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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 CO_2 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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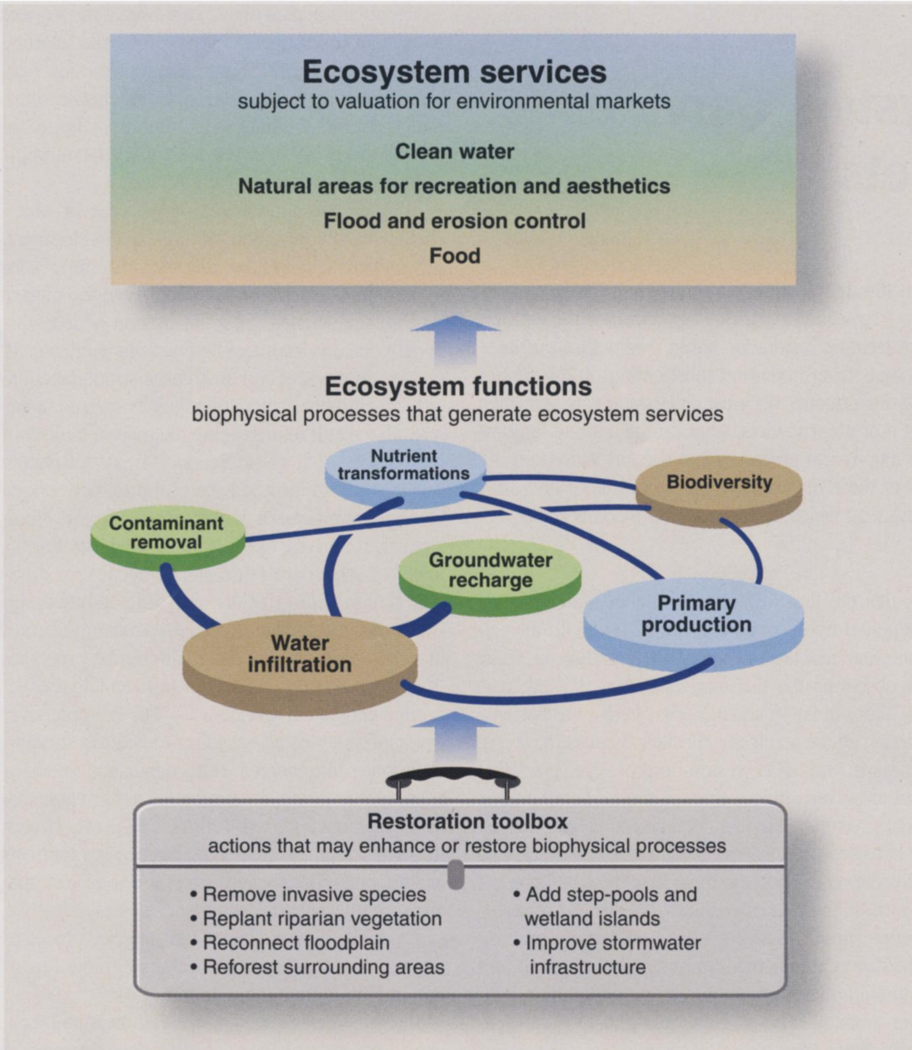

Fig. 1. Restoration of ecosystem services that can be bought, sold, or traded requires actions (use of "tools") that directly influence biophysical processes, such as microbial removal of excess dissolved nitrogen, the uptake of metals by plants, or the infiltration of rainwater into soils. These processes 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 restoration 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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