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A landscape approach towards ecological restoration and sustainable development of mining areas

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ABSTRACT

Mining activities have caused severe environmental pollution and ecological degradation in China. The rehabilitation and ecological reconstruction of mine lands is a key problem for the sustainable development of the mining industry. However, the reclamation rate remains low and restoration is not complete in most areas in China. Based on an analysis of the main environmental problems in mining areas, the utilization of a landscape strategy and "natural" technology in ecological restoration of mine is suggested in this paper. The principles and technologies of restoration ecology and landscape ecology can be used in the process of mine restoration to improve restoration and assure long-term results. A multi-objective integration approach is proposed based on landscape planning for the conservation and wise use of mine lands through local or regional actions and cooperation with the goal of achieving sustainable development in the mining industry in China.

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1. Introduction

Mining activities have resulted in the most intense impact on the ecosystem in mining areas. Severe environmental damage and ecological degradation, such as air pollution, water acidification, soil quality decline, loss of biodiversity and destruction of the landscape, are very common in mining areas. Even after mining activities have ceased, most of these effects persist over large expanses of land. In the face of increasing demands for environmental protection and ecologically sustainable development, mine land rehabilitation and ecological restoration have become a research hotspot.

In China, mining activities have caused serious environmental and ecological problems, although they have also played an important role in the rapid development of the national economy. To reduce environmental pollution and protect the ecological environment, environmental management of mining areas in China first began in the 1950s and 1960s. Since the 1980s, ecological reclamation in China has been developed rapidly (Gao et al., 1998; Cheng and Cheng, 2011), but the reclamation rates are still very low, below 20% (Li, 2006). The restoration efforts are still incomplete, and the ecosystem in mining areas is usually unstable and tends to degrade within a few years. The current restoration practices of traditional revegetation and simple combination of several engineering technologies may not assure full long-term restoration. At the same time, with the rapid economic and social development in China, there is an increase in the demand for a better living environment. Therefore, the objectives of mine restoration should not only be limited to the elimination of environment pollutions and revegetation of plants, but should include the reconstruction of the ecosystem and design of the local landscape. Comprehensive methodologies and technologies based on multiple considerations, including restoration ecology and landscape ecology, have proven to be more effective over a long term.

Ecological engineering (EE) is a scientific discipline that is aimed at applying the knowledge of natural biological systems to achieve human (industrial) objectives in a natural self-sustaining way (Kalin, 2004). Successes have made ecological engineering an increasingly attractive alternative to traditional engineering approaches. In addition, the development of landscape ecology provides a new theoretical foundation for mine restoration. The landscape approach could provide mechanisms for applying integrated ecosystem-based restoration on all scales, from local to regional. Because landscape approaches are more cost effective and eco-friendly and provide integrated environmental benefits, they are conducive to the long-term management of the post-mining areas.

With the development of Remote sensing (RS) and Geographic Information System (GIS) technologies, there are now quantitative methods to evaluate the evolution process of the local landscape

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(Menegaki and Kaliampakos, 2012). Many landscape metrics have been proposed that can quantify landscape patterns or characteristics. Ecological suitability and landscape pattern characteristics can be studied by applying the principles and spatial pattern analysis methods of landscape ecology (Qi et al., 2009). Such methods and tools could be used to evaluate the restoration of the mining areas, which in many areas is difficult by traditional methods.

In this paper, the environmental and ecological problems around mining areas in China are analyzed. To prevent environmental pollution and ecological deterioration in mining areas and promote mine restoration, multiple methodologies and technologies should be used. We discuss the application of the ecological engineering and landscape approach in the whole process of the ecological restoration of mining areas. The concept of ecosystem services (ES) is applied in the evaluation of the restoration of mining areas from the perspective of sustainable development.

2. Ecological environmental problems in mining areas

Mining activities cause serious environmental disturbances, including environmental pollution and ecological degradation (Jia et al., 2001). For effective restoration planning, which involves maximizing the overall success of restoration efforts and minimizing costs, a comprehensive understanding of the environmental problems and the complexity of the ecological process in mining areas is necessary. Mining areas vary depending on the different types of mineral resources and mining methods, which may lead to different environmental problems. Here we will focus on the primary ecological processes that should be taken into consideration for the restoration of mining areas, rather than the particular details of each specific case study.

2.1. Land damages

Because mining resources are often deeply embedded, in addition to the land damage caused by improper excavation, a large amount of waste rocks and tailings are deposited at the surface. Degraded waste land produced by mining activities typically consists of: stripped areas (59%), open-pit mines (20%), tailings dams (13%), waste tips (5%) and land affected by mining subsidence (3%). During surface mining, 2–11 times more land is degraded than by underground mining (Miao and Marrs, 2000). The land-use types are changed greatly and irreversibly by mining activities. The deserted lands, such as abandoned waste dumps, abandoned pit mines and tailings wasteland, usually lose their use value and become inhospitable to vegetation due to their poor water holding capacity and limited capability to supply nutrients. It is estimated that mine use in China is more than 1 hm^2 per thousand tons (Dai, 2010). Because the shortage of useful land is a very serious problem in China, the rehabilitation of these lands is most urgent. Moreover, the rocks and tailings are unstable and may release toxic pollutants to surrounding areas. The geochemical properties of mining tailings, such as their low pH, toxic heavy metal concentrations and low organic matter content, result in the destruction of soil structure, sharp reduction of vegetation cover and a loss of biodiversity, all of which impose ecological risks to the surrounding areas and health risks to humans.

2.2. Environmental pollutions

In the process of mining and smelting, various pollutants are diffused into the adjacent environment, which leads to the pollution of water air and soil (Zhang et al., 2012). Air pollution, water acidification and soil quality decline are common in mining areas. In addition, large amounts of solid wastes are produced and deposited in the surrounding environment. Even when mining activities have finished, the effects of all of these pollutants and the geological hazards of the mining legacy will persist for a long time.

2.3. Eco-system degradation

Nowadays, mining activities cause ecological disruption and degradation in many mining areas. Ecosystem disruption results in a breakdown of the structure and function of the ecosystem, degrading the ecological characteristics that compose the ecosystem components and processes in mining areas. Vegetation destruction, water loss, soil erosion and desertification are very common in mining areas, which greatly deteriorate natural habitats. Thus, the biological populations and species are reduced dramatically, and the loss of biodiversity intensifies with the destruction of structure and function of the ecosystem.

2.4. Landscape damages

The original landscape of mining areas is altered extensively by the search for natural resources. Mining usually involves either open-pit mining or underground mining. Open-pit mining clears the entire land surface and greatly damages the landscape (Slonecker and Benger, 2001). Underground mining extracts minerals from below the surface and leads to the displacement, deformation and destruction of the fractured cover. In the process, new geomorphologic forms, such as collapses, fractures and slope, appear on the mining land. Furthermore, deforestation, land damage and tailing piles are inevitable consequences of mining activities, which greatly change the landscape pattern and increase fragmentation. Both the spatial pattern of the ecological system and the ecological process are affected adversely.

3. A landscape approach toward ecological restoration of mining areas

As discussed above, environmental problems in mining areas are very serious and complicated. Accordingly the restoration processes are time-consuming and difficult. Although it is widely accepted that the mine land rehabilitation and ecological reconstruction are critical for the sustainable development of mines, the theoretical basis and practical technologies to meet people's higher requirements for the environment are still to be developed.

Ecological restoration aims at reconstructing the structure and function of the ecosystem, with the ultimate aim of restoring it to a stable and self-sustainable state. This means that the mining area should be considered on a large spatial scale, i.e., from the ecosystem of the local landscape to the regional scale. In addition, following the mineral extraction activities, besides the environmental damage, mining activities result in a series of ecological, social and economic issues. Thus the ecological restoration in mining areas does not only mean the reconstruction of the ecosystem but should also include the restoration of ecological processes and enhancement of ecological services as well as social and economic development.

Landscape ecological restoration includes ecological design and landscape design, with a focus on spatial heterogeneity and ecological integrity. From an analysis of the causes of mine ecological degradation and the self-regulation of the ecosystem, the original landscape elements are regrouped and new elements are designed to increase the matrix heterogeneity and stability of the ecosystem. This includes the suitable adjustment or reconstruction of the landscape pattern to improve the overall ecological function. Human restoration techniques could be applied to promote this process and improve the environment of mining areas.

In the following section, we discuss three steps, including preparation, planning and evaluation that illustrate the application of

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