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ANALYSIS

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 final 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.

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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. 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

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service units. To address that problem, this paper proposes that environmental accounts focus on *final* services and offers a definition of such 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.¹

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.”² Accordingly, we seek more 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. It also serves to narrow the range of things to be counted, thereby establishing priorities for limited data-collection budgets.³

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. Our overall perspective is that the goal of social policy is to maximize human well-being as opposed to a purely ecological objective. 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 is prices. The second kind of data is 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 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. Instead, units of trade and compensation have to be defined by governments, governments being the trustees of environmental quality. 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.⁵ 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 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

¹ 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.

² This goal is widely shared (Nordhaus, 2005; World Bank, 2005; U.S. Bureau of Economic Analysis, 1994; United Nations Environment Programme, 1993). National accounts do not measure welfare itself (an impossibility), rather they are proxies for components of welfare. For example, GDP is not the value of the economy, it is a *measure* of the value of the economy. Similarly, our ecosystem measure should be thought of as a measure of nature’s value, not the value itself. This distinction is important to any interpretation of national accounting numbers.

³ Smith (2004) makes the same point. Without a theoretical framework, such as the one we provide in this paper, the selection of variables is “subjective and may tend toward a large set since nothing constrains the number chosen.”

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

⁵ See U.S. General Accounting Office (2005b) (wetlands); Ando and Khanna (2004) (natural resource damage compensation); Houck (2002) (water quality); and U.S. General Accounting Office (2000) (federal land swaps).

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.⁶ 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 purpose and underlying rationale and that exacerbate the divide between economic and ecological analysis.⁷ 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 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.⁸ From the standpoint of economic accounting, we seek a framework that is analogous to GDP, in particular to GDP as interpreted as a welfare indicator (Boyd, 2006).⁹ 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 encompassing human and natural production (Mäler, 1991; Peskin and Delos Angeles, 2001; Grambsch et al., 1993; Banzhaf and Boyd, 2005). Within such a framework, final 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.

Throughout this paper, our focus is on the measurement of the flow of final current services (e.g. Mäler, 1991), unlike those that focus only on capital depreciation (e.g. Weitzman, 2003). At the outset, we acknowledge that an important component of welfare accounting involves the depreciation of ecosystem stocks, to account for the effect of environmental degradation on the flow of future services. We have addressed this issue in previous work (Banzhaf and Boyd, 2005) and discuss it briefly in Section 6. However, the measurement of current services is sufficient to motivate our proposed definitions. Moreover, as we argue, environmental asset values are best "built up" from an initial assessment of current flows. In any event, a focus on current service flows simplifies the exposition.

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 ecological quantities and prices (values) (Banzhaf and Boyd, 2005). 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, 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 Delos Angeles, 2001; Grambsch et al., 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

⁶ See Banzhaf (2001) for the treatment of quality changes in the history of price indices.

⁷ For a broad overview, see U.S. General Accounting Office (2004) and U.S. General Accounting Office (2005a).

⁸ Ecologists too are calling for more consistent measurement that accounts for the scale over which biophysical phenomena occur (Kremen, 2005).

⁹ Many national accountants resist this interpretation of GDP. But historically, welfare accounting has in fact been the most important driver of GDP construction and application.

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

¹¹ Again, 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.

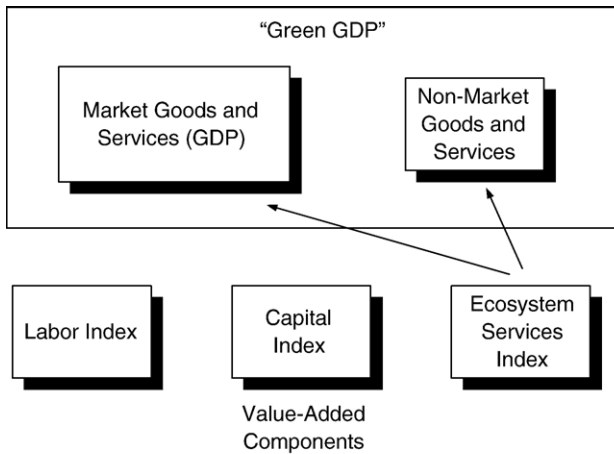


Fig. 1 – Green GDP vs. an ecosystem services index.

nominal, rather than real, GDP. To track real service flows over time, quantities and prices must be measured separately, as nominal GDP must be adjusted with an appropriate deflator (Banzhaf, 2005; Flores, 1999).

To this basic architecture, we must add one further distinction regarding what is to be measured: do we measure all sources of ecological value or measure only those sources not already captured in GDP? This choice is one between two alternative (but complementary) accounting strategies: green GDP and what we call an ecosystem services index (ESI). As we use the term, green GDP aggregates all final goods and services, including final non-market goods and services, into a single index. In effect, green GDP adds those missing ecological elements that are directly enjoyed to GDP. An ESI (Banzhaf and Boyd, 2005) captures all ecosystem end-products, those counted in green GDP plus ecosystem components that are combined with non-ecological inputs to produce market goods.¹² Put differently, green GDP “trues up” conventional GDP to account for non-marketed ecological contributions to welfare. An ESI includes those new elements plus the ecological elements already embodied (as intermediate inputs) in GDP to arrive at a comprehensive measure of all nature’s contributions to well-being, marketed and non-marketed. Or, to put it one more way, green GDP captures all final goods and services, where “final” refers to the point of enjoyment; an ESI captures all final ecosystem services, where “final” refers to the last contribution of the ecosystem. These distinctions are illustrated in Fig. 1.

When all ecosystem services are measured and aggregated according to our definition, the aggregation represents a measure of nature’s total contributions to welfare. It is not the same thing as green GDP, but can easily be adjusted – to avoid double counting of ecosystem services already captured in GDP – to arrive at green GDP.

¹² For example, the value of ecosystem services that contribute to commercial crop production. These are indirectly captured in GDP via food and feed. Consequently, they would not be added to green GDP. But they are a final contribution of the ecosystem and hence belong in the ESI. This latter point is in the same spirit as those green reforms to the system of national accounts which seek to highlight the role of ecosystems as inputs (see e.g. Hecht, 2005).

4. A definition of ecosystem services

We advance the following definition of a final ecosystem service:

Final 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. In the remainder of this section we discuss three features of our definition: that final ecosystem services are directly enjoyed or used, that they are components, and that they are a quantity to be paired with a price (value). We conclude the section with a discussion of the contrast between “services” and “capital” or “assets.”

The first important aspect of this definition relates to the language “directly enjoyed, consumed, or used.” This signifies that final 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 intermediate goods are 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 account. 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 is embodied in the measurement of final ecosystem services. Thus, final services should be the top priority in developing accounting units.

Note that, as end-products of nature, final ecosystem services are not benefits nor are they necessarily the final product consumed. 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 final 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. More fish may be landed simply because better tackle are used — surely an undesirable feature of a measure intended to capture changes in nature’s provision of beneficial services. The fish population, surroundings, and water body are the “ecosystem end products” directly used by anglers to produce recreational benefits. Thus, they are the ecosystem services that should be counted. The case of commercial fishing is similar, but here aesthetics are unimportant, so only the target fish populations need to be counted as ecosystem services.

The recreational and commercial examples also highlight the difference between final ecosystem services and final economic goods — final economic goods being things directly

enjoyed or consumed by households. In the recreational case, the fish population is both the final ecological service and the final economic good. In the commercial case, fish purchased by households are the final economic good. Here, the value of the fish population (relating to commercial harvest) is embodied in the value of fish purchased. Because the distinction between intermediate and final goods and services is so important to welfare accounting, we reiterate that while ecosystem services are nature's end-products, they are not necessarily "end products" for the purposes of GDP.

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 ecological things or characteristics, not functions or processes. Ecosystem components include resources such as surface water, oceans, vegetation types, and species populations. Ecosystem processes and functions are the biological, chemical, and physical interactions between ecosystem components. Functions and processes are not end-products; they are intermediate to the production of final ecosystem 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 processes and functions are called services–nutrient cycling, for example. But nutrient cycling is an ecological function, not a final service. To be sure, it is a valuable function, but it is an intermediate aspect of the ecosystem and not an end-product.

A third feature of our definition is that it facilitates a distinction between the *quantity* (or physical measure) of ecosystem services and the value of those services. This distinction is always present in conventional economic accounts, but is often lost in discussions of ecosystem services. To motivate this point, consider the following model. A marketed input M and a nonmarket ecological input N are inputs into the commodity A , as described by the production function $A=A(M,N)$. 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,

$$P_N = (\partial A / \partial N) P_A. \quad (1)$$

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

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

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

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

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

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? 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, we argue that the appropriate measure of services is the first, dN ([Banzhaf and Boyd, 2005](#)). In our view, only this definition focuses on the ecological input as the quantity unit, while maintaining an appropriate price unit as its mate. Moreover, there are strong objections to the other candidates. The third ($P_N dN$) is inappropriate as it merges value and quantity information. The second, $(\partial A / \partial N) dN$, is harder to rule out at first. Under this definition, the ecosystem service is the contribution of the ecosystem to production of the final good or service, which may seem appealing. But in this case, the units of the ecosystem service are the same as the final output. This problem is exacerbated when we realize that an accounting system requires a total quantity of services, not just a marginal change. In that case, definition (3) would yield a measure of "ecosystem services" equal to A , the final output into which they are an input! The corollary too is that, with this as a quantity unit, we are left with P_A as the price. In other words, the per-unit value of the ecosystem service is identical to the per-unit value of the final output. This seems strange indeed.

We prefer our definition of services, dN for a change, or N for a total, 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](#)).

We conclude this section by addressing a point of confusion that we have encountered when discussing our definition with others. Our definition of "services" leads to measurement of components. But aren't components "things"—goods or capital inputs into production—rather than "services," which would seem to suggest the performance of some activity? For instance, in our angling example, isn't the stock of fish or water quality a capital asset, rather than a service?

Our answer is that, frequently, stocks are a measurement proxy for services. This proxy arises in two settings, both of which have analogues in conventional economic accounts. First, in many cases, the final ecological contribution to well

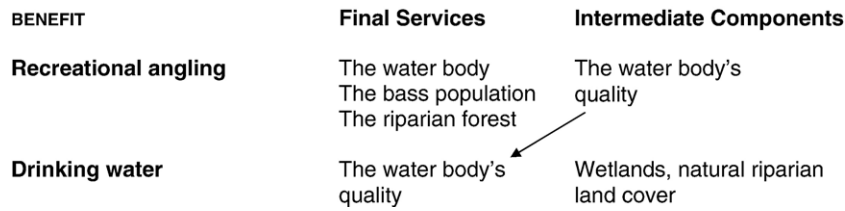


Fig. 2 – Ecosystem services for recreational angling vs. drinking water.

being is in the form of an asset which is a capital input into some production. The stock of fish in the lake or sea for angling or commercial fishing is an excellent example. In such cases, the subtle distinction between a flow of services and the stock of ecological capital is that the “service” is actually the use of the ecological asset over some time period for purposes of fishing. This flow is unobserved, but so long as the service flow is proportionate to the stock, the stock is a valid proxy for the service. In fact, this is precisely the classical treatment of capital services in economic models (e.g. Hall and Jorgenson, 1967) and in national income accounts (see e.g. OECD, 2001).

In other cases, of course, the contribution of the ecosystem is a flow. In the case of pollination (an ecosystem function), the final ecosystem service provided by the function is the delivery of sexually viable pollen to the crop each season. Even here, however, the end product is a component–pollen delivered–and not a process. If some would prefer to substitute the word “good” for “service” in such cases, we do not object. However, we note that the same objection could be made to most so-called “services” in the market economy. Restaurants, a quintessential service industry, deliver a meal. Maids deliver a clean house.

As a final note on this point, we point out that even in the case of these flow outputs a stock input might have to serve as a proxy. Although it would not be our theoretically ideal measure, the stock of bees in a particular location may be a reasonable and desirable proxy for pollen delivered. Again, such proxies have their analogues in conventional accounting. The U.S. Bureau of Economic Analysis and other national statistical agencies frequently 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 the true service.

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, final ecosystem services are components of nature — things or qualities. The procedure for identifying ecosystem services is to first inventory sources of

well-being related to nature. 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, final ecosystem services are the ecological end-products that can be, but that aren't necessarily, used to produce the well-being.

For example, return once more to the case of recreational angling, as illustrated in Fig. 2. Final 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 final ecosystem services associated with angling. The food web and water-purifying land uses on which the target population depends are not final services, because they are intermediate ecological components. The angler's catch also is not a service. Why not? 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.¹³ In the angling example, the water body's quality was not a final service because water quality is an intermediate good in the provision of the target fish population (see Fig. 2).¹⁴ In other words, its value for angling is embodied in its effect on the fish population.

However, a services inventory also will include the provision of drinking water as a source of well-being. For drinking water, access to 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:

¹³ Or, to risk confusion by proliferation of service concepts, particular “final services” that are enjoyed and that the ecosystem produces.

¹⁴ Water conditions such as odor and clarity are ecosystem services because they contribute to the aesthetic experience.

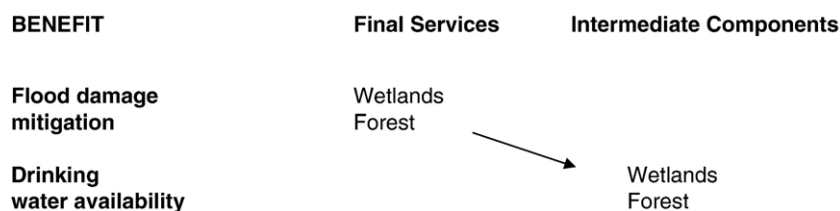


Fig. 3 – Ecosystem services for wetlands.

a given ecosystem component may be a final service in one context and not a final service in another.

Wetlands are another example of how services are defined by the benefit in question (see Fig. 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.

If the benefit-contingent nature of final 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. 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.¹⁵ Our service units can be expressed both numerically and visually via geospatial information systems.

5.3. 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 4.¹⁶ But alternatives, and the confusion they cause, also arise outside of economics. We start with a particularly influential list of services: one from Gretchen Daily's book *Nature's Services*. Part of Daily's list of representative ecosystem services is reproduced in the box below (Box 1). To be clear, Daily's intent was to illustrate the connection between ecology and human well-being, not to generate an accounting system. The point we wish to convey is that our definition advances the ability to use ecosystem services as a practical measurement tool.

Many of Daily's "services" are what we would call processes or functions. For example, is water purification a final 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 – at particular times and places – 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

Box 1

Daily's List of Ecosystem Services (Partial)

- 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

¹⁵ 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.

¹⁶ It should be noted that the authors have in the past themselves fallen victim to similar inconsistency (Boyd and Wainger, 2003).

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). Nutrient cycling is a valuable function because it helps prevent over-nutrifcation, low aquatic oxygen, and subsequent stress on aquatic species populations. It is the aquatic populations themselves that are the final ecosystem services. The nutrient cycling process and dissolved oxygen levels are intermediate functions and processes that affect the final ecosystem service: the populations. Seed dispersal is a function. Measurable delivery of seeds to particular locations is the service arising from this process. Pollination, too, is a function. The service yielded by that function is delivery of pollen to specific crops. Since plant-specific pollen deliveries cannot be practically measured, a measurable proxy is necessary (as discussed in Section 5.2).

Or consider the detoxification of wastes.¹⁷ Detoxification is a process embodied in a set of production functions. These functions yield particular air, soil, and water characteristics — these characteristics are the ecosystem services. 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 final service does not mean it is not valuable. But our corollary is that being valuable is not the same thing as being something we should necessarily worry about counting. 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 final services in an economic accounting sense.

Another taxonomic example is the Millennium Ecosystem Assessment (MEA, 2005), 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

¹⁷ Waste assimilation, as an alternative to other forms of waste disposal, is an ecosystem service in our definition.

Table 1 – Inventory of services associated with particular benefits

Illustrative benefit	Illustrative ecosystem services
Harvests	
Managed commercial ^a	Pollinator populations, soil quality, shade and shelter, water availability
Subsistence Unmanaged marine	Target fish, crop populations Target marine populations
Pharmaceutical	Biodiversity
Amenities and fulfillment	
Aesthetic	Natural land cover in viewsheds ^b
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 ^c
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

^a Managed commercial crops include the range of row crops, marine, and terrestrial species, for food, fiber, and energy.

^b Viewsheds are a topographic concept, delineating the area from which a particular site can be seen.

^c Biodiversity is thought by some ecologists to promote pest resistance.

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 correspond to the kinds of functions and processes listed by Daily (e.g., pest regulation, disease

regulation, hazard reduction, pollination, and 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 final services and there is little guidance given on how to measure them. 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, 2004).¹⁸

5.4. An illustrative inventory

Table 1 above 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 final 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."¹⁹ 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 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.

5.4.1. Harvests

Note that the final 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 non-ecological 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.

5.4.2. Amenities and fulfillment

While these categories can sound intangible, there is ample economic evidence that non-consumptive benefits are important.²⁰ 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 and choice, it is in principle measurable.

5.4.3. Damage avoidance

Are forests that sequester carbon and thus contribute to the reduction of climate-related damages a final 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 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 final ecosystem services and the construction of a useful definition of such services. Our ultimate endeavor, however, is the integration of service measures into an accounting framework, such as GDP or

¹⁸ 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 in the NRC report). See Binning et al. (2001) for excellent ecological and economic illustrations of services using a far more expansive definition than ours.

¹⁹ Exceptions are services associated with existence or bequest values.

²⁰ The term "fulfillment services" is described in more detail in Binning et al. (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.")

some other broad-based assessment of governmental performance.

Broadly, accounting frameworks require at least 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).²¹ 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.²² However, we can outline a rough strategy for collecting and verifying nonmarket weights across services and the landscape.

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.²³ 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.

Depending on the context, a fourth factor in a complete “green GDP” would be the depreciation of ecosystem assets, including intermediate assets and processes that are not ecosystem end-products. Such depreciation, analogous to Net GDP, has played a central role in work on green GDP to date (see Mäler, 1991 and Weitzman, 1976, 2003 for intellectual frameworks, Nordhaus and Kokkelenberg, 1999 for discussion, and Repetto et al., 1989 and U.S. BEA, 1994 for examples). We have de-emphasized this issue here because our purpose has been to contribute to a useful definition of ecosystem services, but in so-doing we do not mean to minimize its importance.

As we have stated previously, intermediate ecosystem components and process have value, but their value is in the provision of final ecosystem services. Proper depreciation of damages to intermediate components and processes thus requires biophysical models to predict the resulting change in the stream of future final services, together with discounted values for those services, a point we have made elsewhere (Banzhaf and Boyd, 2005). While at present this may be possible in some cases, in our pragmatic view the most progress can be made by first improving measurement of current services.

7. Conclusion

Accounting for final 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

²¹ See Fisher (1923) for a seminal review of issues associated with indexing.

²² 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.

²³ 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.

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.

As a parting thought, we reiterate the fact 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 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.

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