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The influence of soil conditions on regeneration establishment for degraded secondary forest restoration, Southern China

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ABSTRACT

To assess the impact of soil conditions on regeneration establishment we chose three diversity indexes as quantitative indicators of the understory of degraded secondary tropical forest, and selected two different function groups of species for subsequent restoration management. By applying redundancy analysis (RDA) the factors affecting understory diversity and species richness and number of different function groups were investigated. RDA showed that soil conditions had a positive effect (all contribution rates exceeded 55%) in explaining regeneration diversity, grouped species richness and number. Soil available P were the main factors affecting understory diversity and species richness, while pH value and available K were the main factors affecting species number and target species. The response of regeneration to pH value, available P and available K were different. This analysis could be used to determine suitable soil conditions for different restoration purposes. The results should be useful for effective and scientific management of regeneration restoration in the future.

1. Introduction

Tropical natural forest is one of the most important regional climax forest types on Hainan Island, China. In this area, nearly 96% regenerated as secondary natural forest after a century of timber exploitation and historical natural disturbance (Zhang, 2006; Wang et al., 2008). To meet burgeoning economic demands for timber and rubber production, extensive areas of these secondary forests have been replaced by fast-growing species such as *Eucalyptus* and *Hevea brasiliensis*, but once abandoned, their recovery is difficult. All of these human activities have caused continuing forest degradation, with a consequent loss of species diversity and ecosystem service functions (Li et al., 1999; Chen and Yang, 2001).

Enrichment of species diversity and ecological functions is very important for tropical forest restoration (Zang et al., 2005). However, the effects of different restoration approaches on the recovery of ecosystem services are little studied, despite wide recognition of the links between biodiversity, functional traits, and ecosystem services (Díaz et al., 2004). The NFPP (China Natural Forest Protection Project) played a role in restoration for a time (Zhao and Liu, 2000; Tang and Sun, 2006), but failure to recognize the importance of the tightly linked relationships between soil nutrients, regeneration establishment, species adaptability and a lack of research on secondary succession has slowed down forest recovery rates (Aide and Cavelier, 1994; Aide et al., 2000; Holl et al., 2000). The strict protection policy of the NFPP not only protected desired species but also protected stranglers such as *Merremia boisiana* and *Mikania micrantha* which have already killed large areas of the Hainan tropical forest (Hou, 2004). Moreover, the NFPP caused a series of problems for human livelihoods in forest regions (Li et al., 2008; Zhang, 2008), which has become a serious barrier to future forest development (Chazdon, 2008). Short-term solutions such as the NFPP are attractive, but forest regeneration and restoration are long-term processes that can take a century or more.

In recent years, there has been consideration of management options to accelerate recovery and restore productivity, biodiversity and other values. These have included high-density plantings of a large variety of tree species once present in the particular area, using indigenous rather than exotic species, creating species mosaics by matching species to particular sites, and planting a smaller number of nurse trees, often early successional species, to attract seed-dispersing birds. Some studies have also been carried out on the direct seeding of rain forest tree species into degraded lands (Yu et al., 1994; Goosem and Tucker, 1995; Kooyman, 1996; Parrotta et al., 1997; Miyawaki, 1999; Aide et al., 2000).

Here we propose an approach to restoration of degraded forest, based on target regeneration species selection and adaptability analysis. Using this approach we have already achieved good plantation rehabilitation results in Pingxiang, Guangxi province (Stone,

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Table 1
Stand characteristics of the early secondary forest (ESF) and near middle secondary forest (NMSF).

	Type	Location	Altitude (m)	Tree species	Tree density (no ha^{-1})	Tree basal area (m^2 ha^{-1})	Regeneration species	Regeneration density (no ha^{-1})
2006	ESF	19°08′N, 109°25′E	389	65	1644 ± 178	17 ± 1.67	61	13,547
	NMSF	19°09′N, 109°27′E	304	59	2044 ± 478	21.1 ± 4.56	63	14,234
2009	ESF	19°08′N, 109°25′E	389	67	1520 ± 135	20.2 ± 1.83	64	15,324
	NMSF	19°09′N, 109°27′E	304	62	1872 ± 237	22.3 ± 2.55	65	15,893

Note: Early secondary forest (ESF) refer to the forest restored from being destroyed for nearly 20 years; near middle secondary forest (NMSF) refer to the forest restored from being destroyed for nearly 50 years.

2009). We reviewed the ecology of regeneration of secondary tropical forest as a tool for restoring degraded lands (Vieira and Scariot, 2006), and showed that soil seed banks and forest micro environmental conditions can encourage germination of different ecotype species and their establishment in degraded land.

Species function and environmental factors were taken into account at the beginning of our restoration studies. When species richness was high in the community, dividing different species according to their structure and function became indispensable in studying function and dynamic change of ecosystems (Zang and Zhang, 2010). Long-lived tree species which can self-renew and grow continuously were regarded as "eco-renewal function species" which increase the elasticity of the ecosystem during secondary succession. Tree species with high economic value were regarded as "valuable indigenous species" which improve the economic value of the forest, and give greater economic interest to local residents, hence helping resolve future conflicts between the NFPP (China Natural Forest Protection Project) and "livelihoods".

The different roles of environmental factors, including light conditions, temperature, moisture, lianas, and leaf litter in the establishment and development of regeneration (Emborg, 1998; Molofsky and Augspurger, 1992; Hörnberg et al., 1997; Schniter et al., 2000; Ibáñez and Schupp, 2002; Isselstein et al., 2002), are a complex area and need more investigation to understand their interrelationships. In this study we used soil conditions as the sole environment variable to analyze regeneration establishment, mainly because soil conditions have a close relationship with forest succession and can reflect successional stages and provide the support matrix for species with different soil requirements (Viereck, 1966, 1970; Lloyd and Pigott, 1967). Also, each soil constituent (N, pH, and P) has a particular role in regeneration (Adedeji, 1984; Vitousek et al., 1989; Huda et al., 2009; Yang et al., 2010), and gradient analysis provides an overall picture of the contribution that each soil property makes. Pre-feasibility studies on the adaptability of regeneration to environmental gradients are important for restoration programs, but few such studies and little management activity have been undertaken previously because of the NFPP policy. In this study, we grouped different species by their ecological and economic functions, and used soil conditions as an environment variable to test the adaptability of the species groups. The objectives of this study were to determine: (1) how natural regeneration may be grouped by different standards for forest recovery and utilization; (2) how the different groups of regeneration species and their diversity responded to soil condition gradients; and (3) which were the main soil elements affecting forest regeneration establishment. Our study aimed to investigate relationships between regeneration and soil conditions and hence provide a scientific guide to species selection and repair planting in the future.

2. Materials and methods

2.1. Site description and experimental design

The study site is located in a mountainous region in the central Hainan province of south China (latitude 18°56′ to 19°29′N, longitude 109°02′ to 109°42′E, elevation 300–600 m above sea level). The region has a tropical monsoon type climate. Mean annual air temperature varies between 22.5 and 25.6 °C, and the minimum and maximum temperatures are 17 and 36 °C, respectively. Annual precipitation ranges from 1500 to 2000 mm, with an average of 1750 mm (Meng et al., 2010). The dominant parent rocks of soils in the study area are granite and sandstone, and the soil supporting the forest is primarily a mountain lateritic red earth (Jiang et al., 2002).

The study was conducted in a multistoried, multi-aged stand of early natural secondary forest. Until the 1950s the site was original tropical virgin forest with various mixes of species including: (1) stable species which cannot be replaced by other species; (2) stable species which can be replaced by other species; (3) short-cycle heliophilous species; (4) accompanying species. It was subsequently subjected to decades of creaming (cutting of big trees rather than clear cutting) for timber production. Large areas of plantations were planted in the low mountain region for economic interests, while the middle mountain region and places that were difficult for plantation management were abandoned to secondary forest succession.

The NFPP was introduced at the end of the last century, after realization of the serious problems caused by natural forest logging. It provided strict protection of both primary and secondary forests. The NFPP offered preconditions for forest restoration, but the absence of high quality individual trees (good seed sources) and valuable species (as sources of regeneration) meant that the forests declined in quality, with large areas of degradation resulting. However, the soil seed bank and soil conditions were not changed completely, making establishment of various species possible in the early secondary forest (Liu et al., 2010). Because of this, analysis of the adaptability of different types of species along soil gradients was proposed prior to the restoration.

In order to make an overall study of the degraded tropical secondary forest, two main kinds of forest types were selected based on their historical records of exploitation and restoration. One of them, early secondary forest (ESF), has restored from being destroyed nearly 20 years ago; another, always called "near middle secondary forest (NMSF)" by local people, has restored from being destroyed nearly 50 years ago. Species with different importance values appeared in both, and the regeneration layer was similar in the two forest types (Curtis and Mcintosh, 1951; Liu et al., 2010). Characteristics of the two forest types are presented in Table 1.

In each forest type, four 50 m × 50 m plots were laid out for trees (DBH ≥ 5 cm) in January 2006, and three typical 5 m × 5 m regeneration quadrats were set up near the corner and center of each plot.

2.2. Species and soil sampling

All woody seedlings between 10 and 150 cm in height were investigated and tagged in the regeneration quadrats. Seedling height, vitality, damage and species ecosystem characterization were recorded in January 2006. To investigate whether soil con-