RESTORATION ECOLOGY

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Contents

Summary

At the onset of the twenty-first century, restoration ecology has become one of the most active areas in ecology. It represents an excellent springboard for discussing and testing current ecological theories. Of these, the most relevant for restoration ecology are probably the theories on ecological succession since they are essential for setting up the objectives of the intervention, thus driving the entire process. At present, restoration practitioners find both a wide range of available techniques and, just as important, an open field to develop new and creative ecotechnology. Ecosystem restoration arises from social demands and its practice is strongly shaped by social moods, which is certainly not an exception in ecology. The exponential increase in scientific studies and management projects in this field needs to be paralleled by improved communication

tools of which specialized journals and databases are a good example.

1. Introduction

During the nineteenth and twentieth centuries human societies developed an exceptional capacity to alter the biosphere. This was accompanied by the recognition that damage, even if unavoidable, should at least be mitigated. From this philosophy emerged the idea of ecosystem restoration. Initiatives to improve ecosystem conditions after severe disturbances can be traced to the first historical records. In most cases they were motivated by the demand for a particular resource (e.g. wood, game), but the objectives of the intervention were often manifold and diverse, thus paving the way for the onset of restoration ecology. Although relevant rehabilitation programmes had already taken place in the nineteenth century in Europe and America (see Figure 1), it was not until 1935 that Aldo Leopold initiated the first recognised attempt to recover a previously identified community, i.e. self-conscious restoration ecology.

Figure 1. An example of late nineteenth century restoration in Sierra Espuna (Murcia, SE Spain). The main objective of the restoration was hydrological control (the project was launched after a catastrophic flood occurred in 1874). It included the introduction of thousands of seedlings of numerous woody species produced in specifically constructed nurseries. The image shows a sparse forest of *Pinus halepensis* surrounded by shrubland. The figure at the base of the trees is c. 1 m tall.

By the end of the twentieth century, restoration ecology had boomed at the scientific, academic and management level. There are still strong dysfunctions in merging restoration principles into social demands and legal regulations. Restoration is the result of voluntary actions and only in very specific cases it has become an essential part of ecosystem use. The problem originates partly in the difficulties of identifying those responsible for ecosystem degradation because they are often anonymous or can no longer be held liable. But the problem is also strongly related to social dynamics and to the re-examination of social priorities. This text provides some discussion on the theory behind restoration ecology and describes some common techniques. Comprehensive lists of techniques and detailed technical descriptions are not included as they can be found in specialized texts.

2. Ecosystem degradation and restoration

2.1. The origins of ecosystem degradation

Life is possible thanks to the increase in the external level of entropy. Thus if we assume that entropy is a measure of disorganization and degradation, we can conclude that any life form has the potential for ecosystem degradation. Not all organisms have the same capacity for altering their environment. Some are so particularly well suited for this purpose that they affect the activities of other components of the ecosystem. This capacity has recently been termed ecosystem engineering. There are examples of ecosystem engineering at all taxonomical levels, from the burrowing of earthworms, that was noted and meticulously described by Charles Darwin, to growth of any single tree. The intensity of environmental alteration is proportional to the duration of the activity, the density of the population of engineers, and a number of other factors. Unfortunately, our knowledge on this particularly relevant aspect of organisms is still too fragmentary to permit any general conclusion on when and why this ecosystem engineering capacity arises, and to what extent it is relevant for natural selection.

Humans are strong ecosystem engineers. Human activities, especially in more economically developed countries, involve the use of extraordinary amounts of exosomatic energy (that is, the energy that is used by the ecosystem but does not originate in the conversion of radiation into chemical energy, as heat and inorganic fertilizers). This surplus of energy permits large-scale environmental alterations with several major consequences, among them environmental degradation. The Neolithic community at Eilean Domhnuill in North Uist, Scotland, provides a good example of a long history of land use and land degradation. This settlement was established on an islet of a small loch around 3800 years B.C. For several generations its inhabitants cultivated barley in the catchment of the loch. Depleted soils, clogging-up of the loch and subsequent flooding of the settlement forced abandonment soon after 3000 B.C. Although the capacity to degrade the environment may have accompanied the development of human civilizations since early times, the intensity and extent of this degradation have increased during the last centuries to reach a global scale. It is important to emphasize that ecosystem degradation—in the sense of disorganization, loss of biotic and abiotic components and loss of functionality—may occur spontaneously in a process encouraged by scarcity in resource availability, extreme conditions, and excessive disturbance. This is the case of tectonically favoured badland generation, climatically driven desertification, landslides generated by an excessive accumulation of biomass, etc. However, it is obvious that the rate and intensity of degradation have soared in recent centuries.

2.2. Thresholds in ecosystem degradation

Degradation is not a linear process; it may proceed in discrete steps (thresholds or transition boundaries). For terrestrial ecosystems, one of these steps is associated with the loss of vegetation cover. By considering the soil resource as a whole, for which both vegetation and erosion compete, and by applying classical models of competition, it has been suggested that a vegetation cover of at least 30 to 40% may be necessary to avoid self-promoting degradative processes (see Figure 2).

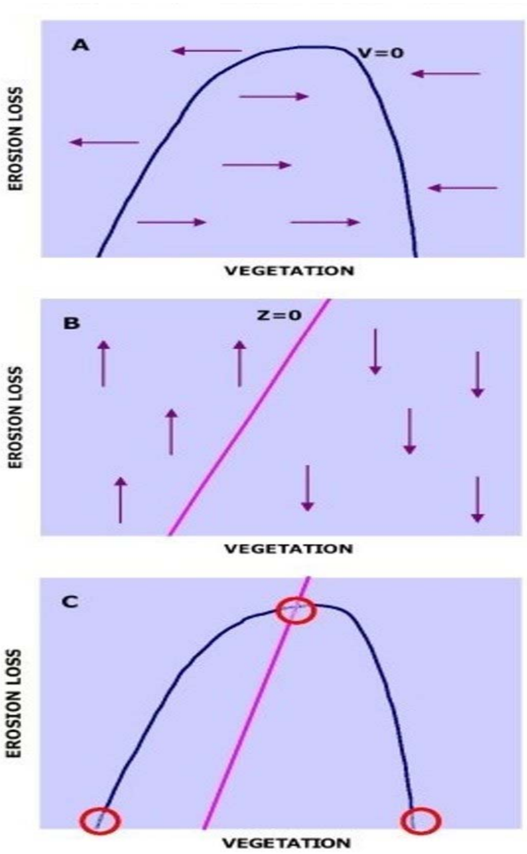

Figure 2. Outline of the model of competition between vegetation and erosion for the soil resource.
Source: *Vegetation and Erosion,* J.B. Thornes (ed.) (1990). J. Wiley and Sons.

Figure 2A represents vegetation dynamics. Points above the isoline V=0 correspond to combinations of vegetation cover and erosion losses that lead to a decrease in vegetation cover (e.g. low vegetation cover at any level of erosion loss). Points below the isoline correspond to increases in vegetation cover. The arrows describe these changes. 2B represents soil dynamics. Points above the isoline Z=0 correspond to combinations of vegetation cover and erosion losses that lead to a decrease in erosion losses. Points below the isoline correspond to increases in erosion losses. 2C is combined vegetation and soil dynamics. The three red circles correspond to equilibrium points.

The loss of vegetation cover is just one of several indicators of degradation. Combinations of indicators may be used at a management level to assess the level of degradation of a particular site or landscape. Lists of indicators, such as ‘vital ecosystem or landscape attributes’, ‘ecosystem health assessment’, ‘landscape function indicators’, have been forwarded. At the ecosystem level they may include attributes related to composition and structure (total plant cover, total and perennial species richness, presence of keystone species and particular functional groups, etc.), and functional attributes (productivity, soil organic matter content, rainfall efficiency, etc.). Although the relative importance of each attribute may be site-specific, many of them can be of general use.

The steps in the degradation trajectory may not be of equal magnitude or importance. Some of them can hardly be reversed spontaneously, at least at a reasonable temporal and spatial scale, and thus are called ‘thresholds of irreversibility’ or ‘transition boundaries’. These steps are of paramount importance to restoration since, in order to be reversed, they require external energy inputs in the form of restoration techniques. Moreover thresholds of irreversibility are not symmetrical in that the energy expended in one degradative step may not be the same amount needed to reverse the system to its original state. This is a strong argument in favour of conservation. Thresholds of irreversibility may be related to the exclusion of particular functional groups (e.g. transitions between grasslands-shrublands-forest, etc.) or species (succession arrested by the dominance of a particular species).Restoration is thus envisaged for a degraded ecosystem when spontaneous recovery is unlikely or too slow for the management objectives proposed, and especially when doing nothing might entail further degradation or even off-site damages.

3. Objectives of restoration

3.1. Time scales in restoration objectives

The most widely accepted definition of *restoration* (see Glossary) is based on the objectives sought. The concepts *reclamation* and *rehabilitation* focus on aspects of ecosystem function, whereas restoration can be interpreted in terms of both ecosystem function and composition. However, it is usually difficult to separate the two sets of variables, as they are intimately connected. Thus much of the theory and practice of restoration is valid for reclamation and rehabilitation, and *vice-versa*. Some authors refer to ecological repair to integrate all aspects of a continuum of objectives. In this text and for the sake of simplicity, the term restoration will be used in this broad sense.

Most definitions of restoration consider the potential vegetation or some kind of previous, undisturbed state of the ecosystem as the final goal of proper restoration. It has been discussed that this theoretical state can hardly be identified in many cases because of the long and intense history of land use and because natural systems may be dynamic enough to elude any comprehensive and static definition. On the other hand, the dynamic nature of ecosystems makes it difficult to anticipate the outcome of restoration practices. There are examples showing that, even in quite dynamic systems, restoration hardly ever recovers the integrity of a disturbed ecosystem.

The solution probably lies in identifying two levels of objectives, a current practice in management-level restoration. One group of objectives focuses on short-term dynamics (years to decades). These may include rather modest and achievable goals such as recovering the presence of a particular species or functional group, or improving ecosystem function (such as soil retention). These objectives are very specific, so suitable restoration techniques can be identified or developed, and implemented. They can also be assessed within a reasonable period of time, for example by using templates where ecosystem attributes are compared with those of undisturbed ones, taking the natural variability of the former and the latter into consideration. In consequence, in the case of failure, measures can be taken to modify the original restoration protocol and eventually revise its goals. The other group of objectives (including the recovery of the 'undisturbed' ecosystem state) is defined with a long-term perspective and may be achieved by autogenic succession and further interventions based on expected and monitored changes. This set of objectives must be foreseen when setting the short-term goals and is obviously subjected to a higher degree of uncertainty. A good example of this two-level *modus operandi* is the National Reforestation Plan launched in Spain in the 1940s. At its completion, some 50 years later, more than 3.5 million hectares of mostly conifer seedlings had been planted. Apart from other considerations (particularly socio-economic; see below), the theory behind this reforestation was that by establishing pine forests some ecosystem functions could be ameliorated (namely control of the hydrological cycle and productivity). In addition, by introducing these—in most cases—early successional species, the establishment of late-successional hardwoods could be facilitated in the medium to long-term. This was connected with the successional theories prevalent at that time. Discussion of the achievements and failures of this plan is beyond the scope of this section, but it illustrates the two levels of restoration objectives previously described.

On the other hand, it is naive to think that the only objectives, or even the most important objectives, in restoration decision-making are biotic in nature. Take the above-mentioned Spanish reforestation plan. The main objective of this plan was to generate employment in rural areas badly affected by post civil war crisis. Similarly, what has been considered the onset of self-conscious restoration, the restoration of native tall-grass prairie in the University of Wisconsin Arboretum, was favoured by the activities of the Civilian Conservation Corps. These activities were associated with federal work relief programmes, and thus with the economic depression that struck the USA. in the 1930s. At this point it should be emphasized that restoration is based on social demands. So not only the extreme degree of ecosystem and landscape degradation reached globally by the second half of the twentieth century favoured the interest in recovering 'natural' ecosystems, but also the emergence of new social demands. Priorities in restoration depend on the society that defines them; they are intimately related to the expectations and demands that each society may have on the restored ecosystem.

3.2. Ecosystem dynamics and restoration

Restoration is intrinsically linked to ecological succession. Consequently, the concept of restoration has evolved in conjunction with the prevailing paradigms of successional theory. A well-known representation of restoration that fits the early definitions given by the Society for Ecological Restoration (SER) was presented by A.D. Bradshaw to describe the reclamation of derelict land (Figure 3). In this Figure restoration follows the same path as spontaneous succession, i.e. an increase in variables related to ecosystem composition and function. However, current knowledge on ecological succession suggests that for a given site it might be not one but several potential metastable end-points as well as a number of successional trajectories. On the other hand, even though in general terms succession represents a simultaneous increase in ecosystem complexity and function, this is not always the case. Successional trajectories often lead to communities dominated by one or a few species that perform well in terms of relevant ecosystem functions such as productivity, resources retention, etc.

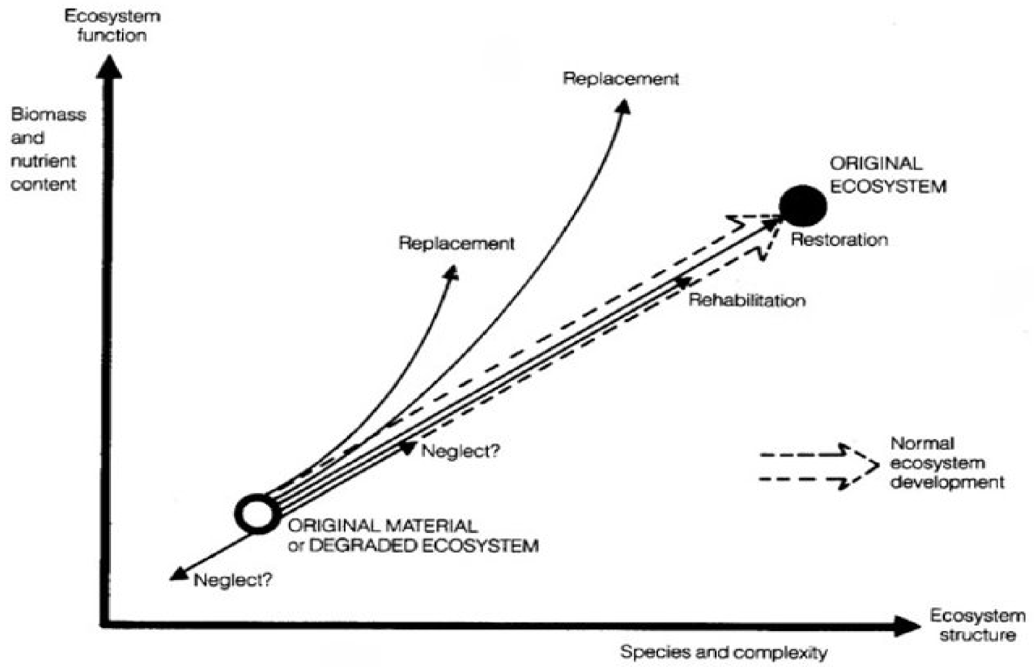

Figure 3. Graphic model of ecosystem development in terms of structure and function, and of the objectives of restoration, rehabilitation and replacement. From A.D. Bradshaw (1984). Ecological principles and land reclamation practice. *Landscape Planning* 11: 35-48 (with permission).

A further development of the Bradshaw graphic model, embracing a wider range of situations, could be that described in Figure 4. This model considers the possibility of several combinations of different structure and function levels, as areas of higher probability (clusters of points). It also considers preferential transitional pathways. In practice, restoration ecologists should identify the different stages of dynamic equilibrium and describe them in terms of composition and function. They should then inform the society that may be more or less directly affected by the outcome of the restoration about the different possibilities available and reach a consensus on the objectives and the final goal of the intervention. Finally, restoration ecologists should know the factors that facilitate or hamper the transition between the different stages, and eventually use available technology or develop new methods to favour the change.

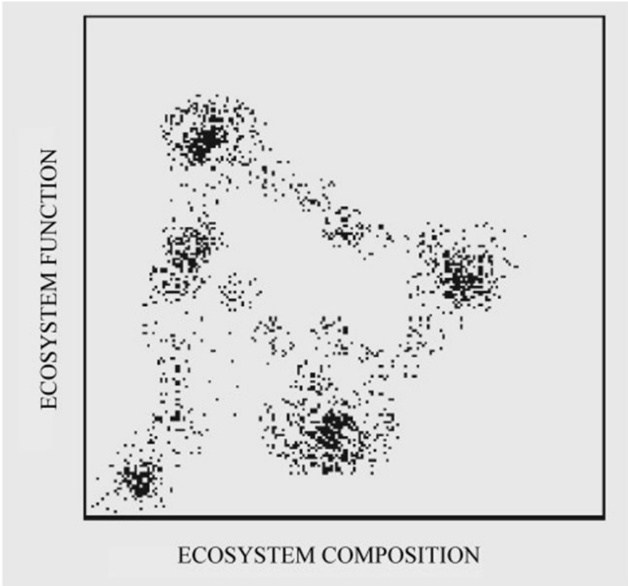

Figure 4. Theoretical model of ecosystem succession in terms of changes in structure and function.

This theoretical framework is coherent with the threshold theory discussed above. To be implemented in the real world it needs a reasonable degree of knowledge on ecosystem dynamics and on the autoecology of the species involved. But how much is reasonable? Restoration initiatives are usually restricted in time: they arise from a momentum and need to be implemented within a given period of time, which is frequently rather short. Thus, there is no point in advising that the restoration be halted until all the details of ecosystem dynamics are known. The so-called reasonable amount of information may be that which is available at the time the activity is performed. This will occasionally lead to failures. This has been the situation since the very beginning of restoration ecology as such.

But the early failures in the restoration of native prairies in the University of Wisconsin Arboretum were of great help in understanding the importance of disturbances such as fire in grassland dynamics, and the way they could be incorporated into restoration practices. Restoration, then should be carried out, at least in part, on a trial-and-error basis. There are mechanisms to avoid large-scale fiascos and the disillusioning effects that they have. These include different levels in the research, technology, and innovation chain: experimental project, pilot project, demonstration project and full-scale management implementation. In this way restoration becomes an invaluable source of knowledge on ecosystem dynamics and management. For this procedure to work it is essential for restoration to be the result of a fluent interaction between scientists, practitioners and the society. Ineffective information exchanges and excessively rigid restoration programmes have been more responsible for the blatant failures in the history of restoration than deficient knowledge on ecosystem dynamics or restoration techniques. A graphic model on how this theoretical framework could work is presented in Figure 5.

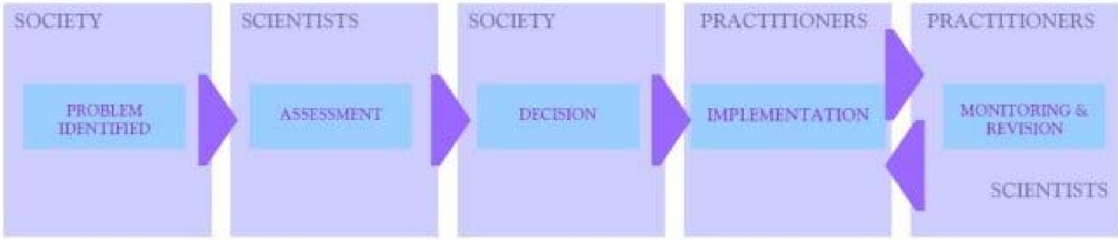

Figure 5. Steps in restoration decision-making and agents involved.
The SOCIETY box includes practitioners and scientists.

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Biographical Sketch

Jordi Cortina-Segarra is a permanent lecturer at the University of Alacant (Spain). He graduated at the University of Barcelona (1986) and received his Ph.D. in biology in 1992 from the same institution. His main research areas are biogeochemistry and productivity of terrestrial ecosystems. Lately he has focused his research on several aspects of ecosystem degradation and restoration, including the study of post-fire regeneration, the analysis of spatial heterogeneity in restoration success, improvement of soil fertility by the use of biosolids and other ecotechnological tools, and assessment of nursery techniques to improve the performance of woody seedlings. Further details on his research and teaching can be found at www.ua.es/personal/jordi.

Ramón Vallejo-Calzada. M.Sc. in Biological Sciences at the University of Barcelona (1978) and Ph.D. from the same institution (1983). He is a permanent lecturer at the University of Barcelona and Head of the Forest Research Programme in the Mediterranean Centre for Environmental Studies (CEAM). He has a long expertise on soil-plant relationships: forest soils and soil organic matter, soil fertility, transfer of radionuclides from soil to plant, effects of forest fires on soil fertility and post-fire ecosystem restoration. CEAM works in close contact with the Forest Administration of the Region of Valencia (Spain) for which CEAM provides assessment and transfers technological innovation on forest management, especially on forest restoration. He has been very active in co-ordinating research projects and promoting the interactions between researchers and restoration practitioners. Further information to be found at www.gva.es/ceam.