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Review Article

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Biodiversity crises a comparative analysis of biodiversity and ecosystem services by ecological restoration. A Review

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Keywords

Species diversity, Cessation, Overgrazing, Hydrological disruption, Logging of Trees and Eutrophication.

Abstract

The practice of renewing and *restoring* degraded, damaged, or destroyed ecosystems and habitats in the environment by active human intervention and action. However, the effectiveness of restoration actions in increasing provision of both biodiversity and ecosystem services have not been evaluated systematically. A meta-analysis of 20 restoration assessments in a wide range of ecosystem types across the globe indicates that ecological restoration increased provision of biodiversity and ecosystem services by 44 and 25%, respectively. However, values of both remained lower in restored versus intact reference ecosystems. Increases in biodiversity and ecosystem service measures after restoration were positively correlated. Results indicate that restoration actions focused on enhancing biodiversity should support increased provision of ecosystem services, particularly in tropical terrestrial biomes. Studies indicate that we have entered into a phase of mass extinctions 4,5, and have altered roughly half of the habitable surface of the earth, impairing and destroying several ecosystems.

Introduction

BIODIVERSITY is the very basis of human survival and economic well-being, and encompasses all life forms, ecosystems and ecological processes, acknowledging the hierarchy at genetic, taxon and ecosystem levels1. The current estimates2 of the total number of species on earth vary from 5 to more than 50 million, with a more conservative figure of 13.6 million species3. Of these, only 1.76 million species have yet been described and awarded scientific names. Thus, our knowledge of diversity is remarkably incomplete. At least five major mass extinctions have occurred in the past at geologic-time boundaries; two most serious were those occurring at the end- Permian and end-Cretaceous7. But while the past extinctions occurred each time over a span of million years or less, the present mass extinction may well occur within a short period of about 200 years. Under the current scenario, about 20% of all species are expected to be lost within 30 years and 50% or more by the end of the 21st century8. A consideration of episodes of the past mass extinctions and the subsequent recovery periods indicates that if the present mass extinction proceeds unchecked, the biosphere shall be impoverished for a period equivalent to at least 200,000 human generations.
Biodiversity has attracted world attention because of the growing awareness of its importance on the one hand,

and the anticipated massive depletion, on the other. This article focuses on the benefits and role, accumulation, distribution and loss, and assessment and conservation of biodiversity. It will be apparent that there are more estimates than empirical data, and more hypotheses than concrete theories. The methodologies for the assessment and conservation of biodiversity also remain inadequate.

Benefits and role

Apart from the ethical values and aesthetics, biodiversity provides to humankind enormous direct economic benefits in the form of timber, food, fibre, industrial enzymes, food flavours, fragrances, cosmetics, emulsifiers, dyes, plant growth regulators and pesticides. Biodiversity is of incalculable value to human health (Table 2), although only 1100 of the world's 365,000 known species of plants have so far been examined for their medicinal properties.

"Ecological restoration" as an "intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability". The fundamental difference between restoration and other conservation efforts is analogous to the difference between disease prevention and treatment. Conservation attempts to maintain and protect existing habitat and biodiversity, whereas restoration attempts to reverse existing environmental degradation and population declines. Targeted human intervention is used to promote habitat, biodiversity recovery and associated gains. The possibility of restoration, however, does not provide an excuse for converting extremely valuable "pristine" habitat into other uses: as in medicine, it better to prevent than to treat. "Treatment" is generally less effective and more expensive than prevention, and "treatment" cannot always restore the condition before the "injury": some habitat and biodiversity losses are permanent. Ecological restoration involves assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed, typically as a result of human activities. Restoration actions are increasingly being implemented throughout the world supported by global policy commitments such as the Convention on Biological Diversity. A major goal of ecological restoration is the reestablishment of the characteristics of an ecosystem, such as biodiversity and ecological function that were prevalent before degradation. Increasing attention is being given to the value of ecosystems in providing ecosystem services i.e., "the benefits people obtain from ecosystems" There is a widespread assumption that ecological restoration will increase provision of ecosystem services but this has not yet been systematically tested.

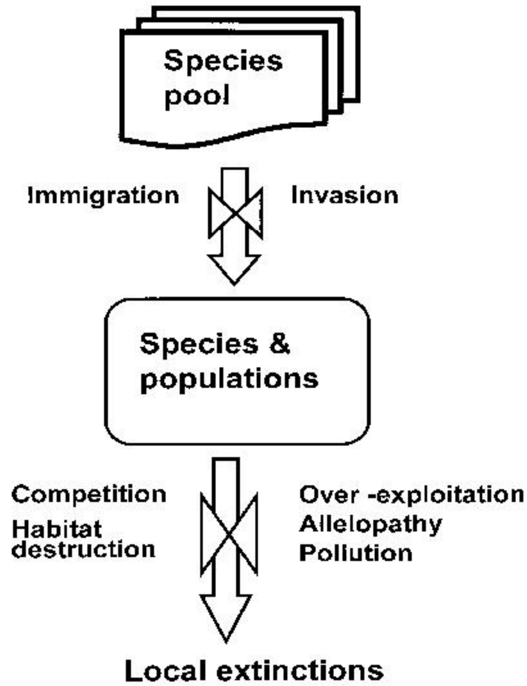
Ecosystem services with high value for supporting human livelihoods include carbon storage, regulation of climate and water flow, provision of clean water, and maintenance of soil fertility. A lack of scientific understanding of the factors influencing provision of ecosystem services and of their economic benefits limits their incorporation into land-use planning and decision making. Many restoration actions are undertaken with the aim of increasing biodiversity. However, despite being the focus of major research attention, the relation between biodiversity and provision of ecosystem services remains uncertain. Restoration actions can provide insights into the dynamics and functioning of ecological systems as they constitute a form of experimental manipulation. Consequently, examination of the effects of restoration actions could provide insights into whether increases in biodiversity are likely to be associated with greater provision of ecosystem services. We used a standardized procedure to select restoration studies from scientific bibliographic databases on the basis of the comparators used and the measures made. In these studies, ecosystems had been degraded by a wide variety of processes (Table 1).

Table 1. Summary of the types of human activity that resulted in degraded ecosystems and the forms of restoration action undertaken in the 89 studies included in the meta-analysis.

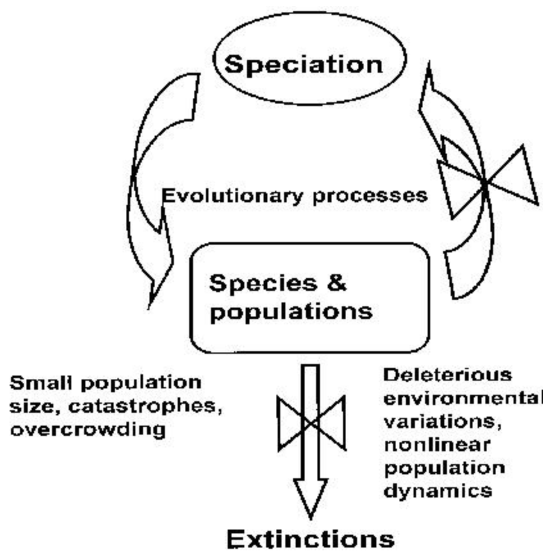
Action	Number of Studies
Degrading action	
Cessation of prescribed burning	2
Cultivation and cropping	10
Disturbance, excavation, or burial of Substrate	12
Eutrophication	2
Hydrological disruption	15
Invasion by non-native species	4
Logging of trees	12
Over-grazing	3
Removal of carnivores or herbivores	2
Soil contamination	4
Restoration action	
Cessation of degrading action only (passive restoration)	10
Extirpation of damaging species (including non-natives)	4
Nutrient removal	2
Planting of forbs or grasses	10
Planting of trees	12
Reinstatement of burning	2
Reintroduction of herbivores or Carnivores	3
Remodelling of topography	28
Soil amendments (to bind or dilute contaminants or restore fertility)	4

Table 2. Hypotheses regarding relationship between diversity and ecosystem function.

Hypothesis	Tenets
Diversity–stability:-	Predicts a linear relationship in which the rate of ecosystem processes increases as the number of species increases.
Rivet–Popper:-	Predicts a positive nonlinear relationship and assumes that all species are equally important – the deletion of species gradually weakens the system, and beyond some threshold number may cause the ecosystem to collapse.
Redundancy:-	Considers most species as superfluous, only functional groups are important; those species within the same functional group are more expendable relative to one another than species without functional analogues.
Idiosyncratic:-	Acknowledges none or an indeterminate relationship between species diversity and ecosystem function; the identity and the order of deletion of species will affect ecosystem function.



Restoration actions generally included the removal or amelioration of the factor causing environmental degradation and/or the reestablishment of key ecosystem components to influence the rate and direction of recovery. The simplest approach was to cease the damaging activity—for example, the abandonment of agricultural land ["passive restoration"].



Distribution

Diversity is not uniformly distributed on the earth; it increases from the poles to the equator and from high elevations to low elevations. Diversity is greater on continents than on islands and rather low in habitats with extreme environmental conditions such as deserts, hot springs, etc. Terrestrial communities normally have greater diversity per unit area compared to marine communities.

Several hypotheses have been proposed to account for the observed patterns of biodiversity distribution. The older, stable climate is expected to support high speciation rates due to more sedentary populations and hence geographical isolation, larger number of generations per year and more opportunities for selection. On the other hand, greater spatial heterogeneity would result in low extinction rates due to greater specialization of taxa, more resources, less competition and smaller size of populations.

Active restoration approaches are summarized in Table 1. Assessment of the impacts of restoration actions typically involved field-based comparisons of different intervention treatments. Time scales of the restorations ranged from <5 to 300 years. To ensure suitable baselines for examination of restoration success, we restricted our analysis to those studies that compared restored (Rest), reference (Ref), and degraded (Deg) ecosystems within the same assessment. We define reference ecosystems as those not subjected to the environmental degradation that the restoration was intended to redress. The degraded system therefore represented the starting point of the restoration and the reference system represented the desired end point. From the 40 studies, we extracted 526 quantitative measures of variables relating to biodiversity and ecosystem services, which were incorporated into a database. The ecosystem services were classified according to the scheme developed by the Millennium Ecosystem Assessment which distinguishes four categories: (i) supporting (e.g., nutrient cycling and primary production), (ii) provisioning (e.g., timber, fish, food crops), (iii) regulating (e.g., of climate, water supply, and soil characteristics), and (iv) cultural (e.g., aesthetic value).We examined only the first three services, because cultural services were not measured explicitly in any of the studies that we analyzed. Measures of biodiversity were related to the abundance, species richness, diversity, growth, or biomass of organisms present. We calculated response ratios of the restored ecosystems compared with both the reference and degraded ecosystems for each measure of biodiversity and ecosystem services. The individual studies were classified into four broad biome types, according to whether they were aquatic or terrestrial and whether they were located in tropical or temperate regions. Using Wilcoxon signed rank tests, we examined whether the response ratios were different from zero to ascertain whether restoration affected biodiversity and the provision of ecosystem services. We also tested whether response ratios differed among ecosystem service categories and among biome types with the use of Kruskal-Wallis tests. Our results indicate that measures of supporting and regulating ecosystem services and biodiversity across the whole data set were higher in restored than in degraded systems (response ratio > 0, Fig. 1).

Provisioning services showed no effect of restoration, but the sample size for this type of service was low. Our data indicate that supporting services, which provide the basis for provision of other services, were restored more effectively than other service types.

It is sometimes questioned whether restoration actions can be effective in enabling degraded ecosystems to acquire the characteristics of reference systems. Median values of response ratios showed that biodiversity and ecosystem services (all three types combined) in degraded systems were only 51 and 59%, respectively, of those in reference systems. Median response ratios of restored systems were sub substantially higher than those of degraded systems, with values of 144% for biodiversity and 125% for ecosystem services. However, the restored systems were not fully rehabilitated, as median response ratios for biodiversity and combined ecosystem services were 86 and 80%, respectively, of those in reference systems. Biodiversity and provision of ecosystem services in restored ecosystems were more similar to degraded or reference ecosystems in aquatic than in terrestrial biomes and in temperate than in tropical biomes (Fig. 2).

Response ratios were not significantly different from zero in tropical aquatic systems, probably because this biome had low sample size. The temperate aquatic biome showed significant effects of restoration only on biodiversity. When compared with degraded ecosystems, restoration was associated with the largest increases in ecosystem services and biodiversity in tropical terrestrial ecosystems (Fig. 2). Theoretical and empirical work has identified a variety of linkages between changes in biodiversity and the way ecosystems function. We tested the hypothesis that a change in biodiversity is positively associated with altered provision of ecosystem services by correlating biodiversity and ecosystem service response ratios across studies. Independent sample unit, Spearman rank correlation analysis showed that biodiversity and ecosystem service response ratios were positively correlated for both restored versus degraded and restored versus reference comparisons (Fig. 3).

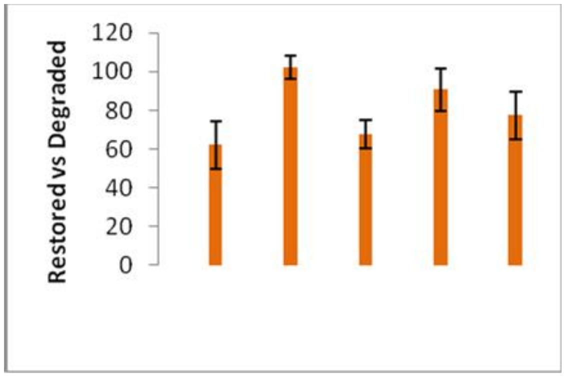


Fig.1. Response ratios of biodiversity and ecosystem services in (A) restored compared with degraded ecosystems and (B) restored compared with reference ecosystems. All response ratios differed significantly from zero (Wilcoxon signed rank tests, ***P < 0.001, *P < 0.05), except those for provisioning services not significant.

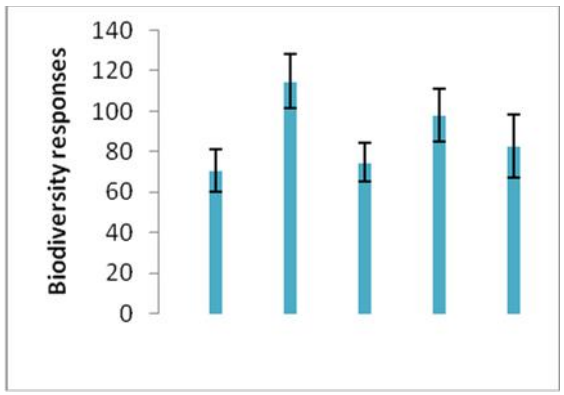


Fig. 2. Significant differences were found between the response ratios for biodiversity and the three ecosystem service categories with the use of Kruskal-Wallis tests [restored versus degraded: H (the K-W test statistic) = 11, N (sample size) =508, P < 0.05; restored versus reference: H = 15, N = 524, P < 0.01].

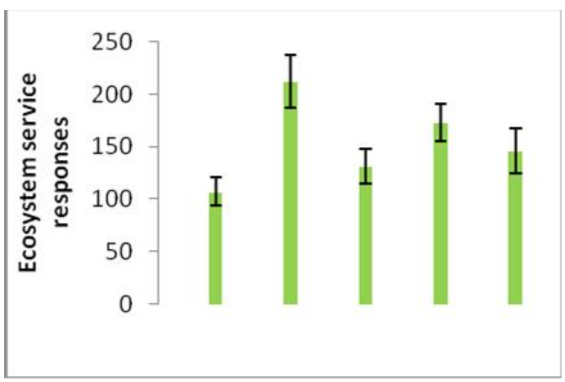


Fig. 3. Response ratios of (A) biodiversity and (B) amalgamated measures of ecosystem services in restored versus reference ecosystems and restored versus degraded ecosystems classified according to broad biome types. Except for biodiversity in the tropical aquatic biome and for ecosystem services in both temperate and tropical aquatic biomes, response ratios were significantly different from zero (Wilcoxon signed rank tests, ***P < 0.001,

The relation was much stronger in the former comparison. This difference in the observed relations may be linked to an asymptotic relation between biodiversity and ecosystem function, whereby increasing biodiversity from low values has relatively strong impacts on individual ecosystem functions, but the relation plateaus at relatively high biodiversity values. Experimental investigations of the biodiversity-ecosystem function relation have generally been laboratory based or have employed small field plots (<100 m2), which arguably have little relevance to the larger scales (hectares to square kilometres) at which land management decisions are made. The current results support suggestions that when studies undertaken at a range of scales are combined, biodiversity is positively related to the ecological functions that underpin the provision of ecosystem services. The relation between biodiversity and provision of ecosystem services is still poorly defined. Preliminary mapping efforts at the global scale have shown that areas targeted for biodiversity

Conservation do not necessarily coincide with areas of relatively high provision of ecosystem services. However, conservation actions and investments typically occur at national, regional, and local scales. Our results suggest that, at such scales, ecological restoration is likely to lead to large increases in biodiversity and provision of ecosystem services, offering the potential of a win-win solution in terms of combining biodiversity conservation with socio-economic development objectives. Because ecological restoration can be effective in restoring natural capital, it should be implemented in areas that have undergone environmental degradation. The impacts of environmental degradation on human communities have been felt particularly heavily in tropical countries, where biodiversity loss and poverty are often associated. The meta-analysis showed the greatest impact of restoration in tropical terrestrial ecosystems, supporting the view that such management interventions could benefit human livelihoods in tropical regions.

Restoration actions cannot be implemented without incurring costs, and therefore, financial incentives will need to be provided for ecological restoration to be widely implemented. Potential approaches include improved markets and payment schemes for ecosystem services Mechanism developed and the Clean Development under the Kyoto protocol. Cost-benefit analyses incorporating the values of biodiversity and associated ecosystem services and analysis of economic pathways are required to maximize return on investments in restoration. Restoration does not necessarily achieve the values of biodiversity or ecosystem services found in intact ecosystems, at least in the decadal time scales adopted in the studies analyzed here, and this highlights the primary need to conserve wild nature and avoid environmental degradation wherever possible. There is also a need to improve techniques for rehabilitating degraded ecosystems that will increase biodiversity and the provision of associated benefits to human society. Such techniques include improved monitoring of both biodiversity and ecosystem service outcomes of restoration actions.

Conclusions

Biodiversity is essential for human survival and economic well-being and for the ecosystem function and stability. Biodiversity at the global scale is a balance between the rates of speciation and extinction and at the ecosystem level, it is a balance between the rates of invasion and local extinction. It is unevenly distributed on the earth, with broad global and regional patterns. The current rates of extinction are 1000–10,000 times higher than the background rate inferred from fossil record. The growing awareness of importance and high rates of loss make it imperative to rapidly assess and conserve biodiversity, both at regional and global levels. Notwithstanding the growing volume of literature, there is a paucity of concrete data, theories and methodologies for all aspects of biodiversity. Successful strategies for people's participation in preserving biodiversity are lacking. India has a rich tradition of conservation, and with growing inputs from the Government, scientists and NGOs, should provide leadership in developing appropriate methodologies and strategies for biodiversity assessment and conservation.

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