✓✓
Intrinsic Value	✓✓✓	✓	✓	✓✓

Symbol	Benefit	Description
-	None	Provides no benefit
✓	Low	Provides minor economic benefit only
✓✓	Medium	Provides benefit between low and high
✓✓✓	High	Potentially provides significant economic value

Figure 3. Potential significance of coral reef restoration benefits.

can be applied to future reef restoration schemes. This should give a detailed breakdown of all cost components in a consistent manner.

The cost of coral restoration schemes varies enormously, depending on many factors. These in particular include the degree of available funds, the cost of labor, the need for substrate preparation, and the density of transplanting corals. More effort is needed to devise cost-effective reef restoration schemes. As with many relatively new products or methods, significant scope does exist for reef restoration costs to reduce in time, as further innovative approaches are developed and tested. Techniques must continue to be developed which reduce restoration costs. In this respect, work undertaken by Lindahl (1998) and others (e.g., Bowden-Kerby, 1999) to develop low-cost reef restoration techniques must be encouraged. The need for such an approach is obviously greater in developing countries.

Many of the economic benefits from coral restoration can be difficult and expensive to value. Indeed, the whole concept of valuing the environment is contentious. Considerably more research is needed into the valuation of coral reef benefits, particularly relating to the benefits of reef restoration. Given the many millions of US$ spent on coral restoration, it is surely worthwhile obtaining a greater understanding of the economic efficiency of such exercises. As more valuation studies are conducted, greater reliability can be placed on transferring the estimated benefits from one scheme/location to another, thereby aiding the decision-making process in a cost-effective manner. This 'benefit-transfer' approach has been successfully adopted by the U.K. Environment Agency for valuing angling, recreation, navigation, conservation, and non-use benefits to economically justify schemes to alleviate low flows on rivers and to improve river and coastal water quality (Environment Agency, 1997; FWR, 1996).

There will always be an element of benefit (i.e., intrinsic value) that cannot be valued. Any valuation undertaken will therefore only identify a minimum economic value. If valuation studies are undertaken, all benefits that are not valued should at least be highlighted.

Cost-benefit analysis can and should be applied more in decision-making regarding the use of funds for managing and enhancing coral reef resources. Its most valuable role is in helping to select the most efficient means of using funds. However, it is only one tool that should be applied alongside others such as environmental assessment, coastal zone management, and use of standards and regulations, etc. Due to the difficulties encountered in environmental valuation, there is certainly a place for the use and development of other quantitative assessment techniques such as cost-effectiveness, multi-criteria and habitat-equivalent analyses.

When applying cost-benefit analysis, the concept of discounting tends to act in a prejudicial way against restoration. Since the reefs take some time to grow back to their former state, benefits will tend to accrue later in the future thus yielding lower 'present-day' values. In terms of economic efficiency, there is therefore a need to concentrate on enhancing restoration benefits and reducing up-front costs. This paper has argued that restoration benefits can be enhanced by identifying and focusing restoration efforts on those factors that affect the value of reefs which can readily be manipulated (highlighted by an asterisk*).

Where appropriate, efforts should therefore be made in coral restoration design to influence these factors in order to hasten the benefit accrual rate, thus maximizing the benefits. A good example of a low-cost approach coupled with attempted benefit enhancement are 'Reef Ball™' products. A company known as the 'Reef Ball Development Group' (Reef Ball Group, 1999) has developed a number of pre-cast concrete structures, which are relatively cheap and easy to install on a reef, and provide immediate fishery, recreation, and coast-protection benefits. However, when assessing the potential use of such an approach, any negative aesthetic impacts and loss of the site's naturalness should be considered in the overall equation.

So, is money spent on reef restoration a worthwhile use of funds and available resources? This will depend on a number of factors. If the original cause of degradation is still present (e.g., from pollution or damaging fishing methods), then restoration is likely to be futile and a waste of money (Spurgeon and Lindahl, in press). It will also depend on the difference between the restoration recovery rate and the natural recovery rate (Spurgeon and Lindahl, in press). However, ultimately it depends on whether the benefits exceed the costs and whether there is a better way to use the available resources.

Prior to going ahead with coral restoration initiatives, it would therefore seem wise to assess a full range of alternative options for using the available resources using cost-benefit analysis (Spurgeon, 1999). Alternative options to enhance a coral reef would generally include improved management of the reef, or off-site activities to reduce other potentially damaging impacts (e.g., from pollution, fishing, future shipping accidents, and recreational activities). All potential costs and benefits for each option should be weighed to ensure that the most economically efficient option is selected.

Unless a thorough benefit-cost analysis is undertaken for a reef restoration scheme, it is difficult to say whether or not the overall benefits will outweigh the costs. As yet, no comprehensive economic studies appear to have addressed the issue. This paper will hopefully encourage such an assessment, but in the meantime has hopefully shown that significant economic benefits could potentially accrue in the long term from reef-restoration schemes. However, it also seems that the cost of some restoration schemes may well be significantly greater than the benefits accruing.

Finally, with respect to the cost of reef restoration techniques, and whether restoration should be encouraged, it is perhaps pertinent to bear in mind that personal computers were once deemed too expensive to ever become commercially viable!

Acknowledgments

Thanks are due to A. Edwards, S. Clarke, and U. Lindahl for freely providing data on their coral reef rehabilitation and restoration efforts. Thanks are also extended to R. Wingfield and the anonymous referees for suggesting improvements to the paper.

Literature Cited

Barton, D. N. 1994. Economic factors and valuation of tropical coastal resources. Univ. Bergen, Norway. Rpt 14/94.

Berg, H., M. C. Ohman, S. Troeng and O Linden. 1998. Environmental economics of coral reef destruction in Sri Lanka. Ambio 27(8): 627–634.

Birkeland C., ed. 1997. Life and death of coral reefs. Chapman and Hall, New York.

Bowden-Kerby, A. 1999. The Johnny coral seed approach to coral reef restoration: New methodologies appropriate for lower energy reef areas. Proc. Int'l. Conf. Scientific Aspects of Coral Reef Assessment, Monitoring and Restoration.

Cesar, H. 1996. Economic analysis of Indonesian coral reefs. Environment Department, World Bank.

Dixon, J. A., R. A. Carpenter, L. A. Fallon, P. B. Sherman and S. Manipomoke. 1988. Economic analysis of the environmental impacts of development projects. Earthscan Publications Ltd. UK.

Edwards, A., S. Clark and B. Brown. 1994. Rehabilitation of degraded reefs using artificial reef blocks. Rpt. UK Overseas Development Administration (R4533).

__________ and _______. 1998. Coral transplantation: a useful management tool or misguided meddling? Mar. Poll. Bull. 37(8–11): 474–487.

Environment Agency. 1997. Low flow alleviation: benefit assessment guidelines. Environment Agency. United Kingdom.

Fernandes L., M. A. Ridgley and T. van't Hof. 1999. Multiple criteria analysis integrates economic, ecological and social objectives for coral reef managers. Coral Reefs 18: 393–402.

FWR. 1996. Assessing the benefits of surface water quality improvements. Foundation for Water Research. United Kingdom.

Gustavson, K. 1998. Values associated with the local use of the Montego Bay Marine Park. Study prepared for the World Bank. World Bank, Washington.

Hufschmidt, M. M., D. E. James, A. D. Meister, B. T. Bower and J. A. Dixon. 1983. Environment, natural systems and development: an economic valuation guide. John Hopkins Univ. Press, Baltimore, Maryland.

Hundloe, T.J. 1990. Measuring the value of the Great Barrier Reef. Austr. Parks and Rec. 26(3): 11–15.

Jameson, S. C., J. W. McManus and M. D. Spalding. 1995. State of the reefs: regional and global perspectives. Int'l. Coral Reef Initiative Executive Secretariat Background Paper, U.S. Dept. State, Washington, D.C. 32 p.

Korhonen, P. H. Moskowitz and J. Wallenius. 1992. Multiple criteria decision support – a review. Europ. J. Opera. Res. 63: 61–375.

Lindal, U. 1998. Low-tech rehabilitation of degraded coral reefs through transplantation of staghorn corals. Ambio 27(8).

Little, I. M. D. and J. D. Mirlees. 1974. Project appraisal and planning for the developing countries. Basic Books, New York.

Mattson, J. S. and A. J. DeFoor. 1985. Natural resource damages: restitution as a mechanism to slow destruction of Florida's natural resources. J. Land Use Environ. Law 1(3): 295–319.

Miller, S. L., G. B. McFall and A. W. Hulbert, eds. 1993. Guidelines and recommendations for coral reef restoration in the Florida Keys National Marine Sanctuary, National Undersea Research Center, Univ. North Carolina at Wilmington, North Carolina.

Milon J. W. and R. E. Dodge. (this volume). Applying habitat equivalency analysis for coral reef damage assessment and restoration. Bull. Mar. Sci.

Mitchell R. C. and R. T. Carson. 1989 Using surveys to value public goods: The contingent valuation method. Resources for the Future, Washington, D.C.

NCRI. 1999. International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring and Restoration. 14–16 April 1999, Ft Lauderdale, Florida, National Coral Reef Institute.

NOAA. 1997a. ELPIS coral reef restoration. http://www-rca.nos.noaa.gov/darp/seregion/elpis.htm

Pearce, D.W. and R. K. Turner. 1990. Economics of natural resources and the environment. Harvester Wheatsheaf.

Reef Ball Development Group, Ltd. 1999. http://reefball.com

Ruitenbeek H. J. and C. M. Cartier. 1999. Prospecting for marine biodiversity: a case study in Montego Bay, Jamaica. Chapt. 13 *in* K. Turner, I. Bateman, and N. Adger, eds. Economics of coastal and water resources: valuing environmental functions. Kluwer Academic Press, Dordrecht.

______________, M. Ridgely, S. Dollar and R. Huber. 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 18: 381–392.

Spash C. L., J. D. Van der Weerff, S. Westmacott and H. J. Ruitenbeek. 1998. Lexicographic preferences and the contingent valuation of coral reef biodiversity in Curacao and Jamaica. Study prepared for the World Bank. World Bank, Washington.

Spurgeon J. P. G. 1992. The economic valuation of coral reefs. Mar. Poll. Bull. 24(11): 529–536.

_______________. 1998. The socio-economic costs and benefits of coastal habitat rehabilitation and creation. Mar. Poll. Bull. 37(8–12): 373–382.

_______________. 1999. Economic valuation of damages to coral reefs. Coral reefs: marine wealth threatened. Conf. by National Univ. Mexico, Cancun, Mexico, 1999.

_______________ and U. Lindahl. 2000. Economics of coral reef restoration. *In* H. Cesar, ed. The economics of coral reefs. Cordio.

Unsworth R. and R. C. Bishop. 1994. Assessing natural resource damages using environmental annuities. Ecol. Econ. 11: 35–41.

Van Treeck, P. and H. Schumacher. 1999. Mass diving tourism – a new dimension calls for new management approaches. Mar. Poll. Bull. 37: 499–504.

ADDRESS: *Principal Environmental Economist/Scientist, JacobsGIBB Ltd, Gibb House, London Road, Reading, RG6 1BL, United Kingdom. Fax +44 (0)118 926 3888, E-mail: <jspurgeo@gibb.co.uk>.*