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HOW MUCH IS NATURE REALLY WORTH?

AN ECONOMIC PERSPECTIVE

by

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Abstract

Recently published estimates of the values of nature's services and the total value of all ecosystem services and of the services of all species raise a number of important questions, including: what is the concept of value being employed? What is the naturethat is being valued? Why should we place monetary values on nature's services? how are these values to be estimated? And do we really know how much nature is worth? In this paper, I address these questions. My conclusions include the following points. Ecosystems are very valuable because they provide a wide array of services that enhance our well being. Thus the relevant concept of value is instrumental and anthropocentric. Economic values are an important form of information as we attempt to manage our impact on nature. The values of ecosystem services can be measured using the tools of market and nonmarket valuation that have been developed in recent years. But the estimates of total value presented by Costanza, et al. and Pimentel, et al. are seriously flawed because neither group has posed a meaningful valuation question and in calculating estimates of the various components of their total values, they have engaged in double counting, used seriously flawed methods, and relied on flimsy data.

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1. INTRODUCTION AND OVERVIEW

There is no question that nature provides us with many valuable goods and services. To drive home this point, Gretchen Daily et al. (1997) asks us to imagine that we are planning to colonize the moon and must decide which species we will take with us, assuming that a suitable climate and atmosphere already exist there. Not only would we have to make choices among the many plant and animal species that provide us with food, fiber, and other material goods and services. But we would also have to determine which other species are necessary to sustain the lives of the chosen species of direct use to us, such as pollinators, pest controllers, and soil micro-organisms. The difficulties of answering such questions and attempting to construct a replica of the natural systems necessary to sustain life are illustrated by the Biosphere 2 experiment, in which researchers in Arizona were unable to sustain human life within the closed system of the Biosphere for the target two years without resorting to outside interventions (Baskin, 1997, pp. 207-209).

In order to emphasize the importance of ecosystem services to sustaining human life on the earth some researchers have begun publishing estimates of the monetary or economic values of ecosystem services. For example, in a group of papers collected by Gretchen Daily (1997), a number of biologists, ecologists, and other scientists presented estimates of the monetary values of such ecosystem services as climate regulation, nitrogen fixation, pollination, and waste treatment, among others. In her concluding chapter, Daily warned against adding up these values to obtain a grand total value of nature, for reasons I will discuss below (Daily, 1997, p. 268). But in the same year, two other sets of researchers have published reports that did just that. Costanza et al. (1997), in a widely cited article, estimated that the total value of the world=s ecosystem services was about $33 trillion per year. The types of ecosystem services valued in this study and their contribution to the grand total are shown in Table 1. Shortly after this estimate appeared, Pimentel, et al. (1997) estimated that the total value of biodiversity, by which they meant the value of ecosystem services provided by the array of species presently on earth, was just under $3 trillion per year. Their results are summarized in Table 2. Both sets of authors argued that their estimates were conservative in the sense that the true values were actually much higher because of gaps and omissions in the coverage of their work.

It is interesting to compare these two tables, both the specification of the services to be valued and the numbers obtained. For example, Costanza, et al. estimate values for nutrient cycling (which is by far the most valuable ecosystem service according to them), disturbance regulation, and cultural value (the second most valuable). Pimentel, et al. do not include any of these services in their analysis. On the other hand, Pimentel, et al. estimate values for pollination, eco-tourism, bio-control of pests and nitrogen fixation, none of which is included in the Costanza, et al. analysis.

And where the two studies estimate values for the same or similar services, the Costanza, et al. numbers range from 2.5 times(food production and waste treatment and disposal) to 10 times (gas regulation or CO_2 sequestration) the values estimated by Pimentel, et al. In fact the aggregate value estimated by Costanza, et al. is an order of magnitude larger than that obtained by Pimentel, et al.

The two sets of authors were clearly aware of each other=s work. Each cites the other=s paper. But they largely rely on different sets of primary sources for their estimates. I am neither surprised nor bothered by the differences in results. I think that this simply demonstrates that the science (or perhaps the art) of ecosystem valuation is still in its infancy and that there is still much work to be done in reaching a consensus on what components of ecosystems= functions and services are valuable and what methods and data are appropriate for estimating these values.

These two studies looked at together raise some interesting and challenging questions which were part of our discussion during our workshop sessions. These questions are:

- What do we mean by nature when we say value of nature? or what is it that we are trying to value?
- What do we mean by value? There are several meanings to this term; I will focus my attention on the economic definition of value, which is also the definition implicitly or explicitly adopted by both sets of authors.
- Should we attempt to value nature? If so, why?
- How do we estimate the values of nature's services?
- And finally, do the Costanza, et al. and Pimentel, et al. studies convey any useful information about the value of nature?

My plan is to discuss each of these questions in turn and attempt to provide answers from the perspective of the discipline of economics. By way of preview, my answer to the last question is "no." This is so for several reasons:

- These authors have not formulated meaningful questions.
- Some of their estimates rest on a questionable biological or ecological foundation.
- They have used flawed economic methods
- Some of their results are based on flimsy data.

II. THE MEANING OF NATURE

I take nature to mean the collection of all of the ecosystems on earth, that is, all the living organism, their interactions with each other, and with their physical environments. This is a more all encompassing definition of nature than that presented by Gilfillan (1999). But since we are both focusing our attention on the services to humans, there is no real conflict between these two definitions.

Several authors have addressed the question of whether humans are part of nature or are something apart from nature. For example, McKibben speaks of "nature" as "the separate and wild province, the world apart from man . . . (1989, pp. 48)." But I think that this is a misguided view, at least from an ecological perspective. We are part of nature because we interact with other organisms and with our physical environment. We have impacts on other organisms and they have impacts on us. And this has been so at least to some degree since the emergence of the human species. Also, as Gilfillan (1999) showed, we are not the only species that can have profound impacts on the structure and functioning of our environment. We have this capability in common with, for example, sea otters, African elephants, and a variety of exotic plant species such as purple loose-strife and kudzu.

III. ECONOMIC AND OTHER CONCEPTS OF VALUE

I briefly discuss two concepts of value: intrinsic value and instrumental value. Simon will have more to say on this question in his contribution to this set of papers. I will argue that although the concept of intrinsic value is attractive in many respects, it does not provide a basis for dealing with the kinds of questions that I will identify below in trying to answer the "Why value nature?"question. The concept of instrumental value and in particular the economic form of instrumental value is well suited to helping answer these questions.

Intrinsic Values. Something has intrinsic value if it is deemed to be "valuable in and of itself, not because of what it can do for us (Callicott, as quoted in MacLean, 1985, p. 11)." Or, "something is of intrinsic value if it is good or desirable in itself (Singer as quoted in MacLean, 1985, p. 15)." Some people have argued that nature has intrinsic value for various reasons including because of its "harmony" or its natural balance. But from the perspective of the Anew ecology@ which emphasizes disturbance and change in ecosystems (Botkin, 1990), this view of an intrinsic value in nature is very problematic.

A conservation biologist might argue that the part of nature consisting of the variety of organisms and their interactions and especially their genetic diversity has intrinsic value. I am sympathetic to this view. But this view does not endow any particular manifestation of nature with intrinsic value. Nature=s value is preserved as long as diversity in the broad sense is preserved. This concept of value is not a useful guide to dealing with the kinds of questions I discuss below.

Instrumental Values. Something has instrumental value if it is valued as a means to some other end or purpose (Singer, as quoted in MacLean, 1985, p. 15).@ In this view, the value of something lies in its contribution to some other goal.[1] In order to assess the instrumental value of nature, it is necessary to specify a goal and to identify the contributions that specific

[1]See, for example, Costanza and Folke, 1997, p. 49.

components of nature make toward the furtherance of that goal.

Economics is the study of how societies organize themselves to provide for the sustenance and well-being of their members. Thus in economics, the goal is increased human well-being. And the economic value of something is a measure of its contribution to human well-being. The instrumental economic value of nature resides in the contributions that the variety of ecosystem functions and services makes to human well-being. Ecosystems provide services in the forms of: materials such as food, fiber, and water; the support of human life through the maintenance of an hospitable climate and breathable air; a variety of amenities that enrich our lives and make them more fulfilling; and the decomposition and recycling of at least some of the wastes of human enterprise.

The economic value to an individual of an ecosystem=s service is defined as that individual=s willingness to obtain an increase in the ecosystem=s service.[2] This measure of value can be interpreted as the monetary equivalent of the change in well-being of the affected individual. To obtain the total value of an increase in an ecosystem service flow, the values to each of the affected individuals are summed. Thus, in economics, ecosystems are valued in terms of their ability to satisfy human needs and preferences.

[2]Alternatively, it could be defined as the individual's willingness to accept compensation to agree to a decline in the level of the ecosystem's service.

The value of an ecosystem=s service can be measured, in principle, by using one of two approaches. The first is by observing the choices that people make in their daily lives as they confront opportunities to make trade-offs between more or less of an ecosystem service and something else. The second is by asking them carefully designed and well structured sets of questions about how they would make these trade offs in certain circumstances. Most introductory level textbooks in environmental economics contain more detailed descriptions of these two approaches along with examples of their application.[3]

I must acknowledge that there are some problematic aspects of basing an economic value measure on individuals= preferences and observations of their behavior. I will mention only two. But an extended discussion of this issue would carry us too far afield. First, individuals may be ignorant about what ecosystems do for them. If individuals are ignorant about the contribution that an ecosystem service makes to their well-being, then their observed behaviors or responses to questions will reflect that ignorance rather than the service=s true value to them. And second, individuals= choices and responses to valuation questions are constrained by their income or lack thereof. If the distribution of income is deemed unfair or unjust, then the values revealed or expressed by these individuals lose their claim to moral standing.

IV. WHY VALUE NATURE IN ECONOMIC TERMS?

I think that the best answer to this question stems from our need to make choices about

[3]See, for example, Field (1997) Or Tietenberg (1999).

how to manage the human impact on natural systems. We live in a world of scarcity. This means, among other things, that we can not have all of the desired quantities of all environmental services at the same time. Greater use of one type of environmental service, or greater protection of one type of natural system, comes at the cost of less of something else that matters to us. We face trade-offs and choices. If we are to make the most of our endowment of scarce resources, we must compare what we gain from an activity with what we give up by undertaking that activity rather than something else. And to do this, we need a way of assessing the net impacts of policy changes on human well-being so that we can choose the best mix (in terms of the contribution to human well-being) of service flows from the environment.

There are also other reasons for estimating the economic values of ecosystem services. One is that if we choose to tax pollution on the basis of the damage it causes to us, we need to know not only the direct damage (for example to human health) but also the indirect damage caused by reductions in other environmental service flows. Second, in order to provide incentives for parties to take better care to prevent adverse environmental effects from such things as oil spills and hazardous waste dumps, we have created a system of legal liability wherein parties are obliged to make payments based on the economic damages their activities have caused. Thus an effective liability system requires estimates of the losses of ecological values caused by the parties responsible for these damages.

And third, some countries have begun to make adjustments to their systems of national income accounts that produce estimates of such things as Gross Domestic Product in order to take into account at least some of the damages that economic activity causes to the environment and ecosystems. There is a variety of such adjustments that might be made. These adjustments are often referred to as "green accounting" and they require estimates of the economic values of changes in the flows of services from ecosystems. For a discussion of green accounting in the context of ecological valuation in, see Peskin (1997).

V. AN ECONOMIC THEORY OF ECOLOGICAL VALUE

The first point to make is that the kinds of uses to which ecosystem values would be put require what are called marginal values, that is, the values attached to relatively small changes in the levels of an ecosystem=s service flow, holding other things constant. This is so for at least three reasons. First, most of the ecosystem changes that we will opt to value for management purposes will be relatively small either in magnitude or spatial scope rather than large changes such as the loss of all pollination or nutrient recycling functions. For example, one might be interested in knowing what is the loss of ecological value associated with a 10% reduction in the water retention capability of a wetland. Or the question might be what is the economic value of the loss of 10% of the wetland area within a larger complex of wetlands and other land forms.

The second reason concerns the way in which economic values are defined. They represent the individual=s willingness to pay for a specified change holding all other things equal, especially the availability of other goods and service that might be substitutes for or complements with the good or service being valued. The bigger an ecosystem change being described, the more these other things are likely to be changing too, making the modeling and valuation tasks much more complicated.

The third reason has to do with the measurement of values. The measurement of the value of an ecosystem service is easier if it can be assumed that the value per unit of the service (which is analogous to a price) is constant. But as the level of a specific service changes, its marginal value is likely to change as well in the opposite direction, that is, as the level of the service flow increases, its value, at the margin, decreases, and vice versa. These changes in marginal value are very important in calculating the total values of environmental services.

Estimating the economic value of an ecosystem service involves three steps. The first is determining the size of the environmental change affecting ecosystem structure and function. The second step involves determining how these changes affect the quantities and qualities of ecosystem service flows to people. The third step involves using existing economic methods where available to assess the changes in people=s well-being, as measured in dollars.

When an ecosystem service supports the production of a marketed commodity, the value of a change in that service is derived from the change in the value of the downstream market activity. Three examples of studies that are based on this principle involve the contribution of tidal wetlands to the commercial harvest of blue crabs and commercial fin fish and impact of improved air quality on agricultural productivity.[4]

When ecosystem functions support nonmarket environmental services, we can draw on the tool kit of nonmarket valuation methods to determine the economic values of changes in these

service flows. For example, when a change in an ecosystem service results in an improvement in the quality of outdoor recreational experiences, travel cost and related models of recreational demand can be used to estimate the value of the service flow.[5]

[4]For further discussion and citations, see Freeman (1997).

[5]See Freeman (1993) for a description of these methods. See Freeman (1997) for examples and additional references.

There is a large and growing literature containing estimates of values for changes in a wide variety of service flows based on both market and nonmarket valuation methods. For example, the chapter on the economic value of biodiversity in the Global Diversity Assessment has 10 pages of references to this literature (Perrings, et al. (1995). See also the papers in Daily (1997).

VI. A CRITIQUE OF COSTANZA, ET AL. AND PIMENTEL, ET AL

In the Introduction, I said that these authors had not formulated meaningful questions. Implicitly, the grand total value measures of these two sets of authors show how much compensation the inhabitants of the earth would require to maintain current levels of well-being if all ecosystem services were to cease or biodiversity to disappear. Since such a world would no doubt be uninhabitable, there is no amount of money that would compensate for such a change. As one wag put it, all that Costanza, et al. have done is to seriously underestimate infinity (Toman, 1998). Furthermore, the simultaneous shut down of all ecosystem services is an unrealistic, if not unobservable, scenario. And finally, any answer to such a question would not inform any meaningful policy question, since as discussed above, policy is made at the margins and requires marginal values.

Costanza, et al. have responded to this criticism of their "total value" measure by arguing that it is an analogue to the GNP measure of economic activity. Both measures are calculated by multiplying a unit value or price of something by a measure of the total quantity of that thing (an economic output in the case of GDP and an ecological service in the case of the value of the world=s ecosystem services) and adding up these products across all relevant things (Costanza, et al., 1998). Is the analogy valid? I think not, for three reasons.

First, Costanza, et al. called their number a measure of the total value of the output of nature, implying that GDP is a measure of the total value to us of our national output. But GDP is not a measure of the total value of national output. The main reason is that GDP uses current prices as the unit values of all of the goods and services included in it. But as I pointed out above, as the outputs of specific goods decrease, their prices or marginal values would increase. And these increases in marginal value are very important in calculating the welfare values and total values of outputs of goods and services. Also, GDP includes activities that simply mitigate the negative effects associated with some of the other components of output. And GDP does not include important components of national output, for example home production, and the imputed rental income of owner-occupied housing, that should be included in a valid measure of total value.

Second, and more important, GDP is calculated from a system of accounts designed to avoid double counting of outputs by adding up only the value added at each stage of production. For example, the statisticians who calculate GDP do not simply sum the value of output of flour and the output of bread since the latter includes the value of the flour that went into its making. To do so would count the value of the flour twice. Both Costanza, et al. and Pimentel, et al. have double counting in their measures. For example, the value of biological pest control and pollination are calculated separately and added to the value of food production from grass lands and crop land, thus counting the pest control and pollination values twice.

And finally, Costanza, et al.=s and Pimentel, et al.=s comparisons of the value of nature with the value of GDP also involve double counting. This is because many of the components of their measures are also components of GDP itself.

The second basis for critiquing these studies concerns the weak biological or ecological foundations of some of the components of the totals. One example, the basis for the value of biological control presented by Costanza, et al., will suffice. Costanza, et al. provided estimates of the value of biological control for each of the marine biome types and for grass/rangelands and temperate forests. The published article emphasizes the reasons for estimating the values of ecosystem services and discusses the overall result The details of the data and methods used are contained in an appendix that can be downloaded from the Nature Web Site (www.nature.com). The meaning of the term "biological control" was unclear to me in the context of the Appendix. In the ecology texts that I consulted, the term is used to describe pest control (de Groot, 1992, p. 62; Begon, Harper, and Townsend, 1990; Ricklefs, 1993) and pollination (de Groot, 1992, p. 63).

Since it was unclear to me how marine biomes provide pest control and pollination services, I queried the authors. I was told that the term refers to "the regulation of ecosystem structure and function through trophic dynamics (Karin Limburg, personal communication, July 23, 1998). As Costanza, et al. note in their Table 1, examples of biological control include "Keystone predator control of prey species, [and] reduction of herbivory by top predators." Given this definition, an example of a valuable biological control function in a marine biome could be the role of sea otters in controlling sea urchin populations and permitting the establishment of kelp forests that serve as food sources and shelter for many marine organisms. This example suggests that the nature of the function and its value are likely to be quite specific to the species involved and to the particular ecosystem.

But it clear that some forms of "predator control of prey species" could have negative economic values by reducing the flows of economically valuable services from ecosystems. For example, it is said that mature cod prey on immature lobsters in the Gulf of Maine and that the collapse of the cod stock may be a contributing factor in the recent record landings of lobsters. If so, then it is the loss of the biological control function that has positive economic value, at least in the short run.

So their estimate of the economic value of this ecological service rests on an inadequate consideration of the specific predator-prey relationships that matter in these biomes and how changes in these relationships affect the flows of services to people.

As for flawed economic methods, I will discuss two examples here, the use by Costanza, et al. of replacement cost values and the treatment of the costs of using nature=s services.[6] It is often suggested that the cost of replacing a function of an ecological system with a human engineered system can be used as a measure of the economic value of the function itself. In a classic example, Gosselink, Odum, and Pope (1974) used an estimate of the cost of a tertiary sewage treatment as the economic value of the nutrient removal function of a tidal wetland. However, replacement cost can be a valid measure of economic value only if three conditions are met: the human-engineered system must provide services of equivalent quality and magnitude, the human-engineered system must be the least costly alternative, and individuals in aggregate must, in fact, be willing to incur these costs if the natural service were not available (Shabman and Batie, 1978). Note that when these conditions are not met, there is no presumption that replacement cost is either an overestimate or an underestimate of true economic value; all that

[6]For similar but more brief discussion of these problems in the Pimentel, et al. analysis, see Freeman (1998).

can be said is that the two numbers are measures of different things.

When replacement costs are used as the basis for valuation, authors should attempt to make a showing that it is reasonable to believe that these conditions are met or at least that they are not wildly implausible. Costanza, et al. used replacement cost to estimate values for nutrient cycling in marine ecosystems which is about 46% of the grand total and both sets of authors used it for treatment of organic wastes. Neither made any effort to establish that the above conditions are satisfied. Given the importance of these services in the grand totals, this question deserves some attention.

Nutrient cycling refers to the ongoing processes of uptake of inorganic nutrients by plants, their passage along the food chain, and their ultimate conversion back to inorganic form by decomposers, detritivors, and various physical processes. Costanza, et al. focus on the two primary nutrients, nitrogen and phosphorus, and assume that the ocean waters are serving as sinks for these elements. They say, "If the oceans were not there, we would have to recreate this function by removing N and P from land runoff and recycling it back to the land (Notes, p. 2),"[7] and they estimate the cost of doing this to be equal to the cost of advanced municipal wastewater treatments of sufficient size to handle the required flow.

What would be the consequences for human welfare of not doing this? Would we be

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[7]"Notes" refers to the Notes to Table 2 in the Appendix that was available on the Nature web page.

willing to spend $17 trillion to send all of the runoff from land through waste water treatment systems in order to remove these nutrients? Costanza, et al. do not address this question. If the oceans existed but were devoid of life, nutrients would accumulate in the water and/or settle out to the bottom; but with no life in the oceans, it is difficult to see what the further adverse consequences of this to human welfare would be and why we would be willing to spend huge sums to prevent it. This is not to deny that there can be problems associated with excess nutrients in our oceans and estuaries. See, for example Malakoff (1998). But the proper approach to valuing these impacts is to estimate the economic values of the other ecosystem services that are impaired because of the nutrient imbalances.

The second methodological flaw concerns the treatment of the costs of suing nature=s services and the difference between gross and net value. A basic concept in resource economics is rent, where rent is defined as the total value of the flow of a good or service from the environment less the cost of harvest or extraction. For small changes in the level of the service flow (so that price or unit value can be taken as constant), rent is a measure of nature's contribution to the total value of the flow. Similarly, harvest or extraction cost represents the contribution to total value made by the labor, capital, etc. used in extracting or harvesting the flow.

Costanza, et al. recognize this point in their discussion of Figure 1 (p. 257) and in their calculations of the values of food and raw materials from Forests and Grass/Rangelands. But they are inconsistent in their application of this principle. Specifically, for food production from marine biomes, they use the landed value of the harvest, which includes harvest costs to arrive at their estimate of value of about $0.8 trillion (about 2% of the total). Since most of the ocean fisheries are open access and are not being effectively managed, economic theory predicts overcapitalization and dissipation of rent. Thus one could argue that a better estimate of net economic value would be zero. Actually, many of the world's fisheries receive substantial subsidies from misguided governments. The Food and Agricultural Organization has estimated that in 1989 the actual cost of the harvest exceeded the landed value by $54 billion, largely because of subsidies (Food and Agricultural Organization, 1993 as cited in Myers, 1998). Accounting for these subsidies would result in a negative realized value for the oceans' food production services under current management and policy.

Finally, a number of examples of flimsy data and poor documentation in the Costanza, et al analysis are noted in the Appendix to this paper.

VII. CONCLUSIONS

How much is nature worth? Or more accurately, how much are ecosystem services worth? A lot! Ecosystems are very valuable because they provide a wide array of services that enhance our well-being. The Costanza, et al. and Pimentel, et al. estimates are useful in that they call attention to this fact. But that is as far as I am willing to go in finding usefulness in these studies.

Estimates of values of changes in ecosystem service flows are very important to help us make better decisions about managing the impacts of human activities on ecosystems. But neither Costanza, et al.=s nor Pimentel, et al.=s numerical estimates of value can be taken seriously. Neither group has posed a meaningful valuation question because they have both posed a poorly defined (to be charitable) or meaningless hypothetical alternative, that is, a world with no species or no ecosystems. Furthermore in calculating their estimates of various components of their total values, they have engaged in double counting, use seriously flawed methods, and relied on flimsy data. The Costanza, et al. paper received a lot of favorable attention in the national media and has been welcomed by many people in the natural sciences. See, for example, the commentary by Stuart Pimm that accompanied the published article. I have to believe that many people fancied the shiny paint job but never looked under the hood to see how the drive train was put together.

Finally, I think that we will never be able to say how much nature is worth. But it is within our grasp to provide estimates of how much changes in specific ecosystem services are worth to us. And this is the kind of information we need to make wise choices about managing and protecting the sources of these service flows. The efforts to obtain such estimates are creating exciting opportunities for interdisciplinary research involving economists, ecologists, and others. It is vitally important that this research make use of sound economic methods and also that it be based on the best possible understanding of how ecosystems work and what the world would be like if various ecosystem services and functions were to be seriously impaired or even eliminated.

APPENDIX

CRITIQUE OF DATA IN COSTANZA, ET AL. ANALYSIS

1. Costanza, et al. estimate the value of biological control from coral reefs to be $5.00/ha/yr, citing de Groot (1992). But de Groot says,

> "No specific benefits (or costs) could be attributed to the biological control functions in Galapagos. Therefore, no monetary value is included in table 4.3.5-1 for this function (de Groot, 1992, p. 224)."

2. The cultural value of wetlands is estimated at $.291 trillion. But the only support for this estimate is the following: "The cultural value of wetlands is considerable although little research has been done on this service. The only references found relate to calculations of the influence of the aesthetic value of wetlands on real estate prices (Notes, p. 16)."

3. The cultural value of continental shelf waters is estimated to be $.186 trillion. There is no documentation for this value in "Notes."

4. The source for Costanza, et al.'s estimate of the value of raw materials from sea grass/algae beds is Norse (1993). The materials are kelp, agar, and carageenan. But Norse provides no references or documentation of how the estimates were derived. It is also unclear whether Norse's estimates are based on revenues or are net of costs.

5. Costanza, et al. attribute $.422 trillion in waste treatment services to forests. There is no documentation for this estimate.

6. There is no documentation for any of the values in Table 2 for the cropland biome.

7. Costanza, et al. estimate the value of pollination by insects in the grass/rangeland and cropland biomes to be $.117 trillion, citing Pimentel, et al. (1996). In the published version of

the Pimentel, et al. paper (Pimentel, et al., 1997), the global value of insect pollination of food and forage crops is given as $.2 trillion. There is no explanation for this difference.

8. Waste treatment is about 5% of the total value of all services. The largest source of waste treatment services (about 60%) is tidal and freshwater wetlands. Costanza, et al. provide replacement cost values; but they do not give the source of these costs. Costanza, et al. also attribute $.422 trillion in waste treatment services to forests. There is no documentation for this estimate.

9. Costanza, et al. report a value for biological control for grass/rangelands, citing Pimentel (1996) as the source. But this service is not described or valued in the published version of this paper (Pimentel, et al., 1997).

10. Values for recreation services are presented for wetlands and forests. But there is no documentation for either value in "Notes."

11. Costanza, et al. provide an estimate of the value of raw materials from the open oceans. They note that limestone may be formed in shallow ocean basins by the deposition of calcium carbonate from marine organisms. After estimating the rate of formation of limestone, they value the stone at the market price of landbased quarried limestone, net of the cost of quarrying the stone. The correct approach is to value the stone at the market price less the cost of quarrying it from the ocean floor. If, as seems likely, the cost of ocean quarrying exceeds the market value of the stone on land, then ocean quarrying is uneconomic and there is no economic value attributable to the formation of this stone.[8]

[8] Actually, if the rate of depletion of landbased limestone were such that ocean quarrying would eventually become economic, the current deposits of ocean limestone would have a small positive value today. But emphasize "small," because of discounting.

12. The estimated value of food production from the open oceans is about $.5 trillion and from the coastal waters about $.29 trillion. These values are based on estimates of the potential catch rather than the actual harvests of recent years. So, the implicit assumption is that all global fisheries are managed to maximize sustained yield, a state that so far has eluded fisheries managers around the world. The way fisheries are managed can have a significant effect on the realized economic values of the resource (Freeman, 1991).

13. Values for recreation are estimated for grass/rangelands and lakes and rivers. These are based in whole or part on spending or revenues rather than on the conceptually correct consumer surplus. Yet there is a substantial empirical literature on recreation values. For reviews of parts of this literature, see Smith and Kaoru (1990), Walsh, Johnson, and McKean (1990), and Freeman (1995).

14. About a quarter of the estimated nutrient cycle value is attributed to Seagrass/Algae Beds. This is difficult to understand, since this biome is not likely to be a significant sink for nutrients. Rather the nutrients taken up by these plants will be released as the plants are eaten or die and decay. 15. Finally, Costanza, et al. provide estimates of the values of three service flows provided by coral reefs: waste treatment, habitat/refugia, and raw materials. The values are based on de Groot's studies of ecological functions in the Galapagos National Park (de Groot, 1992). However for these three service flows, de Groot's estimates are not for coral reefs alone but are for larger and/or different parts of the Galapagos ecosystems. For waste treatment, de Groot's estimate is for the recycling of wastes done by "the Galapagos shelf-sea environment (de Groot, 1992, p. 223)." For habitat/refugia, de Groot's value is for the "many inlets and mangrove lagoons (de Groot, 1992, p. 224)." And for raw materials, the value is for "the extraction of

natural resources (timber, rocks, sand and gravel) from the Special Use Zones ... which are usually located at the border between the colonized zone and the national park (de Groot, 1992, pp. 229-230)."

REFERENCES

Baskin, Yvonne. 1997. The Work of Nature: How the Diversity of Life Sustains Us, Island Press, Washington, DC.

Begon, Michael, John L.Harper, and Colin R. Townsend. 1990. Ecology: Individuals, Populations and Communities, Boston: Blackwell Scientific Publications.

Botkin, Daniel. 1990. Discordant Harmonies: A New Ecology for the Twenty-First Century, Oxford University Press, New York.

Costanza, Robert, et al. 1997. "The Value of the World's Ecosystem Services and Natural Capital," Nature, vol. 387, pp. 253-260.

Costanza, Robert, et al. 1998. "Costanza and His Co-authors Reply," Environment, vol. 40, no. 2, pp. 26-27.

Daily, Gretchen C., ed. 1997a. Nature's Services: Societal Dependence on Natural Ecosystems, Island Press, Washington, DC.

Daily, Gretchen C., et al. 1997b. "Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems," Issues in Ecology, No. 2.

de Groot, Rudolf S. 1992. Functions of Nature: Evaluation of Nature in Environmental Planning, Management and Decision Making, Amsterdam,: Wolters-Noordhoff.

Field, Barry C. 1997. Environmental Economics: An Introduction, 2nd ed., McGraw-Hill, New York.

Food and Agricultural Organization. 1993. Marine Fisheries and the Law of the Sea: A Decade of Change, Rome.

Freeman, A. Myrick III. 1991. "Valuing Environmental Resources Under Alternative Management Regimes," Ecological Economics, vol. 3, no. 3, pp. 247-256.

Freeman, A. Myrick III. 1993. The Measurement of Environmental and Resource Values: Theory and Methods, Resources for the Future, Washington, DC.

Freeman, A. Myrick III. 1995. "The Benefits of Water Quality Improvements for Marine Recreation: A Review of the Empirical Evidence," Marine Resource Economics, vol. 10, no. 4, pp. 385-406.

Freeman, A. Myrick III. 1997. "On Valuing the Services and Functions of Ecosystems," in R. David Simpson and Norman L. Christensen, Jr., eds., Ecosystem Function and Human Activities: Reconciling Economics and Ecology, Chapman and Hall, New York.

Freeman, A. Myrick III. 1998. The Economic Value of Biodiversity, BioScience, vol. 48, no. 5, p. 339.

Gilfillan, Edward. 1999. "Valuing Nature: An Ecological Perspective," paper prepared for the Valuing Nature Workshop, Bowdoin College.

Gosselink, James G.,Eugene P. Odum, and R. M. Pope. 1974. "The Value of the Tidal Marsh," unpublished, Department of Marine Sciences, Louisiana State University, Baton Rouge, LA.

MacLean, Douglas. 1985. "Environmental Ethics and Human Values," unpublished.

Malakoff, David. 1998. "Death by Suffocation in the Gulf of Mexico,"Science, vol. 281, (July 10, 1998), pp. 190-192.

McKibben, Bill. 1989. The End of Nature, Random House, New York.

Myers, Norman. 1998. Perverse Subsidies: Tax$s Undercutting Our Economies and Environments Alike, Winnipeg, Manitoba: International Institute for Sustainable Development.

Norse, Elliott A., ed. 1993. Global Marine Biological Diversity: A Strategy for Building Conservation into Decision Making, Washington, DC.: Island Press.

Pearce, David. 1998. "Auditing the Earth: The Value of the World=s Ecosystem Services and Natural Capital," Environment, vol. 40, no. 2, pp.3-28.

Perrings, Charles, et al. 1995. "The Economic Value of Biodiversity," in V. H. Heywood, ed., Global Biodiversity Assessment, Cambridge University Press, New York.

Peskin, Henry M. 1997. A.Green. "Accounting for the Chesapeake Bay," in R. David Simpson and Norman L. Christensen, Jr., eds., Ecosystem Function and Human Activities: Reconciling Economics and Ecology, Chapman and Hall, New York.

Pimentel, David, et al. 1996. "Economic and Environmental Benefits of Biodiversity," (Unpublished).

Pimentel, David, et al. 1997. "Environmental and Economic Benefits of Biodiversity," BioScience, vol. 47, no. 11, pp. 747-757.

Pimm, Stuart L. 1997. "The Value of Everything," Nature, vol. 387, pp. 731-732.

Ricklefs, Robert E. 1993. The Economy of Nature, 3rd ed., New York: W. H. Freeman.

Shabman, Leonard A., and Sandra S. Batie. 1978. "The Economic Value of Coastal Wetlands: A Critique," Coastal Zone Management Journal, vol. 4, no. 3, pp. 231-237.

Smith, V. Kerry, and Yoshiaki Kaoru. 1990. "Signals or Noise? Explaining the Variation in Recreation Benefit Estimates," American Journal of Agricultural Economics, vol. 72, no. 2, pp. 419-433.

Tietenberg, Tom. 1999. Environmental and Natural Resource Economics, 5th ed., Addison-Longworth-??, Boston.

Toman, Michael. 1998. "Why Not to Calculate the Value of the World' Ecosystem Services and Natural Capital," Ecological Economics, vol. 25, no. 1, pp. 57-60.

Walsh, Richard G., Donn M. Johnson, and John R. McKean. 1990. "Nonmarket Values from Two Decades of Research on Recreation Demand," in Arthur N. Link and V. Kerry Smith, eds., Advances in Applied Microeconomics, vol. 5. Greenwich, CT.: JAI Press.