Practical Measurement of Ecosystem Services: Can We Standardize the Way We Count Nature's Benefits?

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Overview and Objectives

Nature's benefits should be counted. However, counting – and *accounting* – requires precision, uniformity, and discipline. Ecology and environmental economics have to date failed to provide adequate guidance on what it is in nature that should be counted if we want defensible measures of value. Recent work at RFF advocates a way to precisely define the *units of account* necessary to make ecological accounting a reality.

This workshop debated these units of account by bringing together practitioners from government and the conservation community and academic experts on the underlying ecology and economics.

The workshop also debated an important benefit of defined units of account: the ability to standardize environmental measurement. The organizers put forward the following (perhaps controversial) thesis: Green GDP, conservation priorities, benefit transfer in cost-benefit analysis, and trade in ecosystem services should all rely on *the same* units.

Background

Colloquially, the term *ecosystem services* encompasses "the benefits of nature to households, communities, and economies." The term is gaining attention because it conveys an important idea: that ecosystems are socially valuable – in many ways. Conservancies link their missions to the protection of ecosystem services; the Millennium Ecosystem Assessment relies on ecosystem services as a framework concept for its measurement of global ecological conditions; and numerous government agencies are trying to figure out how to measure, manage, and communicate the ecosystem services protected or enhanced by their programs.

This idea has great potential to unite the fields of ecology and economics, form the basis of a unified approach to environmental performance measurement, and foster clear public communication on environmental issues. Some analysts even talk about a trading system for ecosystem services.

However, the term lacks a consensus definition, undermining its promise. Today, if you ask different environmental practitioners what ecosystem services are, you get a disturbingly large – and often competing – set of answers. Numerous competing measurement systems have emerged in the last decade from both the natural and social sciences. These metrics are associated with initiatives in sustainability, government performance assessment, ecosystem services, and national welfare accounting.

What is needed is a common understanding that is scientifically defensible on both ecological and economic grounds. To date, no single set of metrics has emerged to unify the field and foster the transferability of results between applications and across the natural and social sciences. This is understandable. It is worth remembering that our "conventional" economic accounts, such as GDP, have taken literally a hundred years to develop (and are still far from perfect). Moreover, accounting for nature's benefits will always be a far more daunting task. First, nature is more complex than the human economy. Second, the lack of markets for nature's benefits means that there is no mechanism to define prices and quantities for us.

Audience

Our ultimate goal is to provide standardized definitions and measures of ecosystem services that are useful to governments, conservancies, international organizations, and NGOs. Moreover, to be useful, ecosystem service measures need to pass muster in both ecology and economics.

Workshop attendees included representatives from the conservation community, government agencies, NGOs advocating environmental performance metrics, and scholars. Government agencies represented included the Environmental Protection Agency, NOAA, the Army Corps of Engineers, U.S. Forest Service, USGS, the General Accountability Office, and the Office of Management and Budget. Experts from the NGO community, including World Wildlife Fund, American Rivers, American Forests, National Fish and Wildlife Federation, Doris Duke Foundation, and Defenders of Wildlife also participated.

The full list of participants is included as Appendix A.

Applications and Relevance

The measurement of ecosystem service units is an issue central to various issues in environmental policy. These include: government performance assessment, non-market or "green" welfare accounting, natural resource valuation, conservation planning

and priorities, and trade in ecosystem services. Advance in all of these areas (both scientific and public policy) is slowed by a lack of consistent, defensible protocols.

Standardized units of account will advance the following policy and scientific objectives:

Green Welfare Accounts – Conventional welfare accounts, such as GDP, do not measure nature's contribution to wellbeing. The measurement of non-market benefits in these accounts is thwarted by a lack of units consistent with those used to measure conventional economic outputs.

Environmental Valuation – Ecosystem valuations have been conducted for decades. The comparability of these analyses, and the ability to transfer benefit estimates from one location to another, is limited, however. A part of the problem is that valuations do not employ standard units to foster comparison and meta-analysis.

Ecosystem Markets – Systems for trading habitats, ecosystem services, water quality, and other heterogeneous environmental goods have been slow to develop. This is largely due to the difficulty of judging, and monitoring, the qualities of what is traded. Standardization will foster more transparent and defensible rules for such environmental markets.

Conservation Planning and Priorities – Conservancies increasingly look beyond biodiversity as their sole reason for protecting habitat and other natural resources. Protection of ecosystem services, for example, requires conservancies to account for and communicate a much broader set of objectives. Standard units of account will make this task easier.

Government Performance – Agencies are increasingly being asked (by Congress, OMB, and others) to demonstrate the public benefits of environmental regulations, programs, and expenditures. Since ecosystem services are about the benefits of nature to the public, measuring and communicating service outcomes could support important trustee and regulatory activities.

Practitioners in each of these areas were involved in the conference and debated the merits of RFF's approach to ecosystem service measurement as applied to their areas of expertise.

Agenda & Topics

The conference was organized in the following way.

First, the organizers laid out the underlying policy problem: namely, unmet demand for environmental performance and benefit measures. Several sets of speakers

were asked to address this question, including speakers from the regulatory agencies (EPA, ACOE), government evaluators (OMB, GAO, NFWF), and the conservancy community (WWF, Doris Duke Foundation). Additional speakers were asked to discuss institutional, legal, and resource barriers to environmental performance measures.

Second, James Boyd, the conference organizer articulated a proposed solution to the performance measurement and standardization problem. The proposed solution derives from RFF research on the economic definitions of ecosystem services. (A summary of this research is included in the Appendix C) RFF invited Geoffrey Heal, from Columbia University, a renowned environmental economist to offer a critical appraisal of the research from the standpoint of economic theory. The session concluded with discussion and debate arising from Boyd and Heal's presentations.

Third, ecologists were asked to make presentations on "The Ecological Perspective on Performance and Prediction." This session was designed to have ecologists react to the economic definition of ecosystem services presented by the RFF researchers. It was also designed to educate the non-ecologists about recent developments in ecological approaches to measurement of environmental progress and degradation. Particular emphasis was given to the following issues: the ability of landscape ecology to predict impacts of alternative natural resource management options.

The fourth session was devoted to recent developments in ecological measurement and mapping. An ecologist and GIS specialist provided a broad overview of ecological data sources and availability. These data and the GIS techniques associated with them were then related to the types of data prescribed by the RFF approach to ecosystem services management.

The fifth session was used to describe the history of the national income accounts, such as the consumer price index and gross domestic product, to draw institutional as well as economic lessons for the measurement of an environmental performance index.

The first day closed with a discussion of applications – policy areas where standardized performance units could be applied to concrete decisions. Two particular areas were discussed: farm payments targeted to ecosystem services provided by agricultural lands and water and habitat trading programs. In both cases, the discussion focused on the need to develop transparent measures of ecological end-results to discipline payments and trades.

The second day began with two sessions designed to relate the ecosystem services approach to the perspective taken by (1) ecological economics and (2) environmental economics. In both cases, eminent researchers in these fields were asked to comment on the RFF ecosystem services measurement approach. For example, the session on environmental economics focused on the relationship of ecosystem service units to the issue of how those units would be weighted.

The conference concluded with a session devoted to discussion of next steps, opportunities for further work, and the constituencies for economically derived ecological performance assessment.

The formal agenda is included as Appendix B. Not all of the presentations were formal. However, the conference's core presentations are reproduced in Appendix D.

Overview of Conference Results

The meeting achieved its ambition of stimulating a cross-disciplinary debate regarding environmental performance measures, the relevance of ecosystem services to performance measurement, challenges to this agenda, issues in need of clarification, and areas of disagreement.

Areas of agreement and consensus

The concept of ecosystem services – that is the relevance of nature to human well being was uniformly accepted. It was also broadly accepted that the ecosystem service concept is relevant to the measurement of government and conservancy environmental performance (though there was disagreement regarding whether ecosystem services should be the primary form of performance measurement).

The proposed method (advocated by the organizers) for defining and implementing ecosystem services measurement (as laid out in the paper "What Are Ecosystem Services" – Appendix C) was validated up to a point. No critique of its underlying theory was made and the economists asked to evaluate it were supportive. The principle discussant of the proposal commented that:

> "Some of the points are surprising at first sight, but they're right…the quibbles should not be taken to indicate any significant disagreement with anything in the paper."

However, in addition to those quibbles, there the application of the method to particular decision settings was much more controversial (as is discussed below in the section on "standardization").

There was also broad agreement that the principles for ecosystem services measurement that were presented should now be deployed in the real world so that concrete applications can be evaluated. Participants said that

> "We need concrete examples. We've had a theory camp and a practice camp that have been evolving virtually in isolation from each other. Pulling that closer together is an important next step."

> "Really start to get down to a level where concrete information is accessible to the people who have an immediate need and have the ability to make an immediate and potentially significant investment."
>
> **"**A great next thing to do is just try it, and hold your nose when you have to make all these assumptions, and then bring it back for people to throw things at, and a better one will result."

Also, one of the conference's central hypotheses – that environmental trustees need to do a better job of performance measurement – was emphasized repeatedly by the range of participants. Acting Interior Secretary Lynn Scarlett set the tone in her opening remarks by emphasizing three points:

> "The effects of environmental transformations are not often well considered in decisions."
>
> "The benefits from drawing upon nature's capital in investment and policy choices, and private decisions, are still frequently overlooked."
>
> "The results of our environmental policy actions are too often neglected. Success is measured only by the processes we have in place rather than the actual outcomes achieved."

Other participants echoed these observations. For example agency decision-makers made the following points:

> "Our ability to deliver the goods is severely wanting….Without any quantifying metrics, the whole ecological side [of regulatory decision-making] is going to be at a disadvantage."
>
> "We really lack a lot of the tools that we'd like to have, not only in terms of being able to account and monetize the successes and the opportunities that we have, but merely to kind of describe what's really occurring as a result of decisions that we have to make.…We're pretty far short of where we would like to be in terms of describing the results in ecosystem terms."
>
> "I think it's more of a social question of, how do the clans come together and begin to kind of evolve the consistency and commonality of language that will help us sort of develop these measures in a way that serves all of our needs, but also in a way that allows higher level of decision-makers to kind of look more broadly at what's happening?"
>
> [Referring to the human health and risk assessment paradigm] "What we need desperately, and what I exhort this community that is currently at this table to do,

> is to respond in a way that is analogous to what the science community performed in the late 70s, early 80s."

From the conservancy participants we heard that:[1]

> "We're scrambling to react to a new demand for measuring in a more rigorous quantitative way what we do: if we're succeeding, how well we're succeeding, and where over somewhere else. Donors are demanding now, evidence of return on their investments. So they're not considering us a charity as much as something they expect a return from."

> "There's this critique that we can't show whether we succeeded or not without resorting to anecdotes and things. We can't tell what's working better than what, what should get more investment and what should get less. That is why we need to get better at measurement."

> "We figure it would be really terrific if the methodology could be developed so that we could understand, as a society, what it is we get when we conserve an acre in the name of wildlife. Prospectively, going forward, obviously, what will we get if we invest this additional half a trillion dollars in the habitat that's necessary to secure wildlife? So that's the issue that we're most interested in at the moment. And although it seems more of a cost-benefit analysis, it's really resting on the recognition that these lands are conducting many services that are of value to society."

An ecologist noted that our institutions (and ecology as a discipline)

> "We're not programmed to actually go back and be reflective. We just don't do that. And that's a big problem. That's a huge problem in the context of this workshop."

And from government evaluators we heard the following:

> "[Performance assessment] is a greatly frustrating endeavor in the natural resources and environment fields. Over, and over, and over, we have to come back and too often report to our Congressional clients that we are unable to make assessments of effectiveness of program implementation because the data to do it simply either isn't there, or is of such a nature that an honest evaluation of cost and benefits cannot be determined."

> "We can't develop credible and effective measures of monetization until we have a more consistent and agreed-upon set of physical measures, and a better

[1] One participant did offer the following caution: "There are a lot of people in the conservation community who would argue that we shouldn't spend much of our time and money measuring really carefully…. Money spent measuring carefully is money you didn't spend going out and trying to get more stuff done. And they think our assumptions that our interventions lead to good outcomes is strong enough.

understanding of what the impacts of our policies are on those physical measures."

Barriers

There was also broad agreement on institutional barriers to the broad deployment of consistent, national environmental performance measures. Several aspects of the challenge were noted, including lack of consistency and comparability in data, lack of centralized data delivery, and lack of statutory authority and budgets to collect, organize, and deliver environmental data. Participants made the following observations:

"We have lots of data from other governmental organizations; some data from non-governmental organizations. You can just imagine the challenges of trying to find the documentation, both of the sources of the data but also the algorithms that are used to present the data in tables. Any kind of long-term study brings us lots of additional issues for the data and its quality."

"We are somewhat hamstrung on data collection because we do have a principally statutorily driven program. This limits our ability to collect information that would be really interesting as outcome measures, but which are not linked to the compliance-established frameworks that we have to work with."

"This is an enormous challenge requires a huge physical infrastructure. It's not to say it's impossible because measuring GNP is an enormous challenge and it requires an absolutely massive physical infrastructure. Think of the statistical infrastructure that the United States has, primarily from their GNP and some other significant economic variables. It's huge."

There is one area of disagreement regarding data issues: whether we have enough or not. Some feel that we are in a fundamentally data poor environment:

"If there's one thing that stands in the way of metrics and ecosystem service measurement being effective … it's the data poor environment we're in....So I think that is an important question, and regardless of what you think about where we should be standardizing or not standardizing, the fact of the matter is, you're going to hit that problem smack on, that there just isn't enough data in many, many places to do this kind of stuff, regardless of what level you want to do it at."

Others, however, think the problem is not a lack of data but its comparability and ease of access:

"We have a lot of ability to measure features of the ecosystem….There are national data sets. They're nice and consistent across areas. You can do the same analysis in one place that you did in another place, but it's often not useful for answering a lot of the questions we're trying to answer. So then you have to go

down to the state and local level. And increasingly data are available at the state and local level to look at all kinds of things."

The session on GIS data and analysis also concretely illustrated the vast array of spatial data that are already available to analysts.

A final area of agreement arose from the discussion of ecology and its ability to predict ecological changes at the landscape level. This is an important issue because ecological prediction is central to performance assessment. Without predictive ability the future consequences of environmental management decisions made today cannot be adequately addressed.

Participants, ecologists in particular, argued that the complexity of ecological systems, lack of a "performance mindset," and inadequate development of predictive spatial models are significant barriers to this activity. Difficulties funding and attracting ecologists to that kind of activity were also mentioned.

The following participant comments make the point:

"How good are the data that drive biodiversity modeling? They suck."

[Regarding biodiversity prediction] "WWF has some incredible data sets to guide conservation policy at global scales, but they're not very useful for making management decisions about conservation practice, and that's just the nature of the beast right now."

How good are we on the forecasting of ecosystem function? {For] hydrology and watershed protection our understanding is good. Our models are really good. Our data are even worse than the biodiversity data, and that's because the stuff that drives watershed function is really fine scale and nasty data. Think about soil hydronic connectivity that you'd like to have at regional scales. We don't have it. We're not going to get it. It's not remotely sensible, so it's not going to come any time soon.

"Where are we [ecologists] in terms of actually being able to contribute something useful to ecosystem service accounting? I think we're not there yet. I think we'll get there reasonably soon. I think it will be based not on actually counting ecosystem services or rare species, or whatever, but instead be based on macroscopic and probably remotely sensible proxy variables."

"How many of you know of studies where people went back and checked to see where it worked?"

"We don't close the loop. And I think it's because we have this mindset of like, solving a problem and then going on to the next problem. And not solving a problem and then checking to make sure that it stayed solved, or that it got solved

in the first place. That's not about ecology and it's not about economics or policy. It's about the interplay between those different people."

Issues needing clarification

A central distinction in the measurement method prescribed by the RFF organizers is to distinguish ecosystem services in terms of whether they are "final" or "intermediate" economic goods. (For discussion see Appendix C the paper, "What are Ecosystem Services?") The issues generated a fair amount of discussion amongst the participants. Should ecosystem services only relate to the "final" aspects of nature that contribute to human well being? Shouldn't we also count the intermediate aspects?

Reactions to the presentations included the following:

"You didn't mention the whole input-output framework that goes together with the GNP accounting, where we do, in fact, try to measure almost everything that's going on in the economy; all the intermediate transactions. And the reason we do that is to better understand those production functions. That's a reason for maybe not concluding the way that you did that we don't have to measure everything. In fact it is a productive endeavor to measure all of those ecological processes and underlying intermediate flows."

"I think we do need to count the intermediate products as well in order to understand the process, in order to get past just the accounting and into the understanding and modeling and ability to predict and forecast."

"[Ecosystem stocks] are not actually directly affecting human welfare themselves, but nevertheless contribute to what we would call human capital. So if we're worried about depleting human capital we probably need to worry about measuring those. So that increases the list of things that have to be measured."

These issues have helped the method's proponents clarify their terminology and the way different classes of ecosystem services should be applied to different public issues. First, the organizers have adopted a semantic distinction between "final" and "intermediate" ecosystem services. This helps situate their work more intuitively in the already large literature on ecosystem services (though we continue to draw a stark distinction between ecosystem functions or process and ecosystem services).

Also, the need to measure intermediate ecosystem services – in addition to final services – has been clarified. The distinction can be conveyed as follows: final ecosystem services are all that should be measured if the goal is direct measurement of current human welfare related to nature. However, intermediate services are central to many other applications. Most obviously, intermediate services are important to the

science of ecology. In turn, relationships involving intermediate services arising from processes and functions are important to ecology's ability to predict future changes in final services (a capability that is central to welfare analysis). Also, intermediate services may prove to be more easily measured and therefore desirable as proxies for final ecosystem services. Finally, intermediate services may be a marketable commodity (e.g., carbon capture credits) and thus important to measure and track.

> "[The final services argument is] technically correct. I have to agree with that…. It is true that what matters to us individuals is not that carbon be sequestered but that the climate be suitable for human habitation, human activity. However, just as we have interfered with the carbon cycle, we have also interfered in that statement I made just now. We've got carbon markets."

Final services remain the direct measure of human welfare. The clarification is that there is a clear difference between intermediate and final services, and that the choice of which to measure (or give priority) is sensitive to the underlying policy question.

Another issue in need of clarification was the organizers' use of the term "standardization." Several participants interpreted the stated goal of standardization as a requirement to "measure this particular set of things." The organizers failed to effectively define and communicate their definition of standardization in a way that frustrated some of the meeting's dialogue.

One way to put the confusion is that a subset of the audience thinks standardization means "telling people what is important to them." In this interpretation, standardization implies a centralized, top-down determination of what society should care about. By limiting what is counted, society's ability to choose for itself what is important is limited.

> "I think there are real limits with where we're likely to get in rooms full of experts deciding on theoretical grounds what the right set of ecosystem service denomination should be. It's not going to fly. It hasn't flown in any place I've ever seen that's tried to do it."

> "Standardization, and saying there's going to be a "one-size-fits-all," is what technical people always want to do."

> "Out there at program implementation level, there really is no constituency for common metrics or standardized metrics."

> "Let the people out there decide, the person closest to the problem knows best what to do."

> "In some places the ecosystem metric is wetland acres. In other places it's a fish population number. In other places it's the shape of the hydrograph below the

> river. How do you choose these different metrics? It depends on what stakeholders feel is what speaks to them in terms of the environmental outcome."

This is not the interpretation the organizers advocate or wished to convey. Their interpretation of standardization is as follows: "you tell us what is important, and we will standardize the way it is measured." In this interpretation, standardization is achieved by the application of consistent measurement principles. These consistent principles are applied to *any* benefit identified by the public or decision-makers.

Consider the following colloquial metaphor. Let's say we want to know how society benefits from the enjoyment of fruit. To analyze the problem we might want to count the number of apples, oranges, bananas, and grapes our society desires and provides. What we mean by standardization is a consistent way of measuring (weight, size color) and classifying (different kinds of fruit) apples, oranges, bananas, and grapes. The alternative interpretation: standardization is telling me to only count oranges. To be clear: this was not what the organizers meant by standardization. One participant made the point clearly:

> "What I got out of that conversation was that it sounds like what you're proposing is actually the solution to that, which is not to standardize the benefits that you consider in any one project, but how you measure any one particular benefit."

This is exactly the clarification we would like to make. In our view there is no contradiction between allowing communities, individuals, or managers to pick the things that matter to them the most and yet still define and organize measurement of those benefits in a way that fosters consistency and comparison. We don't think there is actually disagreement on this point, just a lack of clarity on what we meant by "standardization."

Areas of disagreement

Some of the disagreement regarding standardization seemed to go beyond questions of definition and interpretation, however. The standardization that was advocated derives at its root from a desire to measure environmental performance against the yardstick of human well being. There is fundamental, perhaps irrevocable, disagreement about whether or not human welfare is always an appropriate yardstick.

One participant made the following set of observations:

> "We've heard about promoting human well-being….We've heard others promoting social equity, how's our economy doing, performance measures, project-level comparisons." [What to count] is de facto a debate about what our goal is for handling those systems is. Who's going to matter? What properties of these systems are going to matter? Just human welfare, or something about keeping the ecosystem intact because we want to do so? These are fundamentally

political value arguments. And unless and until we treat the choice of measures – what we're going to measure, what the indicators are going to be, as something that needs to be negotiated among the key stake- holders, we're going to keep finding that after we've done all the technical work, people come back and say, 'this was a fixed case. It wasn't fair.' Not, 'It wasn't accurate,' – but, 'it wasn't fair.'"

"It doesn't say we shouldn't push towards [standardization], but it says it comes at a really steep political cost.… I would argue that maybe we're a little bit ahead of where we might want to be on that."

Resistance to economically oriented standardization was also offered by a couple of the ecologists. Here the argument is that the goal should primarily be finding ecological indicators that are powerful proxies for ecosystem service provision and focus on the measurement of those.

"The issue for me as picking an indicator…any good one. Because what you're interested in is relative magnitude across the area you're prioritizing. So pick something that indicates the service, almost whatever it is, as long as you know it's a good indicator, and then you can map out its relative magnitude and find the highest values."

"All you need is a good indicator."

"They're pretty complicated systems. And from a systems perspective, all that we require is an index that provides a reliable measure of how well that system is behaving. What makes a good indicator is that it be reliable, easy to measure, repeatable, free from observer bias, robust over time – meaning that if you measure it five years from now, it'll tell you the same information that it does now, and so on."

Our interpretation of this view is that it is largely pragmatic, a choice between doing a broader, systematic accounting of biophysical features related to human wellbeing and searching for a relative small set of summary indicators (proxies) that can economize on measurement. In our view, the only way a small set of proxies can be validated, however, is by conducting a broader assessment of biophysical features. The power of simple proxies can only be tested against that.

Finally, from a regulator we heard the following reflection:

"I don't think there's one set of measures or things that are going to answer all of my questions, and I don't think there has to be…. [Your approach] is not going to answer all my questions, but it will provide a valuable piece of a broader puzzle."

With these qualms in mind, many participants emphasized the desirability of consistency and standardization in the way we measure ecosystem performance. Several spoke of an underlying conflict in terms and objectives:

> "We cannot even think about the common definitions. What ecologists call monitoring and what the evaluators are calling performance – what the social scientists are calling evaluations and impacts – these are different vocabularies; different terminologies."

> "What our managers need to know, as you're all acutely aware, is not the same as scientists want to know."

It was generally agreed that principles should be applied to what is measured and that those principles need to be communicated and transparent.

> "You need concepts or you just measure data willy-nilly. You need to know why you're measuring things."

From the standpoint of decision-makers greater standardization was thought to be particularly desirable.

> I think there is an investor-oriented perspective coming to the environment; that investors like [Foundations] and OMB and multiple other agencies, are saying, 'we need evidence in standardized form, so that multiple players within those institutions can comprehend what we're buying. We need to do intelligent portfolio management of our scarce resource base to perform our responsibility.'"

> "A term I have heard a lot lately that I will unapologetically endorse is the standardization of quantified measures of ecosystem services."

> "One of the advantages of standardization that I haven't heard mentioned yet is that it offers credibility in a policy context….we get suspicious when we see quantified measures that appear very ad hoc because we ask ourselves, 'well, why this particular quantified measure? Is the agency just cherry picking something that makes its regulation look good rather than something else that they might focus on?'

> "By standardization, what I had in mind, and I think that's what a lot of people in here had in mind, is a metric that is used, let's just say – throughout the hierarchy of the organization. And it works up and down in a way to give coherence, and then, better yet, across organizations."

> "Performance indicators vary widely from project to project and usually cannot be compared across projects. … Setting program level priorities in a more theoretically robust way is something that … [people] other than myself would very much like that to happen."

"I think even if we had a consistent way of measuring quantitatively outcome parameters that decision-makers could get kind of used to in terms of seeing similar numbers managed similar ways that mean similar things from rule to rule, it would be an enormous improvement over what we have today where for each situation that we deal with we, in essence, wind up trying to define a tailored set of measures that will help in forming the decision-making process."

"Again, on the other hand, when you're running a national program and you've got a series of inconsistent measures across the program, not only is it hard to explain the cumulative results of what you're accomplishing, it's also hard to make programmatic decisions about which resources should we invest in and which programs."

APPENDIX A

CONFERENCE ATTENDEES

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APPENDIX B

AGENDA

Practical Measurement of Ecosystem Services: Can We Standardize the Way We Count Nature's Benefits?

May 25 & 26

1st Floor Conference Center
1616 P St. NW
Washington DC

Thursday, May 25

8:00-8:30 **Registration and Coffee**

8:30-9:00 **Introduction of Participants & Opening Remarks**

Phil Sharp, President of Resources for the Future

9:00-9:30 **Workshop Overview & Goals**

Jim Boyd, RFF

9:30-11:30 **Session I: The Policy Problem**

Unmet demand for environmental performance and benefit measures: What do agencies, evaluators, and conservancies need?

Agencies

Discussants Al McGartland,
Director, National Center for Environmental Economics, US EPA

Robert Pietrowsky
Director, Institute for Water Resources, US Army Corps of Engineers

Michael Shapiro

Deputy Asst. Administrator, Office of Water, US EPA

Evaluators

Discussants Jim Laity
Office of Management and Budget

Robert Robinson
Managing Director, General Accountability Office

Matthew Birnbaum
Conservation Science Officer, National Fish & Wildlife Foundation

Conservancies

Discussants Taylor Ricketts
Director of Conservation Science, World Wildlife Fund

Mark Shaffer
Program Director for the Environment, Doris Duke Charitable Foundation

Preliminary Diagnosis: What are the roadblocks?

Discussants William Clark
Professor, Kennedy School of Government, Harvard University

Leonard Shabman
Senior Fellow, RFF

11:30-12:30 **Session II:** **A Proposed Solution – Standardized Ecosystem Service Units**

Jim Boyd, RFF

12:30-1:15 **Lunch**

1:15-2:45 **Session III:** Ecology's Role and Reactions to Economically Derived Units of Account

Joan Roughgarden

Dean Urban
Heather Tallis

2:45-3:00 **Break**

3:00-3:45 **Session IV:** The New World of Measurement & Mapping

Lisa Wainger

3:45-5:00 **Session V:** Targets of Opportunity

The 2007 Farm Bill
Bonnie & Heimlich

Ecosystem Trading
Woodward

Global Issues
Costanza

5:00-6:00 **Cocktails**

May 26

8:30-9:00 **Coffee**

9:00-10:00 **Session VI:** Units of Account and Cost-Benefit Analysis

Benefit Transfer
Stated Preference
WTP Indicators

Maler
Krupnick

10:00-10:30 **Session VII:** Performance Assessment and the Role of Integrated Ecological-Economic Modeling

Polasky
Sanchirico

Rob Wolcott EPA

10:30-11:00 **Session VIII:** Green GDP: Lessons from the History of Welfare Accounting

Banzhaf

11:00-12:00 **Session IX:** Is there a Constituency for Systematic Collection of Environmental Accounting Units & Performance Measures?

The Research Agenda

A Bureau of Environmental Statistics

12:00-1:15 **Adjourn**

APPENDIX C

DISCUSSION PAPER

January 2006 ■ RFF DP 06-02

What Are Ecosystem Services?

The Need for Standardized Environmental Accounting Units

James Boyd and Spencer Banzhaf

What Are Ecosystem Services?
The Need for Standardized Environmental Accounting Units

James Boyd and Spencer Banzhaf

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

Contents

What Are Ecosystem Services?

The Need for Standardized Environmental Accounting Units

James Boyd and Spencer Banzhaf[1]

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.[2] 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 is constrains, and thereby standardizes, units of ecosystem account.[3]

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."[4] 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.

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

[1] Senior fellow and fellow, respectively, Resources for the Future, Washington, DC. We thank V. Kerry Smith, Lisa Wainger, Will Wheeler, members of the EPA Science Advisory Board Committee on Valuing the Protection of Ecological Systems and Services, and participants at the Research Triangle Environmental Workshop and a National Science Foundation Biocomplexity Workshop for valuable comments.

[2] See Section 5.

[3] 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.

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

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.[5] 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 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.[6]

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

[5] 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).

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

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.[7] 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 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.[8] 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.[9] 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.

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[7] 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).

[8] See Banzhaf (2001).

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

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.[10] 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.[11] 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—is 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 Angeles 2001; Grambsch, Michaels, and Peskin 1993).[12] 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

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

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

[12] 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).

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 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.[13]

[13] 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 is accounted for in green GDP.

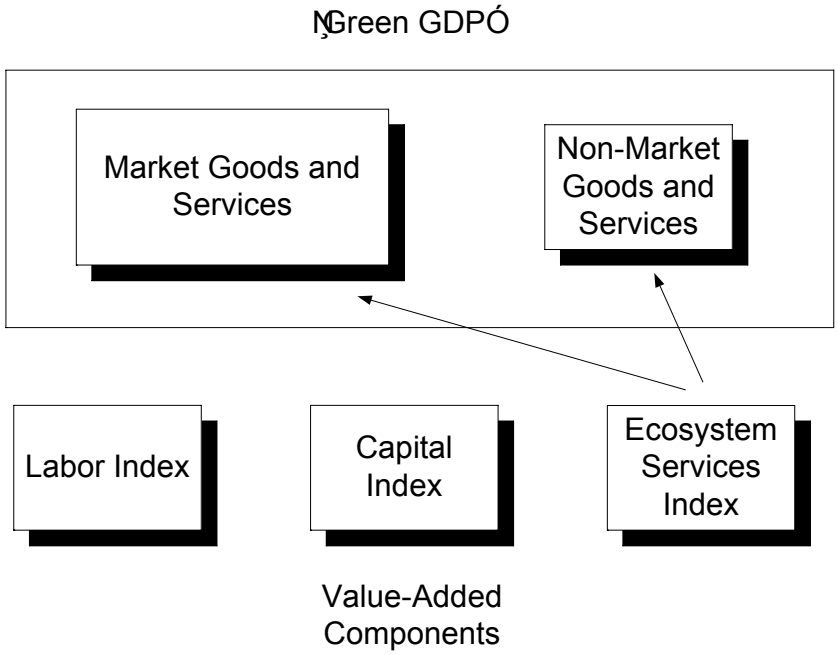

Figure 1. Green GDP vs. an Ecosystem Services Index

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 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.[14]
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 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.[15] 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] 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).
[15] 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

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

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

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

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, $(\partial \mathrm{A}/\partial N)\mathrm{d}N$; and 3) the shadow value of the change, $p_N \mathrm{d}N$.

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, $(\partial \mathrm{A}/\partial N)\mathrm{d}N$, 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 $\mathrm{P_A}$.

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

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

This is a legitimate approach, but note that it requires global knowledge of the production function.[16] Our definition of services does not. However, there is no free lunch. Using our

[16] Another, related approach is to define the service as the marginal contribution: $(\partial \mathrm{A}/\partial N)\mathrm{d}N$. 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.

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 is really desired.[17]

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 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

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

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.[18] 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 population (see Figure 2).[19] 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 land cover	Wetlands, natural riparian quality

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

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

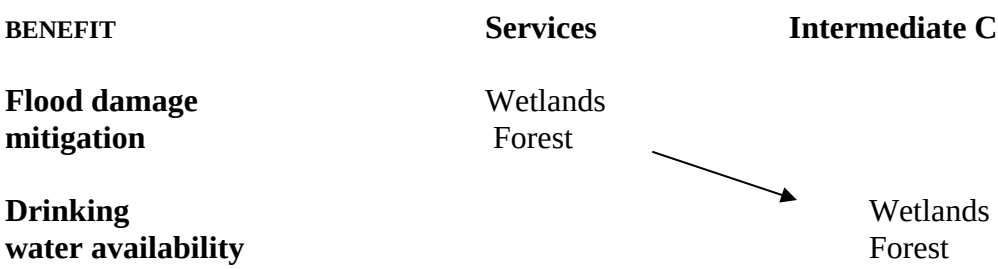

Figure 3. Ecosystem Services for Wetlands

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.[20] 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.[21] 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 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.

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.

[20] 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.

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

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
- maintenance of biodiversity
- protection of coastal shores from erosion by waves
- protection from the sun's harmful ultraviolet rays
- partial stabilization of climate
- moderation of weather extremes and their impacts
- provision of aesthetic beauty and intellectual stimulation that lift the human spirit

Gretchen Daily, Nature's Services, Island Press, 1997

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.[22] 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.

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

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 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).[23]

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."[24] We envision mapping each service at a relatively fine resolution.

[23] 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.

[24] An exception are services associated with existence or bequest values.

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

Table 1. Inventory of Services Associated with Particular Benefits

Illustrative Benefit		**Illustrative ecosystem services**
Harvests		
	Managed commercial[25]	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[26]
	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[27]
	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

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.

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

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. [28] 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 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.

[28] 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.”)

Broadly, accounting frameworks require three things. First, 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).[29] 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.[30] 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.[31] 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

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

[30] 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.

[31] 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.

quality, substitution, and complementary asset landscape factors akin to what we call WTP indicators.

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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