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Valuing Coral Reefs: A Travel Cost Analysis of the Great Barrier Reef

This study examines domestic and international travel to the Great Barrier Reef in order to estimate the benefits the reef provides to the 2 million visitors each year. The study explores the problems of functional form and of measuring travel cost for international visits: comparing actual costs, distance, and lowest price fares. The best estimates of the annual recreational benefits of the Great Barrier Reef range between USD 700 million to 1.6 billion. The domestic value to Australia is about USD 400 million, but the estimated value to more distant countries depends on the definition of travel cost and the functional form. The study conclusively demonstrates that there are very high benefits associated with protecting high quality coral reefs.

INTRODUCTION

Throughout the world, there are many threats to existing coral reefs. Global warming (1), mining (2), overfishing (3), and water pollution (4) all threaten the viability and health of coral reefs. Although these threats are well documented, programs to protect coral reefs are spotty and underfunded. Advocates for coral reef protection argue that there are many benefits to maintaining coral reefs, such as recreation (5), fish habitat (6), and beach protection (7). It is only recently, however, that economic studies have begun to discuss how to measure the direct and indirect benefits from coral reefs. Studies have examined the benefits of reef resources (8, 9), recreation (10, 11), marine parks (12–14), and protected areas (15). However, quantification of the value of coral reefs is rare and badly needed. This paper applies a well known economic valuation method, the travel cost model, to measure the value of the Great Barrier Reef, Australia.

Although the travel cost method has been applied to a host of outdoor recreation sites, most applications entail domestic visitation where travel is predominantly by car. In order to apply this methodology to ecotourism in low latitude countries, the method has to be extended to capture international travel that is largely by plane. This raises a serious measurement issue because the cost of air travel is not well correlated with distance. Many tourists come on packages and the travel cost is not clearly delineated. Some tourists visit on special low fares raising questions about which fares to use. Finally, some countries have no observed visitors and so there are no actual fares. The analyst is consequently faced with several alternative measures of travel cost: actual reported fares, consistent fares from travel agents, and distance. In this study, we compare an OLS estimation using actual and travel agent fares with a 2-stage least squares estimation using all 3 measurements.

Another important methodological issue that we address in this study concerns the fact that many origins may have no visits to the site. Estimation of the demand function must take these zero visits into account through either a participation function or an estimation procedure that truncates the distribution. We utilize both methods by exploring a participation function in one model and using tobit analysis in the other.

Another important issue is choosing the functional form of the travel cost demand function. Analysts tend to examine functional forms for travel cost models as though they are simply a goodness-of-fit issue. However, because these models of demand are being used to estimate consumer surplus, the functional form can have significant impacts on the final results. Some functional forms, such as the log-linear model, are attractive because they provide nonlinear demand functions with few parameters. However, the log-linear models tend to result in higher consumer surplus estimates because they assume prices go to infinity as quantities go to zero. We contrast the log-linear model with a polynomial model of demand in order to show the importance of these assumptions.

In the following section, we review the methods used in the study in detail. We then discuss the empirical results. Finally, we conclude the paper with some policy observations concerning international travel cost modeling and the value of coral reefs.

METHODS

The travel cost method is a well-known and developed methodology for measuring the economic values of outdoor recreation benefits (16–18). Although the travel cost method may have its difficulties (19, 20), the method has the advantage that it infers values from people's behavior. It is the very fact that people are willing to actually travel great distances to see international sites that reveals the high value of these sites. The travel cost serves as a proxy for price. By measuring how visitation varies with price, one can estimate a demand function for a destination. Visitation rates, V, from different origins are regressed on travel costs, TC, and socioeconomic shift variables, X:

$$V = f(TC, X) \qquad \text{Eq. 1}$$

The value of a site is the sum of the consumer surplus estimates for each origin, the area underneath the demand function from the observed price of travel, T_0, to infinity:

$$CS = \int_{TC_0}^{\infty} V(TC, X) \, dTC \qquad \text{Eq. 2}$$

There is a difference between Marshallian consumer surplus as measured by Eq. 2 and Hicksian consumer surplus, the area underneath a compensated demand function. In practice, however, this distinction tends to be small (21). This is especially true in this study where income effects appear to be minimal.

Analysts have generally chosen functional forms in order to fit the observed data more closely. In this paper, however, we argue that one must be careful about choosing the functional form of demand because it has large implications for consumer surplus. Specifically, the behavior of the functional form as visitation approaches zero can be critical. Some functional forms imply prices go to infinity as demand goes to zero whereas other forms estimate finite price ceilings for the demand function. These assumptions can have a large influence on estimates of consumer surplus. In the extreme, some functional forms, for example log-log, imply an infinite consumer surplus if the estimated price elasticity is less than one.
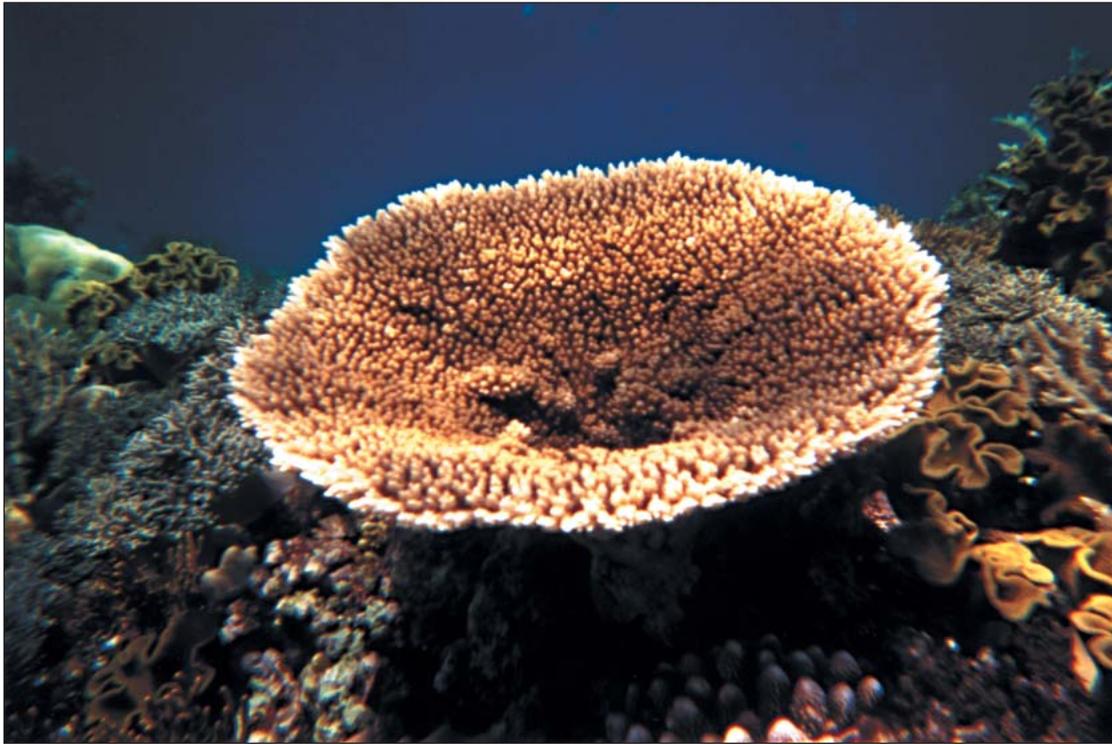
A table coral on Briggs' reef, Queensland, Australia. Photo: L. Carr.

In this paper, we examine 2 general functional forms, a polynomial model and a log-linear model. The polynomial model of demand relies on a polynomial, in this case, a quadratic function of travel cost:

$$V = a_0 + a_1 \, TC + a_2 \, TC^2 + \Sigma \, b_j \, x_j + e \qquad \text{Eq. 3}$$

By introducing squared terms, the model is capable of capturing nonlinear effects. Generally, it is expected that $a_1 < 0$ and that $a_2 > 0$. That is, the demand function would slope downwards but be convex. Integrating Eq. 3 yields:

$$CS = \int_{TC0}^{TC_{max}} a_0 \, TC + 0.5 \, a_1 \, TC^2 + 0.33 \, a_2 \, TC^3 + TC \, \Sigma \, b_j \, x_j$$

TC_{max} is the travel cost that drives visitation to zero. Solving using the quadratic formula reveals that there are 2 solutions for TC_{max}:

$$TC_{max} = -a_1 +/- [a_1^2 - 4^* \, a_2 ^* \, (a_0 + \Sigma \, b_j \, x_j)]^{0.5} / 2^* \, a_2 \quad \text{Eq. 5}$$

In this case, we are interested in the lower value when visits first go to zero. The behavior of the model for prices above the lower TC_{max} must be ignored because they imply first, negative visitation rates, and then a backward bending demand function.

For certain observations, there is an additional problem. The solution to the quadratic formula may be imaginary. For certain values of the parameters, it is possible that the quadratic functional form will bend back while visits are positive and visits never go to zero. In this case, we use a conservative definition of consumer surplus. We examine only the area underneath the demand function between the observed travel cost and this maximum travel cost where the demand function bends back.

Since outdoor recreation sites are jointly consumed, the consumer surplus for a destination is the sum of the consumer surplus estimates for all the origins. Note that if actual travel cost for an origin is greater than the maximum travel cost, the consumer surplus is zero for that origin. Although distant users come a long way to visit, if the site were not there, they would have a lot of travel funds to go somewhere else. This is a paradox of the travel cost method that the most expensive trips have little consumer surplus. In this study, distant origins may fluctuate between having zero and nonzero consumer surplus values depending on the functional form and the definition of travel cost.

In our second functional form, we log visitation rates. Origins with zero visitation rates consequently cannot be included in the log-linear model since the log of zero is negative infinity. Dropping origins without observed visits, however, will bias the results, because only low visitation countries with positive errors will be included. In order to correct for this omission, we predict the probability, Pr, that an origin would participate (send anyone). We then estimate the conditional demand function: the number of visits from countries that are sending visitors. The predicted conditional number of trips is then multiplied by the probability of visiting. Even countries that have no observed visitors will have positive predicted trips.

The log-linear model is therefore a 2-equation model. The first equation is a logit model of participation:

$$Pr = \exp (c_0 + c_1 \, TC + \Sigma \, c_j \, x_j) / (1 + \exp (c_0 + c_1 \, TC + \Sigma \, c_j \, x_j)) \qquad \text{Eq. 6}$$

The second model predicts the conditional number of trips given that one would visit. Looking at only nonzero visitation rates, one would estimate:

$$\log (V) = a_0 + a_1 \, TC + \Sigma \, b_j \, x_j + e \qquad \text{Eq. 7}$$

or

$$V = \exp (a_0 + a_1 \, TC + \Sigma \, b_j \, x_j + e) \qquad \text{Eq. 7'}$$

One could also estimate a quadratic loglinear model:

$$\log (V) = a_0 + a_1 \, TC + a_2 \, TC^2 + \Sigma \, b_j \, x_j + e \,. \qquad \text{Eq. 8}$$

However, Eq. 8 bends backwards when $TC = -a_1 / 2^*a_2$. The consumer surplus for this equation is consequently infinite regardless of the estimated parameters, making it an unattractive form for this analysis. Choosing functional forms is not just a matter of goodness-of-fit but also which model is most appropriate for the purpose at hand.

Integrating Eq. 7 between TC_0 and infinity and multiplying

through by Eq. 6 yields the following equation for expected consumer surplus:

$$CS = Pr * exp (a_0 + a_1 TC_0 + \Sigma\, b_j\, x_j) / (-a_1) \qquad Eq.\ 9$$

The consumer surplus for a destination is the sum of the consumer surplus estimates for all the origins. With the log-linear model, however, no origin has a zero consumer surplus since there is no limit to how high travel costs can go. Thus, the functional form of the demand function has an enormous impact on the distribution of consumer surplus estimates across countries. Eq. 3 allows the empirical data to determine whether consumer surplus is nonzero for distant countries. Eqs 6 and 7 assume that all countries have consumer surplus no matter how far away they are.

A second methodological issue that we address in this paper concerns how to measure travel cost for international visitors. Most travel cost studies in the literature examine destinations where visitors drive vehicles between their homes and the site. Whether the analyst uses distance or reported travel costs has very little effect on the outcome of these studies. The actual travel cost per mile appears to be constant so that the results are unchanged. With international travel, however, most visitors rely on air transport to get to the destination country. There is a great discrepancy between the cost that they face for the trip and the miles traveled. Some countries seem to provide lower cost fares whereas others seem to charge a much higher cost per kilometer traveled. Further, there is often a large discrepancy between the price that visitors state they paid to get to a site and the price that a travel agent quotes for a low cost visit from their country.

We consequently examine 3 alternative measures of travel cost. The actual cost the visitors state that they paid has the advantage of being realistic and representative. However, some people purchase travel packages that do not clearly separate the travel cost from hotels and other services and other people seem to get low fares that are not available to everyone. The second measure of travel cost relies on a consistent set of fares obtained from a single travel agent. The advantage of this measure is that one could specify the conditions of the trip and get a comparable fare across all countries. The problem, of course, is that the specified conditions may not be representative of the types of trips people take from every country. For example, the people from some nearby countries may take 2–3 day trips whereas people from far away may come for a week and the fares for trips of different lengths may not be the same. The travel agent approach may yield a more accurate measure, but it might be measuring the wrong thing.

The third approach we rely upon uses 2 stage least squares to estimate demand. In the first stage, the measurement error on travel cost is corrected with an equation that predicts the unobserved true travel costs. We regress the actual travel costs (ATC) upon the travel agent estimate of costs (TC) and distance (D) squared:

$$ATC = a_0 + a_1\, TC + a_2\, TC^2 + a_2\, D^2 + e \qquad Eq.\ 10$$

We then rely on the predicted value of (Eq. 10) as the estimate of the travel cost. It is then introduced in the polynomial demand function (Eq. 3) and in the loglinear model of participation (Eq. 6) and conditional trip estimation (Eq. 7).

This study was performed at the Great Barrier Reef in Australia. There are approximately 2 million visitors to the region every year (22). The Great Barrier Reef is most likely the single most valuable coral reef in the world. Visitors were interviewed between 1 September and 1 December 2000. Altogether a sample of 607 people was interviewed. Although it is tempting to analyze this data individually, international visitors tend to visit only once. There is very little information in the visitor sample since it includes no data on nonvisitors and few people who visit more than once.

We, consequently, turn to a traditional travel cost method and group people by origin. The observations become large regions of origin and often countries instead of individuals. All the countries of the OECD are included in the analysis. Although non-OECD countries from Southeast Asia could clearly visit the site, their visitation rate in the sample was quite small and so they were dropped from the analysis. This aggregates the data set of 607 individuals into 39 regions of origin. The aggregation loses information about demand shift variables and consequently fewer demand shift variable are significant. However, by grouping people by origin, we implicitly learn about nonvisitors since the dependent variable becomes observed visitors per million people in the population.

Because Australia is a large country and had many visitors in our sample, we divided Australia into 7 regions and calculated travel costs and visitation rates for each region separately. Because of their great distance, most other countries were analyzed as single origins. The only exceptions were Canada, which was divided into East and West and the United States, which was divided into East, Central, and West. Socioeconomic variables were collected for each country such as the domestic temperature and the GDP per capita (income).

RESULTS

Two models were tested: the polynomial visitation model (Eq. 3) and the participation (Eq. 6) and log-linear visitation model (Eq. 7). For each functional form, a separate model was estimated using each of the 3 definitions of travel cost: *i*) actual cost; *ii*) travel agent cost; *iii*) and predicted travel cost.

The results of the polynomial model are presented in Table 1. A tobit model was used to estimate the demand function since many observations had zero observed visits. This functional form had the most significant coefficients of all the models. Temperature, GDP per capita, and a dummy variable for Europe were tried in each regression. The temperature coefficient implies that people from warmer countries are more likely to visit the Great Barrier Reef. For most low latitude ecotourism, the colder the country of origin, the more people are attracted. They are seeking relief from the cold in tropical beaches and forests. The result is the opposite here because most of the visitors are divers.

Table 1. Tobit polynomial model. (Ordinary least squares estimation. t-statistics are in parentheses).

Variable	Actual cost	Travel agent cost	Two stage estimate
Constant	9.3 (1.57)	15.9 (1.89)	14.6 (2.71)
Travel cost	−2.41e-2 (3.84)	−3.21e-2 (3.93)	−2.76e-2 (6.19)
Travel cost squared	5.05e-6 (2.94)	7.05e-6 (3.30)	6.20e-6 (4.92)
Temperature	0.70 (3.38)	0.68 (2.74)	0.50 (2.61)
GDP per capita	1.51e-4 (2.40)	1.64e-4 (2.40)	1.44e-4 (2.87)
Europe	2.80 (1.21)	3.07 (1.17)	2.72 (1.50)
sigma^2	19.8 (3.44)	26.5 (3.51)	14.9 (3.51)
Log-likelihood	−78.6	−82.4	−75.3
Observations	39	39	39

One has to be quite a rigorous individual to dive in cold countries, so domestic temperature serves as a good proxy for diving. As expected, countries with higher incomes are more likely to come to the Great Barrier Reef. Income has the expected sign but it has a relatively small coefficient and it is often insignificant implying that income is not a critical factor. Europeans come to the Great Barrier Reef more than people from other countries controlling for distance. They accounted for a surprising 25% of all visitors.

It is interesting to compare the performance of the different travel costs in Table 1. All 3 models suggest a downward sloping convex demand function. The predicted travel cost model has the highest R-squared, revealing that it fits the data most closely. The coefficients of the travel cost variables are also more significant implying that there is less error involved in the predicted cost measure. The actual travel cost model is close behind, but it suffers from some measurement error. The travel agent measure is the least accurate measure in terms of fit and the t-statistics of the cost coefficients. The polynomial results in Table 1 thus support the 2-stage least square estimation of demand to correct for measurement error of international travel costs.

Table 2 presents the results of the participation model. The analysis relies on logit to predict participation. Very few coefficients were significant implying that the participation decision is either random or it involves unobserved variables. The only variable that is significant is the travel cost, which depresses participation as it rises. Using the estimated coefficients of the logit, the model predicts a participation rate for each origin between zero and one. Note that the model is reasonably good at predicting participation. The accuracy of the predictions from actual travel costs once again outperforms travel agent costs. However, in Table 2, the predicted travel cost has the worst performance. The attempt to correct measurement errors has led to a regression that fits the data more poorly and gives lower t-statistics on the travel cost coefficient. It is not clear that the 2-stage estimation procedure is improving the participation model.

Table 3 depicts the results of the conditional log-linear model for countries with nonzero visitation rates (25 observations). The log-linear model was not able to support any of the socioeconomic shift variables. Quadratic terms for travel cost were significant but they were dropped because they imply infinite consumer surplus values. The coefficients of the linear travel cost variable are significant and negative as expected. The model with actual cost once again outperforms the model with travel agent cost. Interestingly, the model with predicted cost has the worst performance in the conditional trip model. The R squared is the lowest and the t-statistic on the cost coefficient is lower. The 2-stage estimator is not particularly effective in the log linear model.

Table 4 shows the calculations of consumer surplus. For each model, annual consumer surplus for the Great Barrier Reef was calculated for each country. The sample population of 607 was expanded to the reported number of visitors, 2 million. It was assumed that the sample was representative. The total values thus reflect the sum of all the consumer surplus values for the world. Examining the totals, we see that the Great Barrier Reef has tremendous value. Reliable annual values range from USD 710 million to 1.6 billion. We discount the USD 2.2 billion estimate from the polynomial model with travel agent cost given the extraordinary value assigned to Japan and North America. The estimate in the paper fits well with the Great Barrier Reef Marine Park Authority's own figure of USD 800 million. Discounting this annual benefit at 4% per year suggests that the Great Barrier Reef is worth between USD 18 and 40 billion.

It is also interesting to note in Table 4 how the recreational benefits are distributed across countries. The polynomial model with predicted travel costs suggests that Australia enjoys 59%

Table 2. Logit results predicting participation (t-statistic in parentheses).

Variable	Actual cost	Travel agent cost	Two stage estimate
Constant	7.97 (2.87)	4.40 (2.08)	6.62 (2.29)
Travel cost	−3.09e-3 (2.87)	−1.95e-3 (2.49)	−2.59e-3 (2.23)
Log likelihood	−15.6	−20.5	−19.6
Percent correctly predicted	82	72	69

Table 3. Conditional demand using log-linear model (t-statistic in parentheses).

Variable	Actual cost	Travel agent cost	Two stage estimate
Constant	3.06 (6.43)	3.14 (4.73)	2.96 (5.49)
Travel Cost	−1.61e-3 (6.40)	−1.75e-3 (4.59)	−1.45e-3 (5.41)
R-squared	0.64	0.48	0.56
Observations	25	25	25

Table 4. Annual consumer surplus estimates for Great Barrier Reef (million USD yr⁻¹).

	Actual cost	Travel agent cost	Two-stage least squares
Log-Linear			
Australia	319.7	198.7	348.2
Japan	339.1	509.7	342.0
North America	115.0	234.9	230.5
Europe	545.4	502.9	548.3
Total	1378.7	1585.8	1563.0
Polynomial-tobit			
Australia	475.0	328.8	421.2
Japan	632.2	1306.3	205.9
North America	41.4	560.0	58.4
Europe	15.9	4.9	0.0
Total	1187.3	2223.6	709.0

of the benefits domestically and Japan enjoys another 29% of the value. However, with the loglinear model and predicted actual cost, Australia enjoys only 22% and Japan another 22% of the global value of the site. According to the log-linear model, Europe enjoys a large fraction of the consumer surplus (35%). The log-linear model implies much larger consumer surplus values for more distant countries. Whether distant countries have large or little consumer surplus shares thus depends upon the functional form used in the analysis. The definition of travel cost also has a large effect. Using actual travel costs in the polynomial model predicts that Australia enjoys only 40% of the consumer surplus, but Japan enjoys 53%.

DISCUSSION

This paper makes 2 methodological inquiries in a study of the Great Barrier Reef. First, the paper examines the choice of functional form for travel cost models. Choosing the functional form of demand has large implications on consumer surplus and so this decision should not be made solely on the basis of goodness of fit. It is critical to examine the implication the functional form has on consumer surplus values. Some functional forms automatically imply an infinite consumer surplus value, which

is counterproductive to this application. Even with functional forms that have finite values, functional forms, such as the log-linear model, tend to predict higher consumer surplus values and they especially increase the consumer surplus estimates for very distant origins. In this application, the log-linear model fits the data more poorly and estimated fewer significant coefficients. We, consequently, have more confidence in the polynomial model of the Great Barrier Reef.

The paper also addresses an important issue concerning measuring international travel cost. The underlying assumption of most of the travel cost literature is that the cost per mile is constant. However, with international travel that involves flying, there appear to be large fixed costs to trips, so that cost per mile is not constant. These costs appear to vary by origin so that distance is not an especially good measure of travel cost. The behavior of actual travel costs appears to be better than the results from travel agent costs. However, for the polynomial model, a 2-stage least squares estimate of demand provided the best estimate of costs. This was not repeated in the log linear model where actual costs provided the best estimates.

The most important contribution of the study, however, is the estimate of the value of what is likely to be the most valuable coral reef in the world. It is already clear that with 2 million visitors a year, the Great Barrier Reef is one of the world's most popular ecotourism sites. The study finds that the recreational value of the reef ranges from USD 700 million to 1.6 billion per year. Given the estimated 2 million visitors, this suggests an average value of between USD 350 and 800 per visit. This compares favorably to the estimated value of visitors to the coral reefs of Belize who averaged USD 367 per visitor (11). The value is also high compared to the value of visiting other ecotourism sites such as the cloud mountains of Costa Rica in Monteverde (USD 350 per visitor) (23), a site to watch brown bears in Alaska, McNeil River (USD 250 per visitor) (24), or a site to see lemurs in Madagascar (USD 276–USD 360 per visitor) (25).

The results of this study suggest that healthy, intact coral reef systems can have very high values for both coral reef and distant nations. Discounting at a 4% real interest rate, the recreation value associated with the Great Barrier Reef is worth from USD 18 to 40 billion. Domestic Australian visitors enjoy between 20% to 60% of these benefits. Foreign tourists enjoy the rest. The large benefits accruing to foreign visitors suggest that international support for coral reefs is warranted. This is especially evident for many coral reef countries who are substantially poorer than Australia.

Conservation policies to protect these resources are warranted and should be supported. To this end, Australia, through the Great Barrier Reef Marine Park Authority, has been managing the Great Barrier Reef Marine Park since 1975, using zoning plans and controlling all development and use within the park's borders to maintain reef health and sustainable resource use.

Given the estimates we have found for the Great Barrier Reef, it is highly likely that coral reefs in other parts of the world are also quite valuable. It is likely that large-scale forces such as global warming, by raising sea temperatures, will cause significant damage both in physical and economic terms to coral reefs throughout the world. Smaller-scale threats, such as coral mining, eutrophication, and destructive fishing, should all be examined to determine whether the benefits of these activities are worth the resulting damages. Establishing simple programs to dissipate water pollution, limit mining, and limit unsustainable or destructive fishing could all be cost effective for many coral reef countries and may provide additional benefits by increasing coral resilience to other threats (26). Coral reefs possess recreational values that are sufficiently high to justify conservation programs worldwide. Additional travel cost studies should be done around the world to demonstrate precisely how valuable these resources are and why we should continue to preserve them. Efforts also should be made to quantify the extent to which countries who send visitors also benefit. A very good case can be made to protect coral reefs in poor countries using international funds.

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27. First submitted 30 Jan. 2002. Revised manuscript received 11 Nov. 2002. Accepted for publication 15 Nov. 2002.

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