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Contributed Paper

Benefits of Investing in Ecosystem Restoration

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Abstract: *Measures aimed at conservation or restoration of ecosystems are often seen as net-cost projects by governments and businesses because they are based on incomplete and often faulty cost-benefit analyses. After screening over 200 studies, we examined the costs (94 studies) and benefits (225 studies) of ecosystem restoration projects that had sufficient reliable data in 9 different biomes ranging from coral reefs to tropical forests. Costs included capital investment and maintenance of the restoration project, and benefits were based on the monetary value of the total bundle of ecosystem services provided by the restored ecosystem. Assuming restoration is always imperfect and benefits attain only 75% of the maximum value of the reference systems over 20 years, we calculated the net present value at the social discount rates of 2% and 8%. We also conducted 2 threshold cum sensitivity analyses. Benefit-cost ratios ranged from about 0.05:1 (coral reefs and coastal systems, worst-case scenario) to as much as 35:1 (grasslands, best-case scenario). Our results provide only partial estimates of benefits at one point in time and reflect the lower limit of the welfare benefits of ecosystem restoration because both scarcity of and demand for ecosystem services is increasing and new benefits of natural ecosystems and biological diversity are being discovered. Nonetheless, when accounting for even the incomplete range of known benefits through the use of static estimates that fail to capture rising values, the majority of the restoration projects we analyzed provided net benefits and should be considered not only as profitable but also as high-yielding investments.*

Keywords: cost-benefit analysis, economic values, ecosystem restoration, services

Beneficios de Invertir en la Restauración de Ecosistemas

Resumen: *Las medidas enfocadas en la conservación o restauración de los ecosistemas comúnmente son vistas como proyectos de costo neto por los gobiernos y los negocios porque están basadas en análisis de costo-beneficio incompletos y con errores. Después de revisar más de 200 estudios, examinamos los costos (94 estudios) y beneficios (225 estudios) de proyectos de restauración de ecosistemas que tuvieron suficiente información segura en 9 biomas diferentes, desde arrecifes de coral hasta bosques tropicales. Los costos incluyeron inversión de capital y mantenimiento del proyecto de restauración; los beneficios estuvieron basados en el valor monetario del agrupamiento total de los servicios ecosistémicos proporcionados por el ecosistema restaurado. Suponiendo que la restauración siempre es imperfecta y que los beneficios alcanzan solamente el 75% del valor máximo de los sistemas de referencia a través de 20 años, calculamos el valor neto actual de las tasas de descuento social de 2% y 8%. También condujimos 2 análisis de umbral con sensibilidad. Los radios de beneficio-costo oscilaron desde 0.05:1 (arrecifes de coral y sistemas costeros, el peor de los casos) hasta 35:1 (pastizales, el mejor de los casos). Nuestros resultados proporcionan sólo una estimación parcial de los beneficios en un punto en el tiempo y reflejan el límite inferior de los beneficios del bienestar de la restauración de los ecosistemas porque tanto la escasez y la demanda por servicios ecosistémicos están incrementando y nuevos beneficios de los ecosistemas naturales y la biodiversidad están siendo descubiertos. Sin embargo, al tomar en cuenta el rango conocido de beneficios a través del uso*

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de estimadores estadísticos que fallan en capturar valores en incremento, la mayoría de los proyectos de restauración que analizamos proporcionaron beneficios netos y deberían considerarse no sólo como rentables sino también como inversiones con producción alta.

Palabras Clave: análisis de costo-beneficio, restauración de ecosistemas, servicios, valores económicos

Introduction

Worldwide, many or most natural ecosystems have to various degrees been converted into human-designed and managed ecosystems, such as cultivated land, aquafarms, and urban areas. In addition, many ecosystems are relatively degraded or have been abandoned. The bundle of services provided by these various ecosystems differs greatly, but in general these services have declined over time. In particular, there is a general trend at the global scale that favors extraction of marketable provisioning services (renewable and nonrenewable consumable goods), often beyond sustainable levels and at the expense of nonmarket regulating, cultural, and supporting services (Millennium Ecosystem Assessment 2005).

Major international initiatives, including the Convention on Biological Diversity (CBD), the Millennium Development Goals, and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, now explicitly link conservation of biological diversity and natural ecosystems with the maintenance of ecosystem services to support sustainable local economic development and reduce poverty (TEEB 2010). The need to actively restore at least part of the world's "natural capital" (Millennium Ecosystem Assessment 2005) or "ecological infrastructure" to maintain biological diversity and the flow of essential services is becoming increasingly clear (TEEB 2010, 2011). Information on the socioeconomic importance of ecosystem services helps to increase awareness of the need for investments in restoration efforts and has resulted in significant international commitments to large-scale restoration. However, there is almost no information available on the cost-effectiveness of ecological restoration (Rey Benayas et al. 2009; Aronson et al. 2010; Alexander et al. 2011).

As shown in South Africa (Blignaut et al. 2007), Brazil (Calmon et al. 2011), and elsewhere (Edwards et al. 2013), ecological restoration programs contribute substantially to the range and quantity of job opportunities and livelihoods in rural areas (Woodworth 2006; Turpie et al. 2008; Blignaut et al. 2010). Ecological restoration can play a pivotal role in mitigating some of the effects of anthropogenic climate change (Clewell & Aronson 2006; Elmqvist et al. 2010) and increase the ability of biotic communities and ecosystems to gradually adapt to climate change and other global changes. There is also growing awareness of the difference between ecological restoration and offsets, which have been controversial because they may do more harm than good when functioning natural ecosystems are replaced by human-designed ones intended to substitute and compensate for lost systems (Gutrich & Hitzhusen 2004). Furthermore, offset systems generally have high maintenance costs. Ecological restoration can avoid most of the problems associated with offsets and contribute to achieving the goals of the CBD (Aronson & Alexander 2013).

Due to this bundle of attractive features, ecological restoration is gaining prominence as a tool within the context of economic development (Blignaut 2009; Blignaut et al. 2013) and is increasingly cited in the targets and objectives of international bodies, such as the Global Strategy for Plant Conservation and the CBD. At its 11th Convention of the Parties, the CBD declared that ecological restoration and rehabilitation are crucial for the recovery of biological diversity and critical ecosystem services and that 15% of all degraded ecosystems should be "restored" or put on the path toward restoration by 2020 (CBD 2012). One mechanism designed to achieve these objectives is REDD+, an emerging carbon offset scheme aimed at reducing emissions from deforestation and land degradation while improving biological diversity conservation (Venter et al. 2009; van Oosterzee et al. 2012). Payments for ecosystem services (PES) schemes are also being actively explored and developed (e.g., Strassburg et al. 2012).

Despite these promising declarations and policy ventures, ecological restoration, PES, and REDD+ have yet to emerge as integral components of sustainable-development thinking and strategy formulation at the global scale (Aronson et al. 2010; Farley et al. 2010; Alexander et al. 2011). One explanation for this is that, until now, restoration programs have been predominantly viewed as an expense (cost) with few tangible financial and economic benefits. Often this is because of erroneous accounting practices and a tendency for conventional cost-benefit analyses to exclude the effect of human activities on ecosystem goods and services (Rees et al. 2007; Blignaut & Aronson 2008; Farley 2008). We addressed this problem by presenting evidence from the field based on an analysis of over 300 case studies reporting costs or benefits of ecological restoration. Just as conservation of natural capital may be economically beneficial (Balmford et al. 2002), we hypothesize that ecological restoration also may yield excellent returns on investment, provided a mid- to long-term perspective is adopted and that the full range of known benefits is considered.

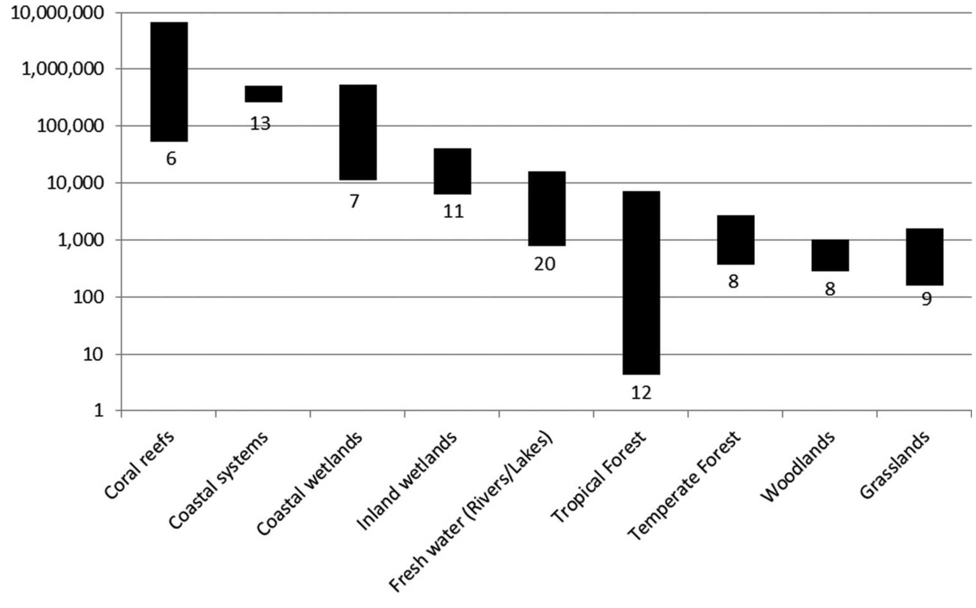

Figure 1. Range of ecosystem restoration costs (log cost in 2007 US$/ha) of 9 major biomes. Numbers below bars represent number of case studies.

Methods

Given the lack of studies that report on economic aspects of restoration in a consistent manner, we developed 2 independent databases, one for the benefits and another for costs, with information from studies conducted in a wide array of biomes in all inhabited continents. This enabled us to generate ranges for both the benefit and cost aspects of restoration, which we then integrated into a benefit-cost analysis.

Calculating Cost of Ecosystem Restoration

Of approximately 2000 restoration case studies examined by Aronson et al. (2010) and Blignaut et al. (2013), 94 provided meaningful cost data. However, not all of the 94 studies disclosed cost data in a comprehensive manner. To avoid misquoting or distorting the meaning of the data and to be consistent across biomes, we carefully analyzed all 94 studies to identify the maximum and minimum cost values for each biome in those studies that disclosed both total cost and the area covered by the project (see Supporting Information for details). From year 2 after restoration onward, we allowed for annual operating (or project maintenance) costs of 5% of the original financial capital cost for all biomes except coral reefs (for which we used 0% assuming they will be self-sustaining once restoration has been concluded) and of 2.5% for coastal systems and wetlands because they are very capital-intensive projects. We based these percentages broadly on the information provided in the studies. We calculated all values for 20 years and standardized them to reflect 2007 U.S. dollars per hectare. To do this, we used a purchase power parity (PPP) conversion factor to allow for the conversion of the national currency to an international standardized one (US$). We used official exchange rates, gross domestic product deflators, and PPP conversion factors from the World Bank's World Development Indicators 2009 to standardize values estimated in different years and different currencies so as to allow comparison with the reported benefits. Figure 1 shows the range of restoration costs for 9 major biomes. Coastal systems include shelf sea, seagrass meadows, estuaries, rocky shores and beaches, and excludes coastal wetlands, specifically mangroves.

Calculating Benefits of Restored Ecosystems

We used the database developed by 2 coauthors of this paper (published in De Groot et al. [2012]), which included 225 case studies and >1350 estimates of the total economic value (TEV) (based on the sum of the monetary values of 22 ecosystem services) in 10 major biomes, to estimate benefit values. We calculated the mean and standard deviation of the range of the TEVs of these 10 biomes as a proxy for the (potential) benefits provided by restored ecosystems (Table 1). Assuming restoration is imperfect and benefits attain only 75% of the maximum value of the reference systems over 20 years we calculated the net present value at social discount rates of −2% and 8%. In the context of slowing global economic growth rates and rising energy prices, an 8% rate probably overestimates risk-adjusted opportunity costs. The negative discount rate (−2%) reflects the possibility that conditions will deteriorate in the future as a result of ecological degradation and resource depletion; hence, the value of any additional wealth will be greater. The negative rate also reflects the likelihood that the marginal value of natural capital and ecosystem services will increase as supply decreases or as demand increases (e.g., due to population or income growth) (Gowdy 2007;

Table 1. Total economic value (TEV) of 10 biomes in 2007.[a]

	No. of estimates	*Mean TEV of all services in* $US\$ \cdot ha^{-1} \cdot year^{-1}$ *(SD)*	*Discounted value (US$)/ha at 75% TEV*[b]	
			SDR −2%	*SDR = 8%*
Open oceans	14	491 (762)	9,167	3,616
Coral reefs	94	352,915 (668,639)	6,589,166	2,598,729
Coastal systems	28	28,917 (5,045)	539,900	212,934
Coastal wetlands	139	193,845 (384,192)	3,619,220	1,427,399
Inland wetlands	168	25,682 (36,585)	479,501	189,112
Rivers and lakes	15	4,267 (2,771)	79,668	31,421
Tropical forest	96	5,264 (6,526)	98,283	38,762
Temperate forest	58	3,013 (5,437)	56,255	22,187
Woodlands	21	1,588 (317)	29,649	11,693
Grasslands	32	2,871 (386)	53,604	21,141

[a] *Adapted from De Groot et al. (2010).*
[b] *Over 20 years; SDR, social discount rate.*

Blignaut & Aronson 2008). (See Frederick et al. [2002] for a comprehensive discussion of discount rates.)

Scenarios

We differentiated among 12 scenarios as follows. For 100% of the maximum restoration cost, we paired the outcome with 3 benefit options (30%, 60%, and 75% of the mean benefit value) at 2 discount rates (−2% and 8%) for a total of 6 scenarios. For 75% of the maximum restoration cost, we paired the outcome with 3 benefit options (30%, 60%, and 75% of the mean benefit value) at 2 discount rates (−2% and 8%) for an additional 6 scenarios.

Among these 12 scenarios, the worst possible case was 100% of the maximum restoration cost and 30% of the mean benefit at a social discount rate of 8%. The best possible case was 75% of the maximum restoration cost and 75% of the mean benefit at a social discount rate of −2%. We also conducted 2 threshold cum sensitivity analyses. First we sought the change in cost required (assuming maximum benefits in year 5 have reached 60% of potential TEV) to achieve an internal rate of return (IRR) of 10%. Second, we sought the change in mean TEV required to achieve an IRR of 10% when only 60% is realized in year 5 and onward and cost is at 100%. The results are expressed in terms of an estimated project IRR, which can be compared with the rate of growth of a project; the higher the IRR, the better or more advantageous the project.

In this analysis, we examined only direct costs (initial capital cost and management cost of the restoration process) and known benefits (ecosystem services). We ignored indirect benefits because they are extremely case-specific. Likewise, when restoration does not take place, the opportunity cost thereof lies in the foregone benefits, which are unknown. Although benefit data were available for marine and open-ocean ecosystems, no comparative cost data were obtained. Accordingly, the results presented are for 9 biomes instead of all 10.

Results

Internal rates of return ranged from −14% (for coastal systems under worst-case scenario) to 59% (for grasslands under best-case scenario). The benefit-cost ratios ranged from 0.05 (for coastal systems under worst-case scenario) to 35 (for grasslands under best-case scenario). Under the best-case scenario, coastal systems yielded a positive IRR of 3% and a benefit-cost ratio of 1.7, indicating benefits exceeded costs (Fig. 2).

Coral reefs and coastal areas had among the highest natural-capital benefit values (Table 1), but these systems had the lowest internal IRRs and benefit-cost ratios of all the restored ecosystem types due to high restoration costs (Fig. 2). In contrast, grasslands and woodlands had relatively low asset values (Table 1), but internal rates of return were 20–60% and benefit to cost ratios were up to 35; thus, they offered very high returns on investment.

The restored ecosystems that offered the most value for restoration investment in absolute terms (i.e., based on net present values) were coastal wetlands and inland wetlands, followed by tropical forests (Table 1).

To achieve an IRR of 10% when benefits equal 60% of the TEV value from year 5 and onward, the costs of restoration of coral reefs and coastal systems must be brought down by 21% and 36%, respectively, of current estimated levels. Costs, however, can increase by as much as 400% with regard to woodlands and grasslands in order to achieve the same outcome. With respect to benefits of ecosystem restoration, the mean TEV, as defined in Table 1, must increase by 485% in the case of coral reefs and by 279% for coastal systems to achieve an IRR of 10%, assuming costs at 100% of the maximum cost. The comparable number for grasslands and woodlands is approximately 22%, implying that the benefits can decline by as much as 80% before the IRR will decline to 10%. Marginal benefits of ecosystem services will of course increase if continued ecosystem degradation leads to declining services over time. This static threshold analysis

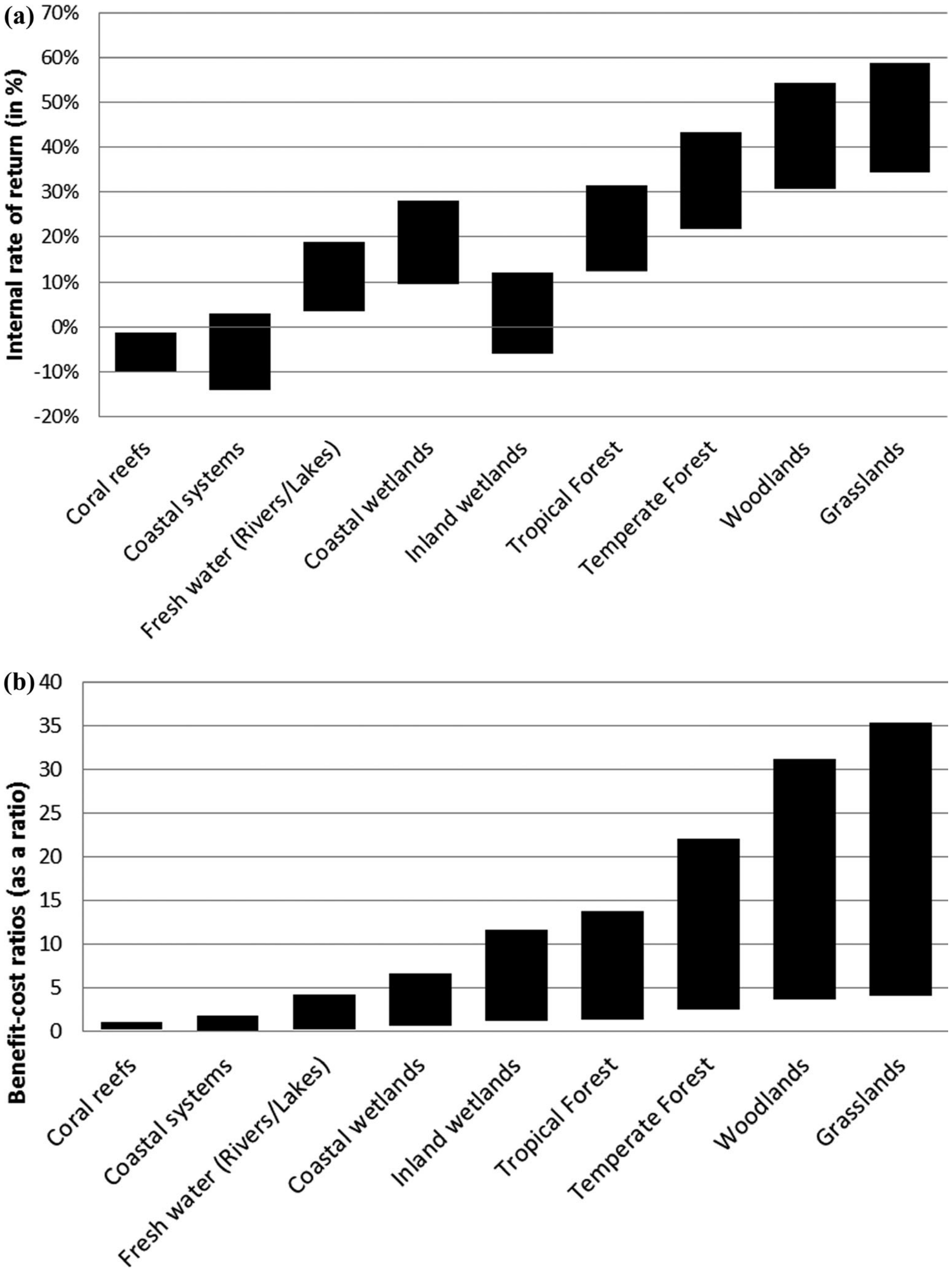

Figure 2. (a) Internal rate of return (IRR) (bars, range of values; bottom of bars, worst-case scenario [analysis conducted at 100% of highest restoration cost reported and 30% of benefits]; top of bars, best-case scenario [analysis conducted at 75% of highest restoration cost reported and 75% of benefits]) and (b) benefit-cost ratios of restoration (bars, range of values: bottom of bars, worst-case scenario [analysis conducted at 100% of highest restoration cost reported, 30% of benefits, and social discount rate 8%]; top of bars, best-case scenario [analysis conducted at 75% of highest restoration cost reported and 75% at a social discount rate of −2%]) across 9 major biomes on the basis of 316 case studies over 20 years with a management cost component of up to 5% of the capital cost.

indicates, with the exception of restoration of coral reefs, coastal systems, and freshwater systems (Table 2), there is much leeway before restoration would be considered economically undesirable.

Unlike calculation of the benefits of restoration, which were determined through use of a range of valuation techniques, including market and nonmarket valuation methods, no standardized approach exists for calculating

Table 2. Results of threshold analysis conducted to estimate the required change in either costs or benefits to achieve an internal rate of return (IRR) of 10% for all 9 biomes considered.[a]

	Change in cost to achieve 10% IRR (%)[b]	*Change in mean total economic value to achieve 10% IRR (%)*[c]
Coral reefs	21	485
Coastal systems	36	279
Coastal wetlands	114	88
Inland wetlands	170	58
Rivers and lakes	72	138
Tropical forest	198	50
Temperate forest	308	32
Woodlands	433	23
Grasslands	487	21

[a] *We used the goal-seek function of Excel to conduct the threshold analyses.*

[b] *Assuming maximum benefits in year 5 of 60%. A value below 100% implies that a reduction in cost is required to achieve a 10% IRR.*

[c] *Sixty percent of total economic value realized in year 6 onwards, assuming cost is at 100%. A value above 100% implies an increase in benefits is required to achieve a 10% IRR.*

restoration costs. Some researchers report on the financial capital or initial restoration cost, whereas others include cost of maintenance and restoration. Still others report direct financial costs, but do not value or report on in-kind contributions by volunteers or materials provided by direct beneficiaries. To complicate matters further, the costs of restoration are directly related to the type of restoration activity. Any given level of degradation in a given biome can be addressed in many different ways, ranging from natural regeneration of abandoned landscapes to very active, hands-on restoration interventions over many years. In the latter case, the work is often labor intensive, capital intensive, or both, and among these possibilities there are myriad options and cost structures.

A restoration approach or strategy intended to address degradation in a specific biome can have different costs and different results when applied to the same biome in a different area due to differences in regional or country-specific cost structures, such as wages paid to workers and fuel costs. Finally, scale matters. Typically, small-scale restoration, often done for research purposes, tends to be much more expensive than large-scale operations. Furthermore, ecological restoration interventions can be expected to enhance ecological resilience (i.e., capacity of ecosystems to absorb disturbances and regenerate [Folke et al. 2004]) and promote societal acceptance of and adaptation to anthropogenic climate change, both directly and by providing educational examples. Greater resilience reduces maintenance costs and costs of further restoration (Rey Benayas et al. 2009; Aronson et al. 2010; Elmqvist et al. 2010; Bullock et al. 2011). Therefore, the differences in costs (Fig. 1) are substantial.

Discussion

We have presented the results of one of the most extensive economic analysis undertaken to date with regard to the costs and benefits of ecological restoration across a broad range of biomes and ecosystem types. Yet, the values presented are only indicative. A different suite of case-specific variables would likely yield different results. Given, however, that we used 225 case studies from around the world with respect to benefits and 94 with respect to costs, we are confident that these ranges offer plausible outcomes relative to the assumptions we made (see Methods). Results of our sensitivity analyses showed that even under a worst-case scenario (i.e., discount rate of 8%, 100% of the maximum cost, and a restoration benefit of 30% of the TEV), investing in restoration still breaks even or provides a financial profit (in TEV) in 6 of the 9 ecosystem types (Table 2). Only coral reefs and coastal systems had IRRs that were negative (Fig. 2a). In the best-case scenario (discount rate of −2%, 75% of the maximum cost, and restoration benefit of 75% of the TEV), restoration yielded a positive benefit to cost ratio in all the ecosystem types considered. We therefore assert that our results are robust and supported by many well-documented case studies (e.g., Aronson et al. 2007; Farley & Gaddis 2007; Goldstein et al. 2008). For example, actors in both the private and public sectors are undertaking coral reef restoration in many marine protected areas and ports around the world, which suggests a positive rate of return for marketable benefits alone (Bottema & Bush 2012). In most cases, there are still services and benefits not captured by the analysis, and growing scarcity increases the value of those already known, which highlights the fact that the benefit to cost ratios are likely underestimates of the welfare effect of restoration. Very high benefit-to-cost ratios were found for restoration of most ecosystems, provided the benefits (and values) of public goods, services of these ecosystems, and social returns on investment were included. There is also a large but as yet little explored potential in urban landscapes to restore ecological processes, functions, and services.

Although we acknowledge the many difficulties in valuing and, especially, pricing of ecosystem services (TEEB 2010), economic data have considerable effect on planning, decision making, and policy formulation, both in the public and private sectors (Neßhöver et al. 2011). Our results showed that in most cases we studied ecosystem restoration pays (i.e., provides more benefits than costs). Proactive investment strategies to maintain stocks of renewable natural capital therefore merit further development and implementation. Fine-tuning of the proper way to do restoration for each ecosystem type is also urgently required (Suding 2011; Moreno-Mateos et al. 2012). Systematic assessments of the benefits of natural capital and creation of natural capital accounting systems and maps will pave the way for combining environmental risk reduction with economically efficient investment (e.g., Kareiva et al. 2011). Money spent on ecosystem restoration is not simply a cost; rather, it is a worthwhile investment that brings multiple benefits and can help achieve policy goals. Detailed studies that monitor costs and benefits of restoration projects over time are needed to determine which techniques and conceptual and technological approaches to ecosystem restoration provide the best possible cost-benefit ratios for each ecosystem type in terms of ecological efficiency and return on financial investment. Promising work in wetland restoration (Merino et al. 2011; Moreno-Mateos et al. 2012) and tropical forest restoration (Brancalion et al. 2012) is showing the way in this regard.

We suggest restoration projects be implemented with a landscape or bioregional perspective and that a holistic approach be used to ensure long-term payoffs and stakeholder buy-in. Ecuador has several such programs (e.g., Pimampiro municipal watershed-protection scheme) (Wunder & Albán 2008). Costa Rica (Janzen 2002; Morse et al. 2009), Indonesia (Pattanayak 2004; Pattanayak & Wendland 2007), Brazil (Calmon et al. 2011; Clewell & Aronson 2013), and South Africa (Blignaut et al. 2007; Blignaut et al. 2010) are also making significant strides in this area. Many more projects are getting underway elsewhere in Latin America and Asia and, more slowly, in Africa and Madagascar. Our results suggest that restoration pays in industrialized as well as developing countries. Several state governments in the United States and provincial governments in Canada and New Zealand (Cullen et al. 2005) and the European Union seem to be getting interested as well (Maes et al. 2013). In the private sector, some far-sighted mining and utility companies are making preliminary moves too (K. Dixon, personal communication), but much remains to be done to make ecosystem restoration a mainstream business endeavor.

In addition to what are often large up-front costs, there are several other obstacles to mainstreaming restoration. First, ecological restoration is site and ecosystem specific; there are major technology and knowledge deficits for most regions and biomes of the world; and scaling up from what is known is vital. Second, many of the benefits of restoration are transboundary public goods that flow to beneficiaries whether or not they contribute directly to restoration efforts. Under such circumstances, high rates of return do not automatically translate into high investments, and fair contributions to restoration efforts must be negotiated.

Proponents and practitioners of restoration who may have resisted exploring cost-benefit ratios in the past, for lack of know-how and data and out of fear that a high cost to benefit ratio would discourage investment and prorestoration policy, may be reassured by our results that cost-benefit analyses can in fact help to make the case for restoration rather than hurt it.

Acknowledgments

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Supporting Information

A list of the 94 case studies considered with respect to the costs of restoration (Appendix S1) and the range of net present values (2007 US$/ha) following restoration over a 20-year period for all biomes considered except marine' (Appendix S2) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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