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Plant diversity patterns of temperate forests with logging and restoration practices in northwest China

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ABSTRACT

Logging and restoration practices have significant impacts on the biodiversity of forest ecosystems. We studied the plant diversity patterns in temperate forests with different logging and restoration histories: the primary forest (no logging history), the secondary forest (natural recovery after logging) and the plantation forest (human planting after logging). In 2014 and 2015, we selected 12 plots with 24 trees, 48 shrub and 48 grass-herb quadrates on the southern slope of the Qinling Mountains in northwest China. We measured tree, shrub and grass-herb species in selected quadrates. Our results showed that: (1) the diversity indexes of the secondary and plantation forests were not significantly lower than those of the primary forests; (2) the secondary forest had the highest tree and shrub species richness, followed by the low-elevation primary forest and the plantation forest respectively; (3) the high-elevation primary forest had the most unique tree and grass-herb species while the low-elevation primary forest had the most unique shrub species; and (4) compared with the primary forests, the species composition similarity indexes of the secondary forest and plantation forest had little difference. Our results indicate that primary forests play an irreplaceable role in forest biodiversity whereas secondary forests and plantation forests are still of biodiversity importance. We suggest that primary forests should be prioritized for protection while natural recovery as secondary forests in Qinling temperate region is an effective approach for maintaining biodiversity.

1. Introduction

Among ecosystems, forest ecosystems support about 65% of the world's terrestrial taxa (Lindenmayer et al., 2006) and vascular plants are bases of the species dimension in biodiversity hotspots, as they are essential to all forms of animal life (Myers et al., 2000). Human activities such as logging and restoration have significantly impacts on biodiversity and can be a major driver of change in the species composition and structure of forests (Frelich, 2002; Maynard et al., 2014). In the 1960s, many countries began to set up nature reserves to protect forests (Andam et al., 2008), and now most of global forests are secondary and plantation forests with logging and restoration (Sung et al., 2012). Therefore, it is crucial to study the plant diversity patterns after logging and restoration in forests.

With different logging and restoration history, forest biodiversity patterns are expected to be different (Liang et al., 2015). Audino et al. (2014) found that species composition in the restoration areas was progressing towards the preserved forests. Biodiversity loss from deforestation may be partly offset by the expansion of the secondary forest and the plantation forest (Barlow et al., 2007; Fischer et al., 2013; Audino et al., 2014), however changes in plant species composition have often led to alteration of plant communities associated with those primary forests (Zhu et al., 1997; Sung et al., 2012).

In China, 57% of forests are naturally generated forests and 37% are plantation forests, while primary forests only account for 6% (FAO, 2015). The Qinling Mountains lie in northwest China and is one of the most diverse and typical temperate forests. It connects the east and west, north and south, and plays a critical geographical role (Shen, 2010). Jing et al. (2008) and Peng and Wang (2009) found that in the middle of the Qinling Mountains, the biodiversity indexes of secondary forests and plantation forests were similar and there was a strong resemblance in the compositions of shrub and grass-herb species after

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40 years of restoration activities. However, more studies are needed to improve our understanding the role of logging and restoration on diversity in temperate forests in China.

In our study, we focus on plant diversity patterns in the forests with different logging and restoration histories: the primary forest (no logging history), the secondary forest (natural recovery after logging) and the plantation forest (human planting after logging). According to the intermediate disturbance hypothesis (Connell, 1978), we assume that secondary forests have the highest diversity and species richness comparing to primary forests and plantation forests. Regarding the species evenness, we assume that plantation forests have the highest evenness because of human intervention. As we deem primary forests are the climax communities of the local regions, there should be most unique and rare species in primary forests, as well as the highest trees or the trees with largest diameter-at-breast height and canopies. Since the secondary forests we surveyed are natural regrowth forests, the species composition there are supposed to be more similar to primary forests than that of plantation forests. We aim at analyzing the plant diversity patterns in there three types of forests and understanding the impacts of different logging and restoration histories on plant diversity and species compositions in temperate forests in northwest China. We hope this study could provide information for improving conservation strategies of maintaining forest biodiversity.

2. Methods

2.1. Study area

This study was carried out in three national nature reserves: Changqing Nature Reserve (CNR), Foping Nature Reserve (FNR) and Guanyinshan Nature Reserve (GNR). All of them are situated on the southern slope of the Qinling Mountains (107°17′~108°01′E, 33°19′~33°46′N) in Shaanxi province in northwest China (Fig. 1a). The elevation of the area ranges from 800 to 3071 m above sea level. This region belongs to a temperate humid region and the average annual temperature is 11.5 °C, with lowest temperature reaching −14.3 °C in January and highest temperature reaching 36.4 °C in July. The average annual rainfall is 922.8 mm. The reserves support three major forest types: conifer forest, mixed conifer-broadleaf forest and deciduous broadleaf forest (Liu et al., 2013; Zhang et al., 2013). Changqing Nature Reserve was established in 1996 and before the establishment it experienced large area of logging since 1967 (Du, 2010). Foping Nature Reserve was established in 1978 and the vegetation has been well protected since then. Guanyinshan Nature Reserve was established in 2003 and commercial logging has been banned since 1998.

2.2. Sampling scheme

In August and September of 2014 and 2015, we randomly established 12 plots on the southern slope of the Qinling Mountains in northwest China (Fig. 1a). Each plot was larger than $100 \times 100\ m^2$ with one uniform forest type. We sampled both in the low-elevation primary forest and the high-elevation primary forest since the species compositions of these two forests are different. Overall, we included four forest types: (i) the low-elevation primary forest with no logging, (ii) the high-elevation primary forest with no logging, (iii) the secondary forest restored naturally after logging, and (IV) the plantation forest restored artificially after logging. Each of four forest types contained 3 plots. Detail information of 12 sampling plots was shown in Supplementary material Table S1. In each plot, there were two $10 \times 10\ m^2$ tree quadrates for tree measuring, with one in up slope and one in low slope (Fig. 1b). Each $10 \times 10\ m^2$ tree quadrate contained two $3 \times 3\ m^2$ shrub quadrates and two $1 \times 1\ m^2$ grass-herb quadrates in shrub quadrates (Liu, 2001) (Fig. 1c). For this study, we established a total of 24 tree quadrates, with 48 shrub quadrates and 48 grass-herb quadrates. We define a woody plant with height ≥5 m as a tree, height < 5 m as a shrub and grass-herbs are non-woody plants (Liu et al., 2005).

2.3. Plant inventory

In each of the 24 tree quadrates ($10 \times 10\ m^2$), we measured all trees and recorded species, number of trees, height, canopy coverage and diameter at breast height (DBH). In each of the 48 shrub ($3 \times 3\ m^2$) and 48 grass-herb quadrates ($1 \times 1\ m^2$), we recorded species, abundance (number of individuals of each species), coverage, and plant height (Table 1). We recorded GPS-coordinates and elevation with a GPS receiver in the center of each tree quadrate, and estimated the slope degree and aspect.

2.3.1. Diversity index, species richness and evenness

We calculated Shannon-Wiener diversity index (see Eq. (1)) to show plant diversity. In each tree quadrate, 2 shrub and 2 grass-herb quadrates were combined together respectively for analysis. Therefore we had 6 tree quadrates, 6 shrub quadrates and 6 grass-herb quadrates for diversity index analysis. We used Kruskal-Wallis test and Mann-Whitney U (2-sided) tests to analyze the difference among four forest types for tree, shrub and grass-herb with SPSS 20.

$$H = -\sum_{i=1}^{S} p_i \log_2 p_i \quad (1)$$

where H is the diversity index, S is the species richness, and p_i is the ratio of the individual number of one species to the total individual number of species.

Species richness and evenness were presented using rank-abundance curves. Rank-abundance curves represent the relationship between species richness and proportion of individual species following the abundance rank sequence (Molles, 2009). Greater evenness was indicated by more gently sloped curves.

2.3.2. Species uniqueness and tree structures

We calculated the percentages of species unique to each forest type and species similarities between different forest types. The percentage of unique species (U_i) was calculated as Eq. (2),

$$U_i = i/z \quad (2)$$

where i is the number of species that is only recorded in this forest type and can not be found in other three forest types, and where z is the total number of species in this forest type. The Jaccard similarity (C_j) was used to analyze the similarity of the species composition (see Eq. (3)),

$$C_j = j/(a + b - j) \quad (3)$$

where j is the number of same species of two forests types and where a and b are the numbers of species in forests A and forest B respectively. Tree structures were represented by tree height, DBH and canopy coverage using percentage stacked column charts.

3. Results

3.1. Plant diversity patterns in the primary, secondary and plantation forests

The patterns of diversity of four forest types and three groups (tree, shrub and grass-herb) showed that the diversity indexes of the secondary and plantation forests were not significantly lower than those of the primary forests (Fig. 2). Based on a Kruskal-Wallis test, we found that the tree group showed significant difference (*p = 0.026*) in Shannon diversity index among four forest types. This was contributed mainly from the difference between trees in the low-elevation and high-elevation primary forests (*p = 0.026*) as well as trees in the high-elevation primary forest and the secondary forest (*p = 0.010*). However,