Estimating the welfare change due to corals loss under different climate change scenarios

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Abstract

The economic significance of services provided by the corals is high especially for the coastal populations. Various services of corals strengthen and enrich the various constituents of human well being. This paper estimates the economic losses of ecosystem services arising out of impacts of climate change on corals in different regions of the world. The economic losses have been estimated under different scenarios of climate change as the intensity of coral reef bleaching is strongly linked with the rise of temperature. For estimation of economic loss, benefit transfer method has been used where by developing a meta-regression function; the valuation of ecosystem services of coral reef has been carried out. Subsequently a statistically significant regression model is used to estimate the values of coral reefs at different marine regions with their current bleaching status considered. According to the prediction of the frequency and severity of coral reef bleaching under different climate change scenarios, we calculate the monetary losses of the coral reef ecosystem globally. Under A2 scenario the loss could be of 13.9 Billion USD while under B2 scenario the loss could be 15.14 billion USD. The difference in the losses under different scenario can guide us on the costs of inaction.

Key words:

Ecosystem services of corals, valuation, benefit transfer method, climate change

[1] Does not necessarily reflect Organization's view, the author represents

1. Introduction

In the paper, first we highlight the ecosystem services from corals. Second we show the economic significance of corals by showcasing the examples from across the globe. Third, we bring the issue of climate change and its impact on corals. Fourth, we estimate the economic value of the world's corals by using value transfer methods. This has been built upon the database collated under the economics of ecosystems and biodiversity (TEEB) project (see http://www.teebweb.org/Home/tabid/924/Default.aspx). Fifth, we analyse the state of Coral reefs under dominant climate change scenarios. We estimate the economic value of the corals under different climate scenarios and then compare it with as usual status and show how much welfare loss would be there due to climate change.

Coral reefs that are three dimensional, shallow water structures dominated by Scleractinian corals and are the most biologically diverse of shallow water marine ecosystems provide various ecosystem services. Humans appropriate these services for different consumptive and productive purposes. It is believed that although coral reefs represent less than 0.2% of total ocean area, they contain more species per unit area than any other ecosystem (Ahmed et al., 2004). In shaping the tropical marine systems, coral reefs have a crucial role, which despite surviving in very low nutrient condition, actually are highly productive systems (Odum and Odum 1955). Consequently, coral reefs are often likened to 'oases' within marine nutrient deserts. Millennium Ecosystems Assessment (MA) (2005) provides a glimpse of the services from corals in Table 1 below:

Table 1 about here

As is evident, most of the services have economic implications in terms of their effect on human well-being. Coral reefs contribute various services to society that directly indirectly strengthen the constituents of human well-being. Some of the illustrative services emanating from corals have been identified in various studies (Spurgeon 1998; Moberg and Folke, 1999; Cesar 2002). Coral reefs represent crucial sources of income and resources through their role in tourism, fishing, building materials, coastal protection and providing new drugs and biochemicals. Globally, many people depend in part or wholly on coral reefs for their livelihood and around

8% (0.5 billion people) of the world's population lives within 100 kilometers of coral reef ecosystems (Pomerance 1999). Estimates of the total number of people reliant on coral reefs for their food resources range from 500 million (Wilkinson, 2004) to over one billion (Whittingham et al. 2003). Some 30 million of the worlds' poorest and most vulnerable people in coastal and island communities are entirely reliant on reef-based resources as their primary means of food production, sources of income and livelihoods (Gomez et al. 1994; Wilkinson 2004). Due to increasing population size, the reliance on reef resources is set to increase over the coming decades.

2. **Driver of climate change for corals**

Various scientific studies also show that we are losing the corals at alarming rate. Wilkinson (2004) suggests that 20% of reefs have been destroyed during last 197-2000. MA (2005) also confirms that more than 20% of the corals are badly degraded or under imminent risk of collapse. Detailed studies done at the WRI (1998) suggest that while 58 percent of the world's reefs are potentially threatened by human activities at the global scale, 80 percent of the corals in South East having richest biodiversity are under medium to high potential threat. In terms of coral biodiversity, 11 percent of the world's reefs are at severe risk. Coral reefs in the best form are found in developing and tropical regions that are hot spots of poverty too. The degradation of corals and slowing down of the flow of ecosystem services from them would throw significant number of people in the poverty trap. Decaying corals can't deliver the critically important ecosystem services providing sustenance to the people especially the poor.

Corals are under serious threat because of several direct and indirect drivers are in operation in different forms. Subsidies on fishing, lack of coastal regulation including pollution control, expansion of unplanned urbanization are some of the indirect drivers. Climate changes, overexploitation for fishing and recreation, inland pollution and dynamite fishing are some of the direct drivers which causing damages to corals across the world. The phenomenon of coral bleaching due to rise in water temperature arising out of climate change has appeared as serious challenge as a consequence of climate change.

CO_2 coral bleaching start at 320 ppm CO_2; the current concentration is at 387 ppm CO_2, and the politically "acceptable target" from the perspective of climate policy is 450 ppm. However, the long-term viability of coral reefs requires a level of atmospheric carbon dioxide that should be reduced significantly below 350ppm. Current emissions are 370 ppm. Accepting a 450ppm target is effectively a death sentence on many coral reefs. The demise of coral reefs is an extinction event of proportions never before. Such situation will impoverish 500 million people dependant on coral reefs for livelihoods, damage global fisheries productivity and chances of stock survival, contribute to future food crises and price shocks, and as fisheries are the main source of animal protein for a billion people in the developing world, it will be a cost to their future health.

Imminent coral reef destruction is both a problem built up by historic emissions of the past. (I.e. the stock of carbon in the atmosphere and influence on sea temperatures) and a problem of new emissions in the present from both the developed and developing world (the "flow" of annual global GHG emissions).

3. Economic valuation of impacts on corals

The impact of climate change on bleaching of corals and subsequent ecosystem services has significant economic implications. The economic analysis of corals and its decline is critical for designing an effective response option. The analysis through economic valuation of damages or improvement in the condition would help the decision makers in the following ways:

a) Prioritising the option where expenditure is best targeted in sustainable utilisation.
b) Help in justifying additional management costs and expenditure.
c) In damage assessments and determining appropriate compensation.
d) To help control people behavior and utilization of resources.
e) To enhance revenue generation.
f) Highlight the winners and losers and facilitate equitable distribution.

As discussed above, coral reefs provide a wide range of commercial and non-commercial benefits to human society. Many of these benefits, or “ecosystem goods and services” are of high value and critical importance to local and national economies. Coral reefs provide habitat for commercially valuable fish, are a magnet for coastal recreation, and reduce the impact of waves on the shore, slowing erosion and beach loss, and lessening damages from storms. Valuation of some of these benefits would greatly help the decision maker. Valuation of goods and services generated by coral reef system had widely been attempted by researchers in different parts of the world. Thus, according to an estimate, the total net benefit per year of the world’s coral reefs is $29.8 billion. Tourism and recreation account for $9.6 billion of this amount, coastal protection for $9.0 billion, fisheries for $5.7 billion and biodiversity for $5.5 billion (Cesar, Burke and Pet-Soede, 2003). However, at regional levels the values ranged widely, mainly due to the variations in type and extent of the coral reef systems and also the underlying socio-economic state of the beneficiaries. For example, in the South East Asia, the total potential sustainable annual economic net benefits per km^2 of healthy coral reef is estimated to range from $23,100 to $270,000 arising from fisheries, shoreline protection, tourism, recreation, and aesthetic value (Burke, Selig and Spalding, 2002). In the Caribbean, the annual net benefits provided by coral reefs in terms of fisheries were estimated to be about $300.0 million (Burke and Maidens, 2004).

In recent years, there have been several attempts to value the services accruing to the society from the corals. Table 2 summarises the key approaches and findings from some of the credible economic valuation.

Table 2 about here

Economic valuation has taken different routes and followed range of methodologies depending upon the purpose of valuation and availability of the data.

4. Methodological approach

In order to estimate the economic value of the corals, we have used value transfer method. Value transfer can be used for transfer of figure from similar study known as ‘study site’ to the site in question known as ‘policy site’. Technically, estimating the value of an ecosystem or ecosystem services by borrowing the existing valuation for a similar system does transfer of value method. Transfer of unit value, uses the value of ecosystem services per unit of spatial scale. Other form of transfer of value could be in the form of adjusted unit value transfer and value function (Brander et al 2009). In the paper, we have used meta-analytic function transfer. Under meta-analytic analysis, primary valuation studies are collated and analysed in the group and the results from each study are treated as single observation in the new analysis of combined dataset. This will enable us to evaluate the influence of the characteristics of ecosystem services, the features of the valuation method and other related assumptions. The resulting regression equations explaining variations in unit values can then be used together with socio-economic contextual data gathered on the independent variables in the model that describes policy site to construct new value. There have been successful examples of application of benefit transfer methods by Eshet et al (2007) and Johnston and Rosenberger (2009).

The general meta-analytic regression model is expressed as:

$$y_i = a + b_S X_{Si} + b_E X_{Ei} + b_C X_{Ci} + \mu_i$$

where *yi* measures the benefit of ecosystem site *i* and is a dependent variable; the explanatory variables include

X_{Si} (the characteristics of valuation studies, such as valuation method),

X_{Ei} (the characterises of valued ecosystem, such as ecosystem service) and

X_{Ci} (the socio-economic, such as income per capita, and geographical context);

b_S, b_E and b_C are the vectors containing the coefficients of the explanatory variables;

a is a constant and μ_i is an error term.

In this meta-analysis, the natural logarithms of the dependent variable, socio-economic variables, gross national income per capita and population density are used to improve the model fit and mitigate the heteroskredasticity.

A lot of experiments have been conducted to fit the regression model. Due to the variation of the values and limited number of samples, a statistically significant model, including the overall model and all the coefficients, is difficult to achieve, when all the characteristics of the studies and sites, and other factors have to be considered. However, some meaningful conclusions can be drawn from the result in Table 3, where the adjusted R^2 is significant, which means the data can be better explained by the model than by other models.

Table 3 about here

It can be seen from Table 3 that the values for services such as genetic biodiversity, extreme event and recreation are higher than the values of food and raw material. That means that coral reefs‘ invisible values are greater than visible provisional ones. Among these coefficients, the one for the recreation service is statistically significant at a 5% level and the one for genetic diversity is significant at a 10% level. For the valuation methods, the direct market pricing and replacement cost methods have higher values than the average of other valuation methods and the replace cost is the highest and its coefficient is statistically significant at a 10% level. However, we cannot say that the coral reefs' value in Africa is the highest one even if its coefficient is the biggest among all the continents. The reason is that the income per capita and population density also have influence on the values. These several factor work together and produce a composite effect. The coefficients for all the continents are statistically significant, except for Asia, and one of the socio-economic factors, population density, is statistically significant at a 5% level.

4.1 Description of primary studies and database

The data for the meta-analysis of coral reef valuation are extracted from the TEEB Ecosystem Service Value-Database. There are totally 152 data points from 43 publications, for which the desired information including coral reef value, services being valued, location, year of valuation and valuation method, is available.

The study sites are marked on the map of the nations as yellow triangles with global monitoring sites of coral reefs as background (red dots on the map) (see Figure 1). As we can see in Figure

1, the study sites are distributed globally and, to some extension, representative. Since these studies are conducted at different time points for different places and with different purposes, a wide variety of units are used for the coral reef valuation. We converted these values to a common metric, a unit value in US dollar at 2007 prices per hectare. In addition, the primary studies which address one individual service of coral reefs at a specific geographic point with a known valuation method, but not the total valuation value or a world average or with the valuation method unknown, are used. For our data set, the statistical mean of the coral reef values for different services by region and valuation method are shown in Figures 2 and 3.

Figure 1 about here

Figure 2 shows that the means of the estimated values for different services of coral reefs are different across the continents. Not all services have been addressed for each continent and the services of Aesthetic, BioControl, Climate and Ornamental are missed at Asia, the services of extreme events and food are missed at America, for example. The only service which has been valued for all the continents is the recreation service and the recreation values estimated at all the continents are relatively high, even if not all of them reach the highest among the services. The genetic diversity service has a biggest varying range across all the continents, with the highest value occurring at America and the lowest at Australia and the range spans from about 10^{-1} to 10^{8} or so. Generally, the estimated highest values are mostly occurring in Americas and Latin America and the lowest ones in Oceania and Asia.

Figure 2 about here

Figure 3 shows the means among different valuation methods. The values estimated by the direct market pricing are usually high while the values by the contingent valuation method are relatively low. The values achieved by benefit transfer are almost always the lowest. The biggest difference occurring among different methods reflect in the estimation of food and raw material services. Among these methods, the group valuation methods give the lowest estimates for food and raw material services, where the benefit transfer method is not used. Since the values shown on the chart are in a log scale, the real values for coral reefs services vary enormously when different methods are adopted.

Figure 3 about here

4.2 Estimations of the values of coral reefs: value transfer method

As discussed earlier, meta-analytic value transfer is the procedure of estimating the benefit of an ecosystem (goods and services from an ecosystem) by borrowing an existing valuation estimate for a similar ecosystem from multiple study results. Rosenberger and Phipps (2007) identify the important assumptions underlying the use of meta-analytic functions for value transfer.

A statistically significant regression model, including the overall model and all the coefficients, is used to calculate the values of the coral reefs at different marine regions. Firstly the model isapplied to all the monitoring sites as shown in Figure 1 to derive an average unit value for each marine region and then the total value of the region can be worked out by multiplying the total coral reef area of the region. The adopted regression model is given as follows:

$$Ln(Y_i) = -9.495 + 6.542 * CAfrica + 3.133 CAmerica + 5.108 CAsi + 4.469 CLatin + 1.26 LnGNI$$

Figure 4 shows the result of the calculation of the unit values of the monitoring sites over the world. The unit values are in natural logarithm and the legend is in the left penal of Figure 4.

Figure 4 about here

For each region, the average unit value is calculated through summing all the estimated values of all the coral reef monitoring sites located in the region and then dividing it by the number of the sites. The marine area has been divided into 8 regions and the unit values for them are given in Table 4. The coral reef areas of the marine regions (also see Table 4) are found from Spalding and Grenfell (1997). The total values are the production of these two factors (see Table 4 for the result).

Table 4 about here

However, the values estimated in the primary studies are somehow the values for a relatively healthy and quality coral reef ecosystem or more than 10 years ago. For example, the estimated value by Ruitenbeek and Cartier (1998) for the Montego Bay, Jamaica is US$893,000/ha/yr. However, after several times of coral bleaching during the recent decade, the unit values have to be discounted. According to the status of the coral reef bleaching, we calculate the proportion of the coral reef sites where different levels of bleaching happen for each marine region. Figure 5 gives the bleaching states of the coral reefs in the world.

Figure 5 about here

Table 5 gives the numbers and proportions of different bleaching levels for all the 8 marine regions. Assume that the values of the highly bleached coral reefs will lose 50% of their original values and the medially bleached will lose 20%, then the total value loss rate of each region is worked out (see the last raw in Table 3 for the result).

Table 5 about here

5. Value of impacts on corals under different Climate Change Scenario

The climate change scenarios are plausible pathways of temperature rise based upon mix of socio economic and natural factors. In the paper we consider most dominant scenarios and how it might the corals and its ecosystem services. The realistic scenarios coming from the IPCC work impacting the corals are:

HadCM3 SRES A2------emission scenario is commonly used for 'business as usual' impact studies, projecting a 3^{o} increase in surface air temperature.

HadCM3 SRES B2------a low emission path, projecting a 2.2^{o}C temperature increase on average across all the models.

Duration considered: *2030-2039* and *2050-2059*

Deterioration of the coral reefs under different scenarios (summarised from Donner *et al.*, 2005):

A monthly bleaching index------A degree heating month (DHM) is equal to 1 month of sea surface temperature (SST) that is 1^{o}C greater than the maximum in the monthly climatology. The annual DHM total of 1^{o}C was the best proxy for the lower intensity bleaching threshold and an annual total of 2^{o}C as the higher threshold, for severe coral bleaching with more associated coral mortality.

The predicted fraction of coral reefs for these two severity degrees and different frequencies by Donner *et al.* (2005) are as in Table 6.

Table 6 about here

Table 6 gives the fraction of corals at 10 frequency points. Among them, 0.1 means that the bleaching will happen 1 year (once) in the decade of 2030s, 0.5 is every 2 years, while 1.0 means that it happens every year. During 2030-2039, the fraction of the corals with the lower intensity bleaching occurring every year will reach 16% in HadCM3 A2 and 20% in HadCM3 B2, and the fraction of the corals with the severe coral bleaching will reach 2% in HadCM3 A2 and 6% in HadCM3 B2. During 2050-2059, the fraction of the corals with the lower intensity bleaching occurring every year will reach 76% in HadCM3 A2 and 50% in HadCM3 B2, and the fraction of the corals with the severe coral bleaching will reach 50% in HadCM3 A2 and 22% in HadCM3 B2.

From Table 6, we can also see that during 2030-2039, the fraction of the corals with the lower intensity bleaching occurring at least every 2 years will reach 94% in HadCM3 A2 and 94% in HadCM3 B2, and the fraction of the corals with the severe coral bleaching will reach 56% in HadCM3 A2 and 60% in HadCM3 B2. During 2050-2059, the fraction of the corals with the lower intensity bleaching occurring at least every 2 years will reach 98% in HadCM3 A2 and 98% in HadCM3 B2, and the fraction of the corals with the severe coral bleaching will reach 95% in HadCM3 A2 and 88% in HadCM3 B2. For other frequencies of bleaching, there are other corresponding fractions of coral reefs.

According to Table 6, we derive another table, Table 7 to reflect a fraction for each frequency (not accumulated frequency) for two bleaching severity degrees.

Table 7 about here

Assumption of loss rates under different situations led by climate change: Rise in sea temperatures by 1^{o}C warmer than the usual summer maxima can cause the coral bleaching and the bleaching occurring at a different frequency with a different severity will lead to a different degree of degradation of coral reefs. For example, frequent low-intensity bleaching even with no coral mortality can lead to long-term degradation of the coral reef ecosystem by slowing coral growth, reducing coral recruitment and reducing resiliency to other disturbances and frequent severe coral bleaching may lead to coral mortality (Donner *et al.*, 2005; Hoegh-Gulderg, 1999). Accordingly, we assume the loss rates under different frequencies of mass coral bleaching as follows (see Table 8) (the loss rate for other omitted frequencies can be derived through linear interpolation, e.g. for frequency F = 0.1 for DHM >1, the loss rate = 2.5% ; for frequency F =0.9 for DHM > 2, the loss rate = 90%).

Table 8 about here

Monetary loss of coral reef ecosystem value under different scenarios: According to the predicted fraction of the bleached coral reefs at different bleaching frequencies and the loss rate defined above, the total loss rate for the two severity degrees can be expressed as following:

$$R_i = \sum_{n=1}^{10} f_{ni} * r_{ni}$$

Where R_i is the total loss rate of coral reefs for i (=2) severity degrees, represented by monthly bleaching index DHM>1 and DHM>2; f_n represents the fraction of the coral reefs bleached at the nth frequency: the first one is once during the decade, the fifth is every two years and the tenth is bleaching every year.

According to this formula, the total loss rate of global coral reef value for the two severity degrees under different climate change scenarios can be calculated and result is given in Table 9.

Table 9 about here

The monetary loss for each marine area can be derived according to their current values and the loss rate due to climate change and the results are given in Table 10.

Table 10 about here

Since the situation when DHM>1 includes the cases when DHM>2, it is not reasonable to achieve an overall loss through adding together the losses at these two severity degrees. If we do so, it will raise a double-counting issue. In order to avoid the double-counting, we assume a 50% discount for the DHM>1 situation, that means that about half of the coral reefs belonging to the situation also belong to the situation when DHM>2, and their loss has been calculated for when DHM>2 and therefore need to be excluded from the loss calculation for when DHM>1. Based on this assumption, we achieve the overall annual monetary loss as 13.9, 15.14, 23.66 and 20.44 billion dollars respectively for climate change scenarios HadCM3A2 and HadCM3B2, for durations of 2030-2030 and 2050-2059 (see Table 11).

Table 11 about here

The present value of loss arising from coral loss would depend upon the kind of discount rate we choose and the type of scenario we value. Even for a 20 years time horizon and A2 scenario the present value of the loss at 2 percent rate of discount would be approximately 6.19 billion USD while at 3 percent rate of discount, it would be USD 4.11 Billion. For infinite time, the present value of the loss would be 13.9 Billion under A2 Scenarios and 15.14 under B2 scenario.

5. Discussion and Conclusions

The economic value of the ecosystem as they exist has no meaning. Economic valuation of ecosystem services must have a purpose. The valuation must be seen in the context of either alternate scenario or conflicting choices (Kumar, 2010). Moreover, the economic value of ecosystem services is instrumental, anthropocentric, individual-based, subjective, context-dependent, marginal and state-dependent (Goulder and Kennedy, 1997; Barbier et al, 2009). So economic value of corals might not make much sense especially to the policy makers who always like to see the value of one step going further. Therefore in the paper we provide the value of corals as per scenarios. The relative difference in the value in one scenario over other should be taken into account. For example the difference of losses in B2 and A2 is 1.24 Billion for if the time line is 2030. This value should be seen in the context of societal welfare loss and provide the rationale for effective action to combat climate change. This value should be analysed as the cost of inaction arising just from coral ecosystems . Various economic values can also be derived under different scenarios projected by the Inter-governmental climate change (IPCC) and the meta value derivesd on the basis of site specific studies is relevant to guide the global community for additional resource allocation to save this critical ecosystems of Corals.

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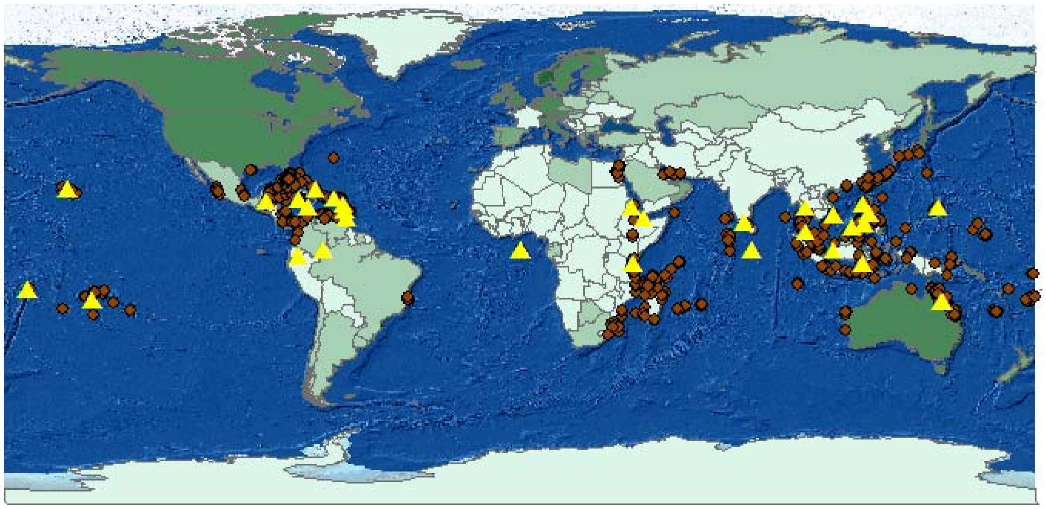

Figure 1 Study sites (yellow triangles) for ecosystem service valuation (source: TEEB database) and global monitoring sites (red dots) of coral reefs (source: ReefBase, at http://www.reefbase.org/main.aspx)

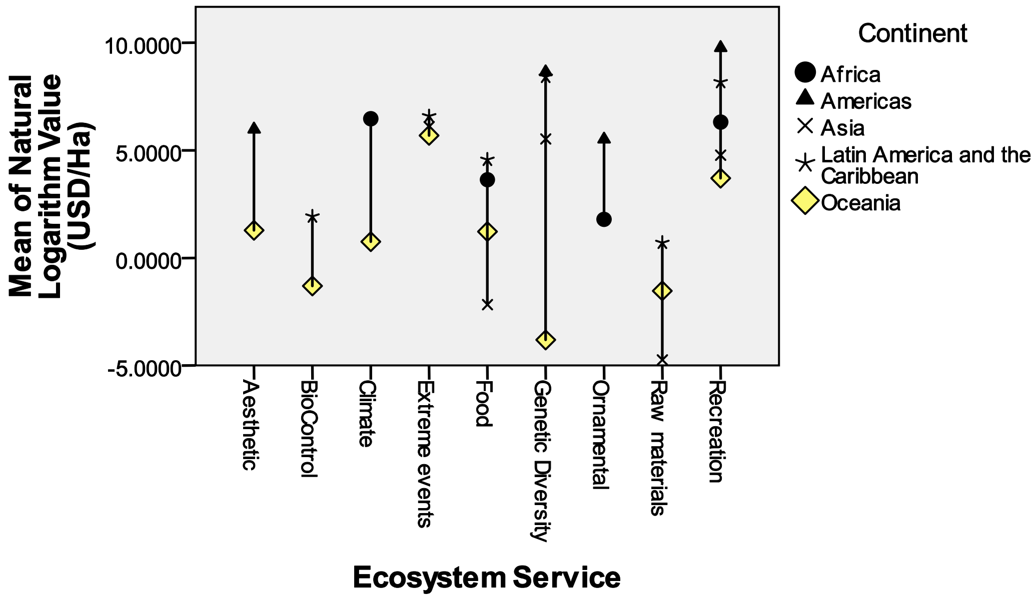

Figure 2 Mean of values of coral reef services distinguished among continents

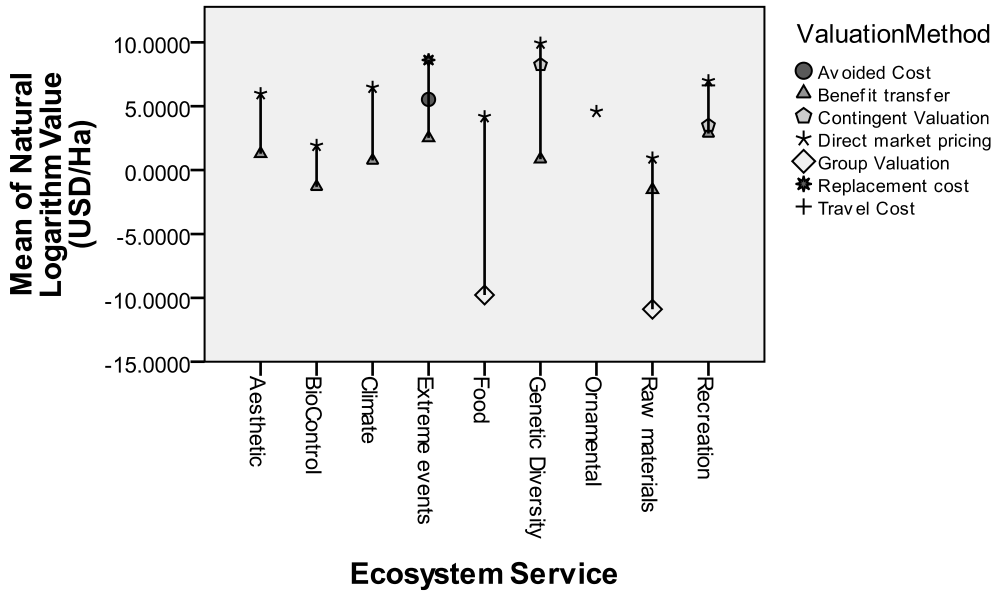

Figure 3 Mean of values of coral reef services distinguished across valuation methods

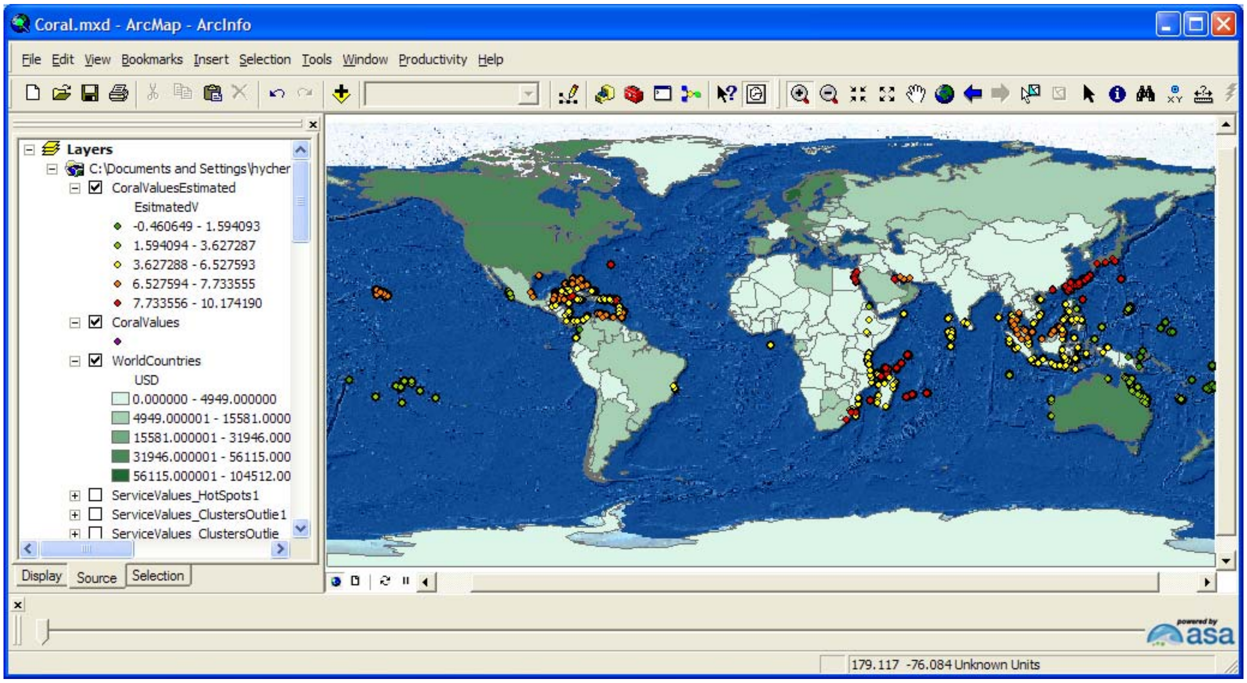

Figure 4 The distribution of the estimated unit value of coral reef ecosystem across the world

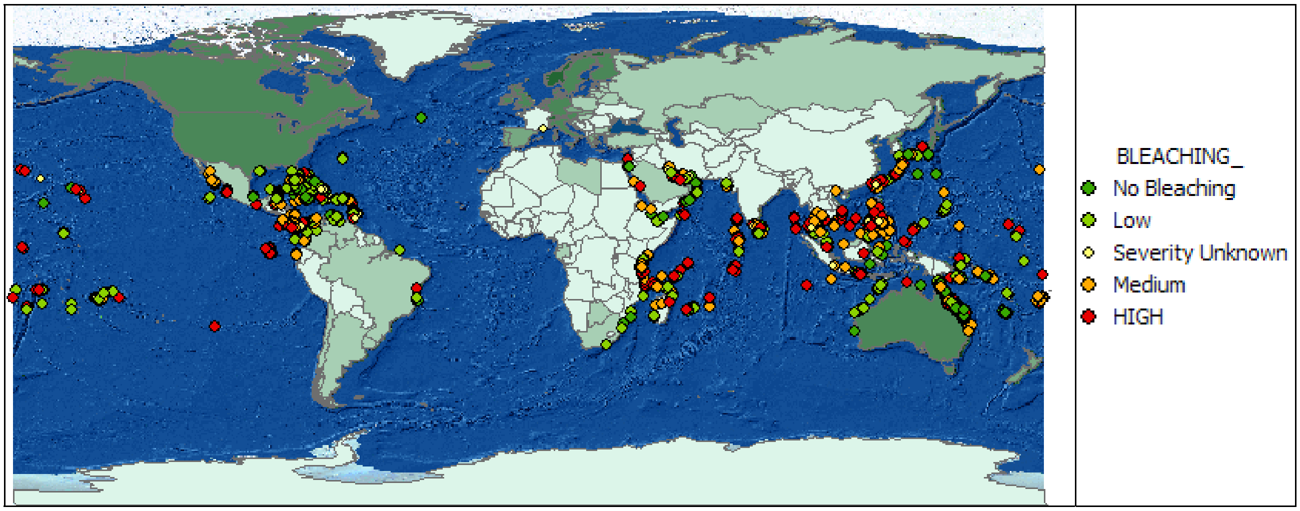

Figure 5 Global states of coral reef bleaching (source: ReefBase, at http://www.reefbase.org/main.aspx)

Table 1 Goods and services provided by coral reefs

Provisioning Services (*Products obtained from ecosystems*)	**Regulating Services** (*Benefits obtained from regulation of ecosystem processes*)	**Cultural Services** (*Nonmaterial benefits obtained from ecosystems*)	**Supporting Services** (*Natural processes that maintain the other services*)
• Food (fish and shellfish) • Genetic resources • Natural medicines and pharmaceuticals • Ornamental resources • Building materials	• Erosion control • Storm protection	• Spiritual and religious values • Knowledge systems / educational values • Inspiration • Aesthetic values • Social traditions • Sense of place • Recreation & ecotourism	• Sand formation • Primary production

Source: Adapted from MEA, 2005

Table 2 Overarching approaches for coral reef valuation

Approach	Fundamental Objective	Methods Practiced	Examples
Welfare economics (encompassing total economic value)	How to allocate the resources optimally among the competing uses for maximization of human welfare	• Market and Constructed Market Va1uation techniques • Benefit (value) Transfers Method • Total economic value • Cost-benefit analysis	Spurgeon et al. (2004) calculated an annual TEV of around U S$10 million for America Samoa based on fishery, recreation, coastal protection and non-use values and compared future TEV under different management scenarios
Economic impact analysis	To assess contribution to, and/or the effect on, local, regional and national economies (e.g. in terms of expenditures and jobs)	• Input-output models • Expenditure surveys • Benefit Transfer methods	Hazen and Sawyer (2001) estimated that the coral reefs of southeast Florida generate US$4.4 billion worth of local sales and US$ 2 billion of income, and support 71300 jobs
Socio-economic analysis	To understand and quantify the social, cultural, economic and political aspects of individuals, organizations and communities	• Qualitative and quantitative • Focus groups Surveys • Interviews • Visualization techniques • Stakeholder analysis •	Hoon (2003) identified 24 different types of socio-economic benefits from coral reefs on Agatti Island (west of India). She also found that 12% of poor households on the island depended on coral reefs for 100% of their incomes, and 59% of poor households relied on reefs for 70% of their incomes
Financial analysis	To determine the financial viability and sustainability of enterprises and organizations, by focusing on transaction /market-based costs and benefits	• Budget forecasts • Profit and loss accounts • Cash Dow analysis • Balan1ce sheets • Business plans	Coastal Zone Management Authority and Institute of Belize (2003) undertook a financial analysis to assess financing options for planned marine park and coastal management in Belize. They estimated potential revenues from Belizeans and non-Belizeans of over BZ$5 million and identified a financing gap of BZ$322000.
Other non-monetary 'value' - based approaches	To highlight the relative importance of biodiversity and of her natural and man-made assets and features	• Environmental and Social impact Assessments • Sustainability indicators • Index of captured ecosystem value Multi-criteria Analysis scoring and weighting techniques Energy-based approaches	Fernandes et al (1999) used multi-criteria analysis to determine the relative importance of various ecological, economic, social and global objectives and indicators amongst different stakeholders for Saba Marine Park. The approach also highlighted the fact that enhanced education and enforcement were commonly agreed by the stakeholders to be the best means of improving upon all four objectives

Table 3 Meta-regression results

Explanatory Variable		Variable definition	Coefficient
	Constant		-10.702*
X_{Ei}	DExtreme	Dummy: 1= extreme event protect service; 0 = other service	2.501
	DFood	Dummy: 1= food provision service; 0 = other service	.480
	DGenetic	Dummy: 1= genetic diversity service; 0 = other service	2.715*
	DRecreation	Dummy: 1= recreation service; 0 = other service	2.675**
	DRawM	Dummy: 1= material provision service; 0 = other service	-2.027
X_{Si}	MDirectMP	Dummy: 1= direct market price method; 0 = other method	1.335
	MReplaceC	Dummy: 1= replacement cost method; 0 = other service	4.243*
X_{Ci}	CAfirca	Dummy: 1= Africa; 0 = other continent	4.597**
	CAmerica	Dummy: 1= America; 0 = other continent	3.151*
	CAsia	Dummy: 1= Asia; 0 = other continent	1.304
	CLatinA	Dummy: 1= Caribbean; 0 = other continent	2.282*
	LNPopuD2005	Natural log of population density	.978**
	LNGNIPerCapita2006	Natural log of gross national income per capita	.838

Significance is indicated with ***, ** and * for the 1, 5 and 10 % level, respectively; Adjusted R^2=0.378.

Table 4 Total values of the coral reefs in different marine regions

	North Pacific	Caribbean	South Pacific	India Ocean	Atlantic	South East Asia	Red Sea	Persian Gulf
Unit Value (Dollar/Ha)	2656.6	1097.5	23.7	2912.9	611.3	798.3	2591.6	4649.3
Area (1000Km^2)*	17	20	91	36	3	68	17	3
Total (Million Dollar)	4516	2195	215	10487	1834	5428	4406	1395

*The source of the estimation is Spalding and Grenfell (1997).

Table 5 The severity of the coral reef bleaching and the value loss rate

Severity	Npacific		Caribbean		Spacific		Indian		Atlantic		SEAsia		RedSea		Persian	
high	67	35%	179	11%	540	24%	109	41%	62	19%	75	34%	8	40%	31	61%
medium	37	19%	432	26%	282	12%	71	27%	91	28%	66	30%	4	20%	8	16%
low	49	26%	582	36%	404	18%	57	21%	119	37%	48	22%	2	10%	5	10%
no bleaching	16	8%	394	24%	962	42%	10	4%	20	6%	13	6%	6	30%	4	8%
unknown	21	11%	52	3%	79	3%	19	7%	30	9%	16	7%	0	0%	3	6%
Total	190	100%	1639	100%	2267	100%	266	100%	322	100%	218	100%	20	100%	51	100%
Loss rate	21.5%		10.7%		14.4%		25.8%		15.3%		15.3%		24.0%		33.5%	
Value left (Million dollars)	3544		1959		184		7779		1554		4599		3349		927	

Table 6 Projected frequency that the world's coral reefs experience annual DHM >1 and >2 during 2030-2039 and 2050-2059. The results are the fraction of 36km grid cells containing coral reefs with a given frequency of exceeding threshold (extracted from Fig. 3 and Fig. 4 in Donner *et al.* (2005))

Time Duration	Frequency	*0.1*	*0.2*	*0.3*	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*	*1*
					DHM>1						
2030-2039	HadCM3 A2	100%	100%	100%	97%	94%	89%	70%	50%	32%	16%
	HadCM3 B2	100%	100%	99.5%	98%	94%	90%	72%	60%	38%	20%
2050-2059	HadCM3 A2	100%	100%	99%	98%	98%	97%	95%	94%	85%	76%
	HadCM3 B2	100%	100%	99%	98%	98%	95%	90%	84%	75%	50%
					DHM>2						
2030-2039	HadCM3 A2	97%	93%	86%	72%	56%	42%	24%	11%	5%	2%
	HadCM3 B2	98%	96%	88%	75%	60%	47%	32%	24%	11%	6%
2050-2059	HadCM3 A2	99%	98%	97%	96%	95%	94%	90%	83%	70%	50%
	HadCM3 B2	99%	98%	96%	94%	88%	78%	70%	59%	40%	22%

Table 7 The fraction of coral reefs which experience a given bleaching frequency during two time duration under different climate scenarios

Duration		***0.0***	***0.1***	***0.2***	***0.3***	***0.4***	***0.5***	***0.6***	***0.7***	***0.8***	***0.9***	***1***
						DHM > 1						
2030-2039	HadCM3 A2	0%	0%	0%	3%	3%	5%	19%	20%	18%	16%	16%
	HadCM3 B2	0%	0%	1%	2%	4%	4%	18%	12%	22%	18%	20%
2050-2059	HadCM3 A2	0%	0%	1%	1%	0%	1%	2%	1%	9%	9%	76%
	HadCM3 B2	0%	0%	1%	1%	0%	3%	5%	6%	9%	25%	50%
						DHM>2						
2030-2039	HadCM3 A2	3%	4%	7%	14%	16%	14%	18%	13%	6%	3%	2%
	HadCM3 B2	2%	2%	8%	13%	15%	13%	15%	8%	13%	5%	6%
2050-2059	HadCM3 A2	1%	1%	1%	1%	1%	1%	4%	7%	13%	20%	50%
	HadCM3 B2	1%	1%	2%	2%	6%	10%	8%	11%	19%	18%	22%

Table 8 Loss rate assumed according to the frequency and severity of coral reef bleaching

Probability	***0.2***	***0.4***	***0.6***	***0.8***	***1***
			DHM>1		
Loss Rate	5%	10%	15%	20%	25%
			DHM>2		
	20%	40%	60%	80%	100%

Table 9 Loss rate of coral reef value under different climate change scenarios

Duration	Climate scenario	Value of Loss	
		DHM>1	DHM>2
2030-2039	HadCM3 A2	0.19	0.49
	HadCM3 B2	0.19	0.54
2050-2059	HadCM3 A2	0.24	0.87
	HadCM3 B2	0.22	0.74

Table 10 Monetary loss in different marine regions

	Duration	Scenario	Loss Rate	North Pacific	Cari-bbean	South Pacific	India ocean	Atlan-tic	South East Asia	Red sea	Persian gulf	Total
				3.54	1.96	0.18	7.78	1.55	4.60	3.35	0.93	23.90
DHM >1	*2030-2039*	HadCM3 A2	0.19	0.66	0.37	0.03	1.45	0.29	0.86	0.63	0.17	4.47
		HadCM3 B2	0.19	0.68	0.38	0.03	1.50	0.30	0.89	0.65	0.18	4.61
	2050-2059	HadCM3 A2	0.24	0.83	0.46	0.04	1.83	0.37	1.08	0.79	0.22	5.63
		HadCM3 B2	0.22	0.79	0.44	0.04	1.73	0.34	1.02	0.74	0.21	5.31
DHM >2	*2030-2039*	HadCM3 A2	0.49	1.73	0.96	0.09	3.80	0.76	2.24	1.63	0.45	11.66
		HadCM3 B2	0.54	1.90	1.05	0.10	4.18	0.83	2.47	1.80	0.50	12.83
	2050-2059	HadCM3 A2	0.87	3.09	1.71	0.16	6.78	1.35	4.01	2.92	0.81	20.83
		HadCM3 B2	0.74	2.63	1.46	0.13	5.79	1.15	3.42	2.49	0.69	17.77

Note: *Unit is in billion dollars*

Table 11 Loss in future value with the interest rate at 2% and 3%

Climate scenario	Annuity Value of Loss infinite time	Loss with 40 years time horizon		Loss in 20 years (in future value)	
Current Total Value (23.90)		2%	3%	2%	3%
HadCM3 A2	13.90	9.28	7.56	6.19	4.11
HadCM3 B2	15.14	10.11	8.23	6.75	4.48

Note: *Unit is in billion dollars*