

PERSPECTIVE

Restoration of Ecosystem Services for Environmental Markets

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Ecological restoration is an activity that ideally results in the return of an ecosystem to an undisturbed state. Ecosystem services are the benefits humans derive from ecosystems. The two have been joined to support growing environmental markets with the goal of creating restoration-based credits that can be bought and sold. However, the allure of these markets may be overshadowing shortcomings in the science and practice of ecological restoration. Before making risky investments, we must understand why and when restoration efforts fall short of recovering the full suite of ecosystem services, what can be done to improve restoration success, and why direct measurement of the biophysical processes that support ecosystem services is the only way to guarantee the future success of these markets. Without new science and an oversight framework to protect the ecosystem service assets on which people depend, markets could actually accelerate environmental degradation.

As early as the 1940s, Aldo Leopold (1) linked the concepts of human reliance on natural systems and restoration of those systems. Today, each of these two seemingly simple concepts is associated with scientific and management quandaries created by joining them as the restoration of ecosystem services. Ecological restoration is an activity or series of activities undertaken to return a degraded ecosystem to a healthy state. Ecosystem services are the benefits humans derive from ecosystems, which have been largely taken for granted, especially since the industrial revolution (2). However, as ecosystems become progressively more human-dominated, the services they provide are increasingly seen as something of economic value, which can be traded in ecosystem service markets (3). At present, the demand in these markets is driven by regulations that require those seeking permits to mitigate or provide offsets for their environmental impacts. Some hope that voluntary ecosystem service markets will expand outside of a regulatory context and result in a net gain of ecosystem services rather than just offsets for lost ones. The most prominent example of regulation-driven ecosystem service markets is for wetland mitigation, although stream mitigation banks are rapidly growing, and although not yet official, “early” trading involving carbon credits created through reforestation of land can be sold to offset CO₂ emissions (4, 5).

We do not disagree about the potential for ecosystem service markets to help solve environmental problems, especially if markets can be created to provide incentives for conservation of natural resources rather than facilitating new environmental impacts because offsets are available. Our concern

is that the flurry of interest in ecosystem markets supplied by restoration is out of step with the science and practice of ecological restoration, and so it is obscuring the fact that restoration projects, particularly those in aquatic ecosystems, are not providing all the services of healthy ecosystems (6, 7). Stream and river restoration projects are often based on reshaping a channel and adding wood or rocks, yet there are few documented cases in which this has resulted in improved water quality or biodiversity comparable to those in undisturbed streams (8, 9). In the case of wetlands, the success of restoration projects has been debated, largely because most are implemented for mitigation purposes, and although they may meet legal requirements, which are sometimes based on simple acre-for-acre compensations, they may not provide the full suite of ecological services (10, 11).

The danger of marketing ecosystem services delivered through ecological restoration without properly understanding the potential shortfalls of restoration is that the level or quality of the ecosystem services provided as an offset may not correspond with the losses. If this happens, these markets may cause an increase rather than decrease in environmental degradation. Hence, before ecosystem service markets that rely on restoration expand further, we must understand why many restoration efforts are falling short and what should be done to improve restoration success.

The broadening definition of what counts as restoration and the limited scale of restoration both contribute to the inadequacy of restoration efforts. In its purest form, restoration refers to returning an ecosystem to an undisturbed or historic state, but today, diverse activities are routinely undertaken in the name of ecological restoration. For instance, “creation” of wetlands and streams where they did not previously exist is now considered a form of ecosystem restoration (8, 12). Because the ecosystem services provided by wetlands and streams depend in critical ways on their context in natural landscapes,

successful restoration of even a subset of the services is unlikely, unless there is very careful site selection and/or management actions at regional scales. Restoration efforts that target improvements on minimally degraded lands offer the most hope for recovering ecosystem services, whereas attempts to create ecosystems offer the least.

When restoration efforts target sites in watersheds with deforestation, mining, or development, it is unrealistic to assume that the full suite of ecosystem services can be restored, given the current state of the science. First, restoration actions that benefit one service may interfere with another (13). For example, wetland restoration undertaken to reduce nitrogen loads to adjacent coastal areas may also result in increasing the bioavailability of mercury to fish (14). Second, final ecosystem services are supported by a complex network of biophysical processes and ecosystem features (collectively referred to as ecosystem functions) (Fig. 1), many of which are not restored because restoration designs are typically not process-based. Instead, most designs are based on structural features of ecosystems or, at best, hydrological processes that may be necessary, but not sufficient, to recover desired ecosystem services (15). For example, river restorations are often based on recreating structural attributes like channel width, depth, and sinuosity, because of making the erroneous assumption that ecological functions will follow. Yet, how a stream looks is not the same as how it processes nutrients and supports life. Designs must focus on restoring processes that support ecosystem services of interest, and careful measurements of how targeted processes respond to restoration are critical to postproject monitoring for adaptive management (16).

It is important to emphasize that measuring ecological processes is not the same as measuring an ecosystem service. The former should be based on well-accepted scientific methods that provide information on how an ecosystem is performing, such as its rate of nutrient processing; the latter should be based on the delivery of a final service or good, like clean water to humans. The metrics of ecosystem service markets are the value or importance societies place on natural systems and associated products at specific locations (2, 3). Without direct measurements of processes that lead to the production of ecosystem services, or surrogate measurements that have been shown to dependably represent the functions that support a service or suite of services (16, 17), there is no way to know if restoration actions are actually leading to the delivery of services. The assumptions that simple proxies, like habitat descriptors, can be used to evaluate restoration success and that single ecological measures, like biodiversity, can be used to evaluate a full suite or “bundle” of ecosystem processes are not only naïve but have been demonstrated to be false for many ecosystems (4).

Despite progress in developing methods for the valuation of ecosystem services, we still lack a clear picture of what biophysical factors support services

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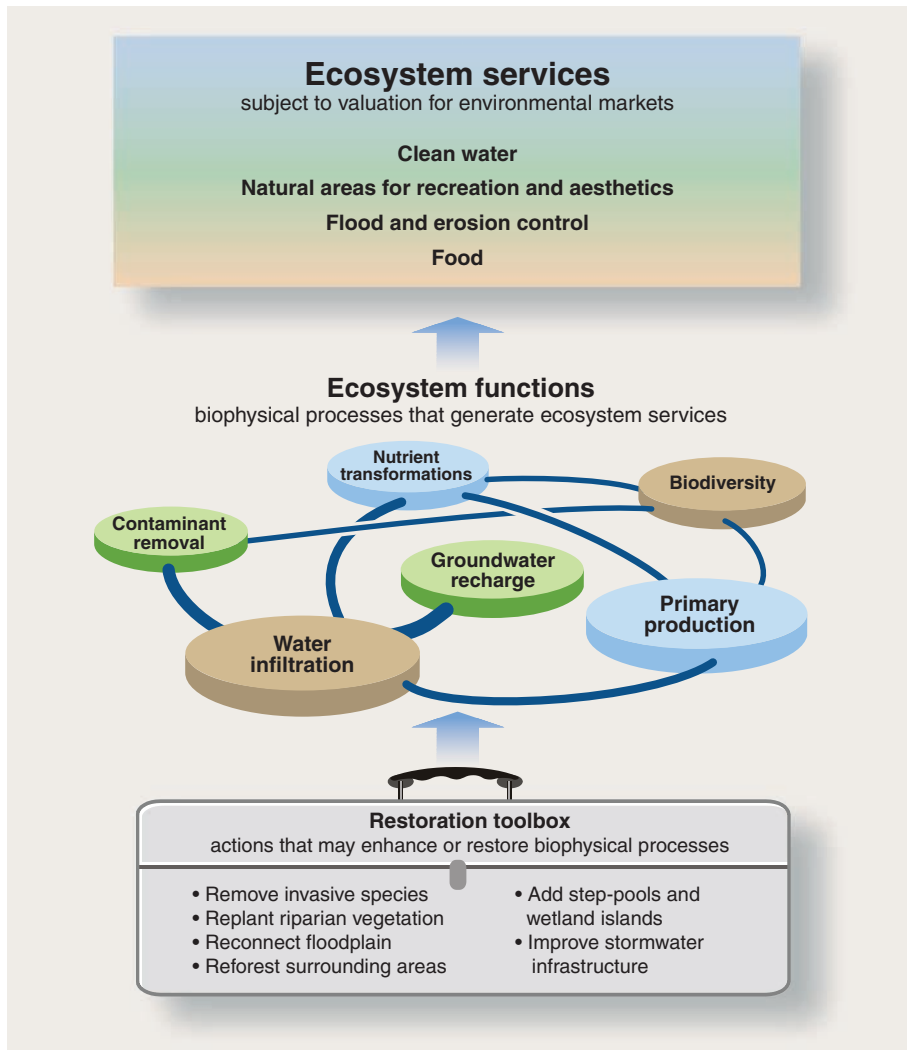


Fig. 1. Restoration of ecosystem services that can be bought, sold, or traded requires actions (use of “tools”) that directly influence biophysical processes, such as microbial removal of excess dissolved nitrogen, the uptake of metals by plants, or the infiltration of rainwater into soils. These processes interact with ecosystem features (e.g., suites of species or surrounding land use) and are collectively called ecosystem functions or ecological processes. To ensure the value of an ecosystem service credit, direct measurements of the service (e.g., clean water without excessive nitrogen) or ecosystem functions that support the service (e.g., denitrification) must be made. For some services and landscape settings, researchers are only now identifying the most relevant ecological processes.

for different ecosystems and in what combinations. This kind of information is absolutely essential to create and/or support the restoration of a full suite of ecosystem services; for now, we can only apply a logical, data-driven approach to prioritize sites and particular services for restoration and to test the efficacy of various restoration tools in accelerating the recovery of biophysical processes critical to those services. As we start to build up a database on process-based responses to restoration treatments and relate these responses to data on a range of project characteristics, we can develop useful relations between local environmental conditions, restoration methods, and probabilities of outcomes.

Until this kind of information is available, the only way to ensure that credits generated by res-

toration of ecosystems can be associated with the delivery of ecosystem services is to have a third-party, unbiased entity verify, through direct measurements, that ecosystem functions were sufficiently restored. Independent and transparent evaluation approaches that do not rely on those who stand to profit or those tasked with regulation have been successfully employed for other environmental issues. For example, third-party, academic-based programs subject to routine peer review provide certification testing of ballast water treatment systems designed to prevent the introductions of non-native aquatic species by commercial ships in the United States (18). Even with such verification programs, the units of exchange in ecosystem service markets need to be fairly complex in order to account for

uncertainties in success, as well as any environmental or social consequences of spatially redistributing ecosystem services (19). Furthermore, the rules of exchange need to contain clear liability guidelines to the buyer or the seller, and long-term monitoring of ecological processes must be required; otherwise, by default, the risks of environmental failure will fall on the general public (20).

Until there is a sound scientific basis for linking restoration actions to changes in biophysical processes and ecological features that result in the delivery of specific ecosystem services, restoration-based markets and trading schemes are a risky business. Devising methods to assign economic value or mitigation credits to an ecosystem service, like clean water, does not mean that the service will necessarily be restored.

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LETTERS

edited by Jennifer Sills

Getting His Goat



IN HIS BOOK REVIEW "TWO DOORS and a goat" (9 October, p. 231), the answer D. O. Granberg offers to the Monty Hall problem is incorrect. He assumes that the contestant should try to win the car. In reality, a car pollutes the environment and adds nothing to the car the contestant already owns. In contrast, a goat replaces noisy lawnmowers and provides milk, cheese, and (if absolutely necessary) a tasty curry.

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Cell Therapy Ahead for Parkinson's Disease

THE NEWS FOCUS STORY "FETAL CELLS AGAIN?" (C. Holden, 16 October, p. 358) indicates that fetal cell transplants for Parkinson's disease patients fell out of favor after control studies suggested that placebo effects may have accounted for positive results. However, there were no proven placebo effects in previous clinical trials. The reason that new trials are funded in Europe is that previous trials used outdated methods for cell therapy.

These outdated methods, combined with patient differences, obscured any difference in average improvement. However, some patients do show spectacular recovery in response to neuronal cell therapy. In the future, with the use of rapidly improving genetic tools and diagnostics, we may be able to identify in advance the patients who will be most responsive to cell therapy. According to available data, with improved cell therapy (very likely stem cell-derived), such patients could have a chance of significant motor and behavioral benefits for 10 to 15 years in the absence of drugs. It is true that Parkinson's disease is more complex than just a lack of

dopamine, but those that use this argument to discourage physiological cell therapy miss the point: Many patients may respond better and have fewer long-term side effects in response to therapeutic dopamine neurons than they would with the available systemic drug therapy, which relies almost exclusively on dopamine pharmaceutical drugs. For these reasons, it is scientifically and medically shortsighted not to test major refinements of cell therapies for Parkinson's disease.

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Environmental Markets: Concentrate on Criteria

IN THEIR PERSPECTIVE ("RESTORATION OF ecosystem services for environmental markets," 31 July, p. 575), M. A. Palmer and S. Filoso rightly promote rigorous science to link ecosystem functioning with the provision of ecosystem services, but they exaggerate the potential downside of market valuation in

restoration outcomes. Well-defined markets delineate which services are relevant and, consequently, the biophysical processes that underlie them, not the other way around. In effect, environmental markets are indispensable compasses for restoration initiatives.

The focus should be on developing and improving valuation criteria, not on adding costly mechanisms that might discourage development. There is currently a large and growing research paradigm, informed by both economists and ecologists, that addresses how economic valuation can better approximate the complexity and nuance of ecosystems (1).

Ecological restoration in modern landscapes must be scientifically driven but socially based (2). As a matter of pragmatism, it is often better to have imperfectly functioning environmental markets, in which nature has some economic value, than to have no environmental markets, where nature possesses zero value. This fits into the broader notion of ecosystems as assets from which society derives vital services (3). Ecological restoration, then, is not merely a rehabilitation of biophysical processes, but an investment in natural capital.

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Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 3 months or issues of general interest. They can be submitted through the Web (www.submit2science.org) or by regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.

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Amazing maize

1071



Who killed the megafauna?

1072



Environmental Markets: The Power of Regulation

IN THEIR PERSPECTIVE (“RESTORATION OF ecosystem services for environmental markets,” 31 July, p. 575), M. A. Palmer and S. Filoso call for direct measurement of ecosystem processes and third-party verification. This step is a critical one for the burgeoning compensatory mitigation industry to preserve, or recover, its credibility. However, Palmer and Filoso did not mention those who actually control ecosystem markets and did not consider how more rigorous restoration quality checks could provide an economic incentive to reduce ecosystem impacts in the first place.

Ecosystem service markets are odd in that they are created and controlled by regulation. For aquatic ecosystems, for example, the Clean Water Act (CWA) and the first President Bush’s administration created a cap-and-trade program for wetlands and later for streams. This produced a demand for restored ecosystems through fiat, not through an inherent consumer need for ecosystem service commodities. The U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (USACE) determine the presence of wetlands and streams on the landscape, their condition, and any requirements for compensation when these ecosystems are affected by development. Thus, by regulating the presence of existing wetlands and streams that might be affected, these two federal agencies are responsible for creating demand for these ecosystem services. In turn, these two agencies bear responsibility for the presence of the supply of restored ecosystem services through approval and certification of specific restoration projects. If the quality and integrity of restoration are lacking in existing aquatic ecosystem service markets, the blame rests largely on the shoulders of EPA and USACE, and these are the agencies through which aquatic ecosystem restoration policy changes must occur.

We agree with Palmer and Filoso that more stringent criteria must be established for restoration as part of ecosystem markets, and we suggest that EPA and USACE quickly institute more stringent standards. But we also emphasize the economic and ecological implications of such changes. Making the suc-

cess criteria of restoration more rigorous will undoubtedly increase the cost of restoration: Project engineering will initially prove more difficult and therefore more costly; financial risks will increase with greater uncertainty, causing investors to increase required rates of return; and verification of project success, whether direct or through third parties, will represent an additional expense.

The net result is an increase in mitigation costs, which will need to be recouped by charging more for mitigation credits. This will, in turn, drive up the costs of affecting aquatic ecosystems, serving as a deterrent to damaging them. That is, increased restoration quality requirements could reduce the demand for compensatory mitigation by providing incentives for avoidance. This is likely the most substantial benefit of more expensive restoration.

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Response

WE AGREE WITH WU AND KIM THAT WELL-defined markets can delineate relevant ecosystem services. However, contrary to Wu and Kim’s assertion, the science underpinning aquatic ecosystem restoration is far too underdeveloped for a mere delineation of ecosystem service in a market context to serve as an adequate “compass for restoration initiatives.” An ever-increasing number of peer-reviewed studies show that the effectiveness of aquatic restoration projects is falling short of expectations (1–3). This is particularly true for projects that attempt to create ecosystems or restore damaged ecosystems at sites that are inappropriate (e.g., lack needed hydrological linkages) or at sites vulnerable to impacts (e.g., downstream of a polluted tributary) (4, 5).

To ensure sound investments in natural capital—which we whole-heartedly support—markets should provide incentives for conservation of natural resources. If the only alternative is restoration, then two steps are required. First, we must invest in science and engineering research aimed at improving

methods to restore well-functioning aquatic ecosystems. Second, we should extend this research to include the development of cost-effective assessment metrics that dependably represent the ecosystem functions that support a service or suite of services (6–9).

Wu and Kim asserted that we exaggerated the potential downside of environmental markets. The focus of our Perspective was on the incomplete nature of ecological science needed to inform markets. We did not delve into the economic complexities associated with ecosystem service markets. However, even to us as ecologists it is obvious that the environmental markets are quite different from routine commodity markets that should be self-governing. Typically, the product bought or traded is a permit or an allowance to affect the environment—not an ecosystem service. The permit to affect the environment is the buyer’s motivation for entering the market. Profit is the seller’s motivation, and it is to his or her advantage to produce a (restoration) product at the lowest possible cost. If the product quality (restoration project outcome) is not easily assessed or if it is not properly evaluated by a regulatory entity, it may not matter to the buyer (10). Quality uncertainty is well known to influence markets.

Riggsbee and Doyle astutely point out that it is the regulator and those establishing the rules of the market that are in the position to evaluate quality. If the regulator does not ensure that the ecosystem services being sold or traded are actually delivered, then the market system will result in further environmental degradation. Furthermore, the potential for political influence on regulatory decisions is great. Regulators are under enormous pressures from multiple sources. Thus, the need for an independent entity that does not answer to elected officials and does not stand to benefit financially is required to complete evaluations and monitor trades.

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Training Scientists to Manage

THE NEWS FOCUS STORY "RESHUFFLING GRADUATE training" (J. Mervis, 31 July, p. 528) details Roald Hoffmann's proposal to improve the U.S. science system by making students more independent and empowered through an increase in government fellowships granted directly to students. Responses to this story included suggestions to increase funding for fellowships ("Increase grants, too," M. J. Castellano and K. E. Mueller, Letters, 18 September, p. 1498) and to provide more stable funding for students ("Stable funding is key," R. J. Butera, Letters, 18 September, p. 1499).

These suggestions are all related to the theme of financially supporting and maintaining the most important resource to modern scientific research: graduate students. How-

ever, although academic culture recognizes the importance of graduate students, it currently does almost nothing to train current and future principal investigators (PIs) to effectively manage this resource. Few Ph.D.s have substantial hands-on experience managing others before they land a faculty position, and even fewer have any formal training in management. Faculty are left to learn this skill on the job at the expense of productivity and the well-being of the people they are managing. Furthermore, there is an emphasis on student independence in this discussion, which is natural; independence is an essential quality in a career researcher. The unfortunate implication is that ideal students are independent from the start. In fact, independence is a skill that can be taught and nurtured, just

like the other skills that are explicitly taught in graduate school.

To improve the efficiency of the science industry, I suggest improving the management of its most important resource. Unproductive students are a consequence of student inexperience and poor advising. Better management of students can be achieved through a range of mechanisms that involve both faculty and students (such as regular mutual evaluations and human resources training for current and future PIs). Such efforts may cost time initially, but will certainly pay off in the long run.

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CORRECTIONS AND CLARIFICATIONS

News Focus: "Looking for a target on every tumor" by J. Kaiser (9 October, p. 218). Lung cancer kills 160,000 Americans a year, not 16,000.

Reports: "Grüneberg ganglion cells mediate alarm pheromone detection in mice" by J. Brechbühl *et al.* (22 August 2008, p. 1092). The next-to-last sentence of the text read "The presence of a GG has been identified in all mammalian species looked at so far, including humans (15, 30)." Instead, it should read "The presence of a GG has been identified in all mammalian orders looked at so far, including human embryos (15, 30)."

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