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Relationships between functional traits and the ability of forest tree species to reestablish in secondary forest and enrichment plantations in the uplands of northern Thailand

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ABSTRACT

Many attempts to restore tropical forests at deforested lands have failed, mostly because the traits of planted species were inappropriate without information on their regeneration. Thus, a new approach for determining the ability of tree species to reestablish in degraded forest land is necessary for restoration practices. We investigated plant functional traits and the factors affecting restoration success in forest communities that had been restored both by natural regeneration and enrichment plantations, in abandoned shifting-cultivation areas within the tropical montane forests of Suthep-Pui National Park Chiang Mai, northern Thailand. Five 1-ha permanent plots (100 m $\times$ 100 m) were established in three different forest management areas: primary forest, secondary forest, and enrichment plantations. The species composition of canopy trees, regenerated seedlings, and saplings were analyzed to determine tree functional traits and the factors governing forest composition, such as the physical environment and recruitment limitation. We found that trees within primary forest tended to have relatively heavier wood and larger seeds than secondary forest species. The dominance of certain species in primary forests was significantly correlated with wood density and seed size, although the correlations in secondary forests and enriched plantations varied among stands. The seedlings of the species with high leaf toughness, large leaf mass area, and wood density tended to be more sensitive to environmental conditions. Species with larger seeds tended to have a more limited recruitment, suggesting that enrichment plantations were more suitable for the establishment of these species. Our results suggest that the restoration of primary forest by natural regeneration is difficult because it is prevented by both environmental conditions and recruitment limitation. The contribution of these factors was species-dependent, which could be partly predicted by their functional traits.

1. Introduction

Forest restoration, defined as the process of assisting the recovery of a forest ecosystem that has been degraded, damaged, or destroyed, is an intentional activity that initiates or accelerates the recovery of a forest ecosystem with respect to its health, integrity, and sustainability (Mansourian, 2005). In the restoration of abandoned land, natural succession processes should be effectively utilized, although the information required is not always adequate (Donahue and Lee, 2008).

Restoration following secondary succession is sometimes prohibited by environmental conditions and/or recruitment limitation (Cordeiro and Howe, 2001; Bohnke et al., 2012). Species assemblies at such sites may depend on both biotic interactions and environmental filtering acting over ecological timescales (Verdu and Valiente-Banuet, 2011). Some degraded lands have environmental conditions that prevent certain species from establishing (Hüttl and Schneider, 1998). The physical environment imposes ecological constraints that create an "ecological filter" such that species with similar ecological requirements are found in similar environments, a pattern referred to as spatial niche clustering (Carlson et al., 2010; Myers and Harms, 2011). Recruitment limitation relates to the dispersal ability of the species (Nathan et al., 2008). Generally, seed and seedling abundance is high in the vicinity of maternal trees (Takeuchi and Nakashizuka, 2007), and planting

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trees facilitates the restoration process (Moral et al., 2007), particularly when recruitment is limited.

Plant functional traits are often used as proxies to determine whether species have different ecological strategies for reproduction and resource capture (Cornelissen et al., 2003; McGill et al., 2006). Approaches based on functional traits have been used to demonstrate the importance of environmental filtering in the structure of diverse ecological communities (Webb et al., 2010; Paine et al., 2011). Thus, information regarding functional traits could be utilized in restoration practices. The functional traits of species present in a recovering community will provide information regarding the factors likely to prevent effective restoration. Some traits may relate to particular environmental constraints and/or dispersal ability, and thus recruitment limitation.

Restoration is critically important for tropical montane forest because many studies have reported the deterioration of tropical montane forests due to human activity (e.g., Chazdon, 2003; Hitimana et al., 2004; Cayuela et al., 2006; Fukushima et al., 2008). In human-dominated agricultural landscapes of tropical highland regions throughout the world, much of the original forest cover has been converted into cropland and pastures, including shifting cultivation (Mertz, 2009), resulting in mosaics of agricultural land interspersed with primary and secondary forests (Mottet et al., 2006; Calvo-Iglesias et al., 2009). The restoration of abandoned areas is now urgently required to ensure biodiversity conservation in the vicinity of such fragmented protected areas.

Tree plantation in tropical montane areas can fulfill both conservation and production objectives as part of a restoration strategy (Guariguata, 2005). Tropical montane forest succession following abandonment can provide important clues to the selection of suitable species to be planted for a given level of site degradation (Holl et al., 2000). Some mismatches between species and environmental conditions have been reported (Benayas, 2005), and thus the selection of which species to plant must be made carefully, considering both environmental conditions and the possibility for natural recruitment (Holl et al., 2000).

In northern Thailand, most of the mountainous areas, constituting the country's most important watersheds, were originally covered by lower tropical montane forest (Bunyavejchewin et al., 2011). However, shifting cultivation by local and hill-tribe people has resulted in severe fragmentation of primary forest (Barnaud et al., 2008; Fukushima et al., 2008), and large areas of degraded forestland require urgent restoration. In areas allocated for economic forestry, conventional reforestation with monoculture plantations (mostly pines) prevails. The Royal Forest Department changed its reforestation policy in 1993, and initiated a nationwide project to replant native forest tree species on 8273 km^2 of degraded forest land (Elliott et al., 2003). The project aimed to plant a wide range of native forest tree species to restore the original forest, although their ecological traits and the prevailing environmental conditions were not carefully considered (Elliott et al., 2003).

A new approach to conserve biodiversity has subsequently become the top priority in restoration management. The Forest Restoration Research Unit (FORRU) has proposed the Framework Species Method, which involves the planting of a moderate number of key tree species selected to accelerate biodiversity recovery, enhance natural regeneration, and create a self-sustaining forest ecosystem. The method has been successfully modified to restore seasonal tropical forests to deforested sites in northern Thailand's conservation areas (FORRU, 2006). For example, 37 framework species have been planted in a seasonal forest in a degraded upper watershed in Doi Suthep-Pui National Park in northern Thailand (the same protected area used in the present research), resulting in nine species that were ranked as excellent and 15 species that qualified as acceptable as framework species (Elliott et al., 2003). Several other proposals have been suggested for forest restoration practices in Thailand. One recommendation is to consider plant phenology in the selection of species used in restoration (Kuaraksa et al., 2012). Others have recommended secondary natural succession in abandoned swidden cultivation areas (Fukushima et al., 2008), or direct seeding in high and low land regions where agriculture has been abandoned (Woods and Elliott, 2004; Tunjai and Elliott, 2012). However, few evaluations have been made of species functional traits and the factors affecting the restoration process.

Our study investigated forest communities that had been restored both by natural regeneration and enrichment plantation, considering plant functional traits and the factors affecting restoration success after the abandonment of shifting cultivation in tropical montane forests. Specifically, we intended to answer the following questions. First, after agricultural abandonment, to what extent can we expect natural regeneration to occur in the forest restoration process? Second, can the functional traits of species be used to predict the regeneration success of each species in deforested sites? Third, do functional traits provide useful information that can be used to improve forest restoration management?

2. Methods

2.1. Study site

This study was undertaken in central Suthep-Pui National Park (18°47′–18°50′N, 98°53′–98°55′E), which is situated 1265–1500 m above mean sea level on Mount Pui, about 10 km west of Chiang Mai, northern Thailand. The mean annual temperature and rainfall are approximately 20 °C and 1700 mm, respectively (Kume et al., 2007). The area has two main seasons: a wet season (May–October) and a dry season (mean monthly rainfall <100 mm, November–April). The dry season is subdivided into cool–dry (November–January) and hot–dry sub-seasons (February–April) (Kuaraksa et al., 2012). Originally, the study site had been covered with lower tropical montane forest (Bunyavejchewin et al., 2011), which was cleared in the 1980s to provide land for the cultivation of cabbages, corn, potatoes, and other cash crops by local hill-tribe peoples. This information was confirmed following an interview with the national park officer. The national park office has subsequently allowed local people to continue to cultivate within the national park area, although some of these cultivated areas have been abandoned and allowed to recover to secondary forests. Some primary forests still remain in this area (e.g., Kog Ma Experimental Watershed) as scattered primary forest fragments among the secondary forests.

In the primary forests at the Kog Ma Experimental Watershed, Fagaceae and Lauraceae have the greatest dominance and species richness (Bunyavejchewin et al., 2011). The secondary forests are dominated by trees of the Fagaceae and Lauraceae together with some shrubs and herbaceous or grass species (Elliott et al., 2003). In the 1990s, the National Park Office planted tree saplings in some secondary forests (approximately 15 years old) to enrich the forests and promote restoration. The planted trees were native species such as *Castanopsis acuminatissima*, *Betula alnoides*, *Cinnamomum iners*, *Diospyros glandulosa*, and *Ternstroemia gymnanthera* (Krawsa-at, 1997).

2.2. Sampling plot selection and species composition

Field studies were undertaken from August 2010 until December 2011. Five study sites were selected. The first was in a typical primary forest (PF) in the Kog Ma Experimental Watershed area (Fig. 1). The next two were in secondary forests, which had been cultivated and then abandoned approximately 30 years previously: an abandoned area far from villages in an area that had not been