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Methods

The quantification and valuation of ecosystem services

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ABSTRACT

This paper explores differences between economic and ecological criteria for identifying, measuring, and evaluating ecosystem services. It argues that economic stakeholders (user groups) generally do well in identifying these services and assigning prices to them. These prices arise spontaneously in—and serve to coordinate—market activity related to the environment. The relevant ecological information which markets gather and apply tends to be dispersed, contingent, particular, local, transitory, and embedded in institutions and practices. Ecologists and other scientists, in contrast, often seek to understand how ecosystems work and which populations and processes provide ecosystem services. The knowledge science seeks, unlike the information markets gather, tends to be centralized, collaborative, collective, and consensus-based; science pursues concepts and principles that are timeless and general rather than ephemeral and site-specific. The paper contrasts the dispersed and decentralized information organized by markets with the collective and centralized knowledge characteristic of science. The paper argues that the conceptual distance between market-based and science-based methods of assembling information and applying knowledge defeats efforts to determine the “value” of ecosystem services in any integrated sense.

1. Introduction

In Kern, Tulare, Fresno, and Madera counties in the San Joaquin Valley of California, citrus growers have planted about 40,000 acres of easy-to-peel seedless varieties of tangerines, clementines, and mandarin oranges. Like many crops—rice, wheat, and maize, for example—these oranges are self or wind-pollinated. If bees cross-pollinate the crop with the pollen of other citrus trees, however, the fruit will develop seeds among other economically undesirable properties. Seeded mandarins fetch only a quarter of the price of unseeded ones.

Chris Lange, a mandarin orange grower, lamented that honey bees by pollinating his crop ruin it for anything but juice. "You can't grow the crop for the juice market," he said. “You have to grow for the premium crop or you won't recover your costs." Growers have threatened to take legal action to force bee keepers to remove their hives. "We've coexisted with them, but we don't need them," said Joel Nelson, executive director of Citrus Mutual, a trade association. "Now we're trying to adapt to changing consumer demands, and we're hamstrung" (Cone, 2009).

This paper discusses representative examples of ecosystem services often cited in the literature. In these examples, such as the work of bees in the pollination of citrus and almond in the San Joaquin Valley, market exchange—including the Coasian bargaining in which interest groups compensate or cooperate with each other—functions fairly well to identify, quantify, and set prices for ecological services and the biological units that provide them. Yet market exchange may not respond to the larger ecological role service-providing units play in the stability, structure, and function of ecosystems. The exchange value of a service-providing unit, but not its ecological function, may vary with changes in trade, taste, and technology. A conceptual distance divides microeconomic efficiency and macro-ecological stability with respect to ecological services. Can ecological economists bridge that divide?

2. Ecosystem services in the San Joaquin Valley

Many articles on ecosystem services cite as a representative example the work of bees in pollinating almond, particularly in California, which produces 80% of the world's crop (Kremen and Ostfeld, 2005; see also Fisher et al., 2009; Kremen et al., 2008; Kontogianni et al., 2010; Ricketts et al., 2008, among others). Almond trees, which grow on the west side of the San Joaquin valley, blossom in February. Almond growers hire beekeepers with tens of thousands of hives to pollinate their crop. In late March, after the almond blossoms drop, the bee keepers move their hives to the east side of the valley where the insects forage on citrus trees. Many orange growers rail against the bees not only because bees may cross-pollinate their crops but also because farmers are not allowed to spray pesticides to control mites and other pests when bees are present. Apiarists have stated a different view of what counts as an ecosystem service. Gene Brandi of the California Beekeepers Association said that the bees need the citrus crop until they are moved to feed on clover in the Midwest. Citrus blossoms support the production of premium orange blossom honey. According to Bandi, “the problem is finding places to

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put bees where they have access to natural food, and citrus is part of that" (Cone, 2009).

To stakeholder or user groups, such as horticulturalists, apiarists, and other interested parties, ecosystem services may appear to depend not on ecological constants but on many kinds of economic variables, including what people want produced, as indicated by prices set in global markets. The exchange value of an ecosystem service—like that of any good—is constantly negotiated in view of market conditions. Technology also changes. One of the largest nurseries in California, the Dave Wilson Nursery, has introduced an excellent "self-fertile," i.e., self-pollinating, almond. If a new cultivar of almond that sets itself proves profitable, the citrus growers might pay the almond growers to adopt it, to eliminate the presence of pollinators.

3. A new conceptual model

Ecologists could follow one of two strategies to guide stakeholders, such as horticulturalists, apiarists, and other interest groups in the San Joaquin Valley. First, they could attempt to learn more than these groups already know about the fluctuations in prices, the vagaries of demand, and the advances in technology that affect market conditions. Conservationists cannot assume, however, that they understand the relevant economic tradeoffs at a finer level of detail and timing than the market players who depend for their livelihoods on those resources and who have bargained with each other often for decades to advance their interests and resolve their disputes.

Second, ecologists could seek to identify general concepts, patterns, and principles that apply to ecosystem services and to the populations that provide them. This more general knowledge would discover ecological constants in service-providing processes, populations, or other fundamental biophysical units. Ecologically-minded economists call for "standardized units of account to measure the value of ecosystem services to society" (Boyd and Banzhaf, 2007, p. 617). Luck et al. (2009a, p. 223) "echo this call" and emphasize "the urgent need for ecologists and environmental managers to identify the primarily biotic components of ecosystems that provide services..." (2009b, p. 446). This approach seeks to establish a periodic table of ecological elements to alert managers and users to the beneficial aspects of ecosystems.

To meet this "urgent need," Luck and colleagues "focus primarily on the generation of services and the key measures that deserve ecologists' attention, illustrating these through selected empirical examples." By using "key examples from the literature to illustrate the new approach," Luck et al. (2009a, p. 223) hope to guide policy makers and user groups alike by generating "a new conceptual model for the interactions among service providers, supporting systems, service provision, and societal and environmental changes."

Ecologists who join Luck and colleagues seek a new conceptual framework—which may be abstract, general, and theoretical—that not only convinces them but also can persuade those stakeholders and interest groups who are used to solving problems by applying dispersed, diffused, partial, particular, and local kinds of information. Without the benefit of a general ecological theory about the structure and function of ecosystems, market players may have gone a long way 1) to identify ecosystem services and service-providing units that concern them and 2) to establish prices that signal the scarcity of these services relative to demand.

The almond growers, citrus farmers, and apiarists in the San Joaquin Valley, for example, may not immediately see that they need a new conceptual model to understand the tradeoffs they make. What do scientists know that the farmers and apiarists do not know? What is the value added by a conceptual model such as Luck et al. pursue to the practical knowledge of user groups? Examples are needed to illustrate how a "new conceptual model" such as Luck and colleagues envision may help people who now use and depend on ecosystem services to better understand and manage them.

An ecologist may reply that since native plants and pollinators may have coevolved, they provide services to each other non-scientists may not recognize. Since almond (*Prunus dulcis*) is native to the Middle East, however, the theory of co-evolution would not apply. What ecological model or theory would apply in this case? Luck et al. (2009b, p. 462) write, "Almond growers would be well advised to explore the cost–benefit tradeoffs... of implementing land-management strategies to support native pollinators." Why do they assume that almond growers have not explored this tradeoff? When almond trees flower in February, native bee species are inactive because they have barely emerged from diapause. Adult feral bees are not abundant in California at that time of year (Kremen et al., 2008, p. 795).

4. Pest control services of great tits

As their lead example of an ecosystem service, Luck et al. (2009a, p. 225) stated, "Mols and Visser (2007) documented the capacity of great tits (*Parus major*) to provide a pest control service in apple orchards by substantially reducing caterpillar damage to the crop." Kontogianni et al. (2010, p. 1482) similarly have written that Mols and Visser "demonstrated how great tits (*P. major*) provided a pest control service in apple orchards by reducing caterpillar damage to the crop. Caterpillar damage was reduced by up to 50% when the density of breeding pairs of birds equaled 1–6 per 2 ha." The Mols and Visser study, the results of which were first published in 2002, is often cited in the literature as an example of a valuable ecosystem service of potential value to user groups (see, for example, Andersson et al., 2007; Stephan et al., 2010; Whelan et al., 2008; Philpott et al., 2009; Van Bael et al., 2008, among others). Have orchardists by failing to construct nest boxes for great tits missed a way to control caterpillars?

In their experiment, Mols and Visser (2007) gathered data on six orchards that practiced Organic Farming (OF) in the Netherlands—studying one orchard for just one year, four over two years, and one over three years (supporting data). They compared the damage caterpillars did to apples grown near boxes where pairs of great tits nested to damage caterpillars caused to apples elsewhere. The data showed "no damage reduction in the OF orchards." The result was disappointing. Great tits failed to provide a pest control service in orchards under OF management.

Mols and Visser (2007) also gathered data on six orchards that practiced Integrated Pest Management (IPM)—studying five orchards for just one year and one for two years. They found that 3% of crop near nest boxes suffered caterpillar damage as compared with 6% of the crop in non-treated plots. From these findings, Mols and Visser concluded that "our study shows that great tits are able to reduce damage at low caterpillar densities in IPM orchards."

According to Mols and Visser (2007, p. 202), "The potential contribution of vertebrate predators such as birds has generally been overlooked...." Here, then, is an opportunity for scientists to alert user groups of an ecosystem service they had neglected. Can ecologists build on this kind of key example, as Luck et al. propose, to identify the primarily biotic components of ecosystems that provide services?

There are problems. First, biotic components (for example, caterpillar-feeding birds) that are useful in one place may be uneconomical in another. Different legal regimes often impose quite different and variable conditions. Since the concept of IPM has no real meaning in Europe, for example, insecticides that are permitted or not permitted differ from place to place. These differences affect the economic relevance of insectivorous birds. Nasty pesticides including chlorpyrifos, which are quite hazardous and quite effective, are permitted under many IPM apple production systems in Europe. When these are present, no caterpillars will survive to feed passerine predators. According to one study, "IPM standards, unlike organic production, are not precisely defined or legally specified in an EU or international agreement." Accordingly, IPM standards are so variable that "the distinction between conventional and integrated production is not always clear" (PAN, 2007, p. 2).

Second, experiments on apples grown under either OF or IPM management are irrelevant to the vast majority of orchardists because apple growers in Europe overwhelmingly adopt conventional methods that employ many kinds of insecticides to eliminate caterpillars (PAN, 2007). Third, orchardists cannot be sure that the short nestling rearing period of the great tit will coincide with the emergence of the caterpillar of the winter moth (Cross et al., 1999; Solomon et al., 2000). If they had interviewed orchardists, Mols and Visser might have found out if apple growers needed this service. Luck et al. (2009a, p. 225) concede that Mols and Visser "did not explicitly quantify the need for this service by local landholders or the broader community."

Fourth, technologies change. For example, genetic engineering and synthetic biology are rapidly constructing "biobugs" for pest control (Alphey et al., 2009). These advances promise breakthroughs in the proven Sterile Insect Technique by making it easy to mass produce in pest insects hearty sterile males while assuring lethality in females (USDA, 2008). Sterile insects constructed by synthetic or recombinant bioengineering are far more hearty than those (all up till now) produced by radiation. It is a nice question whether beneficial creatures (or "biodiversity") produced by genetic engineering or by synthetic biology count because living as "ecosystem services" or because synthesized as conventional pesticides.

5. Tertiary waste treatment by a wetland

Many ecological economists point to the value of wetlands in the tertiary treatment of wastewater. In an excellent study of this kind, Breaux et al. (1995) examined a 6.2 acre wetlands site abutting a Zapp's Potato Chip Plant near the town of Gramercy, Louisiana. This careful research raises the following question: may the value of an ecosystem service, as identified and exemplified in a local context, be generalized to other places and times? Can the recognized importance of a particular wetland at a given time and place suggest a general model for understanding the services these ecosystems may provide more generally?

Breaux and colleagues determined that the potato chip maker at the level of its operations in the early 1990s could use the neighboring wetland for tertiary treatment of its wastes at a cost savings (compared with the next least expensive waste treatment method) of about $26,700 per year. When these researchers computed the present value of the savings over 15 years at a 9% discount rate, they found that the annual stream of savings could have a present value of $215,220. "This is a value of $34,700 per acre for the treatment site!" (Breaux et al., 1995, p. 290).

This study is instructive, first, because the potato chip maker did not simply "externalize" its costs by dumping all its wastes into the wetland. On the contrary, plant owners had to bargain with state and local officials and other interested parties to show that the added nutrients would not harm but could benefit that ecosystem, which for geological reasons was nutrient poor. Coasian bargaining determined the efficient use of the resource even in the absence of explicit market prices. Second, as Mark Plummer (2009, p. 38) noted, "Not all freshwater forested wetlands have an adjoining potato chip factory, and so projecting Zapp's cost savings onto other, similar wetlands would be inappropriate." Third, by taking the "present value" of the anticipated savings over 15 years, Breaux and colleagues had to guess how and how long the company would actually use the wetland. Events played out, as they usually do, in unexpected ways.

In 1985, Ron Zapp established a potato chip factory in Gramercy, Louisiana, that took off in the mid-1990s when its "Cajun Crawtator" was featured on the Oprah Winfrey show. After 1995, as the company expanded, its wastes exceeded the treatment capacity of the swamp and eventually of the town of Gramercy. Zapp purchased and donated to St. James Parish a 20-acre parcel of land, valued at $200,000, to site a major high-tech waste treatment facility which is now operated by a consortium of users. Charlie Melancon, the U.S. Representative from that Congressional district, secured a $150,000 federal "earmark" to complete the project.

What can scientists tell Ron Zapp and his neighbors about the "linkage between ecological outcomes and economic consequences" (Boyd and Krupnik, 2009, p. 2)? What happened to the $34,700 per acre value of the wetland? Many economic, social, and political players—from Zapp to Oprah to Melancon—entered a process of interaction that continually shifted the value of the wetland. Can the findings of ecologists and economists—for example Breaux et al. (1995)—be applied to wetlands generally or to the same wetland a few years later?

The three case studies considered here—pollination services in the San Joaquin Valley, pest control services in the Netherlands, and sewage treatment services in Louisiana—appear in the literature as key examples of the importance of ecosystem services. They all suggest the same lesson. Market actors, interest groups, and property owners seem to have a good handle on the ecosystem services that affect them and they do fairly well in bargaining with each other to manage conflicts and scarcities. It is not clear that any stakeholder or user group would have acted in an economically more efficient manner in the light of "a new conceptual model for the interactions among service providers, supporting systems, service provision, and societal and environmental changes" (Luck et al., 2009a, p. 223). Stakeholders and interest groups respond to knowledge that is dispersed, particular, local, practical, implicit, and transitory. They rely on a constant feed of disparate and diverse empirical information to manage resources. A new conceptual model, however fundamental, that integrates everything may not be relevant to them.

6. Scientistic objectivism

More than a half-century ago, Friedrich A. Hayek inveighed against scientists who tried to apply "objective" measures of biophysical value to plan economic production. Hayek targeted for criticism both socialists, who thought units of labor can be "valued" apart from markets, and ecologically-minded economists who sought to extend objective measures of value to the "labor" of the natural world. Hayek argued that the socialists and the ecological economists of his time shared a "scientistic objectivism" in their "characteristic and ever-recurrent demand for the substitution of *in natura* calculation [of value] for the 'artificial' calculation in terms of price" (Hayek, 1942–44, p. 170). Hayek's argument centered on the complexity of modern society and the impossibility that any individual or group of social and natural scientists could command all the information needed to guide an economy or even how to second-guess economic activity.

Hayek and other economists in the Austrian School at the time engaged in the "socialist calculation debate" over whether a planned economy, which determined or measured value by applying the concepts of social and natural science, would perform better than a society that relied on price signals set by markets (Greenwood, 2007). Scientists—historical and dialectical materialists who investigated the "laws of change" and physicalists in the Mathusian mode—thought that they understood better than the unwashed and uneducated masses the material basis of society. Scientists then set out to determine the fundamental units of value to get national accounts right.

According to John O'Neill (2004, p. 433), Hayek rejected the idea that there exist physical units—including the units of energy that were suggested by Ostwald, Soddy, and Solvay—that could account for economic planning and production. Hayek denied that economic activity "can be ultimately reduced to... the interchangeable units of abstract energy which they 'really' are" (Hayek, 1942–44, p. 91). Against Physiocrats, Hayek (1942–44, p. 53) argued, "Neither a 'commodity' nor an ‘economic good’, nor ‘food’ nor ‘money’ can be defined in physical terms but only in terms of views people hold about things.” Hayek would surely contend that an “ecosystem service” cannot be defined in physical terms but only in relation to the views people hold about things, for example, about what they and other people may want at a given time, about what is likely to be scarce or plentiful, about the prices of substitutes and of complementary goods, and about political, social, and economic conditions.

Today many ecological economists seek to substitute an *in natura* calculation of value for an “artificial” calculation in terms of market price. “This biophysical method does not assume that value is determined by individual preferences, but rather attempts a more ‘objective’ assessment of ecosystem contributions to human welfare” (Liu et al 2010, p. 59). Some ecological economists follow Odum (1967) to apply thermodynamic principles to understand economic value in terms of units of solar energy, photosynthesis, or net primary productivity. Others, such as Luck et al. (2009b, p. 461), refer to “the primarily biotic components of ecosystems that provide services” but leave the identification and measurement of these biotic elements to further research. Kremen (2005, p. 469) has argued that a science is needed to “provide fundamental, ecological understanding of ecosystem services” and to “assist in devising the best management and policy tools for their conservation and sustainable use.” Kremen concedes, “Carrying out such an agenda will present an enormous logistical, financial and scientific challenge, but it is not outside our human potential. We have only to look at the enormous strides made in medicine or space exploration, to name a few, to realize that is possible, given careful planning and sufficient resources.”

A comparison is easy to draw between social and natural scientists today who look for ways to valuate ecosystem services and scientists who over two centuries have followed the French Physiocrats to seek nonmarket measures of production in order to plan economic activity. In this tradition, James Boyd (2008, p. 3) has called for scientific methods to “describe nonmarket environmental commodities in the context of *systems of ecological production*.” Boyd (2008, p. 1) has written, “economists should be involved in defining ecological quantity accounts and work with natural scientists to depict nature in a way useful to utilitarian analysis.” He adds (p. 11) “*The final biophysical units used in an ecosystem quantity index should be the ecological features, quantities, and qualities that are directly combined with other (nonecological) inputs to produce market and nonmarket benefits*” (italics in original).

This statement reflects an assumption many ecologists embrace that nature can be defined and measured apart from or separately from humanity. O'Neill (2001: 3279) characterizes (without endorsing) this assumption as follows: “The ecosystem concept typically considers human activities as external disturbances... *Homo sapiens* is the only important species that is considered external from its ecosystem, deriving goods and services rather than participating in ecosystem dynamics.” On this approach, the role of science, as Bill McKibben (1989, p. 65) has explained, is to describe nature as “the work of some independent force.... In our modern minds nature and humanity are separate things. It is this separate nature I am talking about when I use the word—nature.”

The task of ecology, then, would be to define the important structural and functional aspects of ecosystems apart from human interests and actions to obtain a “consistent definition of the environmental units to which value can be attached” (Boyd and Banzhaf 2007, p. 618). On this approach, nature comprises goods and services—or service-providing units—science can in principle detect and quantify in terms of the structural and functional properties of ecosystems *per se* and without reference to the wants, beliefs, views, and actions of those who not only use but typically alter, manipulate, and transform those resources. Alas, no way can be found to quantify units for valuation in nature apart from the local, transitory, fluctuating, path-dependent, and circumstantial views and beliefs people hold about things. Thus it is not surprising that Boyd (2008, p. 1) discovers that the ecosystem services project confronts not only a “missing prices problem” but also a “missing quantities problem”.

Against the quest for biophysical units of account that Physiocrats pursued in his day, Hayek argued that the complexity of modern society makes it impossible for scientific managers to organize the staggering amount of information relevant to any particular economic action. The economic problem is not to understand the biophysical factors of production but to explain “how the spontaneous interaction of a number of people, each possessing only bits of knowledge, brings about a state of affairs in which prices correspond to costs, etc., and which could be brought about by deliberate direction only by someone who possessed the combined knowledge of all those individuals” (Hayek 1948, p. 50). Reason, Hayek argued, must first recognize its limitations. Markets when properly governed by the rule of law, respect for rights of person and property, and democratic institutions simply *work* as the best method we have to integrate knowledge, including ecological knowledge, into the day-to-day economic activity of individuals.

From a Hayekian perspective, ecosystem services as a general rule already receive more or less appropriate quantification and pricing either explicitly in market exchange or implicitly in the Coasian bargaining that arises in the penumbra of markets and in the shadow of common law. Where “common pool” resources are squandered—“capture” fisheries present well-known examples—property rights, which may be communal, should be established in them. Economists have studied “common pool” or “open access” problems for more than a century. These studies have shown that those who depend on a “commons” may and often do manage it efficiently and sustainably without a periodic table of biotic elements (Ostrom, 2009, 2005).

7. Time to deliver?

Brauman et al. (2007, p. 68) have written, “The term ‘ecosystem services’ emerged in the early 1980s to describe a framework for structuring and synthesizing biophysical understanding of ecosystem processes in terms of human well-being.” This “biophysical understanding,” however, has not materialized. Daily et al. (2009, p. 21–22) have acknowledged, “In promising a return (of services) on investments in nature, the scientific community needs to deliver the knowledge and tools necessary to forecast and quantify this return.” These authors concede that “we have not yet developed the scientific basis, nor the policy and finance mechanisms, for incorporating natural capital into resource- and land-use decisions....”

In an editorial titled “Using Science to Assign Value to Nature,” Ruffo and Kareiva (2009) agree. They have written (p. 3), “The idea that nature provides us with benefits—such as pollination, food, flood protection, clean water, and so on—is a simple and compelling notion. And yet, getting beyond the platitude of nature's value has proven to be a challenge for both science and policy. Why? Because we have not yet found a convincing way to talk about this issue to people who don't yet understand the value of those services.”

On the contrary, scientists may not “get beyond the platitude of nature's value” because they have not found a convincing way to talk with (not “to”) the people who *do* understand the value of those services. Apple growers in the Netherlands do not “overlook” the pest control services of great tits. Horticulturalists, apiarists, and others in the San Joaquin valley may not need the advice of ecologists to recognize the “public good” feral pollinators represent. Sanitary engineers who work for the town of Gramercy, LA, may already understand the tertiary waste treatment potential of a local wetland. Almond growers, orchardists, and potato chip manufacturers, among others, may know a surprising amount about the ecosystem services that are relevant to them, even if their knowledge is local, widely dispersed, implicit, tacit, embedded as know-how and practice, and responsive to price signals. Ecologists and ecologically-minded economists should not assume that they can "deliver" a lot to stakeholder groups who have managed common property resources often for decades. These scientists might better ask what they can learn from these groups and how they can work with them (*sensu* Ostrom et al., 2010).

Ecological scientists assert they can or will understand "the relative value of ecosystem services to different groups in society" and will learn how to design "appropriate incentive mechanisms for the efficient provision of ecosystem services" (Polasky, 2008, p. 42). Not only Hayek but also his "physicalist" critic Otto Neurath questioned the faith that science can mete out values to parts of the living world as a system. Neurath joined Hayek "when reducing the arrogance of some half-popular scholars who like to tell of the extraordinary powers of science, comparable only with the faculty of a seer" (quoted in O'Neill, 2006, p. 65).

The kind of knowledge that is important in managing ecosystem services for human benefit is widely distributed across individuals and is often extremely sensitive to changes in technology, preferences, and tastes. It is less like the knowledge that scientific experts can derive from theory than like the knowledge individuals who depend on those services gain by acquaintance (Hayek, 1948, p. 521; O'Neill, 2009). The elements, components, or units of ecosystems relevant to valuation are determined by and through the economic activity that surrounds them. According to O'Neill (2006, p. 57), Hayek argued that the idea that science apart from the vagaries of markets can establish a "framework for structuring and synthesizing biophysical understanding of ecosystem processes in terms of human well-being" exemplifies the kind of "illusion about the scope of human reason that underpins the socialist project."

The science of ecosystem services has not moved beyond the platitude of nature's value. Hayek gave one reason. The key to his argument, as O'Neill (2004, p. 434) has written, is that relevant knowledge is dispersed—"practical knowledge embodied in skills and know-how that cannot be articulated in propositional form, and knowledge of particulars, local to time and place." Ecological knowledge, like any kind of empirical knowledge that is relevant to economic activity, is too spread out among people and too sensitive to the moment to be captured by any one individual or by any group—even scientists given sufficient resources. A science of ecosystem services that captures or measures economic production or value in "final biophysical units" lies beyond our human potential. The "ecosystem services" project is bound to fail in its attempt to substitute an *in natura* calculus of value for the artifice of market price.

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