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Forest Restoration in China: Advances, Obstacles, and Perspectives

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ABSTRACT

Because of the prolonged history of disturbance caused by intense human activities, restoration in China has been a major task facing many ecologists and land managers. There are six major forest types in China: cold temperate coniferous forest, temperate coniferous and broad-leaved mixed forest, warm temperate deciduous broad-leaved forest, subtropical evergreen broad-leaved forest, tropical rainforest and monsoon forest, and Qinghai-Tibet Plateau alpine vegetation. All of them suffer from degradation due to human interference and various methods and specific techniques have been applied in their restoration. As ecology research on succession is maturing and theories and models on restoration are becoming established, restorationists and ecologists are optimistic. In addition to reporting on the history and progress of forest restoration in China, this article describes its obstacles and future perspectives.

Keywords: forest types, restoration obstacle

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INTRODUCTION

Based on the six national surveys of forest resources during 1950-2003, the coverage of China's forests increased from 8.6% in the early 1950s to 18.2% in 2003 (Zhang 2006). During the same period, the stock of timber in China's forests increased and the structure and functions of forests gradually improved. China has the largest artificial forested area in the world. As of 2003, China's forest cover was 175 million ha, of which 94 million ha were natural forests and 53 million ha were artificial forests (SFA 2005). The percentage of artificial forests increased from 4.5% to 33.8% during 1950-2003 (Zhang 2006). In the latest survey in 2003, timber stocks were 12.456 billion m^3, of which 1.505 billion m^3 were from the artificial forests. China's per capita forested area, however, was only 0.132 hectares, less than one-quarter of the world average (SFA 2005). Further, the distribution of these forests is highly uneven, with forest coverage in 2003 of 34.3% in east China, 27.1% in central China, and 12.5% in western China (Zhang 2006).

At present, less than 5% of China's natural forests are estimated to be free of human disruption, while the rest are mainly secondary forests (Ren *et al.* 2007b). The artificial forests have some undesirable characteristics such as low diversity of native tree species, poor structure due to extensive planting of fast-growing coniferous and exotic species and overuse of ornamental species rather than the functional species (especially in urban greening), lack of mature trees, low ecosystem heterogeneity, frequent outbreaks of insect pests and diseases, low soil fertility. Planted species in artificial forests are mainly selected to produce timber with higher yield and productivity and lack of original endemic,

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Invited Review

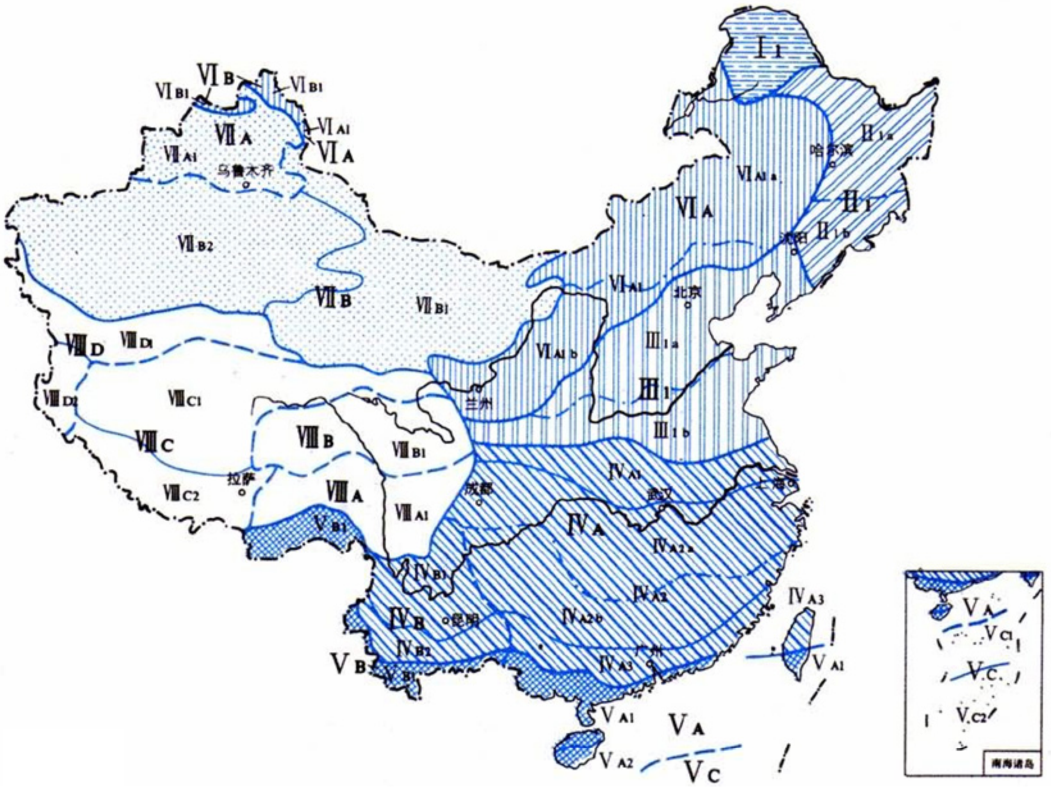

Fig. 1 The distribution of major forest types in China. I: Cold temperate coniferous forest, II: Temperate coniferous and broad-leaved mixed forest, III: Warm temperate deciduous broad-leaved forest, IV: Subtropical evergreen broad-leaved forest, V: Tropical rainforest and monsoon forest, VI: Qinghai-Tibet Plateau alpine vegetation. Revised from the Editorial Board of Vegetation of China (1980).

rare, and endangered species (Li and Xie 2002; Li 2004a; Ren and Wang 2007).

To improve the conditions in the artificial forests, China began managing its forests according to the forest classification in 1995, which is based on the comprehensive charactoristics of forest such as plant species compositions and associated environmental factors. Since then, an important goal of forest restoration and management has been the reconstruction of near-natural forests and the acceleration of the rate at which artificial forests succeed to regional natural forests. Research in forest restoration and management is now recognized as essential for sustainable forest development in China (Zhang *et al.* 2000).

Restoration ecology began in the 1980s and has developed rapidly by integrating theory and practice for the ecological restoration and reconstruction of degraded ecosystems (Jordan III *et al.* 1987; Hobbs 2005). The Society of Ecological Restoration International has proposed a preliminary framework for restoration ecology (SER 2004). Currently, the main theories or concepts in restoration ecology include applications of succession theory, design and self-design theory, assembly rules, adaptive restoration, reference ecosystem, novel ecosystem, biotic and abiotic barriers to restoration processes, and restoration threshold (Ren and Wang 2007; Suding and Hobbs 2009). According to these theories, ecosystem restoration should be achieved in a step-by-step manner by overcoming abiotic and biotic barriers or obstacles to succession (Whisenant 1999). Important abiotic barriers include poor soil and microclimate. Important biotic barriers concern the difficulties in establishing desirable plant species and especially the difficulties resulting from inadequate seed sources. Seed sources are always the primary limiting factor for species settlement. Once these barriers on establishment are overcome, the community or ecosystem will be able on its own to succeed to more natural stages.

Using a restoration ecology perspective, this paper focuses on forest degradation and restoration research and practice in China. It reviews the major forest types in China, the mechanisms of their degradation and restoration, and the problems associated with seed establishment in forest regeneration or recovery. The future directions of forest restoration research and practice are also discussed.

MAJOR FOREST TYPES AND THEIR DEGRADATION DUE TO HUMAN INTERFERENCE IN CHINA

According to the book "Vegetation of China", which was published in 1980, China has six major forest types (**Fig. 1**): cold temperate coniferous forest, temperate coniferous and broad-leaved mixed forest, warm temperate deciduous broad-leaved forest, subtropical evergreen broad-leaved forest, tropical rainforest and monsoon forest, and Qinghai-Tibet Plateau alpine vegetation (Editorial Board of Vegetation of China 1980; Hou 2001). Plant ecologists have also described and clarified the ecosystem types remaining after human interference caused the degradation of the major vegetation zones in China, but most of this research has been published in Chinese (Editorial Board of Vegetation of China 1980; Chen *et al.* 1995; Ren *et al.* 2007b).

The native vegetation in the cold temperate coniferous forest zone is *Larix gmelimii*. The *L. gmelimii* forest has a relatively simple structure, and after disturbance it will degrade into one of the following kinds of forest: *Quercus mongolica*, *Betula platyphylla*, *Betula davidiana*, or *Populus davidiana*. With further disruption, it may degrade into *Corylus heterophylla* bush. After degradation, the recovery rate (the rate at which the original forest reappears) for this kind of forest is slow (Zhang *et al.* 2008).

The native temperate coniferous and broad-leaved mixed forests are mainly composed of *Pinus koraiensis*, *Tilia amurensis*, and *Betula costata*. These could form different forest types under different disturbance intensities. After intensive interference (such as high-intensity selective logging), the original forest could become a broad-leaved mixed forest or a *Quercus mongolica* forest, which could further degrade into grassland after burning. This grassland can naturally succeed to a mixed forest of *Populus davidiana* and *Betula platyphylla*, and then to a regional climax community, i.e., a regional natural forest. If clear cut, the regional natural forest could turn into a shrubland or grassland, which can naturally succeed to a broad-leaved mixed forest or a *Quercus mongolica* forest. The restoration process will be long if the native vegetation is degraded into grassland (Liu and Ma 2003).

Warm temperate deciduous broad-leaved forests were distributed in the same areas where civilization developed in Chinese. This type of vegetation has been greatly altered in China because of repeated human interference throughout the country's history. The main native vegetation types in this area are *Quercus liaotungensis* forest, *Quercus aliena* forest, *Quercus aliena* forest, *Quercus variabilis* forest, *Pinus tabulaeformis* forest, and *Platycladus orientalis* forest. If they are degraded but then allowed to recover, these original forests could succeed into *Populus davidiana* forest, *Betula platyphylla* forest, *Robinia pseudo-acacia* forest, and *Prunus armeniaca var. Ansu* forest. With further degradation, the natural forests or plantations are replaced with *Vitex negundo* bush, *Ziziphus jujube* bush, *Spiraea chinensis* bush, *Corylus peterophylla* bush, *Lespedeza bicolor* bush, and *Cotinus coggyria* bush. If the bush or shrubland is further degraded, these shrubs are replaced by grasses, e.g., *Themida triandra*, *Cymbopogon tortilis*, *Arundinella hirta*, *Zoysia japonica*, *Bothriochloa ischarmum*, and *Artemisia* spp. (Sun *et al.* 2004). The region of the warm temperate deciduous broad-leaved forests is also covered with large, artificial, monospecific commercial forests of *Phyllostanchys*, *Camellia*, *Liquidambar*, *Pistacia*, etc.

The subtropical evergreen broad-leaved forest covers about 25% of China's land area and is dominated by unique Chinese evergreen broad-leaved tree species, such as *Castanopsis*, *Cyclobalanopsis*, *Lithocarpus*, and *Quercus* of the Fagaceae family; *Phoebe* and *Machilus* of the Lauraceae family; and *Schima* of the Theaceae family. These forests are experiencing severe human disturbances. With moderate interference, these forests degenerate into coniferous broad-leaved mixed forest. Greater interference can produce a *Pinus massoniana* forest. If interference continues, the area occupied by the original forest will degenerate into bushland of *Loropetalam* spp., *Rhodomyrtus tomentosa*, *Baechea frutescens*, *Vitex negundo*, *Myrsine africana*, and *Rosa cymosa*. With further interference of the shrubland (by fire, for example), the shrubland will be replaced by *Imperata cylindrinca var. major* shrub-grassland; *Pteridium aquilinum var. latiusculum* shrub-grassland; *Dicranopteris dichotoma* shrub-grassland; *Arundinella hirta*, *Eulalia speciosa*, and *Miscanthus sinensis* shrub-grassland; *Miscanthus floridulus* shrub-grassland; or *Neyraudria reynaudiana* grassland. These degraded systems can be easily and rapidly restored (Song *et al.* 2005).

Tropical rainforests and monsoon forests in China are small and mainly composed of *Bombax malabarica* and species of *Ficus*, *Albizzia*, *Terminalia*, *Vatica*, *Parashorea*, *Horsfieldia*, *Burretiodendron*, and *Terameles*. After being slashed and burned, these forests become communities composed of *Dendrocalamus stricfus*, *Musa balbisiana*, *Macaranga denticulate*, and *Ficus* spp. With serious degradation, the area can become a shrub-grassland composed of *Erianthus*, *Aphluda mutica*, and *Melastoma candidum* (Zang and Ding 2009). By use of effective artificial methods, these degraded communities can be restored (Ren *et al.* 2008c).

The vegetation of Qinghai-Tibet Plateau alpine natural forests consists mainly of *L. griffithii* forest. After logging and fire, this forest usually changes into a *Populus davidiana* forest, a *Betula platyphylla* forest, or a *Pinus densata* forest. Further interference can generate a bushland consisting of *Rosa sericea* and species of *Cotoneaster*, *Berberis*, and *Salix*. If the disturbance is severe, the forest will transform into a meadow of *Kobresia* and *Carex* spp. (Chen *et al.* 1995).

In addition to the above six forest communities, mangroves occupy 25,000 ha in tropical and subtropical coastal areas of China. These mangroves can be degraded into bare beach, which is difficult to restore (Ren *et al.* 2008a; Chen *et al.* 2009; Ren *et al.* 2009).

Before severe human disturbance, forests in China formed continuous vegetation belts, mainly controlled by the latitudinal gradients of temperature and precipitation. As a result of human interference, the belts have been to a lesser or greater extent displaced, and the regional vegetations within the belts now consist of retrograde succession or restoration landscapes. It is worth noting that there are unique restoration mechanisms for three of the forest types (the warm temperate deciduous broad-leaved forest on the Loess Plateau, the subtropical broad-leaved forest in typical red soil zone, and the subtropical and tropical vegetation in the Karst region). These unique restoration mechanisms result from the special characteristics of soils in these forests.

Forest degradation in China has largely resulted from human activity but has also resulted from natural disturbances (Yu and Peng 1996; Wang *et al*. 2005; Yin 2009). The main human causes of forest degradation include over-harvesting of timber and fuel wood, deforestation for farmland, and bio-industry development (Xu *et al*. 2006). The most important natural disturbances are invasion by exotic species, fire, flood, snow, and earthquake. The process of forest degradation is determined by the intensity, duration, and scope of the interferences, and the degree of degradation can be classified as extreme, moderate, and mild (Ren *et al*. 2007b). The degraded forest ecosystems are characterized by change in species composition, change in community or system structure, loss of biodiversity, reduction in biological productivity, degeneration of soil and micro-environment, change in relationships between organisms, and decreased ecosystem services (Chen *et al*. 1995). The process of natural succession is very slow, and succession of a degraded ecosystem to a climax vegetation community may take several hundred years. A current and essential goal for ecological research and forest management is to increase the rate at which degraded ecosystems succeed to reconstructed regional forests that are rich in biodiversity and that provide essential ecosystem services (Chen *et al*. 1995; Li 2004a; Ren and Wang 2007).

RESEARCH PROGRESS ON FOREST RESTORATION

The study of forest restoration in China has always been integrated with the development and implementation of forestry practices (He *et al.* 2007). In 1958, Chinese government proposed a program named "Vegetation Transforms the Nature". China had carried out the following six major forestry projects. 1) The Natural Forest Conservation Program (NFCP), also known as the Natural Forest Protection Program (NFPP) conserves natural forests through logging bans and forestation with incentives to forest enterprises. 2) The Key Shelterbelt Construction Program (KSCP) mainly focuses on how to reduce sand storms, soil erosion, and other ecological problems in Northeast, Northwest, and North China. 3) The Grain to Green Program (GTGP, also known as the Sloping Land Conversion Program and the Farm to Forest Program) focuses on reducing soil erosion. The GTGP converts cropland on steep slopes to forest and grassland by providing farmers with grain and cash subsidies. Extended payments for the GTGP have recently been approved by the central government for up to 8 years (Liu *et al*. 2008). Other programs included 4) the Beijing-Tianjin Sandstorm Control Program (BTSCP), 5) the Wildlife Conservation and Nature Reserve Development Program (WCNRDP), and 6) the Fast Growing Timber Forest Base Program (FGTFBP) in key areas. These six programs encompass 97% of China's counties. The implementation of these programs is a milestone of China's forest management; it marks the end of an era dominated by timber production. In addition, China has also undertaken a number of targeted forest restoration projects, such as the restoration of abandoned mining areas, urban forestry, post-disaster (snow storms, earthquakes, fires, floods) reconstruction, and other forest restoration projects. Because implementation of these projects varies according to land type and forest type, we will now describe these restoration practices by ecological region and forest type.

Restoration of evergreen broad-leaved forests

The evergreen broad-leaved forest is the regional vegetation in subtropical China. Substantial research has been conducted on these forests and especially on floristic composition, species composition, and ecological physiognomy, structure, dynamics, and functions. Field research and restoration stations were developed in evergreen broad-leaved forests on Jinyun Mountain in Sichuan Province, Tiantong Mountain in Zhejiang Province, Dinghushan Mountain and Heishiding in Guangdong Province, Ailao Mountain in Yunnan Province, and Wuyi Mountain in Fujian Province (Peng 1996; Wang *et al.* 2007b). Research on the succession of evergreen broad-leaved forest includes studies of system structures (measurement and simulation of diversity or community composition) and studies of system functions (measurement of material and energy flows and cycles). Understanding community succession mechanisms, i.e., understanding how plant communities regenerate, also requires the measuring of seed rain and seed bank dynamics, seed germination, and temporal and spatial dynamics of seedling growth. It is also essential to study the formation and characteristics of forest gaps and the role of gaps in forest dynamics. More studies investigate the ecophysiological characteristics of the dominant species in these plant communities (Peng 1996; Ding and Song 2004; Song *et al.* 2005).

To understand the degradation and reconstruction of the evergreen broad-leaved forest, researchers have studied the forest's stability and the factors that can speed up or slow down the succession process (Peng 1996). Others investigate the characteristics of a variety of degraded ecosystems and recovery processes, and the mechanisms underlying the forest's establishment. Researchers have also created models of the evergreen broad-leaved forest degradation that incorporated theories and techniques used in the restoration and rehabilitation of degraded ecosystems (Ren *et al.* 2007b). In extremely degraded evergreen broad-leaved forests, this research determined that the most important restoration obstacle is the harsh physical environment (Ren *et al.* 2007b). In moderately degraded forest, the main obstacle is the lack of native seed sources. Additionally, poor establishment of native species is also an important obstacle (Angel *et al.* 2006; Chen *et al.* 2008; Duan *et al.* 2008; Wang *et al.* 2009a, 2009b). Using nurse plant theory, however, research has determined that native tree species can be artificially introduced to accelerate the restoration process (Yang *et al.* 2009a, 2009b).

Degraded evergreen broad-leaved forests differ depending on the nature and severity of human interference. Some degraded forest communities that have high species diversity and unique species compositions make an important contribution to the maintenance of regional species diversity. The sprouts of evergreen tree species play an important role in the structural dynamics of the degraded community (Wang *et al.* 2005). In the restoration of evergreen broad-leaved forests, the characteristics, structures, and competitive pressures as well as the ecophysiological characteristics of the dominant species are all optimized. Soil fertility, soil organic matter content, and other soil physical and chemical properties are also optimized (Li *et al.* 2002). Restoration research on the evergreen broad-leaved forest has also included the study of applications of 3S technology, the ecophysiological mechanisms of forest degradation, forest origin and system development, forest protection and restoration, the ecophysiology and population biology of important forest species, ecosystem services provide by the forest, a regional model of sustainable development, as well as the roles and response mechanisms of this forest in global climate change (Ding and Song 2004; Song *et al.* 2005; Ren *et al.* 2008b).

Forest restoration in the Karst region

Karst rocky desertification involves transition from climax vegetation to shrub-grassland and then to stone desert. In the degradation process, the environment created by Karst rocky desertification leads to the coexistence of calcicolous, drought-tolerant, and rupicolous plants and to the local extinction of shade-tolerant species (Su and Zhou 1995). Degradation is strengthened by positive feedbacks between vegetation, soil properties, and environmental properties characterized by consistency in degradation direction, non-synchronous degradation processes, and non-linear degradation rates (Lu 2007). For restoration of Karst vegetation, different strategies have been applied at different restoration stages, i.e., a renovation strategy in the early stage, a structural adjustment strategy in the midterm stage, and a structure-and-function coordination strategy in the late stage (Yu *et al.* 2000). Karst ecosystem restoration technologies include natural restoration, artificial restoration, and comprehensive management of agro-forestry. The key object of Karst restoration is the optimization of the man-land ecological-economic system. Understanding the processes and mechanisms of Karst rocky desertification and restoration are essential for successful restoration and management of this ecosystem (Su and Zhou 1995; Liu 2005; Ren 2005).

Forest restoration in mountainous regions

Large areas of China's mountains contain fragile ecosystems that suffer serious soil erosion due to reclamation and deforestation. According to the CNKI database, over 82 papers on mountain forest restoration have been published, mainly focused on the vegetation types in the Yanshan Mountains and Taihang Mountains in North China, and on the restoration of plant biodiversity in natural succession (Zhao 2007a, 2007b). Other research has concentrated on the regional- or provincial-scale forest restoration in the East Liaoning Province (Yang 2006), Shandong Peninsula (Wang 2005), Southwest Sichuan (Fei 2004), Hebei Province (Yan *et al.* 2008), and the middle to upper reaches of the Yangtze River (Liu 2002). In most cases, related research is aimed to the return of farmland to forest using forest restoration principles (Li 2004b; Yu *et al.* 2005). Bao and Chen (1998) summarize the basic theories of mountain vegetation restoration and reconstruction, and the methods in evaluation, decision making, tool species selection, and plant communities' design, implementation, monitoring, and optimization.

Forest restoration in dry-hot valleys

The plant species and soils are unique in the dry-hot valleys of China (Zhu *et al.* 2008), where environmental stress and plant resistance are important factors affecting the stability of the community structure and ecosystem optimization. In the Jinsha River dry-hot valley, which has suffered from land degradation, there are two major ecological and environmental issues, desertification and water scarcity. Soil properties and soil moisture are different in various degraded soils (Huang *et al.* 2001; Zhang *et al.* 2002). While local relations between vegetation and environmental factors are important (Lang 2005), restoration at the landscape scale should also be considered (Yang *et al.* 2007; Zhou *et al.* 2008). Specific restoration models for different types of rocky soil, and key technologies in micro-water afforestation, have been proposed and successfully applied in this region (Xiong *et al.* 2005; Li 2008).

Forest restoration in the Loess Plateau

Forest cover was much larger in the Loess Plateau in Northwest China in the past, but the area now suffers from serious soil erosion due to human disturbances (Cheng and Wan 2002; Zhang 2007). The analyses of pollen and water availability show that the major limiting factor for forest recovery is the shortage of water (the annual average soil content water is 8%). Meanwhile, a main goal in restoration in the region is to provide sufficient ecological and economic functions to sustain the human population (Wang 2001). Vegetation restoration and reconstruction should aim to establish artificial vegetation types adapted to the environment especially limited water supply (Dong *et al.* 2006). The local governments' plans for restoration include four methods; i.e., all rainfall should be retained and infiltrated into local soil, rice and grain should be planted on the terrace and flat plateau land, forest and fruit trees should be planted in the gullies and ravines, and grass and shrubs should be planted on the slopes (Zhu 1995). In forest restoration, it is necessary to native plant species that are most suitable to local habitats and also to continue to protect the restored forests. Vegetation restoration and reconstruction will often differ in different regions so as to achieve positive interactions between soil and vegetation (Ma and Jiao 2004; Zhang *et al.* 2004). In general, the dominant vegetation has gradually changed from bushes and trees in the southeast to shrub-grass in the northwest. Restoration of vegetation, revegetation, and vegetation protection should complement each other (Hu and Zhu 2005).

Forest restoration in the eroded red-soil area

Red soil is the common soil type in South China where erosion may occur rapidly when vegetation is absent (Zhang 1999). In such soils, species dominance is often related to the degree of degradation (Zhang and Gong 2003). The relationships between the biological traits of the dominant species in different communities and their adaptability to the environment have been documented. New methods to overcome the limiting factors for restoration and recovery processes are proposed or established (e.g., Lv *et al.* 2003). Niu and Guo (1998) also propose principles concerning the community succession, community structure, suitability of trees to the site, biodiversity, ecosystem, combination of reconstruct and utilization, and community stability to be followed in the vegetation reconstruction process. Ultimately, vegetation restoration and reconstruction models should be established to simulate natural conditions and economic development (Zheng *et al.* 2005).

Restoration after natural disasters and mining

Ecological reconstruction after natural disasters is also a major concern in China. During January to February 2008, South China suffered the worst ice and snow storm in 50 years. The freezing rain, ice, and snow caused enormous damage to mountain subtropical evergreen broad-leaved forests and fir forests. The extent of the damage depended on tree species, tree diameter, and forest topography (Fan 2008; He *et al.* 2009; Su *et al.* 2009; Zhang *et al.* 2009). The catastrophic earthquake occurred at Wenchuan county in 2008 caused landslides, mudslides, and landslips that seriously damaged local vegetation. Under the complex conditions created by such natural disasters, the "micro-site factor vegetation restoration method" can be useful for revegetation (Tian *et al.* 2008). In addition, research has also considered forest recovery and reconstruction after major floods (Wang *et al.* 2007a) and fires and at the mining-induced degradation sites (Peng and Lu 2003; Li 2006).

General methods and specific techniques of forest restoration

Currently, the main forest recovery methods include the closing of hillsides to facilitate afforestation (natural succession), artificial reforestation (planting artificial forests consisting of single or mixed pioneer species), and artificial reconstruction (planting native species after selective logging) (Yu and Peng 1996; Yang 2005; Ren *et al.* 2007b). These methods differ in five aspects, i.e., clean-up and site preparation, forest-species selection, planting density and planting methods, the use of nurse plants, and forest management (Peng *et al.* 2007). Some specific reforestation technologies, such as the use of nutritive cups, water-retaining agents, symbiotic microorganisms, and facilitation by nurse plants, have been developed for implementing the above methods (Yang *et al.* 2009b). For example, Lai and Wong (2005) found that the combining use of tree guards and weed mats can led to significant improvement in seedling establishment of Tick-leaved oak at Hong Kong. In South China, to ensure the colonization of late-successional tree species into the degraded land, the pioneer shrub *Rhodomyrtus tomentosa* can be used as nurse plant (canopy shade effects) to increase seedling survival of zonal climax tree species such as *Michelia macclurei* (Yang *et al*. 2010). At the same time, a number of internal factors (e.g., seed characteristics and seed yield) and a number of external factors (e.g., light, litter layer, and animal dissemination) affect forest restoration and are the most important obstacles for establishment of native species during artificial forest restoration.

Socio-economic effects of forest restoration

Socio-economic effect determines the performance and future of forest conservation/ restoration programs because human activities play an essential role on both destroy and restoration of forests. Both forest degradation and restoration affects the welfare of human beings, especially the welfare of local people who used to live on forestry or sloping agriculture. Simultaneously, the welfare affect directly decide the attitudes and reactions of local people to forest management.

As well-intended as the programs are, both the NFPP and SLCP are top-down initiatives financed by the central government. They have been criticized for the problems in design, implementation, monitoring, and assessment, including shortfalls in subsidies delivered, lack of principals of volunteerism, and insufficient technical support, and budgeting for local implementation costs (Yin 2002; Xu *et al.* 2006; Bennett 2008). Some inventories have shown negative impacts of the forest conservation or restoration projects on the livelihoods of rural communities, consequent dissatisfactions, and potential risks (Liu and Yin 2004; Weyerhaeuser *et al.* 2005; Cao *et al.* 2010).

Previous studies demonstrate that integrated evaluation and integrating those forestry projects into an overall package of complementary polices aimed at the rural sectors would lead to more positive results on income enhancement, labor transfer, and cost efficiency aspects (Dong 2005; Liu 2006; Zhang 2008; Zhang 2009; Kong 2009; Liu 2009; Wu and Cai 2009). Currently, most of socioeconomic studies have concentrated on the SLCP, particularly its socioeconomic effects, i.e., the growth of income, alternative industry, employment, and likelihood of re-conversion. Future work should pay more attention to the NEPP and other programs, and the implementation effectiveness of the programs (Yin 2009).

RECRUITMENT OBSTACLES DURING RESTORATION

Forest regeneration is important in studying vegetation dynamics (Peng 1996). Inadequate recruitment is a major limiting factor in forest regeneration due to seed limitation, seed dispersal barriers, and microsite conditions (Munzbergova and Herben 2005). The process of forest regeneration consists of many stages, including seed dispersal, seed bank formation, seed germination, and seedling establishment. The seed and seedling are the most vulnerable stages in the life cycle of plants. Many abiotic and biotic factors determine the fate of seeds and seedlings and thereby influence the pace and direction of forest regeneration (Barot *et al.*

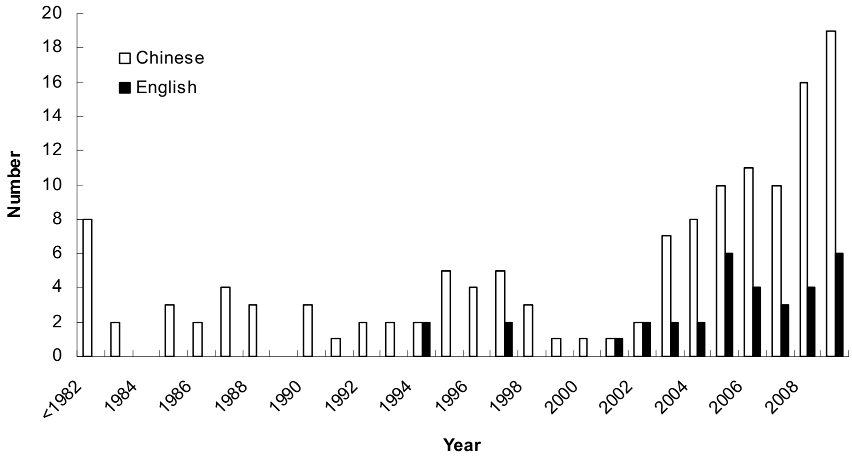

Fig. 2 The number of papers on forest degradation and restoration in China that have been published in Chinese (from the Weipu journal database) and English (from the Elsevier, Springer and John Wiley journal databases).

1999; Huang *et al.* 2001; Ren and Wang 2007; Wang *et al.* 2009b). Considering these limiting factors, restoration practices have focused on disturbance history reconstruction, understory vegetation, dispersal versus recruitment limitation, environmental characterizations, vegetation composition, species richness, seed and seedling life-history traits, the timing of seed dispersal, the distance of seed dispersal, the timing of restoration activities, performance observations, experimental introductions, population ecology, community interactions, predictive models, and landscape-scale approaches (Parciak 2002; Vellend 2003; Flinn and Vellend 2005; Godefroid *et al.* 2005). Currently in China, research on forest regeneration is focused on the factors influencing plant establishment and the mechanisms for overcoming establishment limitations. To evaluate the research published in either Chinese or English, we searched the journal databases of Weipu (in Chinese), Elsevier, Springer, and John Wiley with the key words "forest degradation" or "forest recovery/restoration" and "China". The results show strong increasing trends of research publications in both English and Chinese (**Fig. 2**).

Species-attribute effects

Species attributes are key determinants of plant-establishment limitations (e.g., effects of seed size on seed survival and seedling establishment; Paz *et al.* 2005). Although larger seeds can tolerate a stressful environment for longer times than smaller seeds, the relationship between seed size and seedling establishment is not always positive because larger seed are more likely to be consumed by animals (Gray and Spies 1997; Camargo *et al.* 2002). The optimum habitat for growth may differ with the different life stages of a given plant. For example, seedling survival and establishment are often favored by high light but saplings often grow best in shady understory habitats. With woody plants that suffer low mortality after seedling establishment, seedling recruitment and establishment are the key stages that can lead to population regeneration. Establishment could be considered a form of invasion, and although both community diversity and biomass in combination are thought to enhance resistance to biological invasion (Guo and Symstad 2008), the dispersal ability and functional attributes of the introduced species were suggested as the key factors in determining invasion success (Levine and D'Antonio 1999; Levine 2000). Shade tolerance is another important attribute that can influence plant establishment (Huang *et al.* 2001).

Timing of restoration activities

According to recent research, the timing of restoration activities is an important factor influencing plant establishment (Barchuk *et al.* 2005; Cole and Lunt 2005). Vieira and Scariot (2006) found that in restoring a tropical dry rainforest, collecting seeds at the end of the dry season and planting them when soil has sufficient moisture may increase seedling establishment and reduce their exposure to seed predators. Restoration activities must take both time and life history into account. For example, germination and early establishment in the field are favored in shaded sites, but growth of established seedlings is favored in open areas. Hence, different community development stages require different management strategies. Introducing tree seeds or seedlings from a later successional stage into a degraded system containing many pioneer species is also likely to fail because the late successional species will have difficulty competing with the herbaceous understory species (Holmes and Richardson 1999). In such situations, intensive nursing and management will be required. In pioneer plantations with simple structure (usually with low species diversity), however, direct seeding of indigenous tree species in the understory may be a reliable means to accelerate the succession process to more natural stages (Guo 2003).

Effects of other biotic and abiotic factors

Resource availability, seed predation, and competition also affect plant establishment (Lenz and Facelli 2005; Dupuy and Chazdon 2008). In forests, light is a critical resource influencing plant growth and mortality. Reduced light availability may limit the establishment and spread of indigenous species in established plantations (Lichstein 2004). Guo (2003) found that regeneration of a *Fagus engleriana* forest failed because the young *F. engleriana* seedlings could not tolerate the low light condition under the closed forest canopy, even in the fertile patches on the forest floor. Drought also reduces seed germination and seedling survival (Laman 1995), and seed predation and seedling herbivory by animals can seriously retard plant regeneration (Ostfeld and Canham 1993; Edwards and Crawley 1999; Hau and Corlett 2003).

Plant interactions can strongly influence community structure and dynamics, and can also determine the presence or absence of a given species in a community. For example, nurse plants can facilitate the establishment of target species because they buffer harsh environmental conditions, increase soil water and nutrient availability, protect seedlings against herbivory, or attract pollinators (Padilla and Pugnaire 2006). The above-ground vegetation can also change the community environmental conditions, such as temperature, moisture, light availability, and soil conditions (Callaway 1995). For example, a study by Ren *et al.* (2007a) shows that indigenous tree species cannot colonize severely degraded tropical seasonal rainforests, mainly because of low soil moisture and nutrients and high soil surface temperatures in the dry season, which reduce seed germination and early seedling growth. Recent research has reported that understory vegetation can greatly affect forest regeneration and productivity by influencing plant species composition and belowground processes such as decomposition and nutrient flow. In the short term, the understory plants operate as filters that control the future forest composition, while in the longer term, they serve as major drivers of soil fertility and thereby influence nutrient availability and plant growth (Lai and Wong 2005; Nilsson and Wardle 2005; Wardle and Zackrisson 2005).

Overcoming limitations to establishment

In China, factors limiting the establishment of indigenous tree species in established plantations are currently receiving considerable attention. Most related studies have concluded that the absence of mature forest species in plantations is mainly due to the limited dispersal of native tree species (Ren and Wang 2007). Even near the edge of established, primary forests, seed dispersal of native forest species is often limited (Cain *et al.* 1998; Graae *et al.* 2003). When seeds of indigenous species are recruited, the soil and habitat conditions in the plantation are usually unsuitable. In South China, soils in plantations (even 200-year-old plantations) differ from soils in undisturbed ancient forests (Ren *et al.* 2007a). Researchers in other countries have also reported that the biodiversity and physical and chemical properties of soil in established plantations can never be restored to the pre-plantation stage (Dupouey *et al.* 2002). Such observations have led ecologists to ask whether established plantations can ever resemble the zonal primary forests, and whether human land use has simply created novel ecosystems (Flinn and Vellend 2005). To answer these questions, we require a more complete understanding of the key ecological factors that control the regeneration of native forests and the establishment and spread of natural forest species in plantations.

In the past two decades, ecologists have compared and analyzed the plant composition in primary forests and established plantations for most forest types in China, and especially for the temperate deciduous forests (Li and Ma 2003; Du *et al.* 2008) and evergreen broadleaved forests (Peng *et al.* 2006). All these studies have shown that seed arrival is the precondition for the establishment and spread of native species in plantations. At the same time, environmental conditions can suppress seedling establishment and growth (Zhang *et al.* 2005; Xiao *et al.* 2006; Li and Zhang 2007). Therefore, accelerating the succession of a plantation to zonal natural forest may require both direct seeding and management of the seedling environment (Hau and Corlett 2003).

PROBLEMS AND PERSPECTIVES IN FOREST RESTORATION IN CHINA

Forests in China have faced frequent natural disturbances and increasing human disturbances over the past 7000 years. Today, the challenges are even greater than in the past because of the accelerated climate change, changes in land use and land cover, changes in biogeochemical cycles, population growth, urbanization, as well as the loss of traditional knowledge and cultural diversity. Responding to these challenges and reversing the decline in ecosystem quality will require the restoration of forest ecosystems (Ren *et al*. 2008b). At present, it appears that the practice of restoration and forest management has preceded the research on forest restoration. For example, China has formulated and implemented a national zoning of main ecological areas and functions, and almost all of the natural forests and secondary forests have been assigned to about 3,000 nature reserves for protection. Forestry management in China is increasingly based on forest classification. The forests and plantations in the whole country are classified as either commodity production forests or ecological forests, and some production plantations will be transformed into ecological forests community by improvement and natural succession. Based on the questions generated by experiences in forest practice and management, Chinese ecologists have conducted long-term studies on seed sources, ecosystem and landscape-scale recovery models, as well as cultural and economic issues of restoration (Chang *et al.* 2007).

To date, studies on forest restoration or rehabilitation in China have dealt with most types of forests or plantations, including ever green broad-leaved forests, rain forests, defoliated broad-leaved mixed forests, eucalyptus plantations, pine plantations, poplar plantations, and Chinese fir plantations. Some types of forests or plantations, however, have not been systematically studied (e.g., economic forest, agroforest). In addition, most of the experiments on restoration practices have been scattered, fragmented, short-term, and opportunistic. Little is know about the interactive effects of factors affecting restoration. Long-term integrative studies at the level of watershed and region are scarce. A preliminary understanding of ecosystem degradation has been achieved, but the underlying mechanisms and processes of vegetation degradation remain unclear. Although all the restoration practices have significant ecological and socioeconomic consequences, they are often separately rather than jointly evaluated by ecologists and social scientists. Although social and economic consequences of vegetation restoration are receiving increasing attention due to their importance, more detailed research is still needed. Because ecosystem restoration/reconstruction affects both ecosystems and humans, treating restoration/reconstruction as a part of a complex system that integrates human and natural systems would produce new insights into management policies and impacts (Liu *et al.* 2008). Large-scale ecosystem restoration or reconstruction must be aimed to further improve the sustainable development of regional social economic systems. We believe that if properly implemented, the ongoing and planned projects and policy changes can help China and the whole world in solving the environmental problems of soil erosion, flooding, desertification, and biodiversity losses (Xu *et al*. 2006).

Most research on forest restoration has focused on identifying and overcoming barriers (such as lack of seed sources, poor seed dispersal, and unsuitable habitats). Such research has seldom systematically considered ecosystem structure, function, and dynamics during the restoration processes. Some of the research lacks a deep understanding of the reference ecosystem or of the structures, functions, and processes of the ecosystems (Ren and Wang 2007). Similarly, the research has insufficiently monitored and evaluated projects after the initial publication of the results. In particular, the ecological consequences of restoration research have not been experimentally verified.

Given the concerns about the interdisciplinary research linking restoration ecology to biodiversity, global climate change, ecosystem services, and sustainable development, it would be more meaningful to promote a more integrated subject - resilience ecology (Elmqvist *et al*. 2003; Falk *et al*. 2006). In this context, forest restoration will focus on the ecological restoration problems under global climate change, restoration at the scale of landscape, and the natural and human social and economic issues. Restoration research may shift from the goal-oriented ("restore naturalness"), static, and single-state studies using structure-based approaches with focus on a certain type of ecosystem to process-oriented, positive-feedback generating, dynamic, multistate studies using process-based approaches and multidimensional evaluation criteria (Holl and Kappelle 1999; Temperton *et al.* 2004; Andel and Aronson 2005; Hobbs 2005; Padilla and Pugnaire 2006; Wu *et al.* 2007; Hobbs *et al.* 2009).

Future research on forest restoration in China should focus on the following areas. First, more work is needed to study the mechanism of plant community degradation and restoration, and approaches to maintain system stability, with special attention to the biotic and abiotic obstacles to forest recovery, irreversible barriers to ecological restoration, and the characteristics of ecological restoration proposed by the Society of Ecological Restoration International (Ren 2009). Assessments are needed to evaluate the natural capital in ecosystems, the products and services generated by ecosystem restoration, novel ecosystems, the historic range of variation /ecological memory of degraded ecosystems, and methods to restore self-sustaining ecosystem (Ren 2009).

Second, we need to conduct integrated study of ecosystem functions and ecosystem processes at different interfaces and scales. New efforts should focus on the mechanisms and physical models of the hydrologic cycle, the transforming processes of materials in watershed ecosystems and their effects on regional environment, as well as the mechanisms of erosion on different temporal and spatial scales. More work is needed to examine the process and changes of land use; including the study of the material cycles in soil-plant-atmosphere system, the biogeochemical cycles of major elements, heavy metals and other pollutants, and their effect on the health of ecosystems and human beings.

Third, future studies should link the effects of ecosystem degradation and restoration on regional environments, and the reactions of degraded ecosystems to global climate change. More attention should be given to the integration of vegetation restoration and land-use change, the reaction degraded ecosystems to global climate change, the effects of climate change on ecosystem structure and function, and the development of adaptive vegetation restoration strategies for matching climate change and meeting social-economic requirements.

Fourth, the relationship among vegetation restoration, biodiversity conservation, natural resource utilization, and biological invasion is an important issue. Further research should link biodiversity distribution, preservation, utilization, and evolutionary mechanisms, the effects of biodiversity on ecosystem functions and stability, and conservation for endangered species, and the management of biological invasions.

Finally, the social-economic aspects of ecosystem restoration and reconstruction are also critical. Both forest degradation and restoration processes are mainly affected by human activities, i.e., over-harvesting for timber and fuel wood, and deforestation for land in the past, and forestation for efficient timber production and/or environment protection and improvement at present. Forest restoration is a typical ecological engineering with attributes in both human and natural environments. To develop new ecosystem restoration techniquesand to ensure the healthy succession of restored forests in the future, future studies are needed to link policy/law, environmental sciences, economics, and sociology. The successes of the ecosystem restoration will benefit greatly from a national network of interdisciplinary research on strategy and risk assessment, resource and ecosystem services valuation, cost and benefit analysis, measurements of strategic investments and outcomes, and measurements and balanced strategies of societal well-being over both short and long terms.

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