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Characteristics of the early secondary succession after landslides in a broad-leaved deciduous forest in the south Minshan Mountains

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ABSTRACT

Landslide has been recognized as the major disturbance to the natural vegetation and a key driver of the forest succession in the mountains of the Southwest China. An integrative understanding of the early succession following landslide disturbance is important to explain the formation and maintenance of the species diversity, and useful to the forest ecosystem management and ecological restoration strategies designing. To explore the characteristics of the early secondary succession on landslides, we monitored the plant community on landslides within the Longxi-Hongkou National Nature Reserve, Dujiangyan County, Sichuan Province, China. We set 64 permanent quadrats (2 m × 2 m) on two landslides with similar geography conditions formed in September 2009. Species richness, percent cover, and the height of the each vascular plants in all quadrats were investigated in each spring, summer and autumn from 2010 to 2017. Species richness, cumulative species richness, and Shannon-Weiner index were calculated to describe the dynamics of the species diversity. Jaccard similarity index and species turnover rate were calculated to describe the changes of species composition and species turnover. Our results showed that the species diversity of the vascular plants increased rapidly during the first four successional years and then slowed down since the fifth year. We found a delay effect that the increase rate of the species richness and cumulative species richness peaked earlier in landslide scale than that in 2 m × 2 m quadrat scale. Species turnover rates were high during the first two years and then decreased since the third years. Species composition of both woody and herbaceous species changed greatly during the first three years, but tended to be relatively stable since then. The leading species in the 2 m × 2 m quadrats became more and more diversified in both herb and shrub layer, and substitution of leading species was obviously observed. Our findings suggested that under the set of particular environmental conditions, e.g. a nearby rich-species pool, high precipitation, suitable soil humidity, and moderate atmosphere temperatures, a crashed plant community caused by disasters could flourish again rapidly as long as no any intense disturbances occurred. The high recruitment of the plant species on the landslides also explains partly how the rich biodiversity is formed and maintained in the study area.

1. Introduction

Forest succession is a central theme in plant community ecology, restoration ecology, and forest ecosystem management (Turner et al., 1998; Cook et al., 2005; Johnson and Miyanish, 2008; Mizuno and Fujita, 2014; Briggs et al., 2017). The process and the direction of the succession could, at least locally, reflect the sequences of colonization and extinction, and the dynamics of the species diversity and community structures of the plant community (Francescato et al., 2001; Cook et al., 2005; Zeng et al., 2014). It has long been recognized that disturbance is a main driving force for succession especially the secondary succession. Disturbance would destroy the community structures and ecosystem functions, and reduce the local biodiversity temporally (Wang et al., 2008). However, it would also break the "monopoly" of the dominant species and provide opportunities for the reorganization of the species configurations (Johnstone et al., 2010).

An integrative understanding of the vegetation succession following disturbances is helpful to explain the formation and maintenance of -species diversity and predict the potential direction of the vegetation succession (Prach et al., 2014), and is also useful to practical

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applications of the ecosystem management and ecological restoration strategies designing (Walker et al., 2009; Prach and Walker, 2011).

In recent years, the ecological role of landslides in maintaining plant species diversity is getting more and more attentions (Walker et al., 2009; Seiwa et al., 2012; Walker et al., 2013; Li et al., 2014). Succession on landslides in subtropical and humid climates is more rapidly than that in most of other primary succession (Guariguata, 1990; Walker et al., 2009), thus landslides are excellent to illustrate the succession process following disturbance (Walker et al., 2009).

Previous studies about the vegetation succession after landslide disturbance focused on the temporal and spatial changes in the vegetation cover (Myster et al., 1997; Francescato et al., 2001; Lin et al., 2005), the floristic composition (Francescato et al., 2001; Zeng et al., 2014), the interspecific relationships (Walker et al., 2010), and the biotic and abiotic factors influencing the process of the succession (Myster et al., 1997; Walker et al., 2013) by the methods of remote sensing, space-time substitution (chronosequences), or short-term monitoring. However, there is little information about the change patterns of the species diversity and species turnover on landslides during the early succession.

Oosting (1942) found that the change of the woody plant species followed a logarithmic pattern during secondary forest succession in eastern North America. However, in the Temporal Model proposed by Whittaker (1970), plant species diversity increased rapidly to a maximum in the early stage of post-fire forest succession, and then decreased slowly in later stages. Despite their different results of the changing patterns in later successional stage, the most interesting question is how the plant species change during the early succession. Is the increase rate abrupt or gradual? Is there any peak in the increase of species diversity? It is difficult to find the answers in Oosting's data because of the large time scale, as well as in Whittack's model because it was based on extensive observations and lacked the experimental data. The Biotic Model proposed by Shurin (2007) presented that species diversity is the major driver of species turnover in plant communities. The high diversity would either facilitate the colonization of new species or reduce extinction rates of extant species (Shurin, 2007). A better understanding of the species turnover pattern is central to applied issues of conservation planning and to the issues about the origin and distribution of biodiversity (Buckley and Jetz, 2008), but knowledge on this question is relatively poor especially for the early succession stage. Studies on post-fire succession showed that herbaceous plants were the principle component of the community during the initial stage of succession, with the cover and species richness higher than woody plants (Krefting and Ahlgren, 1974; Wang et al., 2004). However, it is not clear whether this phenomenon also happen in the succession triggered by landslides.

In this study, vegetation secondary succession were monitored on landslides since 2010 in Dujiangyan County, Sichuan, China. The Dujiangyan County locates in the south Minshan Mountains, which is within one of the eleven critical regions of biodiversity conservation of China (Chen, 2000), as well as within a global biodiversity hotspots for conservation priorities, the Mountains of Southwest China (Myers et al., 2000; Li et al., 2015). Landslides in this particular area provide us good opportunities to explore the mechanism of high biodiversity maintenance and the resilience of the forest ecosystems. In addition, an integrated assessment of the forest ecosystem resilience after landslide is quite useful to practical applications of the forest ecosystem management and restoration strategies designing. The aim of this study was to address the following questions:

(1) How does the species diversity of vascular plants change on subtropical landslides during the early secondary succession, and are there any general trends?
(2) What is the characteristic of the species turnover on landslides during the early secondary succession?
(3) How does the leading species change during the early secondary succession?

2. Materials and methods

2.1. Study sites

Our study was conducted within the Longxi-Hongkou National Nature Reserve in Dujiangyan County, Chengdu, Sichuan province, China (31°07–09′N, 103°34–35′E). The Longxi-Hongkou National Nature Reserve locates in the south Minshan Moutains, an important global biodiversity hotspots for conservation priorities (Myers et al., 2000; Li et al., 2015). This reserve was established primarily for the conservation of endangered wildlife (especially the giant panda) and their habitat.

The vegetation in our study area is principally broad-leaved deciduous forest. The overstory is co-dominated by *Acer* spp., *Populus* spp., *Litsea* spp., and *Corylus* spp., with the canopy density 0.5–0.7 and height 10–15 m. The shrub layer is mainly dominated by *Fargesia robusta*, a staple bamboo for the giant panda, with the cover 70–90% and height 4–7 m. The herb layer is undeveloped because of the dense upper plants, with the cover 5–20%. The climate is characterized by high precipitation (annual precipitation 1300–1800 mm), high soil humidity (the annual average relative humidity over 80%), and moderate atmosphere temperatures (mean annual temperature around 10 °C) (Chen, 2000; Zhuang and Gao, 2002).

2.2. Landslide selection and field investigation

We conducted investigations on four rainfall-induced landslides formed in September 2009 within the Longxi-Hongkou National Nature Reserve. All four landslides were triangular approximately, with the bottom width about 200 m, height about 150 m, slope 35–40° in the middle and upper part and 10–15° at the bottom. They had similar aspect (northwest), altitude (1800–1900 m), and original vegetation (broad-leaved deciduous forest) before landslide occurred (Li et al., 2014). In the middle and upper part of the landslides, all the original plants were removed, and the substrate was mainly consisted of gravels (10–100 mm in diameter) with poor sandy soil existed in the gaps between the gravels. In the bottom of the landslides, the substrate was mainly consisted of rocks (100–400 mm in diameter) with a few original individuals (such as *Acer* spp. and *Fargesia robusta*) survived. The upper part of the landslides was not stable especially in rainy seasons. To avoid the effect of the unstable substrate and residual species, the permanent quadrats (2 m × 2 m) were set in the middle of the landslides.

We set 120 permanent quadrats (2 m × 2 m) at 5-m intervals in two lines parallelled to the contour lines at the middle of the landslides. Quadrats at the both ends of the lines were at least 20 meters away from the edge of the landslide in order to avoid the edge effect. Each quadrat was fixed with four thick sticks at the four corners and enclosed with a nylon cord, and was attached with an identification tag. However, two of the four selected landslides slid again with 56 quadrats destroyed in 2012. Thus, only two landslides with 64 permanent quadrats were monitored continuously from 2010 to 2017.

Field investigations were conducted in each spring (April), summer (mainly in July) and autumn (October) since 2010. Percent cover of each vascular plant species was visually estimated to the nearest 5% (except for 1–5% and 99%), with plants less than 1% cover given a 1% value (Miles and Swanson, 1986). The height for all vascular plants were measured by tape (accurate to 1 cm) and the stem numbers of each woody species were counted for all quadrats.

2.3. Numerical analyses

Species diversity was represented as species richness (S), cumulative species richness (S'), and Shannon-Weiner index (H) (van der Maarel