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ECOLOGICAL RESTORATION:OUR HOPE FOR THE FUTURE?

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ABSTRACT: Ecological restoration is widely employed from tens to millions of hectares in space, and from tens of days to thousands of years in time, which forces consideration of it thoroughly. We argue that three questions are the most important among the contents relevant of ecological restoration, including why, what and how to restore degraded systems. Why to restore determines whether or not the degraded ecological systems should be restored. What to restore is the goal of ecological restoration. The explicit goal of ecological restoration is necessary to guide ecological restoration workers in pursuit of excellence and prevent restoration from being swamped by purely technological activities. And how to restore means the methods and steps we should apply. To ensure the final success of ecological restoration, restored sites should be monitored and managed for long time to determine whether the selected methods are appropriate, and can be remedy better. Only to deal with these effectively, ecological restoration would be the hope for the future.

KEY WORDS: ecological restoration; degraded systems; ecosystem monitoring

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1 INTRODUCTION

All organisms modify their environment, and human being is not exception. With the global population propelling towards seven billion, and the power of science and technology expanding, the impact of human beings on the natural environment occurs at a variety of spatial and temporal scales. In the area human beings live on, most natural ecosystems are converted into agricultural or industrial land. The structure and function of original ecosystems have been destroyed, and hardly any ecosystem on the Earth′ surface was free of pervasive human influence. Some ecosystems have been damaged seriously, which resulted in a series of environmental problems, such as industrial pollution, deforestation, desertification, soil erosion, loss of biodiversity and shortage of freshwater. These increasingly serious environmental problems have been and are posing great threat to the living environment of human beings and sustainable development of human society. Fortunately, people have been conscious of the severely environmental problems, and begin to deal with them. Under these situations, a new science, restoration ecology, occurred in the 1980s. The emerging of restoration ecology provides a tool and opportunity to solve ecological problems and realize sustainable development.

Restoration ecology is a new science on ecological restoration, which includes biological remediation, and engineering restoration. Research of ecological restoration has been for approximately 100 years until now. In 1935, LEOPOLD and his assistants restored a pasture about 24ha in the arboretum of Wisconsin University. Subsequently, he found that fire was important in maintaining and managing the pasture (JORDON *et al*., 1987). From 1950 to 1970, people in Europe, North America, and some other countries, noticed the environmental problems, and adopted lots of projects with biological or other measures to study and deal with them, such as restoration of mine, soil erosion, cleaning treatment of polluted water (CAIRNS, 1995; BRADSHAW, 1997). Although there were some positive results, the study on mechanisms of ecological restoration was few. After 1970, on the one hand, practices to restore and rehabilitate ecological resources degraded by overuse had become more and

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more popular all over the world, especially in developed countries. On the other hand, restoration ecologist began to communicate with each other, for example, the International Symposium on the Recovery of Damaged Ecosystems was held in America in 1975. Scientists who discussed the theories and methods on the recovery of damaged ecosystems were asked to collect scientific data and information of damaged ecosystems, to study technology, and to establish the international cooperation. In 1984, the symposium on restoration ecology were held at Wisconsin, USA. In the meantime, some books about ecological restoration had been published in succession. For example, the book *The Recovery Process on Damaged Ecosystems* edited by CAIRNS (1980) was published. In the same year, BRADSHAW and CHADWICK (1980) published the book *Restoration of Land, the Ecology and Reclamation of Derelict and Degraded Land*. In 1985, a series of monographs about ecological restoration on forest, wetland, grassland, coast, were published. The terminology of restoration ecology was first put forward in that year. After the international society of ecological restoration was founded in 1987, especially the journal *Restoration Ecology* was initiated in 1993, restoration ecology got further development. A lot of articles about ecological restoration were published in some journals, such as *Restoration Ecology*, *Restoration and Management Notes*, *Journal of Applied Ecology* and so on. According to *Journal of Applied Ecology* in the recent 40 years, submissions on restoration ecology have increased and now contribute at least 8%–12% of the papers published annually. Examples from subjects such as conservation biology, pollution ecology, and ecological modeling showed that notions of restoration or recovery are now implicit in the philosophy of applied ecology (ORMEROD, 2003).

However, it was relatively late when attention was been paid to ecological restoration in China. In the 1950s–1960s, only a few projects on forest restoration were employed in order to increase the productivity of woods, and enhance the coverage rate of forest. After 1980, ecological degradation, environmental pollution became severer and severer, which attracted the high attention of some governmental departments. According to various degraded ecosystems, such as mined lands, forest, island ecosystems, abandoned farmland and grassland, a lot of restoration projects had been widely applied (LI and ZHENG, 1995; PENG, 1996; CUI and LIU, 1999; HAO, 2001; REN *et al*., 2001; HOU *et al*., 2002; JIANG *et al*., 2002; XIA and CAI, 2002). Due to these, some results and theories occurred and enriched the discipline of restoration ecology in China (ZHANG and XU, 1999; REN and PENG, 2002; XIANG *et al*., 2003).

The final definition of ecological restoration is not clear until now, but ecological restoration becomes more and more popular. Human beings have restored variously degraded ecosystems in different regions, and from different aspects, using diverse technologies, which makes the scope and extent of ecological restoration become larger and larger. However, not all human beings agree with ecological restoration. KLOOR′s article (2000) about the restoration of North America's forests suggested that it might be time to retire the word "restoration". He pointed out that there were at least three problems with the field of restoration ecology. First, the arbitrariness of determining which time period in the past should be the target of restoration efforts. Second, there is an implication of stasis with the word "restored". Third, true restoration is simply impossible. The climate is no longer the same, and key species are absent and new species are present, which make it impossible to truly restore the habitat to any prior state. HIGGS published an article about no justification to retire the term "restoration" to disprove the three points (HIGGS, 2000). He considered that a substantial body of literature addresses the determination of reference conditions, and restoration ecologists have worked hard to refine methods for defining appropriate reference points in time and space, that it is a common tenet in the field that contemporary restoration is a dynamic process of restoring not only composition and structure, but also processes including disturbance regimes and ecosystem functions that lead to change over time, and that ecological restoration promotes the flourishing of indigenous species and communities, ecosystem fluxes, and sustainable cultural practices. He also believed that restoration ecology is the branch of applied ecology that forms the scientific basis for such endeavors.

We argue that the debate about ecological restoration is not ended now, and will exist for a long time in the future, which will be not prevented, but promote the advancement of both theories and practices in the ecological restoration. This paper addresses three most important questions of ecological restoration, that is, the reasons (why to restore?), the scope and extent (what to restore?), and the methods (how to restore?) of ecological restoration. All three questions are primary, indispensable in the discipline of restoration ecology.

2 WHY TO RESTORE

In the three questions mentioned above, the first question is the most important. Because only when we understand why to restore, we could address the following questions. If we do not know why to restore, all the work about ecological restoration would lose meaning. Many people would think the answer to the question is simple. As we discussed above, environmental problems, such as industrial pollution, deforestation, soil erosion, loss of biodiversity and shortage of freshwater, have become more and more serious, and have been great threat to the living environment of human being and sustainable development of the society. Now, we need to decide whether we wish to proceed with this huge transformation of our planet, and in doing so, put our continued existence at increasing risk. Or whether we want to seek alternatives in which we aim to protect the resources, both living and biotic resources, which we have left, and set about repairing some of the damage we have inflicted in the past. It is our hope that we have the collective wisdom to choose the latter course, and it is in this context that we consider the rapidly developing field of restoration ecology (HOBBS and HARRIS, 2001). However, because the degree of damaged ecosystems differs greatly, we should decide whether to "do nothing" (on the one hand, the system is too degraded to warrant restoration, or, on the other hand, biological integrity is relatively intact and therefore either none, or minimal, restoration is required) or to "do something" (because restoration is worthwhile, urgent and feasible) (SAMWAYS, 2000). So we should know whether the damaged ecological systems fall in the two extremes of "do nothing", or not. If one area falls where we do nothing, it may be because the area is so intact that urgent attention will make little difference. On the other hand, we may do nothing because the area is so degraded that to do something truly meaningful would be a monumental task. Except the two extremes, ecological restoration may be necessary and have some meaning.

3 WHAT TO RESTORE

The original definition about ecological restoration adopted by the Society for Ecological Restoration (SER) in 1990 was the longest-lived and the most controversial: "Ecological restoration" is the process of intentionally altering a site to establish a defined, indigenous, historic ecosystem. The goal of this process is to emulate the structure, function, diversity, and dynamics of the specified ecosystem. This definition, and similar ones proposed in its wake indicate a lack of agreement on the most basic issues of what restoration is and what restoration ecologists are attempting to accomplish (HIGGS, 1997). In the recent definition by SER, ecological restoration is the process of assisting the recovery and management of ecological integrity. Ecological integrity includes a critical range of variability in biodiversity, ecological processes and structures, regional and historical context and sustainable cultural practices (http://www.ser.org). This broad definition includes many elements but does not address how to restore a spoiled site or fragmented landscape. Of course, the SER holds no monopoly on definitions. There were also many definitions by restoration ecologists (BRADSHAW and CHADWICK, 1980; ROGERS-MARTINEZ, 1992; CAIRNS, 1995; HIGGS, 1997). Although these definitions are not all-sided, they expand the scope of ecological restoration. HIGGS (1997) argued that defining an end point for restoration was as much an ethical matter as a technical one, but scientifically trained restoration ecologists had largely ignored the former issue. He even argued that good restoration requires an expanded view that included historical, social, cultural, political, aesthetic, and moral aspects. Because the wide context of restoration, there are so many similar terms, such as rehabilitation, reclamation, regreening, and so on (SAMWAYS, 2000). Lack of precision in the definition of ecological restoration has been a controversial issue for decades in restoration ecology as a science, but has not prevented its effective application. Whatever the definition of ecological restoration is, we consider that the important part of the restored system should be harmonious with nature and self-sustaining in the future, and other parts are additional.

Goal definition is more important than definition of the term (ecological restoration), because the clear enunciation of goals is essential for what to restore, and the ability to assess the progress toward success. We should define the goal in restoration projects, because it sets expectations, drives the detailed plans for actions, and determines the kind and extent of post-project monitoring. Not surprisingly then, the nature of restoration goals is the subject of frequent comment (EHRENFELD, 2000). The goals set for restoration projects are highly variable, partly because restoration ecology has a complex, heterogeneous lineage (HOBBS and NORTON, 1996, DIGGELEN *et al*., 2001; HOBBS and HARRIS, 2001). In the meantime, the goals for restoration vary greatly, as the spatial and temporal scales change. The spatial scales have many hierarchies, such as population, community, ecosystem, and landscape. Different perspectives need to set different goals for restoration. Species-centered goals for restoration are reflected in a variety of recent publications, such as invertebrates, fishes, and birds (FALK *et al*., 1996; DONALD *et al*., 2001; WOLFF *et al*., 2001). The advantages of species-centered restoration are clear: species threatened by extinction are rescued, or at least given a better chance of survival. Elsewhere, however, ecosystem perspectives have remained prominent, for example with respect to the restoration of grasslands, forests, heathlands, peatlands, rivers, lakes and wetlands affected by overuse of people. The advantages of using ecosystem-level restoration are that ecosystem-level framework encourages restoration ecologists to recognize the large-scale processes′ necessity for species′ persistence, to recognize the dynamic nature of ecological entities, and to encourage the integration of management goals of diverse agencies, interested groups (EHRENFELD, 2000). Besides these population or ecosystem views, perhaps landscape scale restoration is most challenging, and restoring entire landscape is being discussed recently (LAMB, 1998; RADELOFF *et al*., 2000). Without large-scale support, small-scale restoration may create unstable sites and landscapes (WHISENANT, 1999).

On the other hand, temporal scales are also important for ecological restoration. It is increasingly clear that process rates of both biotic transformations and species turnover are often low and should be expressed in decades rather than in years (DIGGELEN *et al*., 2001). According to this, the goals should be separated into 3 levels: recent goals (achieved in months), intermediatte goals (achieved by years) and ultimate goals (achieved by decades or even hundreds). The ultimate goal of many ecological restoration projects is to return ecosystems structures, functions, and processes to "nature" or reference conditions, while the recent or intermediate goals are the following phase to ultimate goals. People often want to achieve the ultimate goal as quickly as possible, and there is no time to address the problem in a proper scientific way, which may lead to unwanted results.

In all, these goals defined by restoration ecologists are all fine in general terms, but how do we turn them into effective goals or even efficient goals for specific projects? HOBBS and HARRIS suggested that we needed a clear rationale for setting goals, which took into account the nature of the systems being restored, the factors leading to degradation and the types of action required to achieve restoration of different attributes (HOBBS and HARRIS, 2001). We should adjust goals to local conditions, for there are no common templates for all restoration projects.

4 HOW TO RESTORE

Once the restoration goal has been agreed on, we should begin to restore the damaged systems. The first step to follow would be analyzing the current state, history, factors leading to damage the areas. We should establish some reference conditions for restoration, which are based on a thorough study of historical ecosystem structure and processes as well as on knowledge of ecological relationships (ALCOZE *et al*., 2000). We should not only compare with reference areas to estimate the degree of degradation (BRINSON and RHEINHARDT, 1996), but also include an identification of the processes, which have led to degradation. This may not always be obvious, because the effects of fragmentation (DIGGELEN *et al*., 2001), long-distance hydrological interference (GROOTJAN *et al*., 2001) and climate change (KLOOR, 2000) are not clear. If we could not analyze these thoroughly before carrying on restoration, the projects of ecological restoration may be of no use, and even some results may be catastrophic. For example, the riparian forest project in San Diego (KUS, 1998) won a national prize from the Society for Ecological Restoration, but the site subsequently dried out, costly trees died, and upland plants invaded, because the essential hydrology (river flooding) was not ensured over the long term.

The next step should be to establish some scientific strategies, using some ecological principles and other knowledge, according to the goal and the analysis. Different goals need different strategies. But we found there are some commons in these ways. As we know, the usual phenomena of damaged areas are loss of biodiversity or worsen surroundings. The important restoration strategies include two ways: one is the surroundings′ restoration, the other is biological restoration. Studies on the damaged areas on the earth indicate that the major environmental problems may come from soils: such as poor fertility, extremely physical and chemical conditions, etc. Replacement of soil in the land is therefore regarded as the most efficient method to alleviate adverse conditions of substrates; if this method is not available, other alternatives with lime, fertilizers, organic manures, and others can be applicable. As what the famous restoration ecologist—BRADSHAW said that it was essential to concentrate on the soil and its properties to achieve immediate results, otherwise there would be immediate failure (BRADSHAW and CHADWICK, 1980). In the meantime, the restoration of rivers, lakes and wetlands had also been focus on. In the aspect of biological restoration, species with strong resistance and rapid growth, like grasses and herbaceous legume, are always the first choice. These species can improve the surroundings in some degree. We should try to introduce native species into a damaged area, because exotic species commonly compete with and replace native species, which can have unforeseen negative consequences (CARLA and MEYERSON, 2002). Cares should be taken to cause the least possible disturbance to indigenous species and soils as exotics are removed. In some instances, non-indigenous plants are used for a specific purpose in the restoration project, for example as cover crops, nurse crops or nitrogen fixers. Unless they are relatively short-lived, non-persistent species that will be replaced in the course of succession, their eventual removal should be included in restoration plans.

After we apply these strategies to the damaged areas, we should monitor and evaluate the result of restoration, which can remedy our plans better. Unfortunately, monitoring is rarely done, and when it is done, it often suffers from poor design and lack of statistical rigor (BLOCK *et al*., 2001). In clarifying monitoring goals, a clear description of reference conditions should be stated, preferably in quantitative terms. We should decide what to monitor, according to the goals of ecological restoration. A complicating factor in designing monitoring programs is defining the appropriate variables to measure wildlife response to restoration, such as species, numbers, biomass, physical and chemical state of soil, microclimate, and the change of underground water (BERGER, 1991; XIA and CUI 2002). We contend that monitoring restoration activities should always involve experiments because researchers want to know not only if there was an effect after restoration, but also whether that effect was due to restoration or not.

If monitoring is conducted properly, results provide information that can be used to evaluate and adjust restoration practices. There are three strategies for conducting an evaluation (http://www.ser.org): direct comparison, attribute analysis and trajectory analysis. In direct comparison, selected parameters are determined or measured in the reference and restoration sites. In attribute analysis, quantitative and semi-quantitative data from scheduled monitoring and other inventories are useful in judging the degree which each goal has been achieved. Trajectory analysis is a promising strategy, still under development, for interpreting large sets of comparative data. In this strategy, data collected periodically at the restoration site are plotted to establish trends to the reference condition. Under different views, the results of evaluation may be different. For example, the restoration may appear to have been successful in ecological terms, but not in aesthetic terms (SMALE *et al*., 2001). Whatever the strategy is, the purpose of monitoring and evaluating is to ensure that the development of the restored systems continue along the pathways as we wish. However, ecological restoration is employed at different scale, it would be impossible to monitor landscape-level restoration only through field experiments, and managers cannot wait several decades, or hundreds of years to decide which method to select. To make useful prediction of the ecological consequences of a given restoration project, computer simulation modeling can play this role and enable us to assess landscape response across large spatial and temporal scales (MLADENOFF and BAKER, 1999; HE and MLADENOFF, 1999).

5 CONCLUSIONS

Restoration of degraded ecosystems is a relatively new management approach, and effects of most restoration treatments on various system processes and components are poorly understood. Ecological restoration is a complex process, which needs some kinds of professional knowledge. Restoration ecology is developed from practices at the beginning, which is different from other subjects of science (LAKE, 2001). Some theories in ecology are derived from assumptions or quasi-experiments. Ecological restoration can make up for the deficiency, and provide a platform for examining these ecological concepts and theories. Ecological restoration in the world becomes more and more popular, mostly because it satisfies the desire of people to amend the increasing degraded systems. Dobson even regards restoration and conservation biology as hopes for the future. Indeed, ecological restoration is becoming prominent in the discipline of ecology.

However, ecological restoration has some faults. On one hand, ecological restoration lacks sufficient theories to support it. Almost all theories used by ecological restoration come from other sciences, especially in ecology, such as law of the minimum, law of tolerance, law of energy, distribution pattern of population, succession, and so on. Only self-design versus design theory comes from restoration ecology (MIDDLETON, 1999). On the other hand, the subjectivity of ecological restoration is strong, because humans directly or indirectly determine goals, methods and so on. Sometimes, the recognition of structure, function, dynamic of degraded habits is not sufficient. The goals set by humans are different, which will result in the uncertainty of ecological restoration. The goals established for ecological restoration should include ecological, economic, cultural and political aspects, while some projects only emphasize ecological aspect, regardless of other important aspects. Only all aspects have been considered, the restored site will be maintained for perpetuity. In addition, ecological restoration is usually conducted on relatively small spatial and temporal scales. However, ecosystems are not closed systems within which all critical ecological processes are incorporated, which allows ecosystems to interact with others in the landscape through the movement of energy, materials and organisms (PICKETT and PARKER, 1994; PARKER, 1997). These large-scale processes in conjunction with smaller, internal processes determine the specific function of an ecosystem in the landscape (PICKETT and PARKER, 1994). The continuum of restoration efforts should be recognized, ranging from restoration of localized highly degraded sites to restoration of entire landscapes for production and/or conservation reasons (HOBBS and NORTON, 1996; NAVEH, 1998).

Although the total frame for ecosystems to degrade has been recognized, the further studies on the cause, driving factors, process, and mechanism of degradation are still quite superficial, which are essential to restore and rebuild degraded systems. In all, we should continue to absorb more knowledge from new theories, enhance our knowledge level, and expand our views in order to better ecological restoration from all aspects. If why to, what to, and how to restore degraded ecosystems are addressed effectively, ecological restoration will get further progress in the new century.

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