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Integrating indices to evaluate the effect of artificial restoration based on different comparisons in the Wanglang Nature Reserve

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ABSTRACT

To develop the indices to evaluate the effects of artificial restoration during forest restoration, we tested the validity of indices integrated at the Wanglang Nature Reserve by studying the characteristics of an artificial forest based on different comparisons of primary forest, secondary forest, giant panda habitat, and the surrounding environment. The results indicated that the characteristics of the artificial forest and the different comparisons were well described and distinguished by the vegetation coverage, species composition and richness, community structure, tree growth status indices. The artificial forest was different from the primary forest in a number of woody plants in different layers; different from secondary forest in species richness and tree growth status; different from giant panda habitat in trees and bamboo; and different from the surrounding environment in bamboo coverage, species richness, and community structure. Meanwhile, the artificial forest had a more homogeneous tree size than the comparisons. Based on these results, we suggest that an evaluation of the effect of forest restoration should be related to specific factors, because the effects of artificial restoration differ depending on the evaluation standard. We conclude that the indices used in this study can be used to evaluate the effect of artificial restoration, which is useful for forest restoration in Wanglang Nature Reserve and elsewhere.

1. Introduction

The forest is the foundation of survival and development of humans; however, many forests have been seriously disturbed and destroyed (Chokkalingam et al., 2006; Hansen et al., 2010; Li et al., 2017b) due to the influence of human activities, such as logging (Ning et al., 2015), fire disasters (Su et al., 2015), agricultural reclamation (Li et al., 2012), and road construction (Forman and Alexander, 1998). Much effort has been made by different countries, organizations, and individuals to restore degraded forests. In China, forests have achieved sustained restoration after many years of conservation efforts. According to the results of the 8th National Forest Inventory released by the State Forestry Administration of China, the forested area has reached 208 million ha, and forest coverage is 21.63% (State Forestry Administration of China, 2015).

Artificial restoration can be used in seriously damaged areas or areas that need to be quickly restored as an important tool in forest restoration (Whisenant and Zhao, 2008). In China, the artificially forested area has reached 69.33 million ha and continues to be ranked first in the world (State Forestry Administration of China, 2015). However, debate about the effect of artificial restoration has never stopped with the increase in the artificially forested area. For example, some researchers have argued that artificial forests have ecological problems, such as poor stability, low biodiversity, and weak resistance (Zhou and Sheng, 2008; Liu et al., 2010; Chen et al., 2014). Thus, the effects of artificial restoration need to be further discussed to better understand the role of this restoration tool.

Many studies have evaluated forest restoration activities, and some indices have been developed and used (Ma et al., 2010; Gatica-Saavedra et al., 2017), such as vegetation coverage (Zhang et al., 2014; Miao et al., 2015), species composition (Lin et al., 2005; Zhang et al., 2009), community structure (Ouyang et al., 2002; Kang et al., 2017), and species richness (Palo et al., 2013; Suganuma and Durigan 2015). These studies and indices are very important and have played important roles in forest restoration. However, forests distributed in different areas may have different characteristics, so directly applying one region's forest restoration standards and indices to another region must be done cautiously. Thus, establishing the appropriate standards and developing

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the suitable indices that can be adapted to evaluate the effect of forest restoration in a given area is also needed, especially for those forests where rare species are distributed.

We carried out an evaluation on the effects of artificial restoration in Wanglang Nature Reserve, Sichuan Province, China to evaluate the effect of artificial restoration and develop evaluation indices. We focused on the forest distributed in Wanglang, there has the natural forest (Duan et al., 2014) and the artificial forest (Kang et al., 2014). In addition, Wanglang Nature Reserve is also one of the earliest giant panda nature reserves in China (State Forestry Administration of China, 2006). Many rare wild animals live in this nature reserve, such as takin, golden monkey, black bear, and tufted deer (Duan, 2014), Wanglang plays a key role in local biodiversity conservation. Thus, studies in the Wanglang Nature Reserve are representative.

Few systematic and detailed studies related to the evaluation of forest restoration have been made in Wanglang Nature Reserve, so we evaluated the effects of artificial restoration based on the indices we integrated according to the literature published, our experience, and the characteristics of the local forest, such as vegetation coverage, species composition and richness, community structure, and growth status of trees. The objectives were to: (1) describe the characteristics of the artificial forest based on the different comparisons of primary forest, secondary forest, giant panda habitat, and the surrounding environment and (2) test the validity of indices to evaluate the effects of artificial restoration. We were most interested in the woody plants in the forest, but we also paid attention to bamboo because it is an important component of local forests. We aimed to propose indices that can be adapted to evaluate forest restoration in this area. We hope this study will provide important references for forest recovery in Wanglang and elsewhere.

2. Methods

2.1. Research area

This research was carried out in the Wanglang Nature Reserve (103°50′–104°58′E, 32°49′–33°02′N), Pingwu County, Sichuan Province, China, which was established in 1963. The area is 32,297 hm^2 (State Forestry Administration of China, 2006), and elevation ranges from 2320 m to 4891 m. Annual average precipitation is about 862.5 mm. The lowest mean air temperature reached is −6.1 °C in January, and the highest is 12.7 °C in July (Wang and Li, 2008).

2.2. Field survey

Many of the forests in Wanglang Nature Reserve experienced massive logging in the 1950s and 1960s (Li and Shen, 2012; Yang et al., 2013), and artificial restoration was carried out in some of the logged areas to restore the degraded forest. To investigate the characteristics of the artificial forest, we set six artificial forest plots according to the distribution of artificial forest in this area to represent the artificial forest. To develop a more comprehensive understanding on the effect of artificial restoration, we set a series of comparisons as evaluation standards. For example, we set six primary forest plots without logging to represent primary forest, and six secondary forest plots formed by natural recovery after logging to represent secondary forest. Furthermore, Wanglang is an important habitat for the giant panda, so we set six giant panda habitat plots, which were identified by giant panda feces according to the distribution of this species, to represent the giant panda habitat. In addition, we also set six environment plots surrounding the artificial forest to represent the surrounding forest environment.

The plot size was 20 m × 20 m. We recorded the species name and measured diameter at breast height (DBH) for woody plants > 1.3 m in height in each plot (Fang et al., 2009). We defined a tree as a woody plant with DBH ≥ 5 cm, and a shrub as a woody plant with DBH < 5 cm. We recorded the species name and measured the ground diameter and height of the woody plants that were ≤1.3 m in height (defined as regeneration) in each plot. We recorded the species name and number of bamboo clumps in each plot. Furthermore, we also recorded the basic information of each plot, such as altitude, location, canopy, bamboo coverage, and vegetation type. The field survey was carried out in August 2015, July and August 2016, and July and August 2017. A total of 30 plots were used for the analysis (Fig. 1).

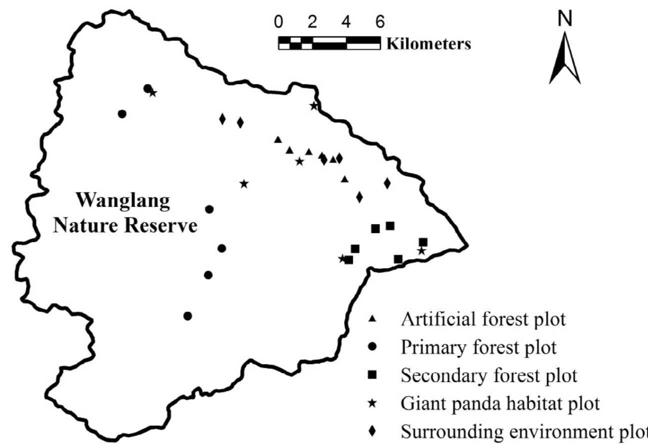

Fig. 1. The locations of the sampling plots in this study.

2.3. Data analysis

To describe the characteristics of the artificial forest by vegetation coverage, we compared the differences in canopy and bamboo coverage in the artificial forest plots, primary forest plots, secondary forest plots, giant panda habitat plots, and surrounding environment plots using the Kruskal–Wallis test (Yan et al., 2015). We then used the Games–Howell test to detect if the differences were caused by the artificial forest plots (Xie and Shang, 2012).

To compare the species composition among the five environments, we first counted the woody plant species in the five kinds of plots. Then, we counted the total and common species in the layers between the artificial forest plots and the other four kinds of plots. Last, we calculated the total and layer similarity coefficients between the artificial forest plots and the other four kinds of plots. We used the Sorensen index to calculate the similarity coefficient (Fang et al., 2009). We also considered the bamboo species in the different kinds of plots.

To identify differences in species richness, the number of species in each plot was counted for the different layers. Then, we compared the differences in species number in the different layers among the five kinds of plots using analysis of variance (ANOVA) when statistical assumptions were met or the Kruskal–Wallis test when statistical assumptions were not met (Du, 2003; Yan et al., 2015). We used Tukey's (variances were homogeneous) or the Games–Howell test (variances were not homogeneous) to detect if the differences were caused by the artificial forest plots.

To detect the differences in community structure, we first used and calculated seven variables related to community structure, such as tree number (total number of tree individuals), tree size, shrub number (total number of shrub individuals), shrub size, regeneration number (total number of regeneration individuals), regeneration size, and bamboo clump number (Kang et al., 2017). Then, we used either ANOVA or the Kruskal–Wallis test to compare the differences in these variables among the five kinds of plots. Tukey's or the Games–Howell test was used to carry out the multiple comparisons.

To analyze the growth status of trees, we first calculated total basal area of the tree and coefficient of variation (CV) (Du, 2003) of tree size in each plot. Then, either ANOVA or the Kruskal–Wallis test was used to