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Natural recovery and restoration in giant panda habitat after the Wenchuan earthquake

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ABSTRACT

Natural disasters affect forest ecosystems in profound and complex ways. Artificial restoration projects have been conducted worldwide to repair disaster damage to forests, but the efficacy of such projects in light of naturally occurring recovery processes is rarely evaluated. To fill such an important knowledge gap, we investigated forest recovery and restoration in the world-renowned Wolong Nature Reserve in Sichuan, China after the catastrophic Wenchuan earthquake (magnitude 8.0) in 2008, which caused considerable damage to the forest and habitat of the endangered giant panda. This was the first multi-year field study to document natural recovery of forests in response to this disaster. Forest sampling conducted in panda habitat over a four-year period after the earthquake revealed that natural recovery was rapid, with vegetation covering roughly 70% of once denuded sites by the fourth sampling year. Vegetation recovery was further improved in sampled artificial restoration sites, which recovered from an average of 30% vegetation cover to 70% in only one year. Factors including soil cover and slope were correlated with successful vegetation recovery. New information learned from the multi-year field data provided a finer scale context for understanding the effects of disasters, a novel contribution considering that the majority of previous work has been conducted at the broader scale using remote sensing. Spatial analysis revealed that restoration sites were mainly distributed in areas of suitable slopes and elevations, but a measurable proportion (30–40%) were located too far from the existing panda distribution area and too close to human settlements. The restoration project has thus far had limited direct effect on giant panda conservation, but has indirect effects on improving forest cover in areas previously affected by human disturbances. This study provides a useful reference for understanding conditions affecting forest recovery, which can inform decision-making surrounding the implementation of forest restoration projects and conservation of endangered species, not only in China but also around the world.

1. Introduction

Ecosystems around the world are affected by a variety of natural disturbances, such as earthquakes, landslides, hurricanes, tornados, volcanoes, and extreme snow events (Turner et al., 1998; Linderman et al., 2006). Forest ecosystems are particularly affected by such disturbances in a number of ways, including negative effects such as loss of forest cover and declines in tree densities (Liu and Ashton, 1999; Hansen et al., 2010; Liu, 2014), and positive effects such as increases in forest diversity as a result of new niches created by periodic disturbance events (Loucks, 1970; White, 1979). While forests have demonstrated remarkable capacity to naturally recover from such disturbances over time (Lin et al., 2005; Millington et al., 2013), humans have also invested tremendous conservation efforts in restoration programs aimed at bolstering or improving such natural recovery (Rodrigues et al., 2009).

Although some forest restoration programs have been conducted, there is considerable debate in the literature as to the necessity and efficacy of such programs (Del Moral and Walker, 2007). Some researchers have pointed out the low chance of success of restoration projects, in addition to significant time and money required for implementation (White and Walker, 1997;

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Ruiz-Jaen and Mitchell Aide, 2005; Cao, 2008; Cao et al., 2010; Liu, 2010). For example, the United States Department of Agriculture (USDA) carried out a restoration project on Mount St. Helens to control erosion caused by volcanic activity (Del Moral and Walker, 2007). The USDA spent over $2 million on seeding of exotic plant species and legumes and application of fertilizer, yet erosion was not reduced and conifer regeneration was in fact impeded (Del Moral and Walker, 2007). Despite such examples of restoration programs, few empirical field studies have been done to critically evaluate the design and implementation of such efforts.

Earthquakes are potentially catastrophic events that involve the creation of seismic waves throughout the Earth's crust. Earthquakes cause earth shaking and ground rupture, which can trigger a number of damaging effects such as landslides, treefalls, avalanches, fires, tsunamis, and floods. Forests are potentially affected by all of these effects in numerous ways, the most severe negative effects being the complete destruction of an entire forest ecosystem. Forests have demonstrated the ability to naturally recover from such disturbances via forest succession, but the greater the intensity of disturbances, the longer time required for such recovery to take place (Garwood et al., 1979; Attiwill, 1994). Humans have made efforts to attempt to hasten vegetation recovery in degraded ecosystems (Sayer et al., 2004), one of the main types including areas affected by earthquake-affected areas.

One such earthquake is the Wenchuan earthquake (magnitude 8.0), which struck on May 12, 2008, in Wenchuan County, Sichuan Province, China (Viña et al., 2011). In addition to causing nearly 70,000 human deaths and an estimated 845.1 billion RMB (126 billion USD) in property damage (China Central Television, 2008), the earthquake also destroyed an estimated 1221 km^2 of forest, grassland, and wetland ecosystems (Ouyang et al., 2008). Of particular conservation interest is the fact that the earthquake occurred within the limited remaining natural habitat of the giant panda (*Ailuropoda melanoleuca*), an endangered species and national treasure in China. Approximately 656 km^2 (6%) of giant panda habitat across an area encompassing 19 nature reserves for giant pandas was lost (converted from forest to bare land) to the earthquake, largely by landslides and mudslides (Ouyang et al., 2008).

In response to the Wenchuan earthquake, the Chinese government initiated a recovery plan involving ecological protection and restoration in the disaster area, particularly for the endangered giant panda. Across the giant panda's range, a total of 49 nature reserves (making up approximately 1200 km^2 of giant panda habitat) created restoration plans to hasten recovery of damaged giant panda habitat (State Forestry Administration, 2008). While the nearly 160 billion USD recovery effort of human communities and infrastructure in the earthquake affected area (Xinhuanet, 2011) has been extensively researched and documented, little research has been done to evaluate the design, implementation, and success of the recovery efforts geared toward restoration of the natural environment from this disaster.

In this study, we sought to evaluate forest recovery occurring naturally in addition to recovery in response to restoration efforts conducted after this major disturbance event. Here we focus on a 111 million RMB ($17 million USD) forest restoration project carried out in 2010–2011 in Wolong Nature Reserve, a world famous protected area widely regarded as a flagship nature reserve for the protection of giant pandas and their habitat (Deng et al., 2011) and a part of a global biodiversity hotspot (Liu et al., 2003). Our main objective was to investigate patterns of forest recovery after the earthquake and determine whether restoration was more successful than natural recovery alone. We were also interested in knowing whether restoration sites were distributed in areas that were suitable giant panda habitat before the earthquake and how much suitable damaged habitat was found outside of current restoration sites. This study has important implications for studying natural recovery processes and evaluating restoration projects following natural disasters worldwide.

2. Methods

2.1. Study area

Our study area is located in Wolong Nature Reserve (102°52′–103°24′E, 30°45′–31°25′N), Sichuan Province, China (Linderman et al., 2005) (Fig. 1). It was established in 1963 as one of China's four earliest giant panda nature reserves (Liu et al., 1999a). In the 1970s, the area of the reserve was extended to 2000 km^2 to accommodate approximately 10% of the total wild giant panda population (State Forestry Administration, 2006). Aside from giant pandas, there are thousands of plant and other animal species found within the reserve (Li et al., 1992; Tuanmu et al., 2010). Wolong is internationally important because it is also part of UNESCO's Man and Biosphere Reserve network (Liu et al., 1999b).

Wolong is located on the Longmen Mountain fault, a major fault line in southwestern China, and an area that has been subject to frequent tectonic activity since the third century glacial events. Since the 1930s, there have been a total of eight earthquakes above magnitude 7.0 within 200 km of the epicenter of the Wenchuan earthquake (China Earthquake Networks Center, 2008), including the Ya'an earthquake that occurred 85 km from Wenchuan in April 2013 (also along the Longmenshan Fault). The distance from the epicenter of the Wenchuan earthquake to Wolong Nature Reserve is less than 10 km, which made it a target for heightened research and management efforts post-earthquake (Wang et al., 2008; Yang et al., 2013). Approximately 56 km^2 (7%) of giant panda habitat in Wolong (total 826 km^2) was lost (converted from forest to bare land) due to the earthquake (Ouyang et al., 2008).

A forest restoration project was carried out in Wolong in 2010–2011 in an effort to restore roughly 40 km^2 of forest in the reserve that was destroyed by the earthquake, mainly due to landslides and mudslides (Sichuan Forestry Development of Science and Technology Industrial Company, 2010). The ambitious plan was estimated to cost 111 million RMB ($17 million USD) and was funded by the investment from the government of the Hong Kong Special Administration Region. The specific objectives of the plan were to (1) restore the ecosystem that was degraded as a result of the earthquake and (2) improve and expand giant panda habitat (Sichuan Forestry Development of Science and Technology Industrial Company, 2010).

The plan laid out four types of target sites for restoration (Fig. 1). The first type was *Planting* of trees and shrubs in the areas affected by landslides. Planting was conducted during autumn and the main planted species included *Cinnamomum longepaniculatum*, *Picea asperata*, *Betula albo-sinensis,* and *Larix mastersiana*. The age of planting stock was 1–0 and the density was 1667 /ha. One other species was also planted (*Salix cupularis*) with an age of planting stock and density of 1–1 and 2500 /ha, respectively. To improve success, a series of tending measures were carried out, including replanting or repositioning plants as needed and monitoring to prevent fire and pest infestation. The second type of target site was the *Seeding* site, where seeding of trees and shrubs in the areas affected by landslides was conducted during autumn. The main seeding species included *Juglans cathayensis* (60 kg/ha), *Pinus tabulaeformis* (30 kg/ha), *B. albo-sinensis* (15 kg/ha), *Coriaria nepalensis* (7.5 kg/ha) and oak plants such as *Cyclobalanopsis glauca*, *Fagus longipetiolata*, *Quercus aquifolioides,* and *Quercus spinosa* (30 kg/ha). Most restoration sites were planted or seeded with mixtures of different species based on the local biophysical conditions and amount of damage received.

The third type of target site was *Low Quality Forest Restoration*, which included areas unaffected by the earthquake but where