

Restoration of ecosystem services and biodiversity: conflicts and opportunities

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Ecological restoration is becoming regarded as a major strategy for increasing the provision of ecosystem services as well as reversing biodiversity losses. Here, we show that restoration projects can be effective in enhancing both, but that conflicts can arise, especially if single services are targeted in isolation. Furthermore, recovery of biodiversity and services can be slow and incomplete. Despite this uncertainty, new methods of ecosystem service valuation are suggesting that the economic benefits of restoration can outweigh costs. Payment for Ecosystem Service schemes could therefore provide incentives for restoration, but require development to ensure biodiversity and multiple services are enhanced and the needs of different stakeholders are met. Such approaches must be implemented widely if new global restoration targets are to be achieved.

Environmental degradation and the role of restoration

Human exploitation and conversion of the ecosystems of the world is causing widespread biodiversity loss and declines in ecosystem condition, leading to reduced provision of ecosystem services [1–3]. International initiatives to address these impacts, including the Convention on Biological Diversity (CBD), the Millennium Development Goals, and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, explicitly link the conservation of biodiversity with the provision of ecosystem services to support sustainable development and poverty reduction [4]. As ecological restoration can potentially contribute to the improvement of human livelihoods, as well as enhancing biodiversity, it is assuming an increasingly central role in global environmental policy [2,5–7]. This is illustrated by the 2020 Headline Targets developed recently by the CBD (<http://www.cbd.int/decision/cop/?id=512268>), which aim for the restoration of ecosystems that provide essential services (Target 14), and the enhancement of the contribution of biodiversity to carbon stocks through restoration of at least 15% of degraded ecosystems (Target 15). Similarly, the European Union

aims to cease biodiversity loss and degradation of ecosystem services by 2020, and to restore them ‘so far as feasible’ (http://www.eu-un.europa.eu/articles/en/article_9571_en.htm).

Although the science and practice of ecological restoration have developed rapidly, the emerging policy focus on ecosystem services represents a significant shift in the objectives of restoration. This might result in both conflicts and opportunities. Some commentators have expressed fears that a focus on ecosystem services might be at the expense of biodiversity conservation [8,9], whereas others have suggested that markets for ecosystem services would provide funding for conservation activities [10]. Here, we explore in detail the implications of this policy shift by examining whether ecological restoration could be effective

Glossary

Biodiversity: biological diversity at all scales: the variety of ecosystems in a landscape; the number and relative abundance of species in an ecosystem; and genetic diversity within and between populations [11].

Direct use value of an ecosystem: the value of directly accessed services; usually provisioning or cultural. These are distinguished from services that have indirect use (notably regulating and supporting), and non-use values, [e.g. the value people place on nature for future use (option values) or for ethical reasons (bequest and existence values)].

Ecosystem services: the benefits people obtain from ecosystems [11]. There are many definitions; but a unifying feature is that services are defined as resulting from ecosystem processes or functions that provide benefits and value to people.

Environmental degradation: the simplification or disruption of ecosystems caused by severe; unprecedented and/or prolonged anthropogenic disturbances.

Millennium Development Goals (MDG): eight goals to meet the needs of the poorest people in the world by the target date of 2015 and agreed to by all the countries of the world; ranging from halving extreme poverty to providing universal primary education (<http://www.un.org/millenniumgoals/>).

Payment for ecosystem services (PES): a transaction whereby a defined ecosystem service is being bought by a buyer(s) from a provider(s); if ecosystem service provision is secured [80].

Rehabilitation: the reparation of ecosystem processes and services, whereas restoration includes the reestablishment of biotic integrity [44].

Restoration: the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed [44].

Return-on-investment (ROI): a suite of measures used to evaluate the efficiency of any investment or to compare the efficiency of several investments. ROI is calculated as a percentage or a ratio of the benefit (return) of an investment divided by its cost.

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in reversing the decline of ecosystem services along with biodiversity. Specifically, we ask the following questions: can restoration achieve the desired increases in both biodiversity and services? Will a focus on ecosystem services enable restoration costs to be offset by their potential economic benefits? Finally, will the economic value of ecosystem services provide a mechanism by which global restoration targets might be achieved in practice?

Restoration of ecosystem services and biodiversity

The evidence for biodiversity effects on ecosystem services

The Millennium Ecosystem Assessment [11] and many subsequent publications [12] suggest that biodiversity and the provision of ecosystem services are positively related, with the implication that management to enhance one should increase the other. However, analysis of empirical evidence shows that this relationship is complex and not always positive [13,14]. Species richness has been linked positively to several ecosystem processes, leading to enhanced provision of ecosystem services [15,16]. On this basis, actions that increase species richness should also benefit services. However, this cannot be considered to be a general rule. Most studies of the relationship between biodiversity and ecosystem function consider a limited number of ecological processes that relate almost exclusively to resource utilisation [17]. Furthermore, the increase in ecosystem processes often reaches a plateau at moderate species numbers [18]. Species identity effects add an extra level of complexity, especially as the rare species frequently targeted by conservation efforts often have minor effects on ecosystem processes, whereas more common species can have a dominant role [18,19]. Ecosystem diversity effects on services are even less clear. Studies are only now beginning to examine how the variation of ecosystems across landscapes affects service delivery [20]. Variation among ecosystems in processes and service provision is not necessarily coincident with differences in either species richness or measures of conservation value. Indeed, mapping of ecosystem services and biodiversity measures at a variety of scales has repeatedly indicated a lack of spatial concordance [21,22].

Impacts of restoration on biodiversity and ecosystem services

The findings summarised above suggest that restoration projects focusing on the enhancement of biodiversity will not necessarily increase the provision of ecosystem services. A meta-analysis of 89 restoration projects indicated correlated increases in biodiversity and ecosystem services in restored compared with degraded systems [23], but this is not necessarily evidence for a causal link and probably reflects common responses to restoration actions. Indeed, rather than treating biodiversity and ecosystem services as a cause–effect relationship, we suggest that restoration projects should be designed with consideration of how biodiversity and ecosystem services will respond to possible management actions and whether these responses will coincide or conflict (Figure 1).

Some restoration initiatives illustrate how benefits to both biodiversity and provision of ecosystem services can

be achieved in practice. For example, the restoration of native jarrah forest on bauxite mines in Western Australia enhanced plant and vertebrate diversity as well as carbon sequestration and water storage [24]. Restoration management of the Arkansas River, by the cessation of heavy metal inputs, increased water quality and enabled the recovery of fish and invertebrate populations [25]. Reinstatement of meanders in German rivers both decreased flooding risk and increased the diversity of the invertebrate fauna [26].

However, other examples indicate that restoration will not inevitably enhance both biodiversity and services. Under the Grain to Green Project (GTGP) of China, which aims to restore services and biodiversity [13], activities include planting non-native trees on agricultural land to decrease soil erosion. This has led to decreased native vegetation cover and increased water use, suggesting negative impacts on biodiversity and water availability in arid areas [27]. The use of non-native species to restore specific services can diminish native species and instigate damaging invasions [28,29]. Restored species-rich grasslands often produce less forage than do their fertilised agricultural predecessors [16]. Restoration of boreal forest structure by felling to encourage the regeneration of broad-leaved trees also provides habitat for bark beetles, which reduce timber production in adjacent forestry [30]. Finally, restoration of oyster populations to reduce eutrophication in estuaries has been projected to have negative effects on pelagic consumer taxa [31].

Limitations on the restoration of biodiversity and ecosystem services

It has long been recognised that the effectiveness of restoration projects must be evaluated against a reference [32]. In practice the reference has often been the attributes of an undegraded ecosystem [23,33–35], which can either be the presumed historic state or an extant natural or semi-natural ecosystem. Although recovery towards the reference varies among restoration projects (Box 1), some generalisations are available. A meta-analysis that included a range of biomes found that restoration was only partially successful in achieving reference conditions, as restored systems had median measures of 86% of the biodiversity and 80% of the services associated with reference ecosystems [23]. Similarly, a study of restored lands across the USA showed that these provided 31–93% of the services supplied by the reference prairie, forest, wetland, or desert ecosystems within a decade after restoration [34]. Therefore, although individual restoration projects can be successful [24,36], multi-site evaluations indicate a widespread failure to restore fully the biodiversity or ecosystem services to those of reference ecosystems [37–40].

The policy shift towards restoration of ecosystem services might lead towards the selection of references based on provision of a single service. An increase in the provisioning of a specific ecosystem service is the clear aim in some restorations, including examples focusing on coastal protection [29], soil stabilisation [41] or aesthetic appeal [42]. It has been suggested that ‘novel ecosystems’ could be created that do not resemble taxonomically any historical ecosystem, but deliver required services [43]. These aims

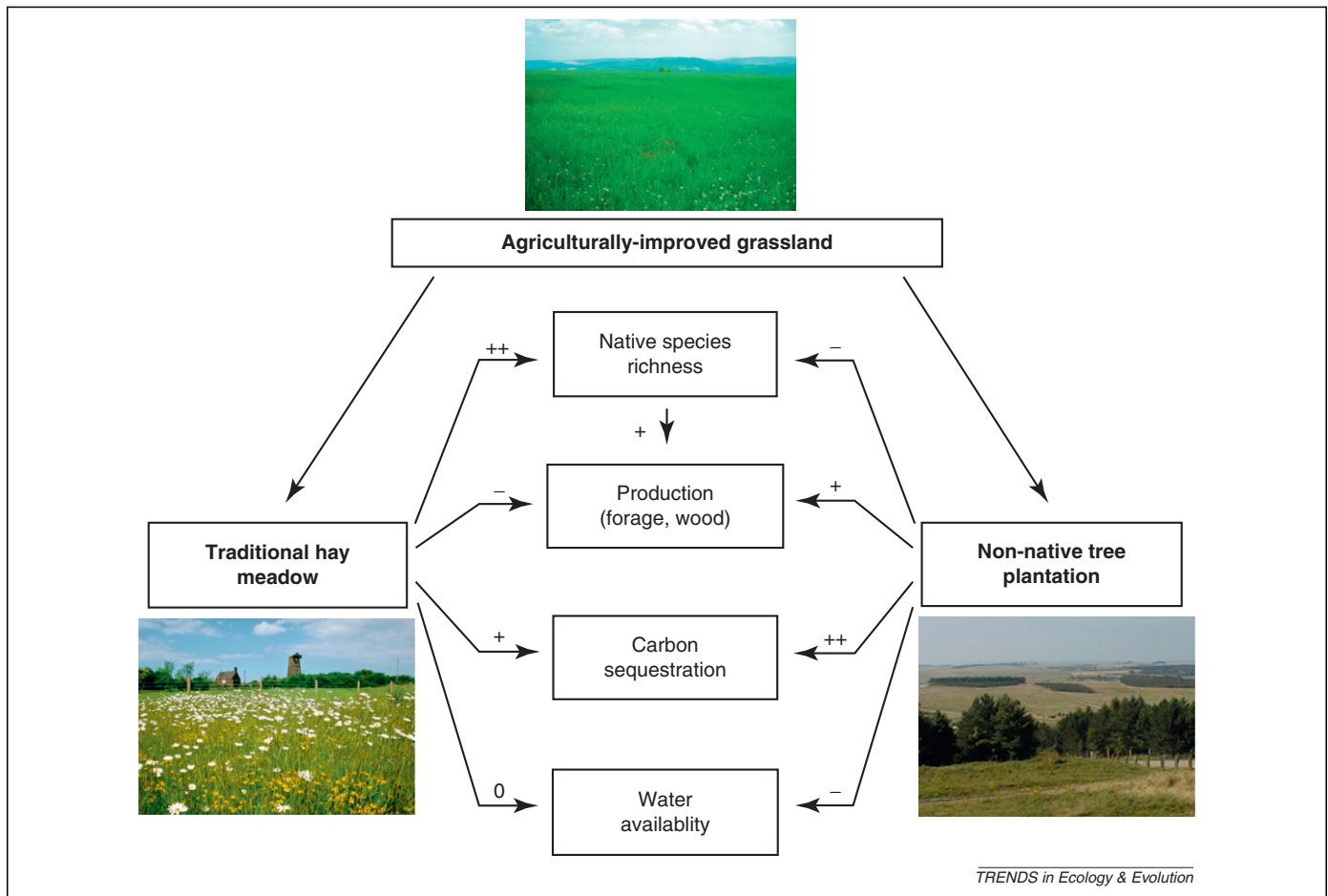


Figure 1. The indirect links between biodiversity and ecosystem services, as illustrated by contrasting outcomes of restoration activities on aspects of biodiversity and ecosystem services. A species-poor agricultural grassland can be converted to a species-rich hay meadow with the aim of enhancing native species diversity. Compared with the original ecosystem, this causes a small increase in carbon sequestration [91], but has no effect on water use and the lack of fertilisers leads to a decline in forage production [16]. A high species number counters the drop in productivity to some degree [16], as indicated by the arrow between the two. Planting of non-native trees with the aim of increasing carbon sequestration also enables the production of wood [92], but native species richness declines and an increase in water use by the vegetation reduces water availability [27]. Other services and aspects of biodiversity will also be affected, but these are not illustrated here for clarity. Impacts: ++, strongly positive, +, positive, 0, no change, -, negative.

might be more easily achievable than restoring the characteristics of reference ecosystems, but they might lead to conflicts with biodiversity conservation [41], and might be better considered as rehabilitation rather than restoration [44].

Do the benefits from ecosystem restoration outweigh the costs?

Although the reference might not be achieved, restoration tends to increase ecosystem services compared with the degraded systems [23]. These ecosystem services can be considered in terms of benefits against which restoration costs can be set. Unfortunately, cost-benefit analyses of restoration projects are scarce; records of restoration costs are rare in the scientific literature, and the benefits to society are not often examined in detail [45]. Approaches to costing are various and hard to compare. For example, a mangrove restoration project in Thailand was estimated to cost US\$8240 ha⁻¹ in the first year followed by annual maintenance costs of US\$118 ha⁻¹ [46]. By contrast, reported annual costs for restoring mangroves in the Gulf of Mexico were nearly double that of the Thailand project [47].

The Economics of Ecosystems and Biodiversity project recently reviewed over 20 000 restoration case studies, yet only 96 studies provided meaningful cost data [48]. The breadth and quality of information also varies among studies. Some provide only aggregate costs, whereas others only report capital or labour costs. Some restoration activities are conducted for research purposes and no accounting is done. Furthermore, some project accountants consider wages paid to labourers as costs, whereas in others (e.g. the Working for Water programs of the South African Government [49]) they are treated as costs and benefits. However, some tentative conclusions can be drawn [48]. Project costs vary with ecosystem type, ranging between several hundreds to thousands of US\$ha⁻¹ (grasslands, rangelands and forests) to several tens of thousands (inland waters), or millions of US\$ha⁻¹ for coral reefs. Costs differ according to timescales for success and the methods used, and these vary as a function of ecosystem type, the aim of the restoration and the degree of degradation.

Accounting for restoration benefits to people

Analysis of the benefits of restoration to people is in its infancy, but recent developments in valuing ecosystem

Box 1. Restoration trajectories and the rate of recovery

Trajectories of biodiversity and ecosystem services towards the desired reference exhibit great variation in the pattern and rate of change. Analysis of actual restoration trajectories of individual measures indicates they can be asymptotic (Figure 1a,b), linear (Figure 1c), unimodal (Figure 1d), or stochastic (Figure 1e) over time [37,38,81–85]. Asymptotic and linear trajectories might approach the reference within a reasonable time period (Figure 1a,c), or might indicate very slow progress (Figure 1b). Unimodal and stochastic trajectories are unlikely ever to reach the reference state. Thus, the restored system might not attain the reference within an appreciable time period for some or all measures.

Different measures of biodiversity and services during a single restoration can show a range of trajectories. In particular, the rate of approach to the reference can vary strongly [81,83,84]; in some cases, the restored trajectory can even exceed the reference [23]. The rate of approach of the trajectory to the reference state is likely to be lower in, for example, less productive ecosystems [23,34,86], if the initial state

is more degraded [39], if certain environmental factors constrain recovery (e.g. inappropriate pH) [38,87], or if less effective restoration methods are used [36,39,85,86].

An analysis of reported recovery times for a range of ecosystems suggested that the pre-perturbation states of biodiversity and ecosystem function measures could be reached in a very few decades or less [35], although many of the ecosystems considered were relatively undegraded at the outset. Other studies have suggested that recovery occurs over longer periods of time. For example, limited overlap in both plant and ant communities was found between restored and ancient calcareous grasslands even after 60 years [37,88]. Soil properties related to water quality in restored wetlands were <50% of reference values after 55 years [38]. Restoration of forest structure and plant species takes at least 30–40 years and usually many more decades [81,89]. Finally, no-take marine reserves can lead to rapid recovery of fish biomass, but it can take decades for target trophic structures to be achieved [82].

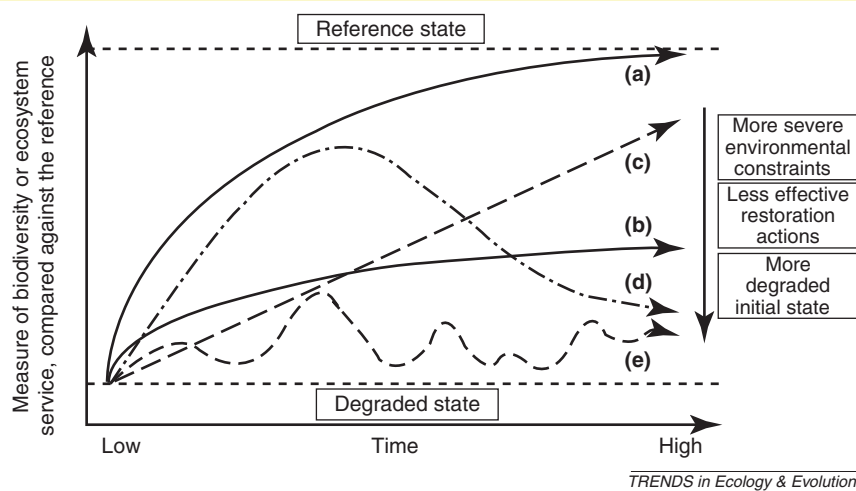


Figure 1. A summary of measured restoration trajectories and the effects of different interventions and constraints.

services provide a basis for estimating economic benefits [50]. Many goods and services can be given monetary value using a range of economic approaches [51]. A crucial aspect of monetary analysis is the discount rates used to assess the present value of future benefits. Different rates can produce highly contrasting economic outcomes [52] and there is no consensus as to what rate, if any, should be applied to restoration projects [53]. In addition, some services cannot be monetised, such as the many cultural services that reflect societal values. In such cases ‘non-monetising’ approaches have been suggested, which involve analysing the choices and preferences of stakeholders [51]. A focus on restoration for ecosystem services will require increasing emphasis on incorporation of such stakeholder values in decision making.

Once valued, the economic benefits of restoration can be compared against costs (Box 2). One approach is to calculate return-on-investment [54], which requires estimates of the total economic value of short- and long-term benefits. As ecosystem benefits are often unknown or imprecise, the measure is often uncertain. When applied to restoration, this uncertainty is even greater because returns will come in the form of a range of different values, potentially over long periods of time. A useful initial step is to compare actual and potential direct-use values (e.g. [55]). However,

indirect consumption values for ecosystem services ultimately need to be factored in, as well as option, existence and bequest values, which capture the possible future use of services.

Despite these uncertainties, and although few analyses of the cost effectiveness of ecological restoration have been undertaken to date, evidence suggests that restoration can be cost effective, at least when relatively low-cost methods are used (Box 2).

Paying for restoration through ecosystem services

Funding restoration through Payment for Ecosystem Services schemes

One of the principal challenges in a restoration project is to cover the costs. Conventionally, restoration has been considered simply as a cost to be paid, for example through government funding [37], by companies restoring ecosystems degraded by their activities [24], or through biobanking and biodiversity offsetting initiatives [56]. An ecosystem service perspective emphasises the social and economic benefits of restoration and implies a role for Payment for Ecosystem Services (PES) schemes, which are designed to compensate individuals or communities for actions that maintain or increase the provision of services [57,58]. In recent years, many hundreds of PES

Box 2. Case studies of the costs and benefits of restoration

The cost effectiveness of three forest restoration approaches in two Latin American dryland landscapes [76] is detailed in Figure I: ‘passive’ (opportunity costs of livestock production); ‘passive with protection’ (added costs of fencing and fire suppression); and ‘active’ (added costs of planting). The net value of four ecosystem service benefits was estimated for each scenario. Passive restoration was cost effective for all landscapes based on these services, whereas the benefits from active restoration were outweighed by the relatively high costs involved. There was substantial variation between landscapes, in terms of current natural capital and marginal change values, demonstrating that service values are context specific. The results of this analysis were sensitive to the market value of carbon; but relatively insensitive to variation in discount rates.

The Maloti-Drakensberg mountain ranges supply much of the water of South Africa through rivers and interbasin transfers. The grassland cover of these ranges is essential for maintaining a regular flow of clean water, but it has been transformed through various unsustainable land uses. To address the question of how to value ecosystem services and finance payments for them; an integrated hydrology–ecology–economic model was developed based on the multi-user potential for managing and restoring the natural capital of Ukombe at farmstead and watershed scales [90]. Compared against current intensive management, restoration actions provide potential returns in terms of several services (Figure II). Furthermore, the economic return on the water flow far exceeds that of conventional water development programs.

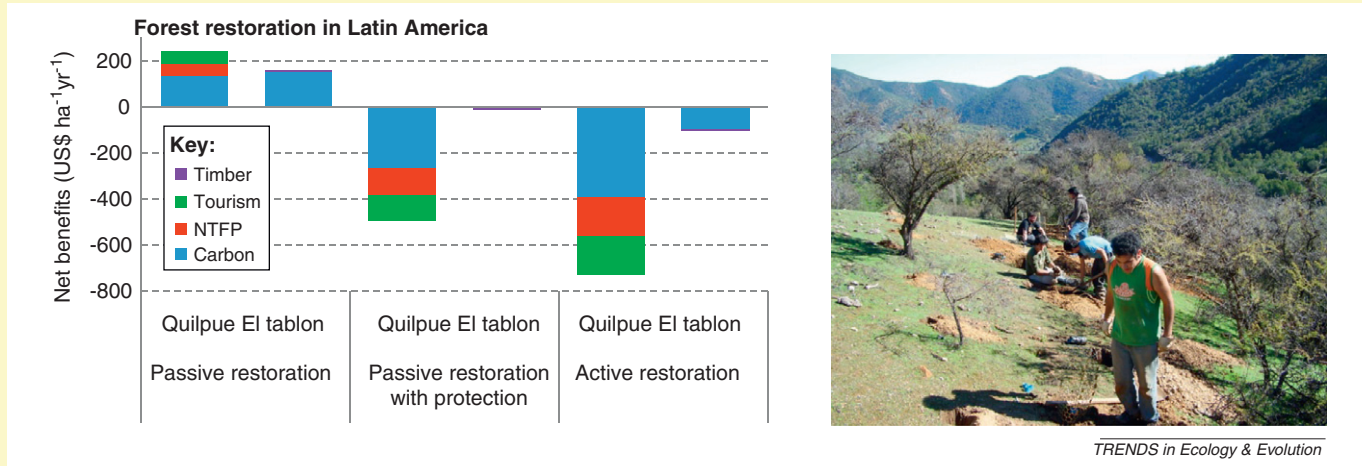


Figure I. Forest restoration in Latin America. Abbreviation: NTFP, nontimber forest products.

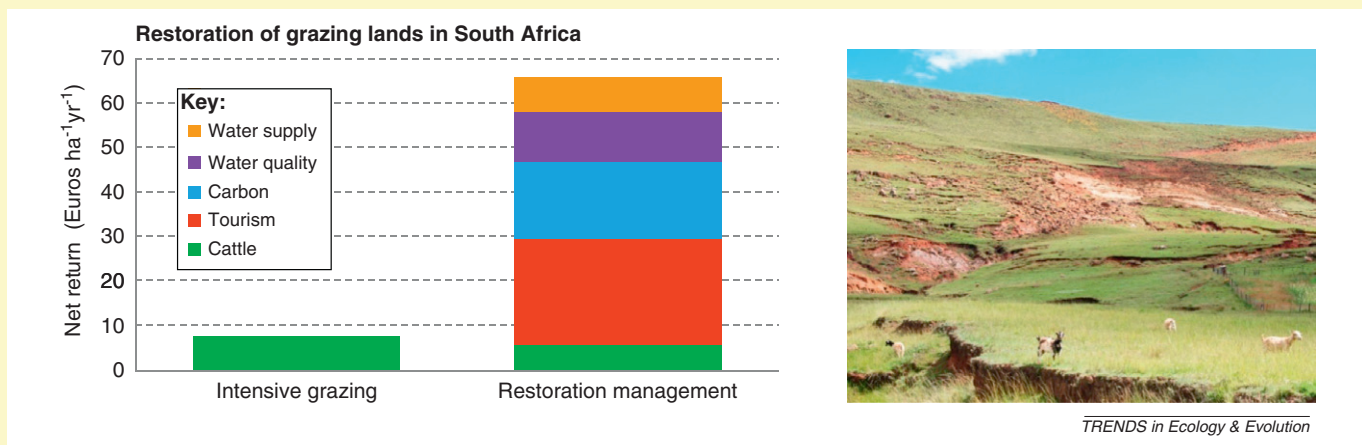


Figure II. Restoration of grazing lands in South Africa.

schemes have been established worldwide to finance environmental management, including restoration [58]. As for any market, the development of a PES system requires that there be willing buyers and sellers of a service, at an agreed-upon price, which is facilitated by a functioning institutional arrangement [59]. Because many returns from restoration will be realised only in the long term and in the realm of broader public interests, government investment is often needed [60]. For some services, the relationship between the buyer and seller is relatively direct; for example, city dwellers downstream from a mountain range that supplies water (Box 2). In other cases,

the relationship between provider and consumer is indirect; for example, long-term carbon storage, maintenance of biodiversity and many cultural services. Here, international agreements and treaties, such as Reducing Emissions from Deforestation and Forest Degradation (REDD1), and voluntary markets will be necessary. REDD1 effectively represents the first global PES scheme [61], providing an incentive for improvements in forest protection and management, including restoration. Billions of US dollars have already been committed to the initiative, greatly exceeding what has previously been provided by PES schemes.

Relatively few PES schemes have focused exclusively on restoration, but some have contributed to this goal. Reforestation schemes that use commercial timber trees, such as the well-known Costa Rican PES [62], have limited ambitions in terms of ecological restoration. The Madagascar 'Mantadia' PES, by contrast, funds forest restoration to facilitate carbon sequestration and biodiversity conservation, with secondary aims that include reduced soil erosion and nutrient depletion [63]. The Chinese GTGP also has a restoration focus [27,64], and farmers receive payments for converting sloping cropland to forest and pasture. From 1999 to 2006, approximately 9 million ha of cropland had been converted. Demonstrable impacts include increased forest cover, reduced water runoff and soil erosion, reduced river sediment loads and supplementing rural household incomes [64]. Other benefits are anticipated in future, including habitat restoration for endangered species such as the giant panda [64], although, as noted above, some negative impacts of GTGP have been reported [27].

Limitations of PES for restoration

One of the principal problems of PES schemes is their long-term sustainability, which is likely to be a key issue for restoration projects as full benefits might take many decades to accrue (Box 1). Land might be reconverted to its original use when the payments cease; in the case of the GTGP, analyses suggest that this has occurred on more than 20% of land [64]. Recent reviews of PES scheme effectiveness have emphasised some unintended consequences of introducing new markets for services and a lack of attention to accounting for the costs of such schemes [65]. This is illustrated by efforts to restore the Everglades in Florida, USA, which have highlighted the high transaction costs associated with making payments for ecosystem services. These costs arise from the need to document the services, to negotiate and execute contracts and to deal with regulatory issues, including those relating to the conservation of threatened species [66].

Furthermore, PES might skew activities towards certain services and neglect other services and biodiversity; for example, where investors favour certain services over others [67]. The REDD1 mechanism has been criticised for its focus on enhancement of forest carbon stocks, as there is a possibility that other services and social issues could be adversely affected [68,69]. Evidence also suggests that there is a trade-off between protecting biodiversity and reducing carbon emissions, indicating that REDD1 funds will need to be carefully targeted to ensure that both objectives are met [70]. Potential negative social impacts include loss of livelihoods or access to lands undergoing restoration, a risk that is particularly high in areas where land tenure is insecure. Such examples highlight the need for further research on not only the use of PES to fund restoration, but also the functioning of PES markets, and their impacts on both people and biodiversity [65].

The potential negative social impacts of restoration, such as the opportunity costs associated with changes in land use, have been little explored. Restoration activities at the Sacramento River in California, USA have been much reduced in response to local opposition, principally from farmers who were concerned about the loss of agri-

cultural production and associated tax revenues [71]. This example highlights the fact that restoration can generate costs at locations other than that at which the restoration takes place. Another issue is that the costs and benefits of restoration should be distributed equitably in relation to the benefits that are provided. In a PES scheme supporting forest restoration in Chiapas, Mexico, the poorest farmers, women and the landless were excluded from project activities in some cases [72]. This case emphasises the crucial role of property rights and local institutions in shaping the distribution of benefits. Approaches needed to achieve equitability are therefore likely to vary among communities and socio-economic contexts [72]. Analysis of factors influencing distribution of the costs and benefits of restoration, and associated ecosystem services, remains an important research priority.

Concluding remarks

New approaches to restoring biodiversity and ecosystem services

Although recent evidence indicates that restoration can be successful in increasing both biodiversity and ecosystem services, it should not be assumed that restoring biodiversity will inevitably enhance ecosystem services, or vice versa. Biodiversity and different ecosystem services might display contrasting trajectories during restoration, leading to conflicts and trade-offs. Restoration actions focusing on a particular ecosystem service could lead to negative impacts on biodiversity or provision of other services, which will need to be considered during the planning process. Resolution of conflicts in delivery of different services and biodiversity will probably require a participatory process to land-use planning. This approach would require a better understanding of how the provision of ecosystem services varies at a range of scales in relation to ecosystem condition; for example, water provisioning is a complex process that can only be managed effectively at the catchment scale in relation to patterns of land use [73].

Global environmental change, including climate change, spread of invasive species and increased pollution could strongly affect the ability to restore systems. One response would be to determine how restoration might be used to increase resilience of biodiversity and ecosystem services to global change [74]. Recent progress in understanding the resilience of coupled social-ecological systems [75] provides a basis for understanding how this might be achieved in practice. Further research should identify thresholds beyond which ecological recovery might be slow or impossible, and should suggest how changes in human behaviour can be achieved to address the causes of ecological degradation.

Restoration success and future benefits

Identification of the benefits from restoration, in terms of both biodiversity conservation and provision of ecosystem services to people, requires an understanding of restoration outcomes. As shown here, the trajectories of ecosystem services and biodiversity in a restoration can vary both in shape and rate of change. Understanding the causes of such variation represents a future research priority and is a key challenge for the development of restoration as a

predictive science. A further important unknown is whether trajectories for the recovery of ecosystem services coincide with those for biodiversity. This is crucial not only when considering the success of a restoration project, but also in calculating its cost effectiveness.

The use of discounting also has major implications for the valuation of benefits in the future, as the exponential function often used short-changes the value of these services to following generations. The ethos of sustainable development requires that the future of nature and human well-being be considered, and this has led to suggestions that discounting is not appropriate in relation to ecological restoration projects [53].

These uncertainties indicate a need for realism in using restoration to reverse environmental degradation and in forecasting benefits. Although it is clear that better ecological and economic information is needed, modelling approaches can help assess the uncertainties in projections and identify those factors that are most influential (e.g. [76]).

Payments for ecosystem services and restoration goals

Although the use of ecosystem service markets to support restoration has been questioned in terms of the ability of restoration to deliver specified services [77], it is also appropriate to ask whether PES can help achieve restoration goals, such as the CBD targets (<http://www.cbd.int/decision/cop/?id=12268>). PES might focus restoration activities on a limited set of services, such as carbon sequestration [8], whereas other services or biodiversity are neglected. This could be a particular problem when international markets are brought into play, which might override local concerns. The desired link between reversing environmental degradation and alleviating poverty might also be undermined by an excessive reliance on market forces, as poor people do not always benefit from PES [78]. As previously noted [79], for PES to be successful, there is a need to develop local and regional institutional frameworks that can cope with the complexity of such schemes, and that can integrate PES within existing rural development policies and programmes. For restoration to contribute both to sustainable development and the alleviation of poverty, it is essential that such financial flows compensate landholders adequately for any costs of restoration and provide an effective incentive to initiate restoration actions. Identifying how this might be achieved, based on an understanding of the potential distribution of benefits among different stakeholders and the conflicts that could arise, represents a major challenge to future restoration research and practice.

Acknowledgements

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