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BIOMASS TO ENERGY:

FOREST MANAGEMENT FOR WILDFIRE REDUCTION, ENERGY PRODUCTION, AND OTHER BENEFITS

APPENDIX 7

PIER FINAL PROJECT REPORT

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APPENDIX 7:
Counting Ecosystem Services: Ecological Endpoints and their Application

A Report to the U.S. Forest Service

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Notice of Change in Scenario Naming Conventions

Key assumptions, modeling structures and terminology were altered and refined to accommodate new thinking during the course of this study. The reader will observe in the appendices that the scenarios are referred to as "Scenarios 1, 2 and 3" or "S1, S2 and S3."

In both the main text of the Final Report and in the Life Cycle Assessment appendix (Appendix 4), the former Scenario 1 (S1) was renamed to the "Reference Case." Scenario 3 (S3) has been renamed the "Test Scenario." Scenario 2 (S2), focused on the relative contributions and impact of Industrial Private Forestry (IPF) has been eliminated from most of the analyses that make up the entire study. These changes better reflect the focus of the study, which is fundamentally about the landscape level changes in wildfire, habitat, and other dynamics. The modification of terminology do not substantively affect the findings or recommendations of the study.

1. Introduction

Ecosystems support more than species and biological functions: they also support the provision of socially valuable services. Ecosystems can purify water, reduce flood and fire risks, support recreation, provide beauty, improve nearby agricultural output, sequester carbon, and enhance air quality (Daily, 1997). When ecosystems are changed or damaged the social value of the services provided by those ecosystems changes. This creates a substantial challenge for natural resource managers. How are ecosystem service benefits to be measured?

This report is motivated by the Forest Service's need to answer such questions, and the substantial scientific commitment it requires. The study presents an architecture designed to clarify and coordinate ecological and economic analyses of natural systems. In so doing it helps articulate a broader research agenda in ecology and economics.

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Throughout, the implications of this architecture are illustrated via reference to an ambitious, ongoing U.S. Forest Service study. The Biomass to Energy (B2E) Project is exploring the ecological and economic consequences of managed forest fuel treatments. These treatments, by design, alter the vegetation of a 2.7M acre study area in Northern California. The project is composed of linked models depicting fire behavior, habitat changes, greenhouse gas and other air emissions, and economic activity arising from the use of cleared vegetation to produce energy. It builds on the Forest Service's considerable expertise in forest and fire modeling

The B2E study addresses a wider range of economic and ecological impacts than is usually seen in the academic literature. However, it is not a *comprehensive* assessment of ecological and economic effects. In part, this paper explains why comprehensive environmental assessment is so difficult to achieve. The paper also suggests a set of ways the dream of comprehensive environmental assessments can be turned into reality.

The paper advocates assessment based around *ecological endpoints*. It argues that the development of ecological endpoints will lead to more coordinated, comprehensive and cost-effective biophysical and economic analysis of environmental management. The scientific agenda implied by ecological endpoints is a focus of the paper.

1.1 The Resource Management Goal

As a manager of land and land cover, the Forest Service already deploys a set of sophisticated measurement and management tools. Understandably, given the Service's political and legal mandates, these tools are focused on timber and fire management. But as a land manager the FS manages much more than timber and fire. Most Forest Service assets also provide shared, public goods associated with ecosystem services. The FS manages and controls a set of resources with huge economic value, but for very good reasons is unable to attach clear value to these resources. The public goods arising from forest assets are the focus of this report. The Forest Service's challenge – and opportunity – is to measure, manage, and communicate the value of these non-timber ecological resources for the benefit of the nation.

Management requires measurement. The question, then, is can we complement existing FS management tools – such as its forest inventories and fire management modeling – by providing managers with data to manage and communicate the Service's public good, ecosystem service inventories? This report describes and advocates a particular strategy – for both economic and ecological science – to move the Forest Service toward this aspiration.

The strategy is to develop *ecological endpoints* and build an accounting system around them. Ecological endpoints have the following characteristics: they are biophysical characteristics or qualities; they are concrete, tangible, and measurable; and they are directly, intuitively connected to human wellbeing. Examples include water availability, species populations, viewable open space, and air, soil, and water quality – all in particular places at particular times. Ecological endpoints are a portfolio of place- and time-specific ecological results.

These endpoints give focus to two related scientific agendas – one in natural science, one in economics. The natural science agenda is to develop management and ecological models to predict changes in the ecological endpoints. How does this portfolio of results change in response to natural and social stressors? Can social policies and active environmental management lead to a better portfolio of outcomes? These questions demand analysis of natural systems and thus are the realm of the ecological, hydrological, and biological sciences.

The social science agenda is to weight or place value on those endpoints to prioritize management and protection actions. Consistent, standardized endpoints will empower economic analysis by fostering and improving benefit transfer methods.

What makes this strategy different from status quo approaches is that it focuses on economically-derived ecological quantities (the endpoints) as the initial and core activity. In general, economic analysis of environmental management does not give particular attention to this quantification issue, focusing instead on the derivation of monetary values. And ecological science, while often focusing on ecological outcomes, does not generally focus on ones directly relevant to economic analysis. Thus, the ecological endpoints can be thought of as a conceptual and quantifiable bridge between the natural and social science agendas central to the evaluation of environmental benefits.

1.2 The Measurement Challenge

Public goods and services are those that are shared and thus resist ownership. Public lands, and the goods and services that arise from them, will produce both private and public goods. Commercial timber harvests are private goods. Timber is bought and sold. We can use the prices and quantities observed in market transactions to place an economic value on that particular good. But the land on which the timber is grown also produces shared, public goods that are not traded in markets. Water and air quality improvements, open space, recreational opportunities, and biodiversity preservation are public goods, not bought and sold in stores.

Economic assessment requires that we first count then weight goods and services if we are to account for their economic value. But what quantity units are we to count when markets are not present, and therefore there is no easy way to track or define what is being used, consumed, or enjoyed? That is the core issue addressed by this study.

Note that market goods usually come in conveniently pre-defined quantity units – the cars, washing machines, haircuts, and restaurant meals consumers buy every day. How many cars and haircuts were consumed this period? For natural capital, its many public, non-market goods and services are not defined, provided, and priced by markets.[2] This means, of course, that we lack the market artifacts – units sold, prices paid – so useful to accountants of the market economy.

[2] Even when nature's goods and services aren't public goods, the private consumption of nature often has ancillary consequences for the scale or quality of public goods. Also, many private good natural resource markets are heavily distorted by inefficient regulatory regimes, rendering the market information they provide suspect.

B2E Application and Discussion **Public Goods**

Most types of land can be thought of as a mixture of private and public goods. However, public lands tend to produce a disproportionately large amount of public goods associated with, for example, recreation. A comprehensive analysis of the B2E landscape thus requires assessment of ecological public goods. Public goods, by definition, lack market data – on quantities and prices.

The B2E's economic analyses are analyses of private good impacts. This is by design, since private good impacts have analogous, observable prices. Public good impacts do not have observable prices or quantities and thus complicate the search for monetary impact estimates.

Not only is there a missing prices problem – how to infer value when market prices are absent – there is also a missing quantities problem. More carefully stated, we need to replicate the market's ability to define units of consumption, but do so in a non-market setting. Accordingly, economists should be involved in the definition of ecological quantity accounts and work with natural scientists to depict nature in a way useful to utilitarian analysis.[3] The strategy advocated here is to use principles from economic accounting, welfare economics, and environmental valuation to define the non-market units – the ecological endpoints – that should be used in a quantity index of ecological goods and services.

2. Motivations for the Endpoint Approach

Endpoints are not a substitute for economic techniques such as econometric non-market valuation. Nor are they a substitute for existing ecological assessment methods. Rather, they are – by design – a way to complement, coordinate, and bring consistency to existing empirical methods in the natural and social sciences. To make this argument, and motivate the desirability of endpoint assessment, this section characterizes – in very general terms – existing economic and ecological approaches to environmental measurement. The section begins be describing the relationship of endpoint assessment to conventional economic valuation methods. It ends with a discussion of how ecological endpoints (as defined in this study) relate to various forms of ecological assessment.

2.1 Endpoint Analysis – Relationship to Economic Methods

Economists for decades have been experimenting with methods to estimate the dollar value of non-marketed environmental goods and services. A comprehensive survey is beyond scope of this document. However, the approach described in this report is motivated in large part by inherent limits to conventional economic valuation. In practice, it is rare to see agency decision-makers, or private conservation organizations,

[3] Banzhaf and Boyd (2005), Boyd and Banzhaf (2007), and Boyd (2006) develop this theme and analyze concrete ways in which economics and ecology can productively interact.

making land use decisions based on comprehensive monetization exercises.[4] There are two broad reasons for this: first, monetary assessment of non-market goods is expensive, technically, difficult, and time-consuming. Also, the methods used to place dollar estimates on natural resources are specific to certain kinds of benefits. This means that a comprehensive assessment of benefits requires deployment of a wide range of economic techniques. Accordingly, it is near impossible to monetize the full range of public good benefits arising from a particular landscape.

The second problem is that micro studies have only limited applicability in different locations. This is known as the benefit transfer problem. It would be useful to take existing monetary estimates and simply apply them to each new landscape we wish to evaluate. But that is difficult. As a result, benefit transfer methods have not gained broad practical adherence.[5]

To understand these limitations it is necessary to provide a brief summary of conventional economic tools. There are both "micro" and "macro" approaches to economic assessment.

Micro-Assessments

"Micro" economic studies derive monetary benefit estimates using hedonic, travel cost, contingent valuation, and other econometrically sophisticated methods. Non-market valuation techniques fall into two general categories: revealed and stated preference methods.[6]

Revealed preference studies look at the price people are willing to pay for marketed goods that have an environmental component. From those prices, inferences about the environmental benefits associated with the good can be made. For example, when people purchase a home near an aesthetically pleasing ecosystem home prices reflect that environmental amenity.[7] Alternatively, when people spend time and money traveling to recreation they reveal a willingness to pay the time and travel costs to access the recreational services. "Travel cost" studies are used to make a benefit estimate based on those expenditures.[8] The travel cost method requires data and analysis linking the number of trips to a site with the quality, size, or location of a site. Changes in these attributes can be valued if there is a perceptible change in the number, length, or cost of trips taken to the site.

Of course, not all environmental benefits are captured in market prices or in observable individual choices. One way around this problem is to move away from reliance on preferences revealed in markets. Stated preference studies are one such alternative. Stated preference studies ask people, in a highly structured way, what they would be willing to pay for a set of environmental improvements. Contingent valuation studies are an example. Stated preference surveys are expensive, controversial, and are

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[4] Bio-physical assessments can be difficult for regualtory staff to apply, even without an economic valuation layer. See McQuaid and Norfleet, 1999 ("Currently, many indexing tools are too complex for NRCS field use…").

[5] See Ecological Economics, Special Issue, 2006.

[6] For a good overview of these methods see Freeman, 1993.

[7] Hedonic analysis is used in this type of study. See, e.g., Mahan, Polasky, and Adams, 2000.

[8] There is a large methodological literature on this subject. See, e.g.,McConnell, 1992.

most reliable when the questions concern specific ecological services provided in specific contexts. The more complex and holistic the improvement, or change, the more difficult the methodological challenge. A principal drawback to this approach is the risk that people may misunderstand the precise service being valued when undisciplined by the need to spend their own real money. For the same reason, they may also overstate their willingness to pay.[9] Nevertheless, these methods are a distinct improvement relative to evaluation techniques that ignore social preferences.[10]

The drawback to these kinds of analyses is that they require econometric sophistication.[11] From a decision-making standpoint, the cost of econometric studies will frequently exceed the benefits. They also tend to focus on the benefits of only a subset of services because the methods used to estimate, for example, recreational values, avoided flood damage benefits, improved water quality benefits, and aesthetic value tend to differ depending on the services in question. As one example, hedonic analysis will only capture the value of services internalized in private housing prices. But the full social value of an ecosystem will usually be greater than the amount that is locally internalized in private property values.[12]

Ecological endpoints allow for an expanded, comprehensive depiction of public good benefits.

"Benefit transfer" studies are one way to harness the benefits of econometric estimation while minimizing the need for costly new site-specific analyses.[13] The benefit transfer method takes the result of a pre-existing monetary study and translates it into a new environmental context. For example, if a study of trout fishing in Colorado yields a per-person benefit of $100 a day, this result can be transferred, with some adjustments, to say something about the value of a fishing day in California.

The problem with benefit transfer methods is that the value of environmental goods and services is highly dependent upon the physical and social context in which they arise. This limits our ability to credibly transfer values across the landscape.[14]

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[9] See generally Kopp et al, 1997, presenting a collection of articles relating to the contingent valuation method.

[10] See Carson, et al, 2001 for a review and defense of contingent valuation's role in the evaluation of environmental goods and services.

[11] An important issue in travel cost studies, for example, is the definition of relevant substitutes for the sites in question. See Arrow, 1993 ("omitting the prices and qualities of relevant substitutes will bias the resource valuations").

[12] The value of some ecosystem services, such as flood protection and aesthetic beauty, may be internalized in property values.

[13] For an overview of benefit transfer methodologies, see the special issue of Water Resources Research devoted to it (1992). Also see Kirchoff, Colby, and LaFrance, 1997, and Kopp and Smith, 1993.

[14] For a description of the challenges associated with benefit transfer studies see Chapman and Hanemann, 2001 ("It is sometimes claimed that the benefit transfer approach provides a convenient solution when the requisite data are lacking. But in this case there was considerable disagreement over basic issues such as whether or not beaches in Florida are 'substantially dissimilar' from beaches in Southern California. If this benefits transfer is problematical, how much more so others! It is striking that, although both parties initially decided to use benefits

B2E Application and Discussion **Benefit-Transfer**

Comprehensive monetization of ecosystem benefits and costs is impractical due to the difficulty of comparing one landscape's value to another. Original service-by-service econometric studies must be conducted with original data. Benefits cannot be easily transferred from existing studies to a new study area, such as the B2E landscape.

See Baerenklau's review of forest valuation studies: "To date there is not a commonly accepted and practical set of standards for 'proper' benefit transfer."

Ecological inputs are not fungible in the way most economic goods and services are. Rivers and forests cannot be shipped across state lines. Similarly, most ecological inputs cannot be accelerated or inventoried across time (though, note that that is precisely the purpose of reservoir management). Moreover, like any benefits, environmental benefits are a function of scarcity, substitutes, and complements. Environmental benefits are often not fungible precisely because substitutes and complements in the economic production function are themselves not fungible.[15] If a beautiful vista is to yield social value people must have access to it. In other words, the vista must be spatially bundled with infrastructure – roads, trails, parks – that are themselves not transportable. Recreational fishing and kayaking require docks or other forms of access. Substitutes for a given recreational experience depend on a recreator's ability to reach them in a similar amount of time. Thus, the location of non-fungible substitutes is important. The value of surface water irrigation is a function of the location and timing of alternative, subsurface water sources. If wetlands are plentiful in an area, then a given wetland may be less valuable as a source of flood pulse attenuation than it might be in a region in which it is the only such resource. Accordingly, not only are ecological goods not fungible, but so are the substitutes and complements necessary to their eventual valuation.[16]

In order to foster benefit transfers, the economics profession and literature in which it publishes must converge toward a set of common – and thus sharable – practices. In order to judge the relevance of a particular to study to a particular new site, it is necessary to know how comparable those sites are. Unfortunately, environmental valuation studies are too heterogeneous in their methods, results, and control variable to make this a practical proposition (Rosenberger and Loomis, 2000; Loomis and Rosenberger, 2006).

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transfer, as the trial approached they each felt compelled to undertake original research to re-analyze the data and re-estimate the models used in the benefits transfer studies ...", at 355.)

[15] This is what has thwarted so-called benefit transfer studies in environmental economics (Ecological Economics, Special Issue 2006).

[16] The role of service zones in environmental valuation is well appreciated. For example, travel cost models require analysis of recreational substitutes which is an inherently spatial issue.

B2E Application and Discussion **Control Variables**

To transfer ecological benefit estimates from existing estimates to a new landscape, we need to control for biophysical differences between the sites. Endpoints, if consistently applied, provide a set of control variables to facilitate such a benefit transfer.

The ecological endpoints and benefit indicators described in this report will hopefully be viewed as a way to meet the challenge posed by these authors. They define standardized measurement and reporting protocols and are rooted in welfare economics. In principle, they can foster future benefit transfer initiatives.

> *Ecological endpoints and benefit indicators are not a substitute for original, site-specific economic studies. Rather, they provide a set of utility-theoretic metrics – relating to both biophysical conditions and their benefits – to standardize the assessment and reporting of econometric results.*

Benefit transfer practitioners increasingly call for more, better, and more consistent documentation of micro-studies.[17] The ecological endpoints discussed in this report are one way to standardize the measurement and reporting of environmental commodities. Their associated benefit indicators are a way to standardize measurement and reporting of the biophysical and social landscape that so strongly affects the value of those commodities.

Macro-Assessments

A different strand of economic environmental assessment is associated with macro-, accounting-based systems – such as so-called Green GDP initiatives. A wide range of these accounting approaches have been created or advocated.[18]

For very good reasons, these green accounts focus on "near-market" clues to nature's value.[19] Examples include economic damages arising from air pollution (using health costs), valuation of timber stocks (using land values) or fisheries (using the value of commercial harvests), and the value of water (for hydropower generation). China's environmental accounting system, for example, focuses on near-market accounts – such

[17] Loomis and Rosenberger advocate the development of protocols for the reporting of research results. "Our suggested protocols cover the general categories of commodity definition and measurement, market area definition and measurement, and welfare measure definition and estimation…We believe a change in how we provide information to our peers and the policy community is long overdue." p. 349.

[18] For descriptions of existing environmental accounting initiatives see Haas et al (2002), Hecht (2000) and (2005), Shi (2004), Heal and Kristrom (2005), Anielski (2006).

[19] As an input to marketed goods, nature's value is partially captured by NIPAs, though nature's specific contribution to the value of the market goods and services is not extractable as an independent set of measures.

as its accounts of environmental expenditures, and aggregate assets such as fish populations, forests, water, and minerals (World Bank, 2006).

To date, most Green accounting systems have adopted what can be called an "aggregate" approach to environmental inventories. Mineral and forest resource accounting, for example, often uses national aggregates, such as the total supply of harvestable timber, copper, and water resources.[20] In these applications, an aggregate approach to commodity definition makes sense. Aggregate measures of these kinds of commodities are appropriate because lumber and copper are fungible (homogeneous, transportable, and storable). Second, it makes sense to make use of aggregate asset prices when they are available, as they are in the case of many commodity-type natural resources. Most existing green accounts exploit the availability of commodity asset prices in just this way, making aggregate asset measures the natural, corresponding quantity measure. It is natural for accounting systems to focus on near-market assets, goods, and services because the near-market is where credible price estimates are most practically derived.

The downside of near-market accounts, of course, is that the scope of these accounting systems is – like the micro-assessments described earlier – relatively narrow. They ignore the environment's public, non-market goods and services in order to focus on goods and services that can be credibly priced.

Also, an aggregate approach to ecological non-market value is often unsatisfactory because of the non-fungibility of many environmental goods and services (described above).[21] While many market goods are bought and sold as assets (real estate, financial products, firms), non-market public goods are unlikely to ever be sold this way. Even when they are, the observed prices should be treated with suspicion, given the necessary role of government in the assignment of quasi-property rights and the setting of prices.[22] Thus, ecological accounting should not expect aggregate, asset-type market prices to be empirically relevant. Rather, the opposite is true. Public good, non-market ecological assets are much more likely to be valued by "building up" the value via valuation of the services flows arising from the asset.

> *The ecological endpoints described in this study complement macro-assessments by defining a set of quantity units amenable to a welfare-significant ecological accounting index. Ecological endpoints complement near-market, aggregate resource commodities with finer-grained measures of non-market, environmental public goods.*

Though recognized as important, ecological income accounts are in an early stage of development.[23] No practical example exists (Smith, 2007, 597).[24] Ecological

[20] For examples, see Peskin (2001), UN et al., (2003), Schoer (2006), World Bank (2006).
[21] Practically speaking, there is always a tradeoff in accounting between the (costly) desire for specificity and the loss of information that attends lumpy, un-differentiated quantities.
[22] In the U.S., for example, the price of oil, gas, and mineral leases may not bear a close resemblance to their true social value.
[23] According to Hecht (2000), existing environmental NIPA efforts "include neither meaningful adjusted macroeconomic indicators nor the value of non-marketed environmental goods and services" (iii).

accounts are beginning to be developed, but these are not accounts in an economic sense.[25] But nature's non-market contributions to welfare may be at least as large as its near-market contributions (World Bank, 2006). It is important and interesting to understand just how large that virtual, natural economy is.[26]

B2E Application and Discussion **No Ecological Accounting System**

Even in the field of environmental accounting (Green GDP and efforts in the National Income and Product Accounts) there is no consensus on how to count, aggregate, and assess ecological impacts. An aspiration of the B2E project has been to count, aggregate, and assess in a scientifically and economically credible way. This implies a 1st effort: defining what biophysical impacts to count.

The macro-and micro-assessment methods described in this section are a desirable approach to ecosystem evaluation because the accounting and econometric tools they employ are objective and have been extensively tested, criticized, and improved over a period of decades. But both types of methods are incomplete. Micro-assessments have to date not fostered benefit transfer and are inherently suited to valuation of only certain ecological benefits. Macro-assessments have tended to ignore the quantification and valuation of pure public goods. The ecological endpoints and associated benefit indicators advocated in this study are designed to address these limitations in a practical way. Ecological endpoints are not a substitute for existing approaches, they are a complement to them.

2.2 Endpoint Analysis and Ecological Methods

Ecological endpoints, as they are defined in this study, will employ specific air and water quality, land cover, habitat, and species data from existing ecological measurement systems. What makes these endpoints different from many existing forms of ecological measurement is, first, that they are defined in relation to utilitarian, human needs and desires and, second, they are defined in the context of an economic accounting system. Using welfare and accounting economics to define what should be measured in nature may be objectionable to those who view nature's contributions to human welfare as beside the point or not relevant to their professional objectives. But if the goal of measurement is an economic assessment of nature's role in our lives, economic principles must be brought to bear on how and what we measure. What is described below is not the only way to measure environmental conditions, but it is an economically defensible way to measure nature's contributions to human wellbeing.

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[24] Describing the recent SEEA handbook on environmental accounting, he observes that "ecosystem accounts are in their relative infancy and are presented more by way of suggested avenues for exploration in the handbook than as clearly worked out recommendations."
[25] See Weber (2007) for discussion of current ecological accounting in Europe.
[26] The U.S. National Research Council (Nordhaus and Kokkelenberg, 1999, p. 23) states the mission thus: "We must not forsake what is relevant and important merely because it presents new problems and difficulties….We must endeavor to find dimly lit information outside our old boundaries of search, particularly when the activities are of great value to the nation."

The Many Forms of Ecological Measurement

Ecological measurement takes many forms, from national scorecards and 'state of the environment' reports (Heinz, EPA ROE), to resource inventories (FSI), environmental quality measures (IBI), and indicator systems of sustainability (cite). Ecological indicator systems are so numerous that at least one academic journal is dedicated to them (Ecological Indicators). At the macro-level Green accounting initiatives, particularly in Europe, include so-called material accounts that track physical resources (assets, forests, marine resources, soils, mineral reserves) at the national scale (cite). Historically, characterizations of species have long been considered a relatively good indicator of other ecosystem features. Accordingly, most early attempts at ecological functional assessment focused on animal populations and were based on field surveys (or, more recently, remote sensing) to detect the presence or absence of certain species.[27] Population surveys are now often supplemented or replaced by methods focused on more permanent biophysical and landscape characteristics—characteristics that signal the suitability of sites as habitat.[28] And increasingly, assessment focuses on "functional" ecological analysis. Examples include methods used to evaluate habitat and wetlands, such as the Habitat Evaluation Procedures (HEP)[29] and hydrogeomorphic (HGM) approach to wetland assessment.[30]

Currently, no particular set of indicators or indictor systems is considered to be a definitive measure of ecosystem conditions. Even for a single environmental concern, such as biodiversity preservation, there is no consensus procedure for describing, much less ranking, any particular type of ecosystem based on its biological components and physical features.[31] Spatial datasets and increasingly sophisticated measurement techniques means that there is a vast array of possible environmental measures that can be included in an indicator system. Indeed, the problem for decision-makers is not that there are too few types of environmental data, but arguably that there are too many.

B2E Application and Discussion **No Ecological Assessment Standard**

There is not a single, standard, way to measure ecological outcomes. Moreover, there is no accepted ecological assessment tool to promote the integration of ecological outcomes into an economic accounting framework. An economic accounting framework is necessary in an economic assessment, in order to avoid double-counting.

[27] See Westman, 1985 and Bakkes et al, 1994.
[28] Under the most widely used approach, a Habitat Suitability Index (HSI) and the total area of habitat are used to quantify habitat. U. S. Dep't of Interior, Fish and Wildlife Service, Habitat Evaluation Procedure (HEP), 1980.
29 U.S. Fish & Wildlife Service, 1980.
[30] See Brinson, 1993.
[31] See Stephen Polasky, Biodiversity Bibliography: Ecology, Economy and Policy, at http://www.apec.umn.edu/faculty/spolasky/Biobib.html (providing a comprehensive summary of the literature on this subject).

The lack of consensus on a set of procedures to bio-physically characterize ecosystems is natural and not necessarily a bad thing. It is indicative of the complexity of those systems, different measurement objectives, and the challenge of comprehensive environmental analysis. But a lack of scientific consensus does have a downside. Decision-makers must pick from an array of competing and sometimes contradictory measures of environmental success. Once a selection is made, detractors can always point to alternative measurements that support their own particular objectives. Ecological science itself may be inhibited by the lack of consistent measurement objectives. Ecological forecasting, causality, and prediction would be aided by more consistent measurement and reporting protocols. As in the case of economic analysis, greater consistency could help promote meta-analysis of environmental issues and strengthen scientific arguments for particular interventions.

The discipline imposed by accounting systems

But how do the sciences move toward a consensus on measurement objectives? One way is to think of environmental measurement from an accounting perspective.

> *An accounting approach to ecological measurement could improve ecology's scientific power and public policy influence.*

Most existing ecological systems are "indicator systems." All accounting systems are indicator systems, but the reverse is not true. The distinction is that accounting systems are constrained by their structure in a way measurement systems are not. Accounting systems rely on *identities* to facilitate and discipline measurement. At the firm level, double-entry bookkeeping is an example. At the national level, so is the definition of GDP and the other National Income and Product Accounts (NIPAs).[32] Accounting identities facilitate aggregation and comparison of an index' components in ways indicator systems do not. GDP can be reported as a single value, despite being constructed from myriad components, because accounting identities discipline its construction.

In the environmental context, and given the goals of this particular measurement system, the most important accounting identity boils down to this: count everything, but only count it once.

> *Rule-based accounting systems, constrained by accounting identities, discipline the measurement of complex systems and promote the social and political credibility of the measurement system.*

Arguably, environmental measurement requires this kind of discipline even more than traditional economic measures, because the complexity of natural systems is so much greater than the complexity of economic systems. It is instructive to compare the state of affairs in economic accounting to that in environmental measurement. Our national economic accounts – developed over many decades of experimentation and debate – are based on measurement practices that are scientifically validated and that capture the market economy's complexity in one coherent set of accounts. Specific

[32] Double-entry bookkeeping means that each transaction results in at least one account being debited and at least one account being credited, with total debits equal to total credits. GDP is defined as the sum of consumption, investment, government purchases, and net exports.

accounting practices are still debated – and will be for years to come – but note that we do not have competing accounting systems. Rather, we have one accounting system that is continuously improved over time. The political and social influence of NIPAs derives largely from the fact that they are rule-based accounting systems and that are not dozens of such systems competing for the public's attention.

The ecological endpoints described in this study are derived from, and consistent with, an accounting approach to environmental assessment.

The ecological endpoints defined in this paper are defined in an economic accounting context. The specific measures, and they way they are eventually aggregated, follow rules imposed by the accounting system. This disciplines measurement and allows the system to be evaluated on the basis of objective principles. Though this is not the only way to impose discipline on a measurement system, the existence and power of NIPAs around the world suggest that it is a time-tested approach worth applying to environmental measurement. When the market economy suffers from inflation, unemployment, or negative growth, our society can largely agree on these facts because they are a culturally, governmentally, and scientifically sanctioned set of measures: the NIPAs. How do we make available to voters a similarly credible set of statistics that reveal the state of our environmental wellbeing?

Capturing nature in a comprehensive way is a tall order. Ecological systems are complex, with an uncountable number of components interacting non-linearly. Is it realistic to think we can capture such a complex system in a practical account? It depends on the goal, of course. If the goal is comprehensive knowledge of nature, that is impossible. But accounting systems serve narrower ends. They provide a rough, but valuable, guide to the more complex systems they describe. The conventional economy is also complex, multi-dimensional, and non-linear. We do not look to GDP and other NIPAs for the complete truth about our economies. Rather, we look to them as important signals of our welfare. Nature's non-market contributions to our wellbeing deserve a similar set of signals.

The discipline imposed by welfare assessment

Nature, taken as a whole, is priceless and resists economic analysis. Since all life depends on natural systems those systems – again, taken as a whole – have an effectively infinite value. What would we give up in order to avoid the collapse of our biosphere? Presumably, we would give up everything but our lives. So in this sense nature is economically unique and priceless.

But while nature as a whole is priceless, its individual, constituent elements are not. The fact is we can, do, and always will choose to live with fewer trees, dirtier air and water, and compromised habitats because nature's components are not *all* society cares about. When economics commoditizes nature (divides it into its constituent parts) it does so in order to systematically depict these social choices.

As a matter of philosophy, economics cares about *anything* that contributes to human well-being, even things of a spiritual, ineffable, and collective character. Economics places no limits on what people think is important or valuable. The desire for beauty, awe, naturalness, and the protection of species other than our own may be hard to measure, but they are all benefits known to economics and accepted as important

social realities that "count." However, economics *only* cares about human wellbeing as the ultimate measure of what is good and bad. Since many things matter to people (beauty, species existence, a sense of wilderness) this is not a huge limitation. But to some, economic assessment of nature is too human-centered (utilitarian) to be philosophically palatable. Nevertheless, the measurement system described here is utilitarian: it hopes to measure what matters to people so the greatest good can come to the greatest number.

> *Welfare-based measurement creates a distinction between intermediate and final goods. Final goods – the endpoints defined and illustrated in this study – are the focus of welfare-significant ecological measurement.*

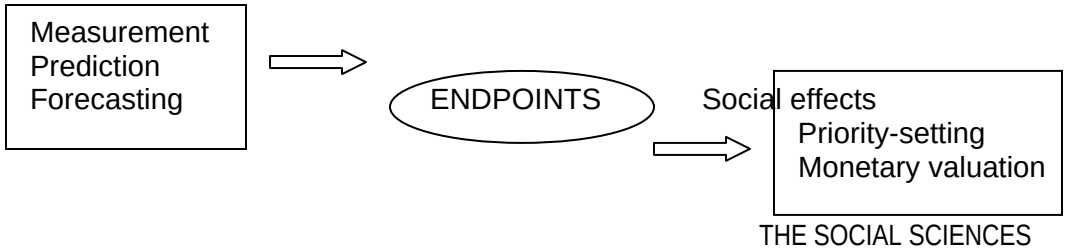
The utilitarian perspective is helpful in one practical respect: it helps us focus on what to measure. With human welfare as the thing to be maximized, we can focus measurement on features directly relevant to human welfare. As will be described below, ecological endpoints are defined as features and qualities of the natural environment that matter *directly* to people. While many, many things in nature will matter to people – and therefore should be counted – endpoints create a distinction between environmental features that are "directly" and "indirectly" valuable to society. The notion of direct vs. indirect goods and services is conventional in the economics of traditional markets. Intermediate goods, for example, are those used to produce final goods. Final goods are what we count in GDP, and the value of final goods embodies the value of intermediate goods used to produce them. This *in no way* implies that intermediate goods are less valuable than final goods. But it does mean that we needn't count everything in nature, only those final ecosystem goods and services that embody the value of the whole system.

3. Ecological Endpoints Defined

Before defining ecological endpoints in technical terms, it is useful to first define their role in the larger assessment activity. Endpoints are not the only components of the system: rather, they are the focus of a larger system that involves both natural and social science.

> *Endpoints are the* product *of natural science. They are the* subject *of social science.*

Once a set of environmental features and qualities is identified as being important to welfare (e.g., the endpoints), the natural sciences not only provide that data, they are necessary to the analysis of how those endpoints can be created, enhanced, protected, sustained – and how they are lost, degraded, or destroyed. Ecology and the other natural sciences are necessary if we are to understand how what we care about is gained and lost. Thus, endpoints need to be a focus of ecological analysis. What ecological management practices, what natural processes, and what social processes lead to gains or losses in the endpoints we care about? Endpoints are the *product* of natural science because they are what natural science helps explain.



In contrast, endpoints are the starting point for economic assessment. They are the environmental features and qualities to which value can be attached. Thus, they are the *subject* of social science. While natural science explains the endpoints themselves, social science explains the importance of those endpoints. Economists could use revealed, stated, or benefit transfer methods to attach value estimates to the endpoints. Political and institutional scientists – even politicians – could use their own to methods to judge and weight the endpoints' importance. Whatever the social science method applied, the questions are the same: Are the endpoints improving or deteriorating? Which of these endpoints are most important?

> *Endpoints do not lead to a single, unified science of nature. Instead, they provide a common focus to separate, distinct scientific missions: natural science on the one hand, social science on the other.*

We often speak of the need to make environmental evaluation "inter-disciplinary." And, of coursed, multiple disciplines are necessary. But there are two ways to be interdisciplinary. The first way is to turn economists into ecologists and vice versa. There is wonderful evidence that this is occurring more and more. [ADD]. But the other way is to coordinate the sciences so they complement each other, rather than seek a full intellectual merger. Arguably, natural and social scientists should do what they are trained to do, not try to become experts in entirely new fields. If they could coordinate better, this might be better for the science of environmental assessment and management. For those inclined to this view, endpoints are a practical way to coordinate and focus the different sciences. They do this by providing a shared point of contact, where the natural sciences leave off and the social sciences begin.

3.1 Endpoints in Health Economics

The coordination of economic analysis and the health sciences is more advanced than the coordination of economic analysis and ecological science. For example, the translation of air pollution into monetized human health costs has played a powerful role in arguments for tighter air emission standards. Similarly, the health and social sciences are increasingly sophisticated in their ability to translate diseases such as malaria into economic terms. While the monetization of human life and health is offensive to some, the coordination of health science and economics necessary to derive these connections is impressive and clearly politically powerful.

It is therefore interesting to note that public health decisions and priorities are aided by the use of *health endpoints* that have been developed and debated for several decades. Health endpoints, while still actively debated, are a lingua franca understood by disciplines as different as pulmonary medicine and urban economics. This common language had to be developed—and still is being developed. In the old days health

impacts were described in highly technical, medical terms, such as oxygen transfer rates in the lung. Today, epidemiologists count things like asthma attacks, reduced activity days, and reductions in life expectancy. In contrast to technical and purely medical descriptions of impacts, these latter measures are intuitive to non-scientists. They more directly communicate the larger truth about how air pollution affects our lives.

> *Health endpoints translate highly technical phenomena into more understandable, human terms.*

The translation of complex, technical scientific understanding is central to public policy and social science. If human health effects cannot be explained in human terms how can social choices be ranked, weighted, prioritized, and chosen? By analogy, ecological endpoints aim at a similar goal: can we translate the ecologically technical into the ecologically resonant. The way to do this is to focus on our *direct* experience of nature.

3.2 The Economic Derivation of Endpoints

This section presents an economic definition of ecological endpoints. The definition is "economic" for two reasons. First, we want the ecological units to be amenable to social welfare analysis. This means that the units bear a close relationship to things that can be ranked or valued in terms of their importance to human wellbeing. Second, the ecological units – and their organization – should reflect the constraints and discipline of an accounting system. Recall that the idea of an accounting system is to count everything, but only once.

These definition, and arguments on which the definition are based, are presented to clarify the role of ecological endpoints in social science. In the next section, once endpoints are more formally defined, we will turn to the implications of this definition for ecological science.

The section is a summary of more technical, detailed descriptions of the method that are available elsewhere. (Boyd, 2007, Boyd and Banzhaf, 2007; Boyd, 2006, Banzhaf and Boyd, 2005). The method employs three distinct economic principles to define ecological endpoints. The three principles are:

- First, clearly and consistently distinguish outcomes – in this case ecosystem goods and services – from the value or weight placed on those outcomes. In economic terminology, this means we must clearly distinguish quantity measures from price measures.

- Second, choose quantity measures – the ecological endpoints – whose value can be credibly revealed through choices or human preferences. In practice, this means choosing endpoints that have direct, concrete meaning to people or that have non-ecological substitutes.
- Third, treat the quantity units as units in an economic accounting system. This implies that all the units that contribute to welfare should be counted, but only be counted once. In practice, it requires a distinction between final and intermediate goods and services.

The distinction between quantity and price

In conventional markets we take the difference between quantity and price for granted. At the store, we are presented with rows and rows of quantity units (the goods and services we buy) and we pay their price at checkout. We take this for granted because markets define the quantities and prices for us. For public, non-market goods, however, the distinction between quantities and their value is not obvious and has in the past been little-studied.

Why wouldn't environmental economics have developed a clear theory to differentiate the quantity and price of public goods? The answer is that most environmental economics studies do not require the distinction. Instead, all that matters is the product of the two, $p \cdot q$. Typically, economic studies compare this product to the corresponding product when we change a policy or make an environmental investment. In effect, we compare $p \cdot q$ in scenario 1 to $p \cdot q$ in scenario 2. The distinction between p and q is unimportant in such as study.[33]

But economic accounting systems (like the NIPAs) require a precise delineation, consistently maintained, of the quantity measured and the price or other weight attached to the quantity. Accounting measures, by their very nature, distinguish between quantity and price. With quantities and prices clearly differentiated one of the quantity/price sets can be held constant. Real GDP, for example, is a measure of quantity, holding prices constant over time. With prices held constant, movements in the output index meaningfully describe changes in quantity produced and consumed. If prices are not held constant in this way, the interpretation of the index is muddied: is an increase in the index evidence of changing prices or changing output? Accordingly, a clear distinction, consistently maintained, between q and p is required by economic accounting systems.[34]

The question, then, is how to define quantities consistently when markets do not define them for us? Because non-market ecosystem goods and services do not emerge

[33] Environmental economics is often called on to analyze the following kind of issue: what are the benefits of a tighter air quality standard in Los Angeles? To answer this question, all that matters is the comparison between $p \cdot q$ before the policy and $p \cdot q$ after it. It is unimportant what part of the benefit is considered an improvement in output, versus an increase in the value of the output. For example, is the number of people in LA, n, considered part of the value of the benefit, or as part of the quantity? It could be either. If the quantity is defined as a per-capita air quality improvement, the number of people benefiting would increase the weight (p) given to the quantity. If on the other hand, we defined the quantity as the change in the total amount of human exposure, n would increase the quantity q, not the weight p.
[34] Irving Fisher called this the "index number problem."

from factories and are not sold in markets, defining and measuring their "units of account" requires theoretical and empirical innovation. The conceptual distinction between ecosystem services and their value is often surprisingly difficult to make.

Accountants use the term "goods and services" to denote the *quantities* measured in accounts. This same convention is applied here: ecosystem goods and services are the quantities to be measured. Prices, virtual and otherwise, are the weights applied to the goods and services. Unfortunately, and as argued in our earlier work, the term "ecosystem services" is not consistently defined by the environmental economics profession. Accordingly, we propose and have defended a particular definition of ecosystem services that facilitates an economic accounting system.

As argued in Boyd (2007) and Banzhaf and Boyd (2005), there are two basic ways to define accounting-based quantities of public goods. The first, and the one we prefer, is to define q as the ecological inputs to subsequent economic production. This sounds obvious, but in fact it is not – at least in environmental economics. Consider several alternatives that are easy to find in the literature.[35] Some studies describe ecosystem services as the beneficial effects of ecological inputs (such as increased crop production) as the ecosystem service. Others describe ecosystem services in terms of their ability to substitute for other forms of capital (such as levies, dykes, or water filtration plants). There is nothing inherently wrong in this. But from an accounting standpoint, these inconsistencies are problematic. In effect, one definition of the quantities to be counted is are ecological inputs themselves, $q = E_1, E_2, E_3, \ldots$ whereas in the other definitions the quantities are depicted as changes in the production of other goods or substitutes, $q = \Delta F(E)$.

The reasons we prefer $q = E$ to $q = \Delta F(E)$ are as follows. First, the latter definition of "quantity" can obscure, rather than clarify, underlying ecological changes and trends. If all we observe and count are changes in final production, we will not know whether those changes are due to changes in the ecological or the non-ecological inputs. In fact, innovation or other changes in production may lead to higher production levels even if ecological inputs are declining in availability or quality. This is an undesirable property for an ecosystem services quantity measure! An ecological quantity index should tell us about ecological conditions directly, rather than require economic interpretation. This desire makes $q = E$ preferable.

Ecological endpoints are spatially and temporally explicit biophysical features or qualities.

Also, ecological measures $q = E$ are concrete, intuitive, make sense to non-economists, and are empirically in the realm of the natural sciences. Economists should have something to say about which elements E are measured. But economists will themselves not do any of that measuring. Also, ecological measures $q = E$ already have a close analogue in national accounting systems. They resemble the "material accounts" already observed in many international systems.

[35] For example, individual chapters in a well-known environmental economics text (Kopp and Smith, 1995, Chapters 2, 7, and 14) define ecosystem services in three completely different ways.

In summary, an index composed of concrete, physical, ecological quantities and qualities is the appropriate place to begin a system of ecological public good accounts. Moreover, such an index – because it is "material and physical" rather than "economic" – provides a natural point of collaboration between the natural and social sciences.

Value-relevant ecological quantities

The preceding argument suggests that what we should be counting as endpoints – the quantities *q* – are biophysical inputs to human wellbeing. As a terminological matter, I use the word "quantity" as shorthand for all of the following: countable biophysical features (e.g., land cover types, species populations), biophysical qualities (e.g., particulate or toxics concentrations), and stochastic depictions of quantities and qualities (e.g., hydrographs). Note that there is nothing economic or social about these quantities. The social and economic implications of these endpoints are derived through the weighting and valuation process, described in section X.

When counting market goods, by definition those goods are subject to consumer choice. In fact, consumer choices in the market are what reveal the value of final goods. GDP, for example, tends to count items that are concrete and subject to tangible consumer (market) choices.[36] In a non-market context the point at which consumers make choices can be less clear. If we are ever to attach welfare significant weights to ecological inputs, the quantities we count should have the same property.

Since we ultimately want to place social weights or valuations on these ecosystem goods and services, we want to measure ecosystem goods and services in a way that is amenable to valuation. The only way to ever estimate real or virtual prices is to come as close as possible to the point at which people reveal those virtual prices through choice.

> *The final biophysical endpoints should be the ecological features, quantities, and qualities that are directly experienced or combined with other (non-ecological) inputs to produce market and non-market benefits.*

With units such as these, virtual prices can then – in principle – be derived via analysis of the ecological inputs' direct contribution to consumer utility or indirect effect on other or substitute market outputs.

A less technical way to explain this prescription is to note that social evaluation of outcomes requires knowledge on the part of society. Accordingly, endpoints should have intuitive resonance with the public. The social sciences tend to rely on the assumption that people are reasonably well informed when they make choices and express preferences. Only if people understand ecological outcomes can social science be a useful way to set priorities and decide what is right.

At this juncture, it deserves emphasis that ecological endpoints do not represent the entire analytical system. Rather, they are the measurement units to which social value can be attached. We certainly do not want to rely on public perceptions alone to determine what is scientifically important. But we must rely on public perceptions if what

[36] This is an over-simplification. The U.S. BEA, for example often relies on proxies for difficult-to-measure service outputs (such as accounting and financial services) (Griliches, 1992).

we are trying to measure is social wellbeing. Only society, with the help of science, can tell us about that.

B2E Application and Discussion **Table 1**

Analysis begins with identification of social benefits derived directly or indirectly from the landscape. With benefits articulated, biophysical endpoints associated with those benefits are then defined. Endpoints are concrete biophysical features or qualities, depicted with high spatial and temporal resolution, when appropriate.

Example Benefits	Example Endpoints
Scenic, aesthetic enjoyment	Undeveloped landcover, untreated landcover (if visible), burned landcover
Residential water provision	Water quality and availability at intake (wells, POTW sources)
Commercial water provision	Water quality and availability at intake (wells, POTW sources)
Irrigation water provision	Water quality and availability at source
Commercially important soils	Soil availability & quality
Recreational open space, aquatic	Boatable waters area, depth, flow
Recreational open space, terrestrial	Parks and public lands
Active hunting and angling	Target species populations (deer, adult steelhead, ducks)
Passive species observation	Target species (songbirds, elk, deer)
Stewardship	Endangered and threatened species not included in active and passive categories, wilderness
Pollutant reductions – Air	Air quality, particulates
Property damage avoidance – Water	Flood events and flood map
Property damage avoidance – Fire	Fire events and fire map
Property damage avoidance – Pests invasives, pollinator losses	Pest, invasive, and pollinator species populations.

Final vs. Intermediate Goods & Services

The distinction between final and intermediate goods and services arises in any economic accounting system. Final goods are not necessarily more important or valuable than intermediate goods. Rather, the distinction arises because of the fundamental accounting identity: count everything, but only count it once. We must distinguish between final and intermediate if we are to avoid double-counting.

Nature is a system composed of complex interrelationships. Even in purely biophysical terms, the ecological "output" of one process will almost always be an "input" to another ecological process. This means that most ecological features and qualities can be thought of in dual terms: as input *and* output. This creates a huge challenge for ecological accounting. Is there any way we can address the double-counting issue in order to improve the quality – and validity – of the accounting system?

Nature presents us with an uncountable number of such inputs. Does that mean we must count all nature's features and qualities in order to comprehensively depict its contributions to wellbeing? The answer is no. Much as GDP does not count all the units exploited and traded in the market economy, an ecological quantity index need not count all the elements of nature. In both cases, a utilitarian approach to accounting allows us – requires us, actually – to focus on *final* units of consumption or enjoyment.

End products can be defined economically as the results of complex processes involving multiple inputs, but where the end product is what is perceived and appreciated by people. End products have a wonderful economic property: the social value of end products includes the value of all the inputs and processes needed to create them.

Consider the issue of double-counting in conventional economic accounts. If we counted both cars and the steel used to make them and then weighted carts and steel by their market prices, we will have double counted the value of the steel. The reason is that the steel's value in car production is embodied in the value of the car. Thus, in the calculation of GDP, final and intermediate goods are distinguished in the following way. If a good or service's value adds to the value of a good or service subsequently sold in the market, it is an intermediate good. Otherwise it is a final good. Cars are final goods. The labor, leather, steel, and human capital required to make the car are intermediate goods.

> *Ecological endpoints are "final" ecosystem goods and services. Final goods and services are not necessarily more important or valuable than intermediate goods and services. Rather, they are the ecological features that embody the value of the whole.*

What do "final goods" mean in an ecological context? Consider an example. What is the value of a natural process (nutrient cycling) and inputs (vegetative cover) that lead to cleaner water? This question can only be answered by placing a value on the clean water itself – the ecological endpoint. If you ask people, how valuable is nutrient cycling, they will first respond by saying "what is nutrient cycling?" Once that is explained, they will conclude that, "the value of nutrient cycling is the clean water it makes available to me." Only the clean water has direct value to people. The value of nutrient cycling, in contrast, must be derived from the value of the clean water provided.

In other words, the value of nutrient cycling and vegetative cover can be backed out of the value placed on the end product clean water. But the value of nutrient cycling cannot be independently derived.

B2E Application and Discussion **Table 2**

The B2E project's core analytical activity relates vegetation to fire behavior. The extent and intensity of fire behavior is an ecological endpoint closely related to several benefits (or costs), including avoided damages to private property (houses, crops, infrastructure) and visual impacts on scenic areas.

However, in many other cases, fire behavior and vegetation are inputs to subsequent biophysical processes with their own outcomes. Some of these outcomes are final goods, some intermediate.

B2E Outcome Measures	Description
Biomass, logs removed	Final ecosystem good for commercial consumption.
Predicted reduction in fire zone	Final good for fire damage avoidance benefit. Intermediate input to most other benefits.
Reduced sediment loads (ERA)	Final good for water provision benefit, may be intermediate input to water quality benefits.
Reduced GHG, SOx, NOx, VOC	Not final goods. Intermediate inputs to atmospheric and deposition chemistry.
Reduced PM10	Final good for certain human health benefits (asthma events) and visibility. Intermediate inputs to atmospheric and deposition chemistry
Improved Habitat (HSI)	Generally, not a final good. Intermediate input to species-dependent benefits.

Another example is the Steelhead population in a particular river. The Steelhead population is an ecological endpoint in terms of benefits arising from steelhead angling. Anglers directly rely on, experience, and consume that population. Of course, Steelhead populations depend in turn on the populations that make up their food chain. But food chain species should not be counted as final goods in this context (the benefits of

recreational angling).[37] Rather, the food chain's value is embodied in the Steelhead population.

B2E Application and Discussion

Several things should be noted about Figure 2. First, note that not all environmental outcomes were assessed by the domains. Second, many of the assessed outcomes are proxies for endpoints, not endpoints themselves (habitat suitability scores, for example). Third, each outcome measure is the result of a unique, technical modeling exercise. The translation of intermediate outcomes into final ecosystem goods (endpoints) would likewise require some form of modeling or statistical translation.

This is why we focus on the measurement of ecological endpoints. The value of intermediate ecological processes, systems, and inputs can *only* be discovered if we first discover the value of the end product. End products must therefore by the focus of any public policy analysis that seeks to link economic and ecological thinking.

A Corollary: Endpoints Are Benefit-Contingent

The definition of a final good is contingent on the social benefit in question. This means that a good can be "final" in the provision of one benefit and "not final" in the provision of another.

Consider a hillside forest and two different kinds of benefit: aesthetic benefits and public health damage mitigation. Aesthetically, people with visual access to the hillside directly enjoy the forest's physical features. Thus, those forest features should be counted as a beauty-related final quantity. In terms of public health, forests may sequester pollutants. In this benefit context, however, the forest is an intermediate, not final good. The final, public-health related good is the air quality itself. The forest has a positive, but intermediate, impact on that final good. Accordingly, from an accounting perspective, the forest is both final and intermediate.

Other examples of this phenomenon abound. The species in the Steelhead's food chain weren't counted as final goods when the benefit under consideration was recreational angling. However, if the benefit being assessed is stewardship value, we would count those species, particularly any that are endangered or threatened.

Wetlands should be counted as final goods for flood protection but are intermediate goods when they lead to improvements in drinking water quality (in which case the drinking water quality is the final good). In a conventional GDP context, the same thing happens. Tomatoes, onions, lettuce, and ground beef are counted if purchased in a grocery store, but are not counted if sold as a McDonald's hamburger.

How many endpoints are there?

[37] These other species may be relevant quantity measures where other benefits are concerned, such as species existence benefits. The fact that final ecological quantities are benefit-contingent is discussed in more detail below.

While a focus on endpoints narrows the field somewhat, there are still a huge number of endpoints to measure. This is primarily because many things about nature directly matter to people. Should we account for every species? Yes, because the continued existence of any species is important to many people. Should we account for wild places, even if people rarely visit them? Yes, because wild places are important to many people even if they never visit them. Should we account for every natural vista in the U.S.? Yes, because sooner or later, if not already, those vistas will matter to somebody. The same holds true for water resources, their availability and quality. The list goes on and on.

B2E Application and Discussion

The number of endpoints to be assessed is a function of the number being affected by the policy, decision, regulation, or investment in question. For example, large-scale land development will tend to generate large differences in a wide range of ecological endpoints.

The B2E intervention (fuel treatment) may have a more limited effect on ecological endpoints if fuel treatments and resulting fire behavior do not significantly alter the underlying ecological processes on that particular landscape.

Because original ecological experimentation was not done as part of the study, it is impossible to say whether substantive ecological change will arise from the treatment scenarios. Rather, certain ecological changes are being inferred (sediment loads, species abundance), based on the assumption that estimates from other studies in other locations are applicable.

While imperfect, most environmental assessment relies on the transfer of results, using models, from an original study area to other study areas.

Also, ecological endpoints are space- and time-specific. Available water matters to a farmer, but only if it is available in a particular place at a particular time. Thus, ecological endpoints must usually be highly disaggregated. From an economic perspective it is meaningless to say that there are a billion acre feet of subsurface water in the U.S. We need to know where that water is and when it is there.

From an economic standpoint, the social determinants of value depend upon the landscape context in which public goods arise. For example, the consumption of public environmental goods often occurs over a wide scale. Habitat support for recreational and commercial species, water purification, flood damage reduction, crop pollination, and aesthetic enjoyment are all public goods typically enjoyed in a larger area surrounding the ecosystem in question. This means that biophysical effects must be tracked or predicted at a larger scale.

B2E Application and Discussion **Off-Site Impacts**

In general, endpoints should be measured and tracked over a landscape broader than the landscape in which management changes are made. Water flows, air quality, and species populations, for example, will have 'spillover' effects outside the B2E landscape. From a social standpoint these effects are potentially as important, if not more so, than on-site effects.

Example off-site endpoint impacts

Downstream reservoir impacts (lost volume) from sedimentation

Changed water flows for recreation, agriculture, navigation

Different downstream flooding risks

Species population changes along migration and forage corridors

Air quality changes, health, and visibility effects in the larger airshed

Summary

This section has used economic principles from welfare and accounting economics to define the properties of ecological endpoints useful to comprehensive social science analysis of nature. These endpoints are by no means all that we care about. They are, however, the units of measurement that will foster the closest coordination between natural and social science. If the goal of analysis is appreciation of nature's role in our economic and non-economic wellbeing, these units are the foundation on which to build. The following section addresses the relationship of endpoints to empirical agendas in natural and social science, respectively.

4. Endpoints and Biophysical Analysis

As emphasized throughout the report, ecological endpoints are not the only components of the analysis. Rather, they are a point of focus. This section describes the central role of the biophysical sciences in the creation and assessment of these endpoints.

The "workings of nature" are fundamental to any social analysis of the environment. In fact, a credible economic or social analysis cannot proceed until the biophysical science is in place. Why? Because the social sciences depict the social consequences of environmental change. But our understanding of environmental change can only come from biophysical analysis. Earlier in this report we argued that endpoints are the *product* of natural science. This section describes in more detail what that means.

Once a set of environmental features and qualities is identified as being important to welfare (e.g., the ecological endpoints), only the natural sciences can tell us

how those beneficial features can be created, enhanced, protected, and sustained. Correspondingly, the natural sciences are also required if we are to understand how beneficial features are lost, degraded, and destroyed.

All of this matters to social analysis because the goal of social assessment is to determine how to enhance welfare derived from nature or avoid welfare losses from nature's degradation. The social sciences help tell us which kinds of degradation and enhancement are most important to welfare, but only the natural sciences can tell us *what will work*.

4.1 Ecological Causality – Predicting Lift and Loss

Thus, biophysical science, as it already does to a great degree, should be focused on ecological process and function. The argument made here is simply that the study of ecological process and function should be in large part geared toward changes in ecological endpoints.

Ecological endpoints create an agenda for biophysical analysis: namely, what aspects of the natural system lead to changes in ecological endpoints?

It is not assumed that these tasks are easily accomplished, but we do ask two basic things of natural science. Given a set of ecological endpoints that we value,

First, what we can do to improve the endpoints' quantity or quality?
Second, what can we do to prevent a loss of quantity or quality?

What creates ecological lift, what creates ecological loss? Environmental management without this kind of knowledge is pure guesswork. The assumption of environmental analysis is that nature is knowable, at least to a point. With knowledge, we can act in a way that leads to better environmental outcomes. As a society we can do a range of things that we hope will positively affect nature. We can use prohibitions, restrictions, and public ownership to minimize human impact on the landscape and its resources. We can focus on specific resources like wetlands, endangered species habitat, and water to ensure that minimum amounts are available. We can actively manage the landscape by restoring habitats and other natural features. And we can regulate human activities to reduce pollution and material demands that put stress on natural systems. These are the things we as a society can in some sense control. The analytical question is, what should we control, how much, where, and when? Ecology, biology, hydrology, chemistry, marine and atmospheric science are the key to translating social action into biophysical outcomes that matter to society.

B2E Application and Discussion

The B2E project revolves around a particular type of environmental management – spatially distributed forest fuel treatments. This is the policy change that triggers a larger cascade of biophysical effects.

The central focus of the project is the prediction of changes in one particular biophysical endpoint – fire behavior.

In what follows, we will rely on the concept of a *production function*. The terminology comes from economics, but is familiar to ecologists and other natural scientists. A production function describes the relationships between inputs and outputs in a system. An economic production function relates different kinds of inputs – capital, skill, labor, ecosystem goods and services – to the market outputs or other benefits they create. Consider the production of bread. Many inputs are required to deliver a load of bread to the grocery, flour and other ingredients, transportation, milling and baking facilities, and the grocery store itself. The economic production function describes how all these inputs come together to produce the final output, a loaf of bread.

An ecological production function also describes the relationships between inputs and outputs in a system. In this case, however, it is not the economic system, but the ecological system that is of interest. The natural sciences describe the combination of biophysical inputs and processes that yield final ecosystem goods and services.

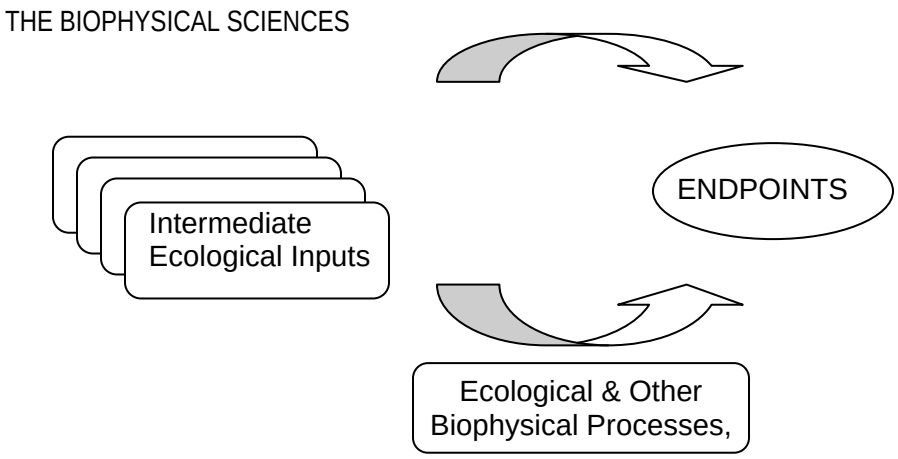
> Ecological *production functions explain the production of final ecosystem goods and services by depicting the inputs and processes that give rise to those goods and services.*
>
> Economic *production functions explain the production of final economic goods and services by depicting the inputs – ecological and not ecological – that give rise to final economic goods and services.*

Knowledge of both kinds of production function is necessary if we are to comprehensively understand nature's role in our welfare. This section focuses on biophysical production, because we are interested in the ways in which ecology can explain improvement in or threats to the ecological endpoints we value.

Consider a pertinent example: the relationship between land cover and downstream water quality. If we alter the vegetation on the landscape (something we can control) can we improve water quality? If so, by how much? It is necessary to understand this causal relationship if we are to make an argument for action and expenditure. Is there something about natural vegetation that would lead to an improvement in water quality? There are many reasons to suspect so. Vegetation can slow runoff and impede erosion. Vegetation can also chemically alter water. Today we know these things as "rules of thumb," or "best professional judgment." Certainly they can be demonstrated to be true in particular locations. But from a statistical viewpoint

we know much less about the exact, empirical relationship between vegetation and water quality. Understandable? Definitely. But still a real problem for analysis.

Lack of comprehensive knowledge of biophysical production functions is understandable for several reasons. First, nature is a highly complex and non-uniform system. Complexity means that causal relationships can only be tested using rigorous, data-intensive empirical and scientific methods. These methods are difficult and costly. Non-uniformity means that even if you establish the causal relationship in one location that relationship need not hold in any other location. Second, empirical analysis of causality requires collaboration between different disciplines (ecology and hydrology, for example). Cross-disciplinary collaboration in any scientific inquiry is always a practical barrier. Third, the biophysical sciences have many other things to study and have limited financial support to do all they are asked to do. If natural science has to date failed to empirically determine these ecological production functions to our satisfaction that failure should be viewed in the most sympathetic terms.



Ecological Production Functions

Three distinct biophysical agendas are important, and all are related to the ecological production functions that describe the ways in which endpoints are enhanced or degraded.

- How can we predict, or forecast, gains or losses in the quality or quantity of the ecological endpoints?

- How can we differentiate and measure differences in the ecological quality of particular endpoints?

- When direct measures of ecological outcomes are impractical, how can we statistically relate measurable proxies to the endpoints we care about?

At the root, these are issues of causality – and the statistical demonstration of causality. Given nature's complexity, the difficulty of monitoring, and the large time scales over which natural change occurs this is clearly a huge challenge. But ecosystem protection and management will be ineffective at best, and dangerous at

worst, if we cannot make credible claims as to about ecological cause and effect. Moreover, the only way to test ecological cause and effect is with spatially and temporally broad data collection. Ecological endpoints create an architecture for that data collection and analysis.

B2E Application and Discussion

The B2E project predicts changes in fire events, locations, and characteristics arising from changed biophysical conditions – Scenarios 1-3. Different fuel treatments can be thought of as different 'ecological input sets.'

<u>Location-specific inputs differ across scenarios 1-3</u>

INPUTS		PROCESS		ENDPOINTS
Vegetation Slope Weather variables	→	Fire process modeling	→	Estimated impact on fire events, location, intensity Carbon, PM10 emitted

The challenge for any environmental impact assessment is to extend this kind of analysis to the full spectrum of endpoint effects. The practical challenge is that each endpoint requires

4.2 Depletion Analysis

It is possible – and many fear – that our current human footprint is robbing our children of future wellbeing. The fear is expressed economically as a concern that we are over-consuming, eating into our natural capital's principal, and consuming natural resources faster than their ability to reproduce or regenerate. A central tenet of economic assessment is that un-sustainable consumption should be made visible to society today. If it is not, we are likely to consume in a way that makes all of us – and particularly future generations – worse off. For both economic and ecological reasons, the future consequences of our actions today must be incorporated into our analysis of nature.

In economic accounting the analysis of future impacts is referred to as depletion analysis. The problem, of course, is that depletion analysis is difficult, since it requires us to know the complex, underlying causes of depletion (El Serafy, 1989). Even in the case of subsoil assets (coal, natural gas, copper) the depletion relationships used in existing environmental accounts are quite crude and subject to ongoing debate. Ecological depletion poses even greater scientific challenges. How do air emissions

from coal-powered plants affect water quality throughout an air-shed? How does a residential subdivision affect species populations in surrounding counties? Today, these questions are known to be important, but we are far from the empirical consensus needed to make depletion adjustments in practice.[38]

B2E Application and Discussion

<u>Location-specific inputs differ across scenarios 1-3</u>

Vegetation (understory)	→	Habitat modeling	→	HSI Scores	→	populations & location
Species						
INPUTS		PROCESS		PROXY		ENDPOINT

The B2E project extends the analysis of impacts to include species effects. It does this by translating vegetation characteristics into habitat suitability scores, via existing HSI models. An HSI score is not the ultimate endpoint measure we seek (location- and time-specific population densities. However, the HSI method is designed to be a practical proxy for those endpoints.

In addition, another set of process models is embedded in the analysis of species effect.

Fire behavior	→	Recovery & regrowth modeling	→	Vegetation Impacts	→	HSI analysis
INPUTS		PROCESS		INPUTS		PROCESS

Note that the outputs of a forest recovery model become the inputs to analysis of post-fire habitat effects. Post-fire vegetation predictions (the bottom model) enter the HSI analysis (the top model).

A richer understanding of ecological causality is necessary if we are to create economic assessments that capture depletion phenomena. Causality will empower

[38] Several NIPAs and green accounts incorporate some form of depletion analysis. However, these efforts primarily demonstrate the empirical difficulties of doing so. See Weber (2007) for an accounting-based view of ecological depletion.

prediction and forecasting, and prediction and forecasting will empower the incorporation of depletion costs into a current economic accounts. The practical question then is: how can we promote a richer understanding of ecological causality? As argued above, an important part of this natural science agenda is a spatially broad and fine-grained depiction of ecological outcomes. If concrete social actions, decisions, regulations, investments can be statistically demonstrated to lift or degrade the condition of ecological endpoints our ability to conduct depletion analysis – and thereby our ability to measure sustainability – will be immeasurably improved.

B2E Application and Discussion **Missing Production Functions**

In order to measure the effect of forest fuel treatments on ecological endpoints (Table 1) a set of additional production functions. Ideally, we would like to translate fuel treatments into their effects on all endpoints of concern. Unfortunately, ecological science is only beginning to explore and develop such production functions.

<u>Production functions needed</u>

- Better species models that incorporate the spatial configuration of habitat. Models of reproduction, forage, predation, and migration to better predict the location and timing of populations. Of interest here are not just valued populations, but pest and invasive populations as well.

- Better hydrological models to link land cover to aquifer and downstream surface water availability. Forests can prevent 'flashy' runoff and thus protect against flood surges. Dense growth is also thought to reduce groundwater delivery.

- Better water quality modeling to link land cover and land management practices to downstream water quality. Forest-related impacts on nutrient cycling and nutrient loads is an example.

- Better understanding of soil quality effects arising from treatment and hydrological processes.

- Better air quality models to allow for the analysis of human health, ecological, and aesthetic impacts.

Some of these models are further along than others. In general, air quality modeling is at a more advanced stage than hydrological modeling because the transport and deposition of air pollutants presents fewer challenges. The USGS Sparrow model is designed to link land use with water quality in a statistically sound manner. However, as a general rule, landscape-level ecological modeling is a young science.

Consistent measurement and tracking of ecological endpoints over time is the best way to foster this scientific agenda. An ecological endpoint account would count

natural features and qualities occurring in a particular place in a given period. In any given period, this provides a single "snapshot" of ecological conditions. Directly, this doesn't tell us anything about the direction or rate of change of those features and qualities. However, enough snapshots over enough time create a multi-layered, national-scale, biophysical time-series database. This would be a huge boon to the biophysical sciences. It would allow, in a way that is not now possible, landscape-level analysis of ecological causality.[39] Depletion adjustments to a current account can occur only if there is an empirically defensible record of ecological causality to justify them. The early years of data collection won't tell us much about the future. But with each passing year prediction will improve – and so will our ability to describe the sustainability of our economies and environmental stewardship.

B2E Application and Discussion **The Larger Scientific Agenda**

Baerenklau's B2E white paper makes the following, accurate observation: "In order to quantify the effects of forest landscape disturbances, it is necessary to estimate how fire risk and forest benefit streams are affected by fire and remediation treatments. Unfortunately, such 'response functions' are not readily available in the literature." The Forest Service is well aware of these modeling needs and is pursuing related scientific initiatives, including ongoing studies in the Teakettle Experimental Forest and Plumas-Lassen and Kings River forests. These studies can be thought of as ways to create and calibrate forest-related ecological production functions.

Comprehensive analysis of ecological costs and benefits requires a broad range of ecological production functions. Even if those production functions already existed their integration – and interaction – on a particular landscape requires significant expertise and investment.

4.3 The Quality of Ecological Endpoints

The quality of ecosystem goods and services matters to welfare. Whenever a particular natural feature's quality matters to people, the quality differences should be incorporated into the endpoints themselves. For example, not all wetlands absorb flood pulses in the same way, healthy species populations are more valuable than unhealthy populations, the specific chemical properties of drinking and irrigation water matter to its value, etc. Because these kinds of quality differences directly matter to people, they should be reflected in the endpoints that are measured. Reliability is another dimension of quality. Is the ecological endpoint (feature or quality) a fluke or is it expected to persist? Will the clean water be available one day out of the year or every day? Here too, the endpoints should differentiate between reliable and less reliable features.

[39] Many ecologists, geographers, planners, and conservationists already think in these terms. But a consistent data network, one that helps unite disparate place-based analyses, is unavailable to these practitioners. The U.S. government sporadically attempts sustained monitoring at the national level, but no one agency has been given such a mandate.

But gradations in quality and reliability pose a practical problem. In theory, every different type of wetland should be treated as a distinct ecosystem good, and thus counted as its own endpoint – in order to reflect their different hydrological properties. Accounted for in this way, we could assign higher value weights to higher quality wetlands. In practice, however, a balance must be struck. Too many differentiations and the system is too unwieldy and costly. Too few, and the system ignores important quality differences.

Note that this issue arises in the way we account for conventional economic goods and services. In general, we do not separately account for "high quality" computers and "low quality" computers. Instead, we lump all computers together and count how many of them are consumed. This is not ideal, just a matter of practicality.[40] Imperfect quality differentiation and adjustment is a recognized limitation of existing market accounts, such as GDP.[41]

B2E Application and Discussion **Quality Differentiation**

With adequate resources and data, ecological endpoints can be defined in a way that expresses quality differences. For example, open space yields aesthetic benefits, but the benefits are likely to depend on the specific qualities of the open space. Instead of tracking open space as a single measure, land cover data can be used to classify open space into aesthetically higher and lower quality types. These can then be tracked as distinct endpoints.

'Ecological quality' is a different concept, but also important. Ecological quality relates to the resilience of ecological process and functions or to the health of a particular species. These quality issues are integral to the analysis of ecological production functions.

Accordingly, biophysical analysis is necessary to discriminate ecosystem goods and services by their quality. In some cases, when quality differences are important -- those discriminations will lead to distinct ecosystem goods, and thus distinct endpoints. In cases where quality differences are less important, biophysical analysis will be the basis of statistical quality adjustments to a more aggregate measure. In either case, quality differentiation is important to measurement and biophysical analysis is the key to quality differentiation.

4.4 The Role of Proxies

[40] Quality is measured to some extent by differences in price. Presumably, lower quality computers sell for less. The lower price leads to a lighter weighting of those computers in the price index.

[41] Again, this issue is mirrored in the national accounts. We count tires sold, rather than the vehicle miles over which the tires last. Prices at the time of purchase reflect consumers' understanding of the quality difference, but ideal output measures would not aggregate products of different quality.

There are many forms of environmental data that are already tracked and monitored. Statutes, regulations, and existing management practices, may mandate the use of particular measures. Some environmental measures exist largely because they are relatively easy and cheap to monitor. These types of data may not be endpoints as defined here. However, that does not mean the information they provide is irrelevant to the measurement of endpoints. In particular, many existing environmental measures are important *proxies* for endpoints that we may lack the money, institutional mandates, or monitoring tools to deploy.

An example of this is the measurement of atmospheric carbon. Atmospheric carbon levels are an intermediate ecosystem quality. Atmospheric carbon has no *direct* consequences for our well-being. Rather, it is a leading, or indirect, indicator of ecosystem goods and services that do have a direct impact. Higher atmospheric carbon concentrations are a leading indicator of global temperature. In turn, global temperature determines location-specific temperature, species abundance, water availability, pest populations, disease incidence, and avoided coastal damages. These latter examples are the final ecosystem features and qualities that are directly valuable (or costly) to us. Similarly in ecology, measures of biodiversity or macro-invertebrate community features are (relatively) easy to measure. But how do they relate to outcomes that are more intuitive to non-ecologists? As in the public health field, there is a need to continue with this kind of measurement. But there is also a need to relate such technical measures to outcomes more closely related to human experience.

Scientists use atmospheric carbon and biodiversity indices as proxies for larger portfolios of effects. This is as it should be. Proxies are important because they economize on information costs and can act as a signal of a range of natural outcomes.

B2E Application and Discussion **Proxies**

Several of the outcomes measured in the B2E study are proxies for endpoints. HSI scores are a proxy for species-related endpoints. Carbon emissions are a proxy for GHG-induced damages.

Proxies are a practical necessity. Ideally, however, the connection of a proxy to its corresponding, ideal endpoint measure should always be clearly stated in at least qualitative terms.

But the availability of proxies should not distract from the basic point: what society cares about is not atmospheric carbon, but rather the *end-results of* atmospheric carbon. We can't place a value on atmospheric without knowledge of how atmospheric carbon translates into ecosystem outcomes that directly affect our wellbeing.

Again, the way we will make this translation is through development of ecological production functions. The point is not to jettison this kind of information, but rather to develop a deeper understanding of how such proxies relate to what society really cares about.

5. Endpoints and Economic Analysis

The biophysical sciences describe how ecosystem management and ecological process and function affect the production or loss of ecological endpoints. That effort alone represents a significant, challenging scientific agenda. Assuming we can measure these endpoints and assess their production and loss, what does social science do with the knowledge? How does social science translate changes in ecological endpoints into their implications for human welfare?

5.1 Endpoints as an 'Environmental Language'

Nature's complexity hinders discussion of its role in our lives. The technical languages of economics and ecology cloak nature in obscure jargon and thus hinder public discussion and learning. Endpoints, because they translate complex technical phenomena into terms that are socially meaningful, will promote the development of a clearer environmental language. The clearer politicians, resource managers, communities, and voters are about environmental outcomes the better our decisions will be.

Social decisions may under-emphasize the importance of natural capital because we lack a clear language to describe the environment's contributions to wellbeing.

It also deserves emphasis that economic methods are not the only social science methods available to weight and prioritize outcomes. In particular, the political process weights, prioritizes, and makes tradeoffs every day, usually without the benefit of monetary estimates of how much things matter. In fact, weights achieved through the political process are more likely to hold up in practice than weights derived by a relatively small number of professional economists. Economics can and should inform the weighting of outcomes in nature. But economic analysis is unlikely to be the predominant way in which this is done.

Ecological endpoints are desirable, regardless of the method – economic, political, institutional – used to weight their importance.

Ecological endpoints – even with no subsequent economic analysis – may by themselves lead to better social decisions simply because they make nature's role in our lives more concrete, noticeable, and intuitive. Put differently, ecological endpoints should be developed even if they are not ultimately used in economic analysis. Either way, society will be better off if the biophysical sciences can translate their understanding of nature into more human terms.

B2E Application and Discussion **From Outcomes to Priorities**

Biophysical analysis based on ecological production functions allows us to distinguish between management scenarios in terms of gains and losses to ecological endpoints. Management scenarios typically result in a menu of positive and negative ecological changes. Typically, this menu of changes presents the decision-maker with tradeoffs.

If ecological outcomes are expressed in an intuitive manner (via endpoints) decision-makers, voters, and politicians can make more informed judgments about the tradeoffs. Economic analysis further informs the decision by 'scaling' the ecological changes. This is the purpose of economic, environmental valuation.

The rest of this section describes the more technical role of ecological endpoints in economic assessment.

5.2 Endpoints in Economic Production

Two basic economic questions must be addressed in order to translate ecological outcomes into statements about human welfare. They are,

- First, what are society's preferences for final market-and non-market goods and services?

- Second, how are ecological inputs and non-ecological inputs, such as capital and labor, combined to create those final goods and services?

The first of these is obvious. We must be able to distinguish and rank the products of ecological and market production. Are subdivisions more important than open space? Is irrigation water more important than aquatic habitat? If we can produce beauty, recreational opportunities, avoid health and property damages, and protect nature as a trustee, we then need to know the relative importance of these things. Social science uses a variety of techniques – from monetary valuation, to opinion polls, to referenda – to better understand society's preferences. Ecological endpoints will aid the discovery of social preferences because, by design, they are a translation of ecological conditions into outcomes meaningful to and interpretable by society.

B2E Application and Discussion **Underlying Preferences**

The B2E project has not conducted research into the social preferences for ecosystem endpoints affected by vegetation management. This is due to the expense and technical difficulty of conducting original research on underlying preferences.

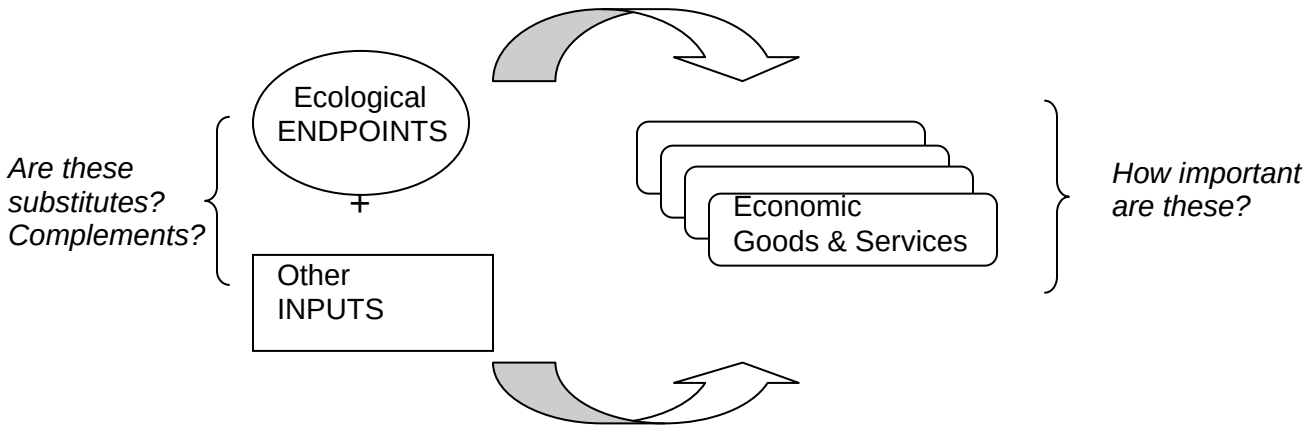
The economic fire damage assessment uses capital replacement costs and certain property market values to make inferences about preferences. This is possible, however, only for the market good damages assessed in that B2E domain. Certain recreational losses are also assigned dollar values by transferring results from pre-existing studies. Without a formal benefit transfer study, however, it is assumed that preferences for recreation on the B2E landscape are approximated by the preferences from pre-existing economic studies. Thus, original research into underlying preferences in the study area is not available.

Preferences are not the only data we can exploit, however. It is easier to collect and communicate data related to the scarcity, substitutes for, and complements to, ecological final goods (endpoints). In principle, economic understanding of the B2E landscape's ecological value could be enhanced even without knowledge of underlying preferences, by creating benefit indicators that illuminate the economic production function of ecosystem services. That is the objective of the EBIs described below.

The second question is equally important. Our preferences for ecological and non-ecological goods and services depend on the scarcity of those goods and services. Scarcity depends on the degree to which we can substitute ecological for non-ecological inputs. This is where we require knowledge of economic production functions. Recall that economic production functions describe how ecological and non-ecological inputs are combined to create final goods and services.

By design, ecological endpoints foster analysis of ecological inputs' scarcity and substitutability.

It should be emphasized that not all ecological inputs will have non-ecological substitutes. We cannot use technology to substitute for polar bears or the experience of wild nature, for example. And that matters to welfare analysis. The less ability we have to substitute, all else equal, the more socially important losses or gains are likely to be. However, in some cases there are substitutes for natural capital. We can prevent waterborne disease by having cleaner water or by vaccination. We can avoid flood damage by preserving wetlands or building levies. The argument is not that vaccines and levies are perfect substitutes for natural capital. Rather, that there is some degree of substitution and that the ability to substitute is likely to affect society's preferences.



Economic Production

Recall from section 2.2. that ecological endpoints are "the ecological features and qualities that are directly experienced or combined with other (ecological or non-ecological) inputs to produce market and non-market benefits." The reason to define endpoints in this way is to foster social science assessment of the scarcity and substitutability of ecological outcomes. Economic production functions depict how this "combination" of ecological and non-ecological inputs yields final goods and services.

5.3 Implications for Measurement: Benefit Indicators

Alone, ecological endpoints tell us nothing about their relative importance or value. Somehow, we must pair endpoints with information relating to their economic importance.

In order to translate ecological endpoints into social welfare measures, economists require knowledge of both economic production functions and society's underlying preferences. Underlying preferences are not directly observable – hence the need for sophisticated non-market valuation techniques.[42] Must we conduct econometrically sophisticated studies to say something about value, priorities, and importance? The answer is no.

[42] Described in Section 2.1.

B2E Application and Discussion **Monetization Vs. Quantification**

When monetary valuation is practical ecological changes are translated into dollar amounts that can easily be compared to other monetary costs and benefits. Dollar values allow the ecological outcomes to be compared on the basis of single metric.

However, monetary valuation requires the use of data and methods that substantially add to the assessment burden. Typically, each benefit or cost stream arising from the natural landscape must be analyzed with different data and econometric methods. It is common in studies to see only a single environmental benefit monetized, due to the costs of such studies.

A comprehensive evaluation of benefit streams in practice precludes comprehensive monetary valuation. Quantification of value-related factors is a more practical approach to comprehensive assessment. It does not deliver results in a single, common metric (dollars). But quantification of economic factors is a practical way to inject important economic information into assessment of multiple ecosystem services.

This section describes what can be called ecosystem benefit indicators (EBIs). Benefit indicators are countable features of the physical and social landscape. They are environmental and social features that influence – positively or negatively – ecosystem services' contributions to human wellbeing. EBIs convey information about the production of benefits involving ecological inputs. However, they tell us nothing about the underlying preferences for goods and services. Thus, they provide *some* information relating to welfare, but by themselves do not allow for monetary valuation.

As argued in Section 2, ecological endpoints should be spatially and temporally explicit biophysical features or qualities. This is also true of their associated EBIs. Location- and time-specific EBIs help us understand the larger social and physical landscape so that we can better assess the relative importance of particular services in particular places at particular times. Many ecological goods are not fungible in space and time. This is also true of the substitutes and complements necessary to their eventual valuation.[43]

This section describes EBIs as a standalone form of measurement and the economic information they convey. The next section relates EBIs to econometric revealed and stated preference valuation methods.

> *EBIs marry ecological endpoints with data on the endpoint's scarcity, substitutes, and complements and with rough measures of the populations and economic activities they support.*

We can draw welfare-significant conclusions even without knowledge of underlying preferences. This is true because economic production obeys certain

[43] The role of service zones in environmental valuation is well appreciated. For example, travel cost models require analysis of recreational substitutes which is an inherently spatial issue.

fundamental properties, or principles. For example, all else equal, we can always say the following:

- The scarcer an ecological feature, the greater its value.
- The scarcer are substitutes for an ecological feature, the greater its value.
- The more abundant are complements to an ecological feature, the greater its value.[44]

Note that we can measure scarcity and the abundance of substitutes and complements without detailed knowledge of underlying preferences.

> *We can measure scarcity and the availability of substitutes and complements – and thus say something about the value of ecological endpoints – without knowledge of preferences.*

For any of the endpoints found to vary as a result of management, policy, or protection we can say important things about the social value of the change by exploring the scarcity of what is gained or lost. For example, a waterbody whose quality is enhanced will – all else equal – be more valuable if it is scarce. Is it the only swimmable lake in the county, or one of many? The same holds true of parks, open space, and wilderness. Are these land uses scarce or plentiful? Knowing the answer to these questions may help decision-makers make more informed choices about impacts and priorities.

Substitutes are also important to analyze. If water flows in a stream are reduced, but there are alternative groundwater sources for irrigation or drinking, the social costs of reduced flows will – all else equal – be lower than if there are no substitutes. The benefits of fire and flood damage are likewise influenced by the availability of averting actions which are a substitute for fire or flood risk reductions. Flood pulse attenuation is less valuable in watersheds where there are built flood controls such as levees, dams, and reservoirs. It is more valuable when those built substitutes are absent.

The scarcity of, substitutes for, and complements to many ecosystem goods and services are relatively easy to assess. In many cases, metrics can be derived from social and biophysical GIS data. (Boyd and Wainger, 2002, 2003).

[44] Though note that not all ecological inputs require complements to yield a benefit.

B2E Application and Discussion **Scarcity & Substitutes Indicators**

The 'service zone' is the landscape region over which the service is enjoyed. In general it is a larger zone than the management zone itself.

Endpoint (w/benefit)	Scarcity Metric	Substitute Metric
Undeveloped land in viewshed (Aesthetic Enjoyment)	% landcover undeveloped in service zone	% landcover lightly developed land
Water quality (Drinking, Irrigation)	Degree to which consumption constrained by availability?	Other water sources, Wells, POTWs
Water availability (Irrigation, Commercial)	Degree to which consumption constrained by availability	Other water sources Wells, POTWs
Boatable waters, depth, flow (Recreation)	Number, size of waters in service zone	n/a
Parks & public lands (Recreation)	Number, size of lands in service zone	n/a
Species (Hunting, Subsistence)	Population density in service zone	Substitutable target species (bass for trout)
Species (Observation)	Population density in service zone	Substitutable target species
Species (Stewardship)	Global or regional population viability	n/a
Wilderness (Stewardship)	Global or regional wilderness availability	n/a
Fire events (Damage avoidance)	n/a	Protective actions (fire breaks, water)
Flood events (Damage avoidance)	n/a	Protective actions (levees, dams)

Complements Metrics

Some ecological features require non-ecological complements to yield an economic benefit. For example, recreation typically requires access in the form of roads, trails, docks. Like the above metrics these can be counted and mapped using GIS data.

Depending on the ecological feature we can often go further than this. For example, the social value of some environmental features is often a direct and increasing function of the number of people with access to them. Similarly, the social value of some environmental features is often a direct and increasing function of the economic value they protect or enhance. Accordingly, we can often – but not always – say the following:

- The larger the population benefiting from an ecological feature, the greater its value.

- The larger the economic value protected or enhanced by the feature, the greater its value.

All else equal, a park with 10,000 visitors a year is more recreationally valuable than a park with 100 visitors a year. In terms of recreational and aesthetic benefits New York's Central Park is clearly more valuable than a comparable park in a less populated area.[45] Similarly, an aquifer's value as a source of drinking water is greater the larger the number of households with hydrological access to it. Ecological features that limit mosquito populations are more valuable the more people are protected by mosquito-borne disease.[46]

Similarly, a wetland that provides flood protection to property worth $10M is more valuable than one protecting property worth $1M, all else equal. A pollinator population near a thousand acres of commercial agriculture is worth more than one near only a hundred acres.

> *We can measure (1) the number of people benefiting from ecological features or (2) the monetary value of economic activity protected or enhanced by the feature.* In some cases – though not in all – *these measures say something about the value of ecological endpoints, even without knowledge of underlying preferences.*

EBIs are relatively simple measures to develop. Short of full-blown economic assessment, they provide useful economic information. They are a practical middle ground between no economic analysis and full-blown econometric value estimation.

[45] Note that this statement pertains only to the park's recreational benefits. As a source of wild nature Central Park is likely to be less valuable than a comparable land use elsewhere.
[46] We cannot always assume that "more people means more benefit." For example, recreational benefits may decline if the number of recreators in a particular location becomes too large. This is known as a "congestion externality."

B2E Application and Discussion **Population & Usage**

Most ecological endpoints can be associated with a population that benefits. The strategy is to relate the particular ecosystem endpoint to an ecosystem service area and then collect population, use, and access data to the endpoint.

Endpoint	Relevant Population
PM10 (Visibility damages)	Populations, including transient populations (recreators, commuters, vacationers) in affected viewshed
PM10 (Health damages)	Populations (including all above) in airsheds with health-significant PM10 concentrations
Open space	Populations in open space viewsheds
Parks and public lands, Boatable waters	Usage data and populations with access
Species populations	Recreational populations with access, usage data

In general, the larger the populations benefiting (or avoiding damages) the larger the economic benefit of the endpoint.

EBIs' simplicity and transparency is a benefit. As noted earlier, the weights assigned to goods and services can be derived in ways other than econometric analysis of revealed behavior. Expert elicitation, citizen juries, mediated modeling involving stakeholders, and political referenda are all processes whereby weights are either explicitly or implicitly derived. Typically, these methods involve a collective process whereby alternatives, relationships, and values are actively debated as part of the weighting process. Even alone, EBIs intuitively convey economic principles and the dependence of human wellbeing on natural assets. They can be expected to improve the understanding of decision-makers and stakeholders and thereby lead to better decisions.

B2E Application and Discussion **Property Value Protected**

Some ecological endpoints are protective of private property. (Note that this is the focus of the fire loss asset analysis domain). If so, the endpoint can be associated properties likely to benefit or avoid damage. The value of those properties provides information on the likely benefit of the endpoint.

Endpoint	Property Protection (or Enhancement) Metric
Pest populations (Commercial agriculture)	Value of crops protected
Soil quality	Value of crops protected
Flood events (Housing, infrastructure, farming)	Value of structures, roads, other capital, cropland protected
Sediment delivery	Costs of reservoir capacity loss or dredging

5.4 Endpoints and EBIs as inputs to monetary valuation

EBIs are a practical standalone method for conveying economic information. However, the ultimate goal of economic assessment is to capture society's underlying preferences for environmental goods and services. This section describes the relationship of endpoints and their associated EBIs to preference-revealing economic methods.

Endpoints and EBIs are, by design, value-relevant measures. Endpoints are value-relevant ecological features or conditions and can be used to characterize changes in those features and conditions. EBIs are value-relevant measures of the endpoints' role in the production of final benefits. Endpoints and EBIs are a potentially standardizable set of location- and time-specific metrics relating to both biophysical conditions and their benefits.

As is increasingly argued by benefit transfer practitioners, the economics profession and literature in which it publishes must converge toward a set of common – and thus sharable – reporting practices. (Rosenberger and Loomis, 2000; Loomis and Rosenberger, 2006). Endpoints and EBIs are the foundations for just such a protocol. They are relatively easy to measure and provide a consistent approach to the spatial measures necessary for environmental valuation. Standardization is a virtue because environmental valuation studies are too heterogeneous in their methods, results, and control variables to make meta-analysis and benefit transfer a practical proposition.

Recall that benefit transfer studies are a way to harness the benefits of econometric estimation while minimizing the need for costly new site-specific analyses. In essence, the benefit transfer method takes the result of a pre-existing monetary study and translates it into a new environmental context. To do so credibly, however, requires the calibration of a benefit transfer function. This is because the value of environmental goods and services is highly dependent upon the physical and social context in which they arise. Calibration controls for variation in ecological and social features across study sites. The endpoints and EBIs proposed in this study can be thought of as the location-specific independent variables necessary to transfer dollar-based valuations.

Standardized endpoints would bring consistency to *what* is being valued in an econometric study. Ideally, economists would consistently describe the commodity they value. Endpoints are a way to foster this kind of consistency.

> *Endpoints are a way to standardize "commodity measures." EBIs are a way to standardize spatial, value-relevant control variables. Both forms of standardization would be a boon to benefit transfer methods.*

Similarly, standardized EBIs would bring consistency to a set of value-relevant control variables. Preferences for ecosystem outcomes, while not directly observable, are a function of various characteristics that are observable. For example, is the scarcity of the resource at study site A comparable to the scarcity of the resource at site B? Because scarcity is so intimately related to value, controlling for scarcity – and in a consistent way – could improve the econometric validity of the transfer function. Econometrically, the weight, or virtual price for a given ecological feature or conditions p_i can be denoted as a function of indicators I, so that $p_i = F(\boldsymbol{I})$. This function, on an endpoint-by-endpoint basis, can be calibrated by relating observable indicators I to existing willingness to pay estimates. Conceptually, this is an old approach to benefit transfer econometrically speaking (e.g., Walsh et al. 1992), the contribution here is to suggest the precise metrics to be used as indicators. The predictive power of these proposed metrics on existing dollar-based WTP estimates should be tested. But if validated, EBIs are a bridge between relatively isolated econometric studies and regional or national mappings of ecological benefits.

Note that these arguments are true for both stated and revealed preference methods. In both cases, the informational power of a given study would be improved by having greater consistency – in commodity definition and spatial, benefit-related controls.

5.5 Communication

To people who aren't economists, environmental valuation is an opaque set of practices, out of which emerge statements like "that beautiful beach provides $1 million in annual recreation benefits" or "wetlands are worth $125 an acre." A bottom-line dollar figure is useful in many contexts – particularly at higher levels of government where a simple answer is often desired.

But economic analysis should just deliver more than these final, dollar-coded answers. Economic analysis should also help people think about nature for themselves. Ecological endpoints and their associated EBIs represent a language that could foster

public learning about nature's value. By design, they are concrete, intuitive measures that convey something about nature, and something about its value.

B2E Application and Discussion **Communication**

When endpoints are presented along with EBI information, the social importance of ecological outcomes can be communicated in a way that is non-technical, but nevertheless ecologically and economically substantive. Consider these hypothetical examples:

<u>Example communication derived from endpoint and EBI analysis</u>

The proposed management action will…

… improve the aesthetic environment by adding Y square miles of undeveloped landcover (the endpoint) viewable by X households and commuters (an EBI) in a viewshed where Z percent of the landscape is developed (an EBI).

… lead to healthier communities by reducing PM10 concentrations by Y percent (the endpoint) in an airshed with X children, seniors, and at-risk adults (an EBI).

…improve recreational opportunities by adding Y adult steelhead (the endpoint) to a watershed with X number of access points (an EBI) in a region where it is the only fishable river (an EBI).

…lower agriculture's irrigation costs by increasing aquifer volumes by Y (the endpoint) used by X acres of farmland (an EBI) producing Z million dollars of output per year (an EBI).

…improve canoeing and kayaking opportunities by providing adequate water flows Y days of the year (the endpoint) in a county where there are 3 boatable rivers (an EBI) used by Z thousand recreators a year (an EBI).

Endpoints and EBIs are, by design, spatial measures. In fact, many will be drawn from geo-coded data sets, including satellite imagery; county, and regional growth, land-use, or transportation plans; federal and state environmental agencies; private conservancies and nonprofits; and the U.S. Census. A nice thing about geo-coded data is that it allows ecological outcomes to be visually depicted. *Where* do we get ecological changes? Pictures, of course, are a valuable learning and communication tool for many types of audience. If we can provide quantitative and visual depictions of endpoints and benefit indicators we can enlighten public discussion about nature's value in a way we cannot if all we deliver is a single, dollar-based answer.

6. Conclusion

Economic analyses of nature tend to take one of two forms. The preferred form is econometric estimation of society's willingness to pay for a particular environmental feature or quality. In practice, monetization limits what can be analyzed to benefits associated with available market prices or other signals of value. Moreover, the cost of original econometric analysis, and its technical difficulty, also acts as a limit on the range of benefits that can be analyzed. The second form of analysis is qualitative discussion all the benefits that are not captured in monetary terms. We tell stories about nature to invoke intuitions of its value.

Between these two forms of analysis lies a strangely empty territory: *quantification* of ecological gains and losses that stop short of monetary values. This report describes an ecological and economic agenda organized around the principle of quantification.

The ecological agenda is to develop ecological production functions (sometimes called damage functions) that depict ecological gains and losses in socially meaningful language, yet still quantitative language. The development of these *ecological endpoints* would greatly magnify ecology's impact on decision-making.

The associated economic agenda is to use these ecological endpoints as a standard way to depict ecological commodities. This is fundamental if we are to improve the statistical underpinnings of benefit transfer methods. Benefit transfer fails today largely because economists do not associated their dollar estimates with a common set of descriptors. Ecological endpoints are en economically derived set of such descriptors.

The paper also describes the use of *ecosystem benefit indicators* (EBIs) as signals of social value. EBIs are a counterpoint to endpoints. Endpoints describe biophysical outcomes. EBIs provide data related to the social value of those outcomes. EBIs are not "economic values" by themselves. Rather, they are readily-available geospatial data about landscape and social factors likely to be economically important.

EBIs, like the ecological endpoints to which they are attached, are another set of descriptors that could eventually improve our ability to conduct benefit transfer.

Together, endpoints and EBIs create an *ecological quantification agenda*. They are designed to fill the niche between qualitative storytelling and the often impractical pursuit of full-blown monetary estimation. They are real numbers, derived from ecological and economic theory that can help communicate the social value of nature and its ecosystem services. For resource managers, conservationists, and environmental decision-makers they are a practical way to bring ecological and economic rigor to public discussions of nature.

To illustrate these ideas concretely, the study has related the underlying theory and motivation to the U.S. Forest Service's Biomass to Energy project. This project ois an ideal case study because it represents – and attempts – the most ambitious kind of environmental analysis. First, it originates with biophysical modeling of a management action (forest fuels treatment) and the implications for wildfire and subsequent revegetation. Linked to this biophysical analysis are several others, including models of sediment delivery to downstream waters and habitat affects arising from changes in

vegetation. Second, it links these biophysical outcomes to economic analyses. These economic analyses, of property and recreational losses, are used to derive monetary estimates of certain benefits linked to the management options. Finally, the project does all this in an explicitly spatial, landscape framework. Spatial analysis is essential to both biophysical and social outcomes. The technical difficulty and expense of such a prohect inevitably leaves gaps. Endpoints and benefit indicators, if empirically applied to the B2E landscape could help fill many of those gaps. They could also be the beginnings of a data architecture and scientific agenda on which the Forest Service – and other resource trustees – could build.

To make this a practical agenda requires investment. In particular, much more natural science is needed. Today, there are simply too few ecologists working with too little money and too little data to deliver the complex ecological production functions necessary. Without more basic analysis of how landscape preservation, management, and degradation (real choices) affect ecological outcomes, the natural and social sciences cannot deliver – in a way that is scientifically credible – the comprehensive answers we all want.

APPENDIX: ALTERNATIVE DERIVATION OF QUANTITY UNITS

The model features a final good *F*, and two inputs, capital *K* and an ecosystem good *E*. The final good and the inputs have prices P_F, P_K, and P_E, where P_E is a virtual, not observed, price. The production function is some $F = F(K,E)$.

There are two common approaches to the depiction of the ecological input. First, the value of the ecological input can be derived from the value of its productivity with respect to the final good, times the price of the final good.

(1) $P_E = (\partial F/\partial E)\, P_F$.

Second, using the production function itself and some rearrangement of terms, the ecological input's value can be expressed via the other input's role in production. Specifically,

(2) $$P_E = \frac{\partial F/\partial E}{\partial F/\partial K} \cdot P_K ,$$

where here the ecological input's value is derived from its substitution relationship with the capital input, times the price of the capital input.[47]

Now consider a marginal change in the ecological input, ∂E. The total value of that change can be expressed in three different, but equivalent ways.

(3) $$P_E \cdot dE \quad = \quad (\partial F/\partial E) \cdot P_F \cdot dE \quad = \quad \frac{\partial F/\partial E}{\partial F/\partial K} \cdot P_K \cdot dE.$$

Do these expressions provide a clear guide to the "quantity" – the ecosystem good or service – and the "value" of the good or service *p*? Both in principle and practice, the answer is no.

Economic studies, such as those found in Kopp and Smith, 1995, Chapters 2,7, 14) define ecosystem services in three completely different ways. One defines the service as the total value – $q = P_E \cdot E$ in our example. Another refers to the service as the contribution of the environmental input to production of the final good as *E* changes. Denote this as $q = \Delta F(K,E)$.[48] Yet another refers to the service as the environmental input itself, $q = E$. In a total benefit framework each of these definitions is consistent with the identity in equation (3). In other words, none of the definitions is "wrong." But from an accounting perspective, greater terminological clarity and consistency is important.

[47] Algebraically, this is derived from the producer's tangency condition $(\partial A/\partial E) / (\partial A/\partial K) = P_B / P_K$.
[48] For example, if the ecological input goes from E^1 to E^2, $q = F(K, E^2) - F(K, E^1)$.

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