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Short communication

Complexity of ecological restoration in China

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ABSTRACT

Land degradation is a primary issue that affects environmental conservation and socioeconomic development. However, ecological restoration has complex and poorly understood consequences for the structure and composition of future ecosystems and socioeconomic systems. To illustrate the complexity of ecological restoration, we discuss the potential links between China's ongoing large-scale ecological restoration practices and the resulting changes of natural factors such as landscape characteristics, climate, and vegetation communities. These changes may lead to restoration difficulty when the goal is to rebuild a system that resembles the pre-disturbance state. Even though the intentions of ecological restoration may be good, it is necessary to harmonize the ecological effects with simultaneous and future social changes, thereby benefiting both nature and society. Any simplistic or extreme approach to ecological restoration is potentially dangerous because the long-term effects on nature and society are generally unknown, so careful monitoring will be required, particularly for large-scale projects.

Ecological restoration plays a crucial role in rebuilding ecological equilibrium at degraded sites and reversing ecosystem degradation. Few countries face degradation problems as severe as those in China. To control widespread soil erosion and desertification, protect species resources, and supply timber and forest products, China's government has implemented projects and policies to restore vast areas of degraded land, thereby restoring the ecosystem development trajectory that existed before the degradation began (Cao et al., 2011; Hilderbrand et al., 2005). These projects, and especially several key national projects, have affected huge areas of China, accompanied by equally huge investments. Environmental communiqués issued by the Ministry of Environmental Protection between 2004 and 2009 indicate that China invested 1636 billion RMB (ca. US$260 billion) in environmental conservation from 2003 to 2008. As a result, some environmental parameters have improved; for example, in some regions, the vegetation cover and carbon sequestration have increased and wildlife habitat has improved (Cao, 2008; Piao et al., 2009).

However, the ecological and socioeconomic consequences of large-scale measures sometimes differ from the planners' expectations (Gong et al., 2012; Suding et al., 2004). For example, many areas of China that are undergoing afforestation are unsuitable for forests because there is insufficient precipitation to sustain trees in the long term; as a result, high tree mortality and exacerbated ecological degradation are occurring (Cao, 2008). Due to the many components of ecosystems, the complex changes of internal and external conditions, and the even more complex human–nature interactions (Byers et al., 2006; Moran et al., 2007), it is difficult to achieve the goal of restoring the original ecosystem conditions.

Because of the severity of the environmental problems that China faces and the large sums of money being spent to solve these problems, it is necessary to understand the unexpected negative effects caused by restoration measures that have not fully accounted for the complexity of ecological restoration. The purpose of ecological restoration is to reverse degradation processes and restore ecosystems to something near their original stable state: a healthy and sustainable ecosystem. However, understanding the complexity of ecological restoration requires planners to deal with issues ranging from natural systems, such as the atmosphere, hydrosphere, and lithosphere, to human society, so they can benefit both nature and human society.

When we perform ecological restoration, it is clearly necessary to consider internal factors, such as vegetation patterns, the species composition, and soil conditions, that have been adversely affected. But it is also necessary to consider external factors as such climate, precipitation, and human interventions resulting from rapid population increases, industrial development, urbanization, deforestation, afforestation, and grazing (Loehle, 2004; Proulx, 2007). In this paper, we have analyzed the causes of unsatisfactory restoration efforts from the perspectives of nature, society, and the relationships between them. Based on this review, we propose

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future perspectives that may solve these problems and increase the likelihood of successful restoration.

1. The problem with simplistic solutions: an afforestation example

Afforestation is generally considered to be an excellent way to restore degraded ecosystems, but it is simplistic to assume that afforestation will only have good consequences. For example, Arora and Montenegro (2011) showed that afforestation can lead to climate warming, especially at higher latitudes. This can increase the difficulty of restoration if the goal is to rebuild a system that resembles the pre-disturbance state (Hilderbrand et al., 2005). The consequences become even more difficult to predict when planners choose non-native species or species that are poorly adapted to the conditions at degraded sites, particularly when this leads to monocultures or highly simplified ecosystems. In both cases, early growth of the new vegetation may be promising, but subsequent performance may be disappointing, and it may be impossible to achieve a nearly natural ecosystem within a reasonable time frame; a better strategy would be to choose a mixture of plant species that are adapted to the ecological conditions and that increase the likelihood of creating an ecosystem sufficiently diverse to survive and grow more complex in the long term (Cao, 2008; Hilderbrand et al., 2005).

Afforestation is also a popular approach to improve water conservation, drought resistance, and flood control in degraded land (Farley et al., 2005; Liu et al., 2008). However, trees tend to have low water-use efficiency compared with other vegetation, and may therefore be an inappropriate choice under certain climates. Recent studies have indicated that afforestation may be inappropriate for some types of degraded land (Cao, 2008; Laurance, 2007). For example, there is insufficient precipitation to sustain trees in most of arid and semiarid northern China, particularly where evaporation and transpiration rates are high (Wang et al., 2010). To sustain tree growth, the roots exploit and deplete the limited soil water in surface horizons, and eventually penetrate deeper than the roots of other vegetation; if the trees deplete the soil moisture within the reach of other plant species, those species will have difficulty becoming established, and even established vegetation may eventually die from a lack of water (Cao et al., 2009a; Wang and Cao, 2011). The more soil water that is consumed by the trees, the higher the risk that other vegetation will die, leaving the soil surface exposed and vulnerable to desertification. In addition, the decreased sunlight under the dense canopy produced by many tree species may prevent the establishment or decrease the survival of other species, further decreasing the vegetation cover and aggravating soil erosion.

Even where water is abundant, as in much of southern China, afforestation may be a poor choice if other factors become more important constraints. For example, soil nutrition is a common limitation for trees in this region (Gao et al., 2011). One reason for choosing trees in areas with heavy rainfall is the belief that trees can prevent flooding. Although tree roots can increase infiltration of water into the soil, and can hold soil in place both in flat and sloping terrain (Schwarz et al., 2010), their ability to prevent flooding is not guaranteed, particularly after an unusually heavy rainfall (Laurance, 2007; Wang and Cao, 2011).

For these reasons, managers should carefully consider whether trees are appropriate given the climatic, soil, and other conditions at a degraded site. Alternatives, such as different vegetation types or species more suited to the site conditions, may make it easier to achieve success (Cao et al., 2011; Jiang et al., 2006). The evidence we have discussed suggests that as a rule of thumb, afforestation is not the best approach if the natural climax community of an area is not forest vegetation. It also suggests that when planning to restore a degraded ecosystem, managers should start with a clear understanding of the nature of the original vegetation community; understanding why that community survived for centuries or even millennia gives managers a chance to choose species that will emulate the original community composition and ecophysiological characteristics and greatly increase the chance of success. Understanding why vegetation began to disappear from a site is also essential; large-scale processes such as warming and drying of the regional climate may prevent re-establishment of the original vegetation community, and may instead suggest the need to support natural vegetation succession to a more xerophytic ecosystem.

Although severely degraded ecosystems may require artificial restoration, some studies have shown that degraded land that has not crossed an ecological "threshold" can self-repair if it is protected from further disturbance (Cao et al., 2011; Lamb et al., 2005). Degraded grasslands, even those that have been severely damaged by unsustainable grazing, can often be restored within one or two decades by means of grazing exclusion (Akiyama and Kawamura, 2007; Jeddi and Chaieb, 2010). Therefore, recognizing the threshold between sites that require artificial restoration and those that can undergo natural recovery is essential for determining the most appropriate approach (Bestelmeyer, 2006; Sasaki et al., 2008). In some cases, it may be difficult or impossible to restore the original ecosystem within the human lifespan, and it may be necessary to accept a different, but stable and viable, ecosystem.

2. Institutional challenges

Though scientists generally understand the consequences of ignoring natural factors and human factors, institutional factors may discourage or prevent them from applying this knowledge. For example, socioeconomic factors such as GDP growth and increased employment are the primary criteria for rewarding and promoting government officials in China (Zheng and Cao, 2011); as a result, there is a strong incentive to pursue projects and develop policies that guarantee short-term success, even if the long-term consequences are disastrous (Cao, 2010; Liu, 2010). A similar problem relates to how government departments achieve status. Departments that propose expensive, large-scale projects with large budgets often achieve higher status than those that pursue less dramatic but more effective projects. As a result, departments sometimes focus on short-term success rather than the long-term success of ecological restoration (Gong et al., 2012).

China's national forest agency assigns restoration tasks to local governments based on national plans (Guan et al., 2011). However, these plans fail to account for unique characteristics of each local environment, leading to inappropriate prescriptions. Given the massive investment in forestry reforms, and the involvement (usually uncoordinated) of several departments and levels of government ranging from the national level to the county level, local governments often receive contradictory instructions and insufficient funds to guarantee effective implementation of these projects (Wang et al., 2007).

Ecological restoration projects may be designed for implementation over a relatively short period, from as little as a few years to as long as a decade. However, restoration is a complex process that affects biomass changes, nutrient cycling, material flows, and many other ecological processes that may occur over decades and possibly even centuries, as in the case of natural ecological succession (Ehrenfeld, 2000; Harris et al., 2006). Therefore, restoration measures must be suited to the local environmental conditions over the short term, but must also account for management at later stages, many years later, to increase the chance of a sustainable and long-term success (Higgs, 1997).

3. Relationships between natural and socioeconomic systems

Nature and human society are not independent. Even when the intentions of ecological restoration are good, and the restoration strategy is suitable for the environmental conditions, it is necessary to account for the socioeconomic consequences (Gong et al., 2012). Particularly in a country as densely populated as China, where economic development is proceeding rapidly, it is necessary to develop strategies that provide both ecological and socioeconomic benefits (Cao et al., 2010a). In some rural parts of China, the goods and services provided by forests are an important source of income for local people. Restoration strategies based on the protection of such resources can prevent the residents of affected areas from obtaining these goods and services. For example, after severe flooding in 1998, the Natural Forest Conservation Program prohibited logging of natural forests as a strategy to control soil erosion (Liu, 2010). Such policies will inevitably reduce the goods and services provided to the local community by forests (Wang et al., 2007). The result is an exacerbation of poverty (Cao et al., 2010b). Without a guaranteed livelihood, even local people who understand the importance of environmental protection may be unable to support this activity. In contrast, programs designed to provide a livelihood and alternative sources of income to residents affected by a restoration program can achieve both ecological restoration and socioeconomic development (Cao et al., 2009b).

Even when local governments compensate local farmers or livestock herders for their losses, large-scale conservation policies that do not adequately account for local socioeconomic conditions can produce unexpected results. For example, in the Wolong National Nature Reserve, which provides safe habitat for pandas, the local residents have divided into smaller households to receive more subsidies, which are allocated per household. The greater number of households that accompanies the reduction in household size has increased the demand for fuelwood and for the land required for house construction (Moran et al., 2007).

4. Perspectives

As the population increases, so does resource consumption. However, the carrying capacity of existing ecosystems and the recovery rate of degraded ecosystems that provide these resources and withstand the resulting stresses may be unable to keep up with the increased consumption (Cao et al., 2007). Therefore, ecological restoration is not something that will happen without accounting for the social pressures on ecosystems. When we perform ecological restoration projects, we must begin by understanding the local environmental conditions, how these conditions are changing, the economic conditions of local residents, and how these residents earn their livelihoods. Planners can then consider how their proposals will affect and be affected by each of these factors. Sometimes achieving one goal will require compromises in other goals and a strategy to compensate anyone who is adversely affected by those compromises. Finally, monitoring must be performed to learn the long-term effects on nature and society. The key principle of ecological restoration is to harmonize the ecological effects with simultaneous and future environmental and social changes, thereby benefiting both nature and society. Several strategies may increase the likelihood that ecosystem recovery and socioeconomic growth can remain in harmony:

First, the inefficient extensive type of resource consumption should be changed to more efficient intensive consumption to alleviate the pressure on ecosystems and provide sufficient time for their recovery (Cao et al., 2009b; Hilderbrand et al., 2005). For example, modern agricultural techniques (e.g., the use of inorganic fertilizer and modern plant cultivars, raising livestock in barns instead of grazing in natural grassland) can produce yields that are similar to or superior to traditional methods, but in a much smaller area and with lower environmental impacts.

Second, managers should carefully consider why degraded sites need ecological restoration. The primary reasons are to rescue endangered species, increase biodiversity, restore ecosystem functions, and enhance ecosystem services (Ehrenfeld, 2000; Hilderbrand et al., 2005). By clearly identifying which goals are most important for a given ecosystem, and identifying the steps required to achieve each goal and each component of a goal, it becomes possible to identify approaches and policies that account for the diversity of the ecological and socioeconomic constraints. Managers can then develop efficient restoration plans that minimize the investment, resource, labor, and time requirements (Higgs, 1997).

Third, successful ecological restoration requires more expertise than professionals from any one field can provide, so a multidisciplinary approach is required. At a minimum, restoration requires the combined efforts of ecologists, agronomists, economists, and sociologists. In addition, planners must identify all government departments that have responsibility for the ecological and socioeconomic systems in a project area. They can then bring these government stakeholders together to cooperatively develop an approach that takes maximum advantage of each department's expertise and eliminates the inefficiencies that occur when one department's efforts interfere with another department's efforts. This is difficult when government departments have competing goals and are rewarded more for accomplishing those goals than for cooperating. Thus, institutional change to reward cooperation will also be necessary.

Underestimating the ecological and socioeconomic complexity of ecological restoration typically leads to failures. Because researchers do not fully understand this complexity, it will be necessary to perform long-term monitoring of the changes in ecological and human communities that occur after a restoration project has been implemented. Projects that appear successful in the short term may have unexpected long-term consequences, and if those consequences can be detected early through monitoring, it will be easier to solve the problems before they become serious. In addition, external natural (e.g., climate) and socioeconomic conditions may shift over time, thereby changing their impacts on a restored ecosystem and making it necessary to both consider historical results and predict future trends. This greatly complicates the planning task. Nonetheless, only by recognizing and accounting for the complexity of ecological restoration in China will it be possible for national and local governments to develop successful ecological restoration projects.

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