DISCUSSION PAPER

January 2006 ■ RFF DP 06-02

What Are Ecosystem Services?

The Need for Standardized Environmental Accounting Units

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Abstract

This paper advocates consistently defined units of account to measure the contributions of nature to human welfare. We argue that such units have to date not been defined by environmental accounting advocates and that the term "ecosystem services" is too ad hoc to be of practical use in welfare accounting. We propose a definition, rooted in economic principles, of ecosystem service units. A goal of these units is comparability with the definition of conventional goods and services found in GDP and the other national accounts. We illustrate our definition of ecological units of account with concrete examples. We also argue that these same units of account provide an architecture for environmental performance measurement by governments, conservancies, and environmental markets.

Key Words: Environmental accounting, ecosystem services, index theory, nonmarket valuation

JEL Classification Numbers: Q51, Q57, Q58, D6

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1. Introduction

This paper articulates a precise definition of "ecosystem services" to advance the development of environmental accounting and performance systems. Colloquially, ecosystem services are "the benefits of nature to households, communities, and economies." The term has gained currency because it conveys an important idea: that ecosystems are socially valuable and in ways that may not be immediately intuited (Daily 1997). Beyond that, however, ecology and economics have failed to standardize the definition and measurement of ecosystem services. In fact, a brief survey of definitions reveals multiple, competing meanings of the term.[1] This is problematic because environmental accounting systems increasingly are adopting "services" as the units they track and measure. The development and acceptance of welfare accounting and environmental performance assessment are hobbled by the lack of standardized ecosystem service units. To address that problem, this paper proposes a definition of services that is objective, rather than qualitative, and rooted in both economic and ecological theory. A virtue of the definition is that it constrains, and thereby standardizes, units of ecosystem account.[2]

Loose definitions undermine accounting systems. They muddy measurement and lead to difficulties in interpretation. Our ultimate goal is the development of national-scale environmental welfare accounting and performance assessment, potentially consistent with national income accounting and hence a broad "green GDP."[3] Accordingly, we seek more

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[1] See Section 5.

[2] Similar debate over the definition of goods and services in the conventional economic accounts has taken place over the last hundred years. Today, we take these definitions largely for granted (e.g., the units of goods measured by GDP or the bundle of goods used to calculate the cost of living). In fact, they are the product of decades of debate within government and the economics profession.

[3] This goal is widely shared (Nordhaus 2005; World Bank 2005; U.S. Bureau of Economic Analysis 1994; United Nations Environment Programme 1993).

rigorously and consistently defined ecosystem service units. In this context, an operationally useful definition of services will be clear and precise, consistent with the principles of the underlying ecology, and with the economic accounting system to which it relates.

The paper proceeds as follows. First, we demonstrate the public policy demand for standardized units of ecosystem measurement. Second, we advance and defend an economic definition of units of account. Third, we contrast this definition with existing definitions of services and environmental accounting units. Fourth, we concretely illustrate our definition via an inventory of measurable ecosystem services.

Clear units of account are fundamental to two policy initiatives whose social desirability we take as self-evident: the effective procurement of environmental quality by governments and clear national measures of well-being arising from environmental public goods and market goods—otherwise known as a green GDP.[4] As we will argue ultimately, one particular set of accounting units is applicable to both of these broad applications. Before turning to our definition, however, we discuss the need for standardized units, relate them to accounting and procurement, and explain why such units have been slow to develop.

2. Standardized Units Will Improve Environmental Procurement and Accounting

If green accounting is to be taken seriously, the accounts must not be only concerned with the ways in which services are weighted (the missing prices problem) but also with the definition of services themselves. Moreover, it is desirable to define ecosystem service units in a way that is methodologically and economically consistent with the definition of goods and services used in the conventional income accounts. In a nutshell, the national income accounts add up things bought and sold in the economy, weighted by their prices, in order to arrive at an aggregate, such as the nation’s gross domestic product (GDP). These accounts are by no means simple to devise, but they are aided by two kinds of readily available data. The first kind of data are prices. The second kind of data are the units of things bought and sold (cars, homes, insurance policies, etc). Because these things are traded in markets, we tend to take their units for granted. Everyone

[4] In this article, “green GDP” denotes explicit accounting for the services of ecosystems enjoyed by people, the approach advanced by Mäler (1991); Peskin and Angeles (2001); and Grambsch, Michaels, and Peskin (1993). This is different from, but not inconsistent with, depreciating changes in ecosystem stocks (Repetto et al. 1989, U.S. BEA 1994). For overviews, see Hecht (2005), Lange (2003), and Nordhaus and Kokkelenberg (1999).

knows what a car or a house is. If we are to similarly account for environmental welfare, however, we run into an immediate problem: there are no such defined units.

Because most ecosystem services are public goods, markets are not available to provide clear units of account. This point can be made most forcibly if we consider the challenge of creating markets for ecosystem services. In practice, such markets tend to stumble over the issue of trading units. When regulators attempt to compensate for ecological losses, they inevitable rely on coarse units for trade, such as “acres of wetland,” “pounds of nitrogen,” or “equivalent habitats.” These units are coarse because they are compound bundles of multiple goods and services. In other words, a wetland provides numerous distinct public and private benefits, not just one. The imprecision of these measures is understandable but problematic from a policy perspective. Ideally, we want to disentangle the benefits to account for them. When course, compound units are exchanged in trade or to compensate for damages, there is no guarantee that what we really care about is preserved: namely, the benefits of nature.[5]

The problem with ecosystem service markets is that the market itself does not define the units of trade (whereas conventional markets do). Instead, units of trade and compensation have to be defined by governments, governments being the trustees of environmental quality. This is a point often missed by advocates of trade in ecosystem services. In a conventional market, the buyer is concerned selfishly about the quality of the “unit” they buy. In an ecosystem market, the environmental good is a public good and the buyer is therefore indifferent to its quality. The buyer is concerned only about satisfying the regulator’s definition of an adequate unit. The question then is, do governments do a good job of defining units and policing their quality? There is ample evidence that they have not.[6] An aim then of our inquiry is to advocate units that will improve governments’ ability to consistently and defensibly measure and police environmental quality affected by regulation, ecosystem trades, compensation, and expenditures.

While the challenge is significant, the history of markets and income accounting gives us hope that such problems can be overcome. We draw three lessons in particular. First, for millennia governments have played an active role in creating and stabilizing markets by

[5] Our perspective throughout is that the goal of social policy is to maximize human well-being, rather than a purely ecological objective.

[6] See U.S. General Accounting Office (2005b) (wetlands); Ando and Khanna (2004) (natural resource damage compensation); Houck (2002) and Bingham and Desvousges (2005) (water quality); and U.S. General Accounting Office (2000) (federal land swaps).

establishing uniform weights and measures and monetary units of account. The fact that these measures are now firmly entrenched in tradition makes the role of governments easy to forget but no less important. Second, as national income and price accounts were established in the early decades of the last century, the pioneers of those systems faced daunting problems of their own. They did not have "readily available" prices and quantities. They had to gather those data. Moreover, they often faced a great deal of heterogeneity in product quality and in the forms of price quotes (apples of various grades, each by pound, bushel, or number). Finally, even today, the keepers of price and income statistics are faced with ever-shifting heterogeneity (faster cars, bigger houses, etc.). Each of these problems has posed challenges for the best way to define conventional marketed goods and services.[7] Though in the task of defining ecosystem services we cannot turn to the activities of actual markets, we can benefit from these models.

If the nation's environmental status is to be characterized and tracked over time, units must be clearly defined, defensible ecologically and economically, and consistently measured. At present, the government and the public are presented with an over-abundance of poorly defined units of measurement that are unclear in their origin and that exacerbate the divide between economic and ecological analysis.[8] Often within a single agency there are multiple, competing paradigms for what should be measured. The balkanization of performance measurement confuses decision-makers and the public and thus hampers the public's ability to judge whether governments are effectively procuring environmental benefits. While we risk adding to this confusion, the way out of it is to debate and defend definitions that are rooted in ecological and economic science.

While environmental economics has grappled for decades with the challenge of missing prices for environmental amenities, it largely has neglected the other central issue: the consistent definition of the environmental units to which value can be attached. Why is this? There are two main reasons. First, environmental economics historically is more concerned with the valuation of discrete actions, damages, or policies than with the comparison of benefits across time. Second, ecological valuation often relies on marketed outputs of nature, such as harvests, to derive a (partial) value of nature. Economists do this for a reason: because there are prices and

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[7] See Banzhaf (2001).

[8] For a broad overview, see U.S. General Accounting Office (2004) and U.S. General Accounting Office (2005a).

units available! But this dodges the issue of interest here: units related to nature's public goods and services.

3. The Architecture of Welfare Accounts

We seek to clarify the meaning of ecosystem services within the context of both an economic accounting system and ecological models.[9] From the standpoint of economic accounting, we seek a framework that is analogous to GDP. This provides the discipline of an existing, logical system. It also provides an opportunity to create a broader green GDP that can provide an aggregate measure of well-being that encompasses human and natural production (Mäler 1991; Peskin and Angeles 2001; Grambsch, Michaels, and Peskin 1993; Banzhaf and Boyd 2005). Within such a framework, ecosystem services are weighted by their virtual prices (or marginal willingness to pay) and aggregated in the same way as market goods and services in GDP. This allows for direct comparison of ecosystem-related inputs to well-being and other inputs such as labor and capital.

An important point—and a motivation for this paper—is that welfare accounting requires consistent separation of quantity and price measurements. To consistently track changes in welfare over time, the weights (prices) assigned to particular outputs are held fixed over time. The welfare change is thus driven purely by changes in quantities of goods and services.[10] The implication is that accounting economics demands a precise definitional distinction between quantity and price. This challenge is unique to index theory and measurement. It does not arise in environmental valuation, for instance, where the focus has been on cost–benefit applications. There total benefits—the product of quantities and values—are all that is important.

An example will illustrate this. Consider a cost–benefit analysis of an air quality improvement in Los Angeles. Many things matter to this valuation, including the population benefiting from the improvement. Is LA's population a measure of the quantity of the improvement or the value of the improvement? In a cost–benefit analysis, the answer is, "it doesn't matter." If the environmental improvement (the quantity) is defined as health benefits per capita, then LA's population affects the total willingness to pay (the value). If, on the other hand,

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[9] Ecologists too are calling for more consistent measurement that accounts for the scale over which biophysical phenomena occur (Kremen 2005).

[10] If prices and quantities are both allowed to change, a variety of problems arise. Collectively, these are known as the "index number problem."

the environmental improvement (the quantity) is defined as health benefits to the citizens of LA, population appears in the quantity measure, not the willingness to pay measure. Either way, population is included in the total and the total is all that matters. Cost–benefit analysis does not lead to a consistent distinction between *q* and *p* because there is no reason for a consistent distinction.

This distinction between prices and quantities also has been obscured in several existing applications of green GDP that calculate GDP for a single time period or separately for separate time periods (Peskin and Angeles 2001; Grambsch, Michaels, and Peskin 1993).[11] Such static analyses do not require the price/quantity distinction either, since the marginal value weights are not changing at a single point in time. However, this kind of accounting is analogous to the measurement of nominal, rather than real, GDP. To track real service flows over time, quantities and prices must be measured separately, or nominal GDP must be adjusted with an appropriate deflator (Banzhaf 2005; Flores 1999).

With this basic architecture, we must make one additional choice: to measure all sources of ecological value or only those not already captured in GDP. This choice is the choice between two alternative accounting strategies: green GDP and what we call an ecosystem services index (ESI). As we use the term, green GDP aggregates all sources of well being, including goods and services produced with non-ecosystem services, into a single index. By contrast, an ESI (Banzhaf and Boyd 2005) isolates the contributions of nature to well-being. The way in which an ESI relates to green GDP helps to illustrate the practical measurement of ecosystem services.

It is important to note that conventional GDP is already somewhat green insofar as it includes the value of ecosystems to the production of marketed goods and services. For example, ecosystem services that contribute to crop production are captured in GDP because food is counted and weighted in GDP. The value of food purchased at the grocery store includes the net value added at the store itself, during transportation and storage, at the farm, and so on, including such inputs to the farm as fertilizer, seed, and machinery. GDP can be measured equivalently as the gross value of the final goods (purchased at the store) or as the net value added at each of these stages. Green GDP can be thought of as GDP plus the value of final ecosystem services directly enjoyed by households. Of course, some ecosystem services are inputs into final market

[11] We are referring to frameworks that account for environmental service flows. Green applications of the net GDP concept, which deflate environmental capital, are dynamic in a different sense (Repetto et al. 1989; U.S. BEA 1994).

goods (like food) and are not enjoyed directly by households. As we define it, an ESI includes the value of final ecological services (i.e., green GDP minus ordinary GDP) plus the value added by the ecosystem to market goods. A third, equivalent measure of GDP is the sum of all factor payments to labor (wages), capital (interest), entrepreneurs (profits), and privately owned land or other resources (rents). As illustrated in Figure 1, the ESI accordingly also can be thought of as (virtual) factor payments to the ecosystem.[12]

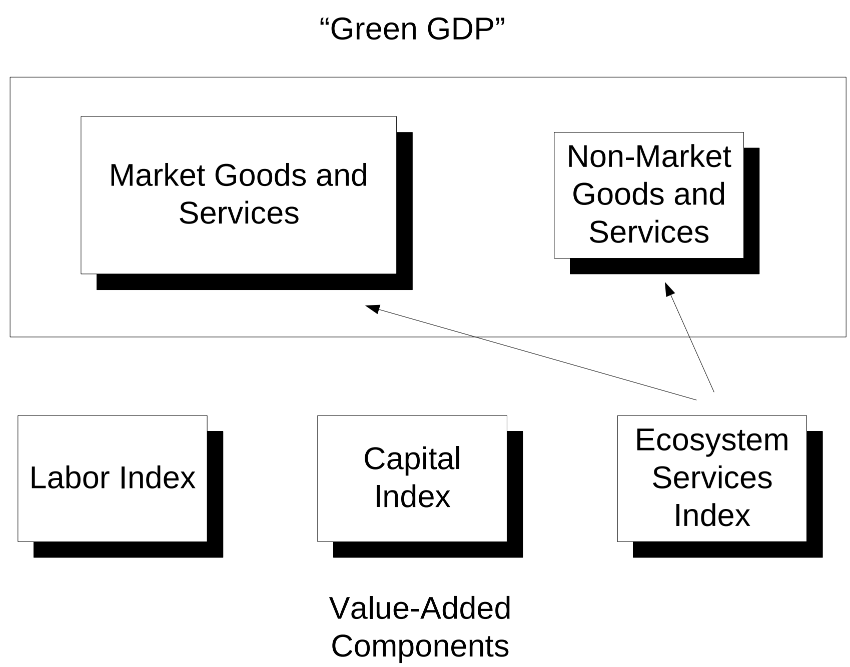

Figure 1. Green GDP vs. an Ecosystem Services Index

When all ecosystem services are measured and aggregated according to our definition, the aggregation represents an index of nature's total contributions to welfare. It is an index of ecological value added. Thus, it is not the same thing as green GDP, and it cannot be simply

[12] Although it may appear novel, this accounting identity is simply the realization of the general equilibrium associated with the well-known system of virtual (or shadow) prices. Virtual prices are the prices that people would be willing to pay for the level of ecosystem services that they in fact receive, if their income were augmented to cover the increased expenditure. Those virtual payments and the additional virtual income are precisely what are accounted for in green GDP.

added to GDP to arrive at green GDP. To do so would double count the contribution of ecosystem services already captured in market goods and services. Measurement of an ESI, however, is a precondition to green GDP.

4. A Definition of Ecosystem Services

We advance the following definition of an ecosystem service: Ecosystem services are components of nature, directly enjoyed, consumed, or used to yield human well-being.

This deceptively innocuous verbal definition is in fact quite constraining and has important properties from the standpoint of welfare measurement.

One important aspect of this definition relates to the language "directly enjoyed, consumed, or used." This signifies that services are end-products of nature. The distinction between end-products and intermediate products is fundamental to welfare accounting. If intermediate and final goods are not distinguished, the value of intermediate goods is double-counted because the value of intermediate goods is embodied in the value of final goods. Consider a conventional market good like a car. GDP only counts the car's value, not the value of the steel used to make the car. The value of steel used in the car is already part of the car's total value. The same principle holds with ecosystem services. Clean drinking water, which is consumed directly by a household, is dependent on a range of intermediate ecological goods, but these intermediate goods should not be counted in an ecosystem service welfare account.[13]

In addition to being directly used, another important aspect of our definition of ecosystem services is that they are components. This means that services are things or characteristics, not functions or processes. Ecosystem components include resources such as surface water, oceans, vegetation types, and species. Ecosystem processes and functions are the biological, chemical, and physical interactions between ecosystem components. The reason that functions and processes are not services is they are not end-products; functions and processes are intermediate to the production of final services. A manufacturing process can be thought of as an intermediate service in the conventional economy. The value of a manufacturing process is not included in GDP, again because its value is embodied in the value of its end-products. Often, ecological

[13] Care must be taken in use of the terms final and intermediate. As we explain in more detail below, when combined with market goods and services, ecosystem services may be a final service in the sense of being directly enjoyed (aesthetic values, for example) or an intermediate good in the creation of a final market good (agricultural produce, for example).

processes and functions are called services—nutrient cycling, for example. But nutrient cycling is an ecological function, not a service. To be sure, it is a valuable function, but it is an intermediate aspect of the ecosystem and not an end-product.

Many, if not most, components and functions of an ecosystem are intermediate products in that they are necessary to the production of services but are not services themselves. We emphasize that this does not mean these intermediate products are not valuable, rather that their value will be captured in the measurement of services.

A final, important constraint imposed by the definition is that services are not benefits nor are they necessarily the final product consumed.[14] For example, recreation often is called an ecosystem service. It is more appropriately considered a benefit produced using both ecological services and conventional goods and services. Recreational benefits arise from the joint use of ecosystem services and conventional goods and services. Consider, for example, the benefits of recreational angling. Angling requires ecosystem services, including surface waters and fish populations, and other goods and services including tackle, boats, time allocation, and access. For this reason, angling itself—or "fish landed"—is not a valid measure of ecosystem services.

Consider the alternative ways to think about an ecosystem service and its associated value. In particular, consider a marketed input M, a nonmarket input N, and a production function $A=\mathrm{A}(M,N)$ that produces a commodity A. This commodity can be one of many things, including a product, an amenity, or an avoided damage or cost. The respective values of M, N, and A are P_M, P_N, and P_A, where P_M has an available market price, P_N does not, and P_A may or may not.

To illustrate the issue associated with defining the nonmarket service, consider first the input's value. Production theory provides two perspectives. First,

(1) $P_N = (\partial \mathrm{A}/\partial N)P_A$.

The value can be derived from the input's productivity, times the value of the final commodity (see e.g., Freeman 2003, Ch. 9).

[14] The ecosystem service is the end-product of nature, not necessarily the end-product ultimately produced with the ecological end-product.

Repeating this tangency condition for the market good and suitably arranging terms, we also have

$$(2)\ P_N = \frac{\partial A / \partial N}{\partial A / \partial M}\, p_M\,.$$

In other words, the nonmarket input's value can be derived from the value of the market input and the substitutability of the market and nonmarket inputs. This type of relationship is often used in nonmarket valuation studies of home production of health and other commodities (see e.g., Freeman 2003, Ch. 10).

Now consider the effect of a change in the nonmarket input on the total value of the commodity produced. For a change dN, the change in total value is

$$(3)\ (\partial A/\partial N)P_A dN = P_N dN = \frac{\partial A / \partial N}{\partial A / \partial M}\, P_M\, dN.$$

Which part of this expression should be considered the measure of the nonmarket service and which part should be considered the value of that service? Interestingly, the environmental economics literature is surprisingly ambiguous. A classic text on nonmarket valuation, for example (Kopp and Smith 1993, Chs. 2, 7, and 14), variously equates the service with: 1) the change in the nonmarket input, dN; 2) the change in the final commodity, $(\partial A/\partial N)dN$; and 3) the shadow value of the change, $p_N dN$.

Of these three definitions, our preferred measure of the service is the first, dN (Banzhaf and Boyd 2005). The third is inappropriate as it merges value and quantity information. The second, $(\partial A/\partial N)dN$, is harder to rule out. Under this definition, the ecosystem service is the contribution of the ecosystem to production of the final good or service. This definition has three advantages: it is defined in terms of the final good or service consumed by households; it is easily measured in units such as number, pounds, or bushels; and—when the final output is a market good—it has the readily observable value weight P_A.

The difficulty arises because an accounting system requires a measure of the total quantity of services, not marginal changes in those services. In a total quantity framework, our preferred definition of services (dN) is N, the total level of the final ecosystem input to the final good or service's production function. Likewise, the "final goods and services definition" of services becomes A or the total quantity of the final good or service. Unfortunately, this obscures, rather than isolates, the contribution of the nonmarket good. After all, if market inputs increase, A may increase even if the nonmarket input N decreases. Accordingly, total output of the final good or service is a poor measure of nonmarket services.

One solution, of course, is to measure the change in the final good or service holding all nonmarket inputs fixed. If this is possible, we can define the ecosystem service as

(4) $A(\overline{M}, N) - A(\overline{M}, 0)$.

This is a legitimate approach, but note that it requires global knowledge of the production function.[15] Our definition of services does not. However, there is no free lunch. Using our definition of services requires us to shift production function analysis to the analysis of the shadow value p_N. Nonmarket valuation of p_N, for example, requires knowledge of the substitutability of market and nonmarket inputs in the production function, albeit only local knowledge.

We prefer our definition of services, N, however, because it puts the ecosystem inputs on an equal footing with market inputs and outputs by identifying the point at which they come together in production. This is desirable because it means our definition allows for the eventual integration of an accounting system based on our definition into a more comprehensive set of national accounts. In other words, our definition of services is consistent with that used in conventional income accounting, so that our ESI could be combined with conventional GDP for a measure of green GDP (see e.g., Peskin 1989 and Hecht 2005).

In this regard, we stress that the conventional accounts do not measure the analogue to $(\partial A/\partial N)dN$ either. Conventional welfare accounts define goods and services by what can be measured directly. To be sure, this is a known limitation on what is measured by the accounts. For example, GDP does not measure the contribution of computers to computing satisfaction. It simply counts computers, despite the fact that units of computing satisfaction are what are really desired.[16]

Note finally, that our definition of ecosystem is derived from a desire for consistency between conventional market accounting units and ecosystem accounting units. Interestingly, this leads to measurement of units that are in fact biophysical, rather than social or economic in nature. An economic definition of service units therefore leads naturally and necessarily to a

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[15] Another, related approach is to define the service as the marginal contribution: $(\partial A/\partial N)dN$. This is the linearized contribution of the nonmarket input stock. This approach is more tractable, as it requires only local, rather than global, knowledge of the production function. It also is analogous to the price terms. However, it is an odd measure of quantity, overcoming these problems only with the error introduced by the linearization.

[16] See Norhaus and Kokkelenberg (1999, p. 46–47) for a discussion of this example.

bridge between economic and biophysical analysis. No ecologist should think that the economic definition of services leads away from biophysical analysis. In fact, the opposite is true.

5. A Services Inventory

With verbal and mathematical definitions behind us, we now turn to concrete illustrations of services and their measurement. As noted already, ecosystem services are components of nature. The procedure for identifying ecosystem services is to first inventory sources of well-being related to nature and natural resources. By sources of well-being, we mean things like aesthetic enjoyment, various forms of recreation, maintenance of human health, physical damage avoidance, and subsistence or foraged consumption of food and fiber. Once these are identified, ecosystem services are the natural end-products that can be, but that aren't necessarily, used to produce the well-being.

For example, return again to the case of recreational angling, as illustrated in Figure 2. Ecosystem services associated with angling include the water body, visually available natural resources abutting it, and the target fish population. The water body is a service because it is necessary for angling. Visually available natural resources in proximity are a service because they contribute to the aesthetic enjoyment of the angling experience. The target fish population in the water body is a service—assuming that the possibility of a catch is important to the experience. Now consider things that are not ecosystem services associated with angling. The food web and water-purifying land uses on which the target population depends are not services, because they are intermediate products. Why isn't the angler's catch the ecosystem service? The catch is an inappropriate definition because it includes more than the contribution of the ecosystem; it includes the skill of the angler, the quality of equipment, and the time invested.

5.1 Services are Benefit-Specific

An important characteristic of an ESI is that the ecosystem services are contingent on particular human activities or wants.[17] In the angling example, the water body's quality was not a service because water quality is an intermediate good in the provision of the target fish

[17] Or, to risk confusion by proliferation of service concepts, particular "final services" that are enjoyed and that the ecosystem produces.

population (see Figure 2).[18] In other words, its value for angling is embodied in its effect on the fish population.

BENEFIT	Services	Intermediate Components
Recreational angling	The water body The bass population The riparian forest	The water body's quality
Drinking water	The water body's quality	Wetlands, natural riparian land cover

Figure 2. Ecosystem Services for Recreational Angling vs. Drinking Water

However, a services inventory also will include the provision of drinking water as a source of well-being. For drinking water, water of a particular quality is a service directly relevant to a consumption decision. Should a household boil their water, rely on municipal treatment, or choose to drill a well? These decisions depend directly on the chemical composition of the water. This is illustrative of a general implication associated with our definition of services: a given ecosystem component may be a service in one context and not a service in another.

Wetlands are another example of how services are defined by the benefit in question (see Figure 3). For example, wetlands can absorb and slow flood pulses. Accordingly, wetlands are a natural capital substitute for conventional damage-avoidance investments such as dykes, dams, and levees. Thus, wetlands are an ecosystem service associated with flood damage avoidance. However, they are not an ecosystem service associated with drinking water provision—not because they are not important to water quality, but because the water quality itself embodies the wetland's value.

[18] Water conditions such as odor and clarity are ecosystem services because they contribute to the aesthetic experience.

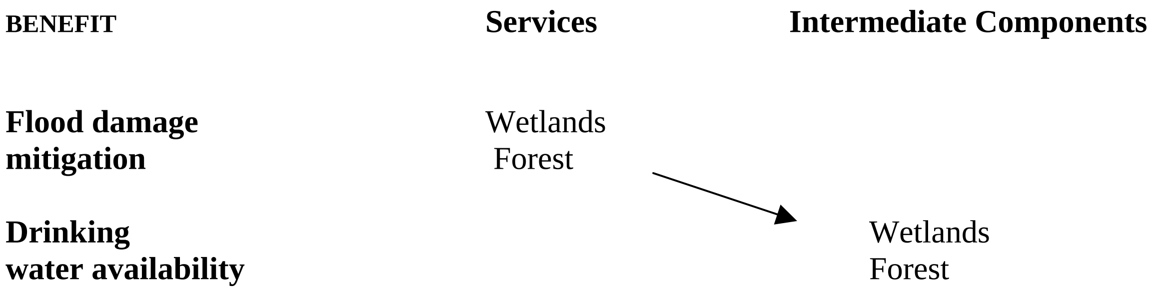

Figure 3. Ecosystem Services for Wetlands

If the benefit-contingent nature of services seems odd, note that the same property is present in conventional welfare accounts. Consider harvested apples. GDP counts apples if they are sold as apples in stores. If, instead, the apples are used to make applesauce, they are not counted (the apples are embodied in what is counted, units of applesauce).

5.2 Proxies for Services: Stocks, Inputs, and Practical Units of Measurement

Note that in many cases, our proposed measure of ecological service flows (outputs) are in fact what an economist would call stocks. The number of fish, as a measure of services into recreational fishing, and the number of bees, as a measure of pollination services, are two examples. This can arise for two reasons. First, as we have emphasized, the theoretically appropriate measure is the ecological input into a human activity (fishing or farming in these two cases). Mechanically, from a modeling perspective, this can be thought of as the component that enters a production function. In some cases, this may be a stock. It is the stock of fish at any given time that determines the landings of a fishing expedition, for example.

In other cases, a stock measure may not be theoretically ideal but may be a pragmatic proxy. In the case of pollination, we ideally want to measure the grains of sexually viable pollen delivered by bees and other insects. “Grains delivered” may not be measurable but may be closely proxied by the number of bees in the area. Similarly, habitats supporting the bee population may be an even more practical proxy.

Again, we can turn to the conventional accounts for support. Even the National Income and Product Accounts, the U.S. Bureau of Economic Analysis, and other national statistical agencies rely on proxies for difficult-to-measure service outputs (see Griliches 1992 for discussion). For example, the real quantity of banking services is difficult to define and observe. Accordingly, banking services are proxied by inputs like labor hours in banking and the number of ATM machines. Similarly, legal services are proxied by hours billed, rather than a more meaningful measure of output. These kinds of measurement shortcuts will have to be employed in the measurement of even harder-to-define ecological services. Nevertheless, proxies should be used with full understanding that they are in fact proxies for what the true service is.

5.3 Services are Spatially Explicit

Ecology is accustomed to the idea that the spatial layout of resources is important to their productivity and quality. Plant and animal species reproduce, hunt, forage, and migrate across the landscape. At the process level, ground, surface, and precipitated water link distant areas. Likewise, food webs can span both the horizontal and vertical dimensions. Ecology depicts a rich set of interrelationships that are spatially explicit.

For different reasons, the social value of ecosystem services also is spatially explicit. Return again to our economic definition of services, where individuals, households, firms, and governments consume ecological components. Typically, ecological components are not spatially fungible—that is, a lake, a fish population, or an attractive forest buffer cannot be transported to another location. Many ecological services are best thought of as differentiated goods with important place-based quality differences. Ecosystem services' scarcity, substitutes, and complements likewise are spatially differentiated. This property is important to measurement. The chain of reasoning is as follows: Unlike cars, which can be transported by buyers and sellers, ecosystem services do not allow for spatial arbitrage. In turn, this means that the benefit of the service is spatially explicit. If the benefit is to be measured and is spatially explicit, the service's units must be spatially explicit.[19] Our service units can be expressed both numerically and visually via geospatial information systems.

5.4 Our Definition of Services Compared to Others'

We have already noted that economists are not consistent in their definition of services (Kopp and Smith 1993, Chs. 2, 7, and 14), equating services with each of the three definitions described in Section 4.[20] But alternatives, and the confusion they cause, also arise outside of

[19] This has important implications for data collection. Even if the quantity of services is the same for everybody in a given area (the same air quality, for example), peoples' values will differ. For prices of market goods, the law of one price may approximately hold true within an area. Because no arbitrage exists to enforce this law for public goods, a wider sampling of prices across households is required.

[20] It should be noted that the authors have in the past themselves fallen victim to similar inconsistency (Boyd and Wainger 2003).

economics. We start with a particularly influential list of services: one from Gretchen Daily's influential book *Nature's Service*. Daily's list of representative ecosystem services is reproduced in the box below (Box 1). The point we wish to convey is that our definition restricts the units of account relative to many ways in which ecosystem services commonly are used.

Box 1. Daily's List of Ecosystem Services

- purification of air and water
- mitigation of droughts and floods
- generation and preservation of soils and renewal of their fertility
- detoxification and decomposition of wastes
- pollination of crops and natural vegetation
- dispersal of seeds
- cycling and movement of nutrients
- control of the vast majority of potential agricultural pests

Many of Daily's "services" are what we would call processes or functions. For example, is water purification an ecosystem service? Not according to our definition. Rather, purification is a function of certain land cover types that help produce clean water. In our terminology, purification is embodied in the production function of the service but is not the service itself. Rather, clean water is the service and is valued for its connections to health, recreation, and so forth. Our insistence on the distinction between intermediate ecological processes and final services may seem like a quibble. From the standpoint of practical measurement, however, it is not. Measuring processes is much more difficult than measuring the outcomes of processes. One reason ecology may have failed to produce accounting units is that ecology is drenched in the analysis of these underlying processes.

Returning to the list, the preservation and renewal of soils and the cycling of nutrients are processes. These processes yield, via a production function, soil characteristics that are services (e.g., a soil's nitrogen content). Or consider the detoxification of wastes.[21] Detoxification is a process embodied in a set of production functions. These functions yield particular air, soil, and water characteristics. Moreover, several of Daly's items are benefits, not services. Consider flood control. Flood control is a benefit to which natural assets can contribute, not a service. Rather, components of the natural landscape that prevent flooding (e.g., wetlands) are the ecosystem services. Wetlands, after all, are an input, along with dikes and other man-made inputs, into the production of property protection. Similarly, "aesthetic beauty and intellectual stimulation that lift the human spirit" are benefits of certain kinds of natural landscape. The services used to create this benefit are more specific components of the landscape, such as undeveloped mountain terrain, unbroken vistas, or a large conifer forest.

Having drawn this distinction, we reiterate that just because something is not a service does not mean it is not valuable. But our corollary is that being valuable is not the same thing as being a service. Recall our earlier examples. In the angling example, the lake's chemical and biological water quality is a valuable input to the production of bass. It is not, however, an angling-related service that we would measure because the bass population as an end-product will embody the value of all the processes and components necessary to create the population. These qualities of the lake are important and valuable but are not services in an economic accounting sense.

Another taxonomic example is the Millennium Ecosystem Assessment (MEA), an ongoing, multinational effort to track ecosystem conditions. The MEA is a good example of an accountability assessment that has adopted the ecosystem services paradigm to motivate measurement. We agree with this paradigm and with many of the tracking measurements suggested. However, the MEA also is a good example of an overly generic definition of services that can confound practical measurement. Here we refer to Table 1, "Global Status of Provisioning, Regulating, and Cultural Ecosystem Services" (MEA, p. 41). Certain delineated services found in this list, such as timber, cotton, wood fuel, livestock, and crops, are consistent with our definition. But when it comes to public goods, the MEA does not deliver particularly constructive definitions. For example, it labels a set of "regulating services" that roughly

[21] Waste assimilation, as an alternative to other forms of waste disposal, is an ecosystem service in our definition.

correspond to the kinds of functions and processes listed by Daily (e.g., pest regulation, disease regulation, hazard reduction, pollination, climate regulation). Some within this category are what we would call functions, some are benefits. The MEA's "cultural services," including "spiritual and religious values, aesthetic values, and recreation and ecotourism," are particularly unsatisfying. These things are benefits and very generic categories at that. None of the "services" listed in these two categories are what we would define as services and there is little guidance given on how to measure these services. Again, we do not take issue with the MEA's general goal, rather we strive for a more operational definition of units of account. Numerous, similar taxonomic examples are available (National Research Council 2005).[22]

5.5 An Illustrative Inventory

Table 1 below expands on our examples to provide a larger inventory of services associated with particular kinds of benefit. Several things should be noted about this list. First, the examples are not exhaustive of either the benefits arising from nature or the ecological services associated with a particular benefit. Second, these are the services associated with an ESI (our measure of the ecosystem's value as a subcomponent of green GDP). Thus, it includes ecological contributions to both market and nonmarket goods and services. Third, each of the illustrated service measures is a generic depiction of a spatially explicit measurement. In other words, wetlands in the table below in practice means "wetlands in a particular location."[23] We envision mapping each service at a relatively fine resolution.

As this inventory of services is compared to others, several things should be kept in mind. First, as we have stressed, an economic accounting perspective does not require the measurement of "all that is ecologically important." Rather, we can economize on measurement by monitoring only the end-products of complex ecological processes. By definition, these end-products are ecological components that are consumed directly or combined with other kinds of inputs (labor, capital) to produce benefits. It is for this reason that our inventory does not include ecological processes or functions. Second, all of the services listed should be measured in the most spatially explicit manner that is practicable. This is because the social value of a particular service

[22] The NRC report provides a verbal definition of services similar to ours, but then illustrates the measurement of services by reproducing a set of taxonomies (including Daily's) with no logical relationship to the definition (Tables 3-2 and 3-3). See Binning (2001) for excellent ecological and economic illustrations of services using a far more expansive definition than ours.

[23] Exceptions are services associated with existence or bequest values.

Table 1. Inventory of Services Associated with Particular Benefits

Illustrative Benefit		**Illustrative ecosystem services**
Harvests		
	Managed commercial[24]	Pollinator populations, soil quality, shade and shelter, water availability
	Subsistence	Target fish, crop populations
	Unmanaged marine	Target marine populations
	Pharmaceutical	Biodiversity
Amenities & Fulfillment		
	Aesthetic	Natural land cover in viewsheds[25]
	Bequest, spiritual, emotional	Wilderness, biodiversity, varied natural land cover
	Existence benefits	Relevant species populations
Damage Avoidance		
	Health	Air quality, drinking water quality, land uses or predator populations hostile to disease transmission[26]
	Property	Wetlands, forests, natural land cover
Waste assimilation		
	Avoided disposal cost	Surface and groundwater, open land
Drinking water provision		
	Avoided treatment cost	Aquifer, surface water quality
	Avoided pumping, transport cost	Aquifer availability
Recreation		
	Birding	Relevant species population
	Hiking	Natural land cover, vistas, surface waters
	Angling	Surface water, target population, natural land cover
	Swimming	Surface waters, beaches

[24] Managed commercial crops include the range of row crops, marine, and terrestrial species, for food, fiber, and energy.
[25] Viewsheds are a topographic concept, delineating the area from which a particular site can be seen.
[26] Biodiversity is thought by some ecologists to promote pest resistance.

depends on its location in the physical and social landscape. Finally, several aspects of the inventory deserve more detailed explanation to illustrate our accounting definition of services.

Harvests

Note that the ecosystem services are different for managed and unmanaged harvests. Managed, row-crop agriculture involves the combination of various capital and labor inputs. For this reason, we do not want to use managed harvests as a measure of ecosystem services. Too many nonecological inputs affect such harvests. However, subsistence crops and many hunted marine populations are not actively managed in this way. Here, we would use the available population or crop as the ecosystem measure, because the ecosystem itself is delivering the harvest opportunities.

Amenities and Fulfillment

While these categories can sound intangible, there is ample economic evidence that non-consumptive benefits are important.[27] Recreational benefits and property values, for example, are influenced strongly by visual amenities. Any environmentalist can describe the emotional benefits of contact with nature, as hard as these may be to measure. Bequest and existence benefits are somewhat more controversial in that some believe that their value derives from a moral imperative, rather than from an economic calculus. As such, the argument goes, their value cannot and should not be expressed in economic terms (Sagoff 1997). As economists, however, we take the view that if it is expressed in human action, it is in principle measurable.

Damage Avoidance

Are forests that sequester carbon and thus contribute to the reduction of climate-related damages an ecosystem service? Our answer is no. To be sure, forests may be a service for other reasons (recreation) but not for climate-related reasons. In our framework, climate-related damages to natural resources are accounted for already. Consider the effect of climate-related sea-level rise on beach recreation. If sea-level rise damages beaches, and thus recreational benefits, that will be captured in our beach-related ecosystem service measures (e.g., beaches themselves). The fact that forests sequester carbon is certainly important but in an intermediate

[27] The term “fulfillment services” is described in more detail in Binning (2001). (“A factory is an adequate analogy for the systems that deliver commodities and the physical services of ecosystems, but cathedrals, theatres, museums, universities or great art galleries are more appropriate analogies for the life-fulfilling services.”)

sense. The social cost of not sequestering carbon already will be captured in our other service measures.

As for health damages, we seek measures of the ecological conditions that directly affect health, such as air, soil, and water quality. Similarly for property damages, we seek ecological characteristics that are most directly capable of limiting property damage. These include wetlands (which prevent flood damage to property) and biodiverse natural land cover (which prevents crop damage due to drought, erosion, and pests).

6. From Units of Account to Green GDP

This article has focused on the measurement of services. Our ultimate endeavor, however, is the integration of service measures into an accounting framework, such as GDP or some other broad-based assessment of governmental performance.

Broadly, accounting frameworks require three things. First is the definition and measurement of quantities—the focus of this paper. Second, accounting requires aggregation or the adding up of the quantities. Aggregation is the province of index theory, a subject we have applied to ecosystem service analysis in previous work (Banzhaf and Boyd 2005; Banzhaf 2005).[28] Aggregation leads to a third requirement: weights for the individual elements in the index. The simplest indexes weight elements equally. Indexes aimed at welfare measurement need weights that correspond to the relative value of the elements (the services in this case). Conventional economic accounts have the luxury of using market prices, which act as a proxy for relative value. In general, we do not have that luxury, since we are counting services not sold in markets.

This paper has devoted relatively little attention to the measurement of prices or other weights attached to services.[29] However, we can outline a rough strategy for collecting and verifying nonmarket weights across services and the landscape.

[28] See Fisher (1925) for a seminal review of issues associated with indexing.

29 We do not wish to minimize the challenge and its importance to an accounting system such as the one we advocate. After all, units of ecosystem services that cannot be appropriately and practically weighted will inhibit the development of welfare-based performance measures such as green GDP.

The aspiration of economic analysis is willingness-to-pay (WTP)-based weights. Where are these weights to come from? The simple answer is: from nonmarket valuation studies. However, nonmarket valuations tend to focus on single services at discrete locations or, at best, at a regional scale. Even if all the existing dollar-based, nonmarket studies were put together, their coverage of WTP weights would be very spotty.

In conventional accounting, arbitrage allows us to assume a single market price. For many ecosystem services, there is no arbitrage. Also, many ecological services are best thought of as differentiated goods with important place-based quality differences. Accordingly, the WTP-based weights assigned to services should be spatially explicit. Methodologically, an ecological welfare index demands the continued development and application of benefit transfer techniques. Meta-analysis of existing value estimates can be used to calibrate benefit transfers.

Such meta-analyses might be facilitated by what we call WTP indicators. WTP indicators are countable measures of things that raise or lower willingness to pay for ecosystem services. This method is detailed elsewhere (Boyd and Wainger 2002, 2003; Boyd 2004), but involves geographic information system measurement of site-specific measures of ecosystem service scarcity, substitutes, and complements.[30] WTP, while not directly observable, is a function of various characteristics that are observable. WTP weights p_i can be thought of as a function of landscape indicators I. In principle, this function, on a service-by-service basis, can be calibrated by relating observable indicators I to existing WTP estimates of service value. Unfortunately, most published nonmarket valuations do not include such information—a major barrier to their use in meta-analysis and benefit transfer.

Other approaches include the use of stated preference techniques to place weights on units of account using place-specific scenarios. In other words, the scenarios presented in stated preference surveys could rely on standardized service units and ways of measuring place-based quality, substitution, and complementary asset landscape factors akin to what we call WTP indicators.

[30] Consider flood control benefits. Wetland acres are a service measure. The density of wetlands is a measure of their scarcity (the greater the density, the lower the value of a particular wetland acre). In a recreational context, recreational species populations are a service measure. Complementary goods such as roads, trails, docks, and boat ramps are observable complements that in principle increase the value of the service.

7. Conclusion

Accounting for environmental services is important to public policy because those services contribute significantly to human welfare and are not captured in existing welfare accounts. We come at ecosystem services accounting from an economic perspective. Economic accounting requires an economically derived definition of ecosystem services. We have articulated and defended such a definition in this article.

Our economic definition of services employs two fundamental insights. First, that ecosystem services should be isolated from nonecological contributions to final goods and services. Once ecosystem services are combined with other inputs, such as labor and capital, they cease to be identifiably "ecological." For example, recreational benefits and commercial harvests are not ecosystem services because they arise from the combination of ecosystem services with other inputs. Second, that economic accounting is concerned with ecological end-products, not the far larger set of intermediate processes and elements that make up nature.

Relative to more eclectic definitions of services—which have an "everything but the kitchen sink" quality—our definition yields a more concrete and parsimonious set of ecological elements to be counted. Moreover, our definition is motivated by the economics of national welfare accounting and thus has practical implications for green GDP. Efforts to promote green GDP have stumbled because the definition of ecological factors to be measured have been unarticulated or flawed.

We conclude by returning to the argument that most ecosystem services must be procured by governments, rather than provided by markets. As public goods, these services suffer both from a lack of market provision and effective oversight. We believe that governments should be pushed to account for and communicate trends in ecological conditions. Our definition of services provides an architecture for performance accounting. Leaving aside the difficulties associated with weighting services according to their relative value, governments can begin systematically counting what is important about nature.

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