Comparing Ecosystem Goods and Services Provided by Restored and Native Lands

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We determined the relative benefits for eight categories of ecosystem goods and services associated with native and restored lands across the conterminous United States. Less than 10% of most native US ecosystems remain, and the proportion that is restored varies widely by biome. Restored lands offer 31% to 93% of native land benefits within a decade after restoration, with restored wetlands providing the most economic value and deserts providing the least. Restored ecosystems that recover rapidly and produce valuable commodities return a higher proportion of total value. The relative values of the benefits provided by restoration vary both by biome and by the ecosystem goods and services of interest. Our analysis confirms that conservation should be the first priority, but that restoration programs across broad geographic regions can have substantial value. "No net loss" policies should recognize that restored lands are not necessarily equivalent to native areas with regard to estimated ecosystem benefits.

Keywords: restoration, conservation, ecosystem services, ecosystem valuation, ecosystem goods

Humans influence every ecosystem on Earth, leading to impairment of natural ecosystem structure and function (MEA 2005). Converting native land to row-crop agriculture, suppressing fire, diverting water flow, increasing nutrient and toxic pollution, altering global precipitation patterns and gas concentrations, and homogenizing and lowering global biodiversity are a few of the ways humans have altered ecosystems. North American forests, savannas, and grasslands have experienced substantial losses, whereas woody savanna, shrubland, and desert areas have expanded because of desertification and woody expansion into grasslands (Wali et al. 2002), inevitably leading to changes in ecosystem function.

Conserving native land cover is an important component of maintaining ecosystem structure and function. Preservation is not always a viable management option, because many regions lack sufficiently large undisturbed areas to sustain biota and ecosystem function without improvement. Therefore, restoration is an essential activity for modern land management and conservation (Hobbs and Harris 2001). Setting achievable goals for restoration policies covering broad regions involves not only defining ecological potential in the region but coupling that potential with societal demands and economic feasibility. Valuation of ecosystem goods and services can help managers estimate long-term economic feasibility (Costanza et al. 1997). This coupling of the success of restoration with the value of ecosystem benefits leads to a definition of restoration as "the process of restoring one or more valued processes or attributes" of an ecosystem (Kahn 1995). The restoration of specific ecosystem goods and services, in addition to merely restoring the native complement of species in an area, has thus become the focus of many restoration ecologists.

Estimating some of the benefits of lands used by humans can be fairly straightforward, particularly when the commodities produced have market value (e.g., the annual value of crops produced per hectare) and when externalities are ignored. Ascribing an economic value to some ecosystem goods and services, by contrast, can be difficult (Kahn 1995, Costanza et al. 1997), and sectors of the economic community have criticized such valuation (Bockstael et al. 2000, Spash and Vatn

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2006). Nonetheless, ecosystems provide some recognized benefits, and the valuation of these benefits could become a major tool for directing policy and making land-use decisions (Turner et al. 2007). Attempts to document the relationship between land restoration and the improvement of the supply rates of ecosystem goods and services have been made mainly in small-scale studies. We explore the hypothesis that the temporal trajectory of ecosystem goods and services supplied by restored lands varies across ecoregions and among the different goods and services. We test this hypothesis with respect to restoration across broad regions (i.e., continental), but some of the principles could be refined and applied also to specific restoration projects. We focus on the effects of restoration on ecologically based temporal trends in rates of benefit production from ecosystem goods and services, because that is an area where ecologists can provide useful information for use in future cost-benefit analyses.

Our analysis involved four steps. First, we defined our ecosystem goods and services. Second, we defined restoration and created a "restoration index" to compare the value of native and restored lands. Third, we defined the ecoregions in our study and calculated the area of native and restored lands within each ecoregion. Last, we conducted a literature review to collect the data needed to parameterize our restoration index.

Ecosystem goods and services

We calculated values for 8 categories of ecosystem goods and services, condensed from a previously published system (Costanza et al. 1997) with 17 categories. Our categories were (1) gas regulation (including carbon sequestration, methane sequestration, and factors that regulate climate change), (2) disturbance regulation (storm protection, flood control, and drought recovery), (3) water supply (storage and retention of water), (4) nutrient cycling (storage, cycling, and processing of nutrients; nitrogen fixation; and the nitrogen and phosphorus cycles), (5) soil erosion control, (6) rate of production of commodities (raw materials, native crops, fish, and game), (7) production of biodiversity and associated services (genetic resources, biocontrol agents, pollination, and refugia [organisms serving as habitat or refuge for other desirable species]), and (8) recreation (the opportunity for recreational activities such as hunting, fishing, hiking, and wildlife viewing). Other frameworks have been used to categorize the benefits of ecosystem goods and services (e.g., MEA 2003), but we based our framework on that of Costanza and colleagues (1997) because their assessment could serve as a baseline that we could readily update with more specific numbers related to restoration. A more complete accounting of costs and benefits, including influx and efflux of materials from environments, has been used to establish standards for environmental and economic accounting (UN et al. 2003). We could not use this approach, however, because many of the studies on valuation of ecosystem goods and services that are currently available do not employ this methodology.

Functional definitions of restoration and the restoration index

We defined "native" operationally on the basis of ecosystem descriptions in the published literature for each ecoregion (described below). Although it is easy to debate what is truly "native," in most cases, assigning the state of the ecosystem was fairly straightforward: a filled wetland, a prairie or forest converted to cropland, or a paved field is no longer native. That is, all ecosystems have some human influence, but inventories of land coverage derived from remote sensing and aerial photography make it relatively easy to create distinctions based on fairly obvious, broad categories and on strongly influenced habitats. We defined "restored" areas as those where restoration efforts had been applied. For example, Conservation Reserve Program lands, constructed wetlands projects, and revegetated lands that are not used for commercial purposes fall under the category "restored." We used published estimates (mostly governmental) to calculate the total area of restoration; these estimates did not distinguish the quality of the restoration.

We used a restoration index to represent the ratio of the value of restored land to native land. Restoration index values less than 1 indicate that restored land provides less valuable ecosystem services than native land. We assumed that the ratio of ecosystem services was equal to the ratio of values:

$$RI_{r/n} = V_r / V_n$$

and

$$RI_{r/n} = ES_r / ES_n$$

where $RI_{r/n}$ = ratio of value production rates of restored to native (the restoration index), V_r/V_n = ratio of restored to native monetary benefit production, and ES_r/ES_n = ratio of restored to native rates of ecosystem goods and services. These equations allowed us to estimate values and restoration indices when both V_r and V_n were known, or when V_n or V_r and ES_r/ES_n were known. Where possible, we used the ratio of ES_r/ES_n to estimate the restoration index, because this obviates the need to assign a specific monetary value to any given ecosystem good or service. Some features, such as commodities and recreation opportunities, mainly have economic value per unit time; in these cases, we used the ratio V_r/V_n to estimate the restoration index. Monetary values derived from the literature across different years were converted to 2004 US dollars. Most of the monetary values were derived using willingness-to-pay methods. In cases where several literature values were reported for a parameter, we used the median of the estimates. We recognize that estimating the restoration index using either the ratio of values or the ratio of ecosystem goods and services assumes a linear relationship between value and service. However, we are aware of no well-defined functions for relationships between value and service, so assuming a linear relationship seemed to be the most parsimonious approach. We examine this assumption further in our discussion.

Ecoregions and area estimates

Ecoregions were classified following the US Environmental Protection Agency (EPA) level I ecoregions for North America (Omernik 1987). We included the five largest ecoregions in the conterminous United States in our study: eastern temperate forests, great plains, North American deserts, western forested mountains, and West Coast marine forests. We also included a wetlands ecoregion, because wetlands provide many important ecosystem goods and services and are often a target of mitigation and restoration programs. We calculated three area estimates for each ecoregion: (1) area of pre-European settlement, (2) current area of native land, and (3) current area of restored land.

The pre-European settlement area for the five EPA level I ecoregions was calculated using ArcGIS version 8.2. The present area of native and restored land for the three forest ecoregions was based on Forest Service estimates (USDA FS 2001). The native area of the Great Plains ecoregion followed Madsen (1990). Restored area within the Great Plains was calculated using estimates from the US Department of Agriculture (USDA) Conservation Reserve Program for states inside this ecoregion (USDA FSA 2004). Values for native and restored area in the North American desert ecoregion were unavailable. Values for historical and remaining wetland area within the conterminous United States were similar to the estimates of Cox and Cintrón (1996). The area of restored wetlands was determined from estimates in Heimlich and colleagues (Heimlich et al. 1998, Heimlich 2003).

Parameterizing the restoration index

We conducted a literature review to obtain either published monetary values or ecosystem service rates for all ecosystem goods and services possible for native and restored lands in each biome. We determined monetary values (in 2004 US dollars per hectare per year) for each ecosystem service as described below.

Gas regulation values (ES_r and ES_n) were obtained by calculating metric tons per hectare per year of carbon dioxide or methane sequestered in restored and native lands. We report both carbon dioxide and methane values for those ecoregions where data for both gases were available. Methane values were converted to carbon equivalents. Carbon values were based on Battelle's second generation model (Council of Economic Advisors 1998), a World Energy Council statement (2004), and Moura-Costa and Stuart (1998). We averaged ES_r/ES_n values for each gas within an ecoregion and used this averaged value to represent the restoration index for gas regulation in each ecoregion. Nitrous oxide was initially considered, but because all ecoregions were net sources of the gas, it was not included in the analysis.

We based disturbance regulation values (ES_r and ES_n) on the proportion of vegetation types, soil characteristics, and area of a given ecoregion as described in *USDA Handbook 296* (USDA NRCS 2006). We estimated runoff curve values for each of the land-cover types in each ecoregion in accordance with Wanielista and colleagues (1997). We combined these runoff curve values into weighted average saturation values and excess water curve values based on the proportion of each land-cover type within each ecoregion. The range maximum was obtained by assuming that the entire ecoregion was restored to its potential native land-cover type under good conditions, whereas the range minimum reflected the current land-cover type under poor conditions. For each ecoregion, the ratio of the saturation values for the current land-cover type to the values for the completely restored land-cover type yielded the percentage improvement per hectare, determined by multiplying the area of a given ecoregion by its percentage of improvement from current land-cover values to restored values. This value was multiplied by \$166,661 per hectare per year for each 1% reduction in flow (Leschine et al. 1997).

Soil erosion control values (ES_r and ES_n) were acquired by comparing the amount of soil lost from degraded land, restored land, and native land. The values for soil loss from restored and native land were each compared with the amount of soil lost from degraded land in the same ecoregion. These fractions were multiplied by the annual cost of soil erosion per hectare in the United States, which is \$196 (Pimentel et al. 1995). This monetary value represents the value of soil conserved in restored or native habitat per hectare of land.

We calculated water-supply values on the basis of estimates of damage to water quality due to soil erosion for each state, provided by Claassen and colleagues (2001). The average dollar value per metric ton of soil lost was multiplied by the amount of soil conserved in restored or native habitat per hectare of land. Similarly, nutrient cycling values were tied to soil erosion rates using damage estimates of nitrogen fertilizer runoff for each state from Claassen and colleagues (2001).

Commodity and biodiversity values were based on the published market values of commodity goods (e.g., average hay values for native and nonnative grasses harvested in Kansas, Oklahoma, Missouri, and Texas, obtained from archival data of the Agricultural Marketing Service of the USDA) and on the economic rate of value of services provided by biodiversity (e.g., pollination), respectively (Southwick and Southwick 1992, Nabhan and Buchmann 1997, Pimentel et al. 1997). The ES_r and ES_n values for biodiversity were used to calculate the restoration index.

Recreation values were estimated as annual economic gains resulting from hunting, fishing, hiking, wildlife viewing, and other outdoor activities. We determined estimates for the three forest ecoregions using values from Cosgrove and colleagues (2000). Values were considered similar for each forested ecoregion and were divided by the number of hectares of restored and native lands contained in each ecoregion. Estimates for grassland recreation values were assigned using economic values generated by the Conservation Reserve Program for the USDA and the US Fish and Wildlife Service (*www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp-st*). We estimated the recreational values of deserts using US National Park Service statistics on daily use, multiplied by entrance fees and divided by area for 12 national parks (Arches, Big Bend, Canyonlands, Capitol Reef, Carlsbad Caverns, Death Valley, Grand Canyon, Great Basin, Joshua Tree, Petrified Forest, Saguaro, and Zion) within the desert ecoregion.

Wetland abiotic values (gas regulation, disturbance regulation, water supply, erosion control, and nutrient cycling) were based either on direct valuation of those services or on cost-prevention estimates (i.e., flood control). Restoration indices were calculated on the basis of the relative amount of each service provided (e.g., the nutrient cycling rates in restored wetlands were only 75% of those in native wetlands).

We based our wetland biotic ecosystem values (commodity production, biodiversity, and recreation) on a monetary value comparison per hectare and an ecological comparison of restored and native wetlands. Commodity production (per unit time) and recreational values were determined through annual market values and willingness-to-pay indices, respectively. We calculated the relative value of biodiversity by comparing the number of species in restored and native wetlands.

The influence of time since restoration

Different ecosystem services require different amounts of time to recover, and recovery time may also vary widely among different ecoregions. To accommodate differences in restoration trajectories, we limited our analysis to the value of restored lands within 10 years following restoration efforts. The 10-year window scaled values similarly across all services and ecoregions, allowing for comparison values across services and ecoregions. We felt this was a realistic, albeit conservative, approach, as the public is probably willing to forgo the benefits accrued from restoration for some period after the restoration begins, but many political frameworks do not allow substantially more than a decade for most projects (although examples of longer restoration time frames exist, such as the Chesapeake Bay eutrophication abatement program; Boesch et al. 2001).

Services that required more than 10 years to restore were assigned only a fraction of their potential economic value. For example, grasslands could provide high-quality forage production within 10 years, so we assumed that forage production in restored grassland was as valuable as that in native grassland on an annual basis. By contrast, forested areas could not provide usable lumber within 10 years. If a forest would require 80 years to produce lumber as a commodity, then we assumed the rate of value accrual reported in the literature for lumber for that habitat after 10 years was only 12.5% of its potential. The fractional addition of value after 10 years is conservative in terms of assigning value to restored land. In the example of forests, usable lumber achieves value only when it is of marketable size. We did not perform a true cost-benefit analysis, and we did not discount future values. We take the view that values of ecosystem goods and services are given equal weight when applied to current and future societies (Goulder and Stavins 2002). We recognize that monetary values for ecosystem goods and services are tentative and therefore limiting, but they can be used to make broad comparisons of the relative benefits of restoration and comparisons across ecosystem types.

Remaining native and restored lands

Our assessment of the United States indicates that the proportions of remaining native area were largest for wetlands (48%) and the Great Plains (10%). Forested ecoregions (eastern temperate, western mountain, and West Coast marine) had less than 5% of native area remaining (table 1). We could not find information on the amount of remaining native North American deserts. The area of restored lands was greatest in eastern temperate forests (where croplands have reverted to forests), whereas wetlands had the least amount of restored

Table 1. Historical (presettlement) and current native area, percentage of native area remaining, area of restored land (in hectares), and corresponding values of ecosystem goods and services within six ecoregions in the conterminous United States.

Ecoregion	Native area remaining (percentage)	Presettlement area (millions of hectares)	Native area (millions of hectares)	Restored area (millions of hectares)	Native values (billions of dollars per year)	Restored values (billions of dollars per year)	Total values (billions of dollars per year)
Eastern temperate forests	< 1	243	< 1	146	< 1	548	548
Great plains	10	229	23	10	1189	384	1574
North American deserts	–	148	–	–	–	–	–
Western forested mountains	5	75	4	54	9	114	123
West coast marine forests	3	39	1	16	4	57	61
Wetlands	48	89	43	0.34	26,217	196	26,413
Total	–	823	71	226	27,420	1299	28,719

Note: Overall benefits for native and restored lands were calculated by multiplying the total ecosystem service values for each ecoregion (table 2) by the native and restored area, respectively, within each ecoregion. Total values for each ecoregion are the sum of native and restored values.

area (table 1). The benefits of native lands were substantial across types (table 2).

Comparing the restoration index among ecoregions

Restoration indices—the ratio of restored to native values or of restored to native ecosystem goods and services—varied among ecoregions, but none of the total values for restored lands were greater than those for their native counterparts (figure 1, tables 2, 3). The lowest restoration index occurred in the North American desert ecoregion (0.31; figure 1). The greatest proportional value can be gained by restoring wetlands, eastern temperate forests, and western forested mountains, which all had restoration index scores of about 90% (0.93, 0.88, and 0.89, respectively; figure 1). The value of restored areas in the Great Plains was estimated at about 70% that of native plains (0.72; figure 1).

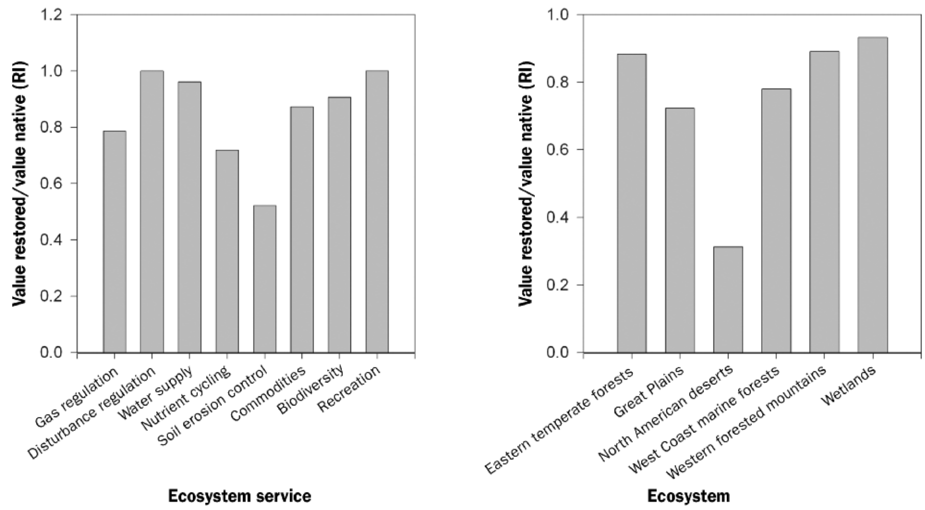

Figure 1. Relative native and restored benefits of ecosystem goods and services by service and by ecoregion. The relative value (RI) is determined as the ratio of values summed across rows or columns from tables 2 and 3.

Comparing the restoration index among ecosystem services

Disturbance regulation and recreation had the highest average restoration indices of all of the ecosystem services examined (1.0; figure 1). The average restoration index of 1.0 for both disturbance regulation and recreation indicates that restored and native lands were generally equivalent in terms of these services. Water supply, biodiversity, and commodities had the next highest average restoration indices (0.96, 0.91, and 0.87, respectively), indicating that restored lands provide approximately 90% of these services compared with native lands. On average, restored lands were not quite as good as native lands at providing gas regulation and nutrient cycling services; these services had restoration indices of 0.79 and 0.72, respectively (figure 1). A notable exception is the West Coast marine forest ecoregion, which provided greater gas regulation services in restored areas (table 3). Soil erosion control had the lowest average restoration index score (0.52; figure 1).

Comparison of values

The values of native and restored wetlands were 10 times greater per unit area than any other habitat (figure 1, tables 2, 3). Wetlands had the greatest value for each of the ecosystem services that we examined, in both native and restored habitat (tables 2, 3). The most valuable ecosystem goods and services that wetlands provided were disturbance regulation and nutrient cycling, with calculated values, respectively, of 1000 and of 5 times greater per unit area than the next most valuable ecoregion. The greater value per area of wetlands did not translate to an equally large disparity in total value, because the total area of wetlands is substantially less than that of terrestrial ecoregions within the United States (table 1). The Great Plains had considerable total value because of the large amount of total land area and the substantial value of the ecoregion per hectare. Comparatively, the total value of North American deserts was the least.

Table 2. Estimated values per native hectare per year (in 2004 US dollars) of ecosystem services for six ecoregions within the conterminous United States.

Ecosystem service	Eastern temperate forests	Great Plains	North American deserts	West Coast marine forests	Western forested mountains	Wetlands
Gas regulation	104	7	–	31	64	265
Disturbance regulation	6	7	2	3	11	31,736
Water supply	79	28	85	46	21	2954
Nutrient cycling	1508	22	60	2431	159	15,985
Soil erosion control	241	241	237	241	241	–
Commodities	710	3853	–	4	1	6029
Biodiversity	6	46	–	6	6	384
Recreation	1874	1003	16	1874	1874	3617

Table 3. Restoration values (per restored hectare per year, in 2004 US dollars) and restoration indices (ratios of the values of restored and native lands) of ecosystem services for six ecoregions within the conterminous United States.

	Eastern temperate forests		Great Plains		North American deserts		West Coast marine forests		Western forested mountains		Wetlands	
Ecosystem service	RV	RI	RV	RI	RV	RI	RV	RI	RV	RI	RV	RI
Gas regulation	49	0.6	6	0.8	–	–	100	3.2	22	0.4	193	0.7
Disturbance regulation	6	1	7	1	1	0.3	3	1	11	1	31,736	1
Water supply	47	0.6	19	0.7	25	0.3	28	0.6	13	0.6	2954	1
Nutrient cycling	905	0.6	15	0.7	18	0.3	1458	0.6	95	0.6	11,989	0.8
Soil erosion control	145	0.6	175	0.7	65	0.3	145	0.6	96	0.6	–	–
Commodities	729	1.03	2490	0.65	–	–	1	0.1	1	1	6029	1
Biodiversity	6	1	50	1.1	–	0.6	6	1	6	1	338	0.9
Recreation	1874	1	1003	1	16	1	1874	1	1874	1	3617	1

RI, restoration index; RV, restoration value.

Of the terrestrial ecoregions, the Great Plains provided the highest values of commodities in both native and restored lands. These high values were primarily due to the agricultural market values of hay, and to the fact that hay can be harvested yearly—and potentially multiple times per year—on any given unit of area (i.e., any given pasture). Commodity values for the Great Plains were higher on native lands because of the higher price of native hay. Eastern temperate forests were third in commodity production values in both native and restored lands because of harvested wood products such as large sawtimber, small sawtimber, and pulp. West Coast marine forests and western forested mountains provided relatively small commodity values. Native West Coast marine forests provide at least eight times greater economic value than restored forests, because decades are required for restored forests to produce timber with substantial value. We were unable to identify and evaluate widely available commodities of North American deserts.

Native and restored Great Plains lands supplied the largest economic values of biodiversity per unit area of the terrestrial ecoregions, followed by eastern temperate forests, West Coast marine forests, and western forested mountains (figure 1, table 2). The economic values of biodiversity did not differ between native and restored forests (table 3). Somewhat surprisingly, the biodiversity of restored land was slightly more valuable than that of native land in the Great Plains, because nonnative pollinators contributed to the value of pollination. Although no economic value could be assigned to biodiversity in North American deserts, only about two-thirds of the biodiversity present in native deserts was found in restored deserts after 10 years.

Of the terrestrial ecoregions, the three forest ecoregions provided the highest economic values for recreation, followed by the Great Plains and North American deserts (table 2). Restored lands provided all of the opportunities for recreation that were assigned values in our analysis (e.g., hiking, hunting, and wildlife viewing), though our valuation does not include visitors who expressly prefer visiting native habitat.

Relevance to other estimates and uncertainties

Our values per unit area exceeded most comparable estimates reported by Costanza and colleagues (1997) in their initial paper. For example, our total values for wetlands per hectare per year were up to four times greater than those reported by Costanza and colleagues (1997), mainly because of increases in the water regulation and nutrient cycling values of wetlands. We assigned values for nutrient cycling and gas regulation in a number of habitats that were absent from Costanza and colleagues' treatment. We assigned greater values to more ecosystem services, because more published valuations are now available. Also, our analysis used mostly values obtained from the United States and Europe, whereas Costanza and colleagues (1997) presented a global analysis. Some services, such as flood protection, may have much more value in an area where there is substantial investment in infrastructure (e.g., the cost of repairing flood damage or the willingness to pay for recreation may be higher in a developed country). Likewise, individuals in more affluent countries could be willing to spend more on recreational activities (willingness to pay increases with disposable income). Using data mainly from the United States and Europe avoids part of the problem of transferring environmental value estimates from developed to less-developed areas (Spash and Vatn 2006).

Some values could not be determined, so our estimates of total value of native and restored lands are generally conservative. Still, most of the restoration index values should not change much, since they are generally influenced by the rates of recovery of ecological processes, and these rates are similar within a biome.

Our methods had inherent uncertainties. Our equations assumed linearity between value and the rate of commodity production or of ecosystem process. For example, if a set amount of biodiversity was assigned a value, then half of that biodiversity was assumed to have half the value. We can envision cases in which distinct nonlinearity occurs, and none of the literature we reviewed investigated general trends by ecosystem service to test such an assumption. For example, a restored forest may not have the cultural or aesthetic value of an old-growth forest until it is no longer distinguishable from old-growth forest. Distinct nonlinearity could occur with restoration. Water-quality problems increase rapidly in watersheds when more than 15% of the watershed area is converted to impervious surfaces (Schueler 1994).

Another issue is that the methods used here are more prone to double counting than a full accounting of inflows and outflows would be (Costanza et al. 1997). In this article, as in the one by Costanza and colleagues (1997), the number of detailed estimates needed to investigate broad trends simply was not available, as it eventually would be if the United Nations' methodologies (UN et al. 2003) were more broadly implemented. Despite criticisms of Costanza and colleagues' (1997) methodology, however, their results correlate well with other methods, such as the ecological footprint index (Sutton and Costanza 2002). The ecosystem service valuation relates well to other global measures of ecological integrity and can be coupled to biodiversity conservation (Turner et al. 2007).

The use of commodities to assign value to native ecosystems is somewhat problematic in that the production of commodities might result in the loss of ecosystem services. However, in the interest of obtaining an index value, we assume either that the value of commodities on restored lands would remain unrealized or that the production of commodities (e.g., by repeatedly cutting hay from restored prairie) would not eliminate ecosystem services.

A deeper criticism of the method of assigning economic values is the logical conclusion that payments could be used to offset ecosystem damages rather than restoring or conserving any particular ecosystem. We agree that there are aspects of ecosystems that defy economic valuation, and the Earth will be biologically and morally impoverished if economic considerations alone are used to decide conservation and restoration policy. The case has been made that ecological economists need to consider nonprice influences on human behavior (Gowdy and Erickson 2005), and this includes the inherent noneconomic values of natural ecosystems.

Given these issues, it is obvious that our determination of benefits cannot be used in a cost-benefit analysis of any specific restoration project. Rather, the estimates should be viewed in the context of what we might expect from ecosystem restoration with respect to the restoration of ecosystem goods and services. Just as a full accounting of the economic costs of water pollution or of the costs of upgrading sewage plants was not necessary before legislation was passed to regulate water quality, a general idea of the benefits of restoration could be of positive use even without a full accounting of all the variables involved.

Temporal trajectories of restoration of value

In the best case, ecological restoration accelerates the natural processes of succession. Because succession occurs along a temporal trajectory, the passage of time plays an important role in restorative attempts. Functional succession does not proceed until the structural components necessary for a specific service of a habitat have been restored, because most ecosystem goods and services are dependent on the biological structure of a habitat. The time required for complete restoration will vary both by the type of habitat being restored and by the services that ecosystem provides.

Wetlands are relatively resilient over short time scales in terms of benefit recovery, whereas other habitats, such as grassland, forest, and desert, take longer to recover. Two major factors influence value recovery rates: (1) the generation time of the organisms to be restored and (2) the environment's ability to support the reestablishment of species.

Some ecoregions, such as desert, require very long periods of time to recover ecosystem structure and function. Lovich and Bainbridge (1999) found that the recovery of desert plant communities (structure) to predisturbance conditions could take 50 to 300 years, and that the complete restoration of desert ecoregions (structure and function) could require more than 3000 years. Because our analysis limited restoration processes to 10 years, and the recovery of North American deserts may take an order of magnitude longer than this limit, we found that restored deserts had attained a small proportion of their monetary value. In contrast, wetlands can be very productive over shorter time periods, because of their unlimited water availability and because they are dominated by organisms (e.g., microalgae, macroinvertebrates, microcrustaceans) whose rapid turnover time allows them to respond quickly to restoration. However, some wetland species are long-lived (e.g., some species of larger fishes, mussels, and emergent trees can live for decades), and functions dependent on these larger plants and animals may take longer to recover (Norse 1990).

Some ecosystem goods and services need only partial structural restoration to attain prior function and will regain full benefits quickly. For example, in wetlands, disturbance regulation requires (a) a physical structure to retain excess overland flow and (b) restored vegetation to retard flow. Therefore, any form of water retention will provide an almost immediate benefit, even though the complete ecosystem structure (e.g., diversity) of the wetland has not yet recovered. Erosion control and disturbance regulation also recover quickly. If the initial condition is bare soil, then any type of ground cover may provide a large increase in the erosion control and disturbance regulation provided by that habitat. Again, even though the complete structure of the habitat is not yet in place (e.g., only annual plants and small shrubs in an area that was once an eastern temperate forest), the service can be achieved through partial restoration of ecosystem structure.

Many of the ecosystem services considered in our analysis have the potential to produce an asymptotic temporal response to restoration. Norse (1990) stated that in early stages of forest growth, the potential for gas regulation (carbon sequestration) is much greater than in more ancient forests, but cautioned that considering carbon sequestration independent of other processes provides only a partial picture of the processes occurring in old-growth forests. Nutrient cycling value per unit area also may decrease with time since restoration. For example, early in wetland restoration, phosphorus retention can occur at high rates. However, as the wetland becomes saturated with phosphorus, the retention rate decreases (Dodds 2002). Terrestrial habitats can behave similarly, as vegetative demand is high during the initial reestablishment phase and then decreases with time.

Many ecosystem goods and services have the potential to recover slowly at first and then become more valuable as time progresses. Perhaps the best examples of this are commodities obtained from a recovered forest. During the first few years of growth, there is no value associated with small saplings, but their worth increases sharply when they become large enough to log, and they continue to accrue value as they grow. Similarly, early in the restoration process, a habitat may not be able to support game species, and thus may have a negligible recreation value.

The 10-year period chosen for assessment of benefits was related more to human needs than to specific ecosystem properties. An old-growth forest continues to accrue value after more than a century, but this future value is not likely to be a politically important issue if the public cannot appreciate the benefit. The time course of restoration explains why conservation of native lands is so important. There is a considerable length of time before many restored ecosystems attain the benefits that native lands already have.

Conclusions

The rate at which individual ecosystem goods and services recovered after restoration clearly varied among ecoregions and among types of ecosystem services. Thus, restoration benefits must be computed for specific services within an ecoregion of interest. We outline a general framework for using ecosystem goods and services to compare restoration success across broadscale ecoregions; the calculation of explicit benefits (restoration indices) for specific restoration projects must be made on a case-by-case basis.

In a broad sense, we demonstrate that restored lands typically should not be expected to provide benefits equal to or exceeding those of native lands ($RI_{r/n} < 1$ over a decade), but that restoration can improve the benefits of many ecosystem goods and services over a 10-year time frame. Thus, both conservation and restoration have definite benefits and should be a priority of managers and policymakers in the United States and around the world. Independent analyses of conservation assign a benefit-to-cost ratio of 100 to 1 for conserving wild lands (Balmford et al. 2002). Unequal value per unit area may be an important consideration for management approaches such as "no net loss," where restored habitat is substituted for destroyed native habitat. Given that very small proportions of some native ecosystems remain, restoration will continue to be a necessary management activity. That some benefits of ecosystem goods and services can be wholly or partially recovered upon restoration confirms the potential importance of restoration. We provide initial support for the idea that the time frame of restoration projects could be an important determinant of how the values of ecosystem goods and services are restored, and attainment of value can depend both on the habitat being restored and on the category of goods and services of interest.

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