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Impacts of Wenchuan Earthquake-induced landslides on soil physical properties and tree growth

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ABSTRACT

How earthquake-induced landslides impact the growth of existing trees remains unknown worldwide. Therefore, we established an experiment with two tree species (*Cupressus funebris*, *Cryptomeria fortunei*) and two landslide conditions (non-impacted and impacted stands) near the northern section of the fault belt one year after the Wenchuan Earthquake (8.0 M_s) that occurred in China in 2008. At site I, two plots of each species were located in non-impacted stands. At site II, three plots of *Cu. funebris* were established in non-impacted stands, and three plots were established in impacted stands. At site III, three plots of *Cr. fortunei* were placed in non-impacted stands, while two plots were placed in impacted stands. All plots were 20 m × 20 m in size. At each plot, we measured the diameter at breast height and the height of each tree and used their mean values to select five trees representing average growth. Two to three small fine roots (≤2.0 mm in diameter, >20 cm long) were sampled in just three of the five selected trees to investigate root parameters. Leaf, branch and root water contents of the sampled trees were also examined. Soil samples were collected from 0 to 10, 10 to 20 and 20 to 40 cm depths at the center and near the four corners of each plot to analyze soil physical properties. The study revealed that saturated water content, capillary moisture capacity, field water capacity, total porosity and capillary porosity were lower in the impacted stands than in the non-impacted stands. Conversely, bulk density was higher in the impacted stands, indicating that the soils in the impacted stands had become compacted and dry. Soil water content, saturated water content, capillary moisture capacity, field water capacity, total porosity, capillary porosity and non-capillary porosity were greater in *Cr. fortunei* stands than in *Cu. funebris* stands, while bulk density was lower, indicating that impacted stands of *Cu. funebris* were more compacted and dry than those of *Cr. fortunei*. In impacted *Cu. funebris* stands, mean tip length/length and mean tip length/biomass decreased, while plant organ water contents did not change. In impacted *Cr. fortunei* stands, in contrast, these root parameters as well as specific root area, specific root length and leaf water content increased. These patterns suggest *Cr. funebris* experiences a much higher root growth than *Cu. funebris* in landslide impacted stands. Survival and recovery may be more difficult for *Cu. funebris* than for *Cr. fortunei*.

1. Introduction

Strong earthquakes not only directly destroy vast forests through mountain collapses and debris flows but also lead to the death of existing trees in the disaster areas in subsequent years. For example, after a 7.3 M_s earthquake in Songpan County, China, in 1976, more than 80% of the bamboo in earthquake-induced landslide areas died within five years of the earthquake (Schaller et al., 1985). Similarly, tree mortality was increased by 75% in a mountain beech (*Nothofagus solandri* var. *cliffortoides*) forest within seven years of a 6.7 M_s earthquake in New Zealand (Allen et al., 1999). The mechanisms of these potential impacts of earthquakes have not been investigated.

The Wenchuan Earthquake (8.0 M_s) in southwestern China, which occurred on May 12, 2008, triggered numerous landslides in which forested areas moved as much as 60 m downhill from their original elevations along the slopes (Cheng et al., 2009). The landslides did not heavily damage these trees but left leaning trees,

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some cracks in the branches and trunks of the trees and fissures in the soils. Although these trees survived the landslides, many of them are likely to die within the next several years. Their deaths may be related to disturbance of the soil environment and tree root growth.

Earthquake-induced landslides alter the physical properties of soils. Strong earthquakes (>7.0 M_s) cause large-scale soil losses through mass movements (Schuster and Highland, 2007) in mountainous regions and loosen the upper soil layers (0.0–50.0 cm), resulting in increased soil aeration, water content, drainage, bulk density and temperature (Vittoz et al., 2001; Liu and Sheu, 2007). As a result, soil drying occurs due to the enhanced exchange of water, air and heat energy between the soil and the atmosphere (Liu and Sheu, 2007). These changes differ markedly within landslides where vegetative cover has been removed (Velázquez and Gómez-Sal, 2007; Walker et al., 2009). Plant growth and vegetation recovery may differ in landslide areas that are exposed to more light and heat (Walker and Shiels, 2008) compared to those where forests persist.

Earthquake-induced landslides disturb tree growth because many soil abiotic factors, such as water, bulk density and porosity, influence the aboveground and belowground growth of trees (Walker and Shiels, 2008; Pupin et al., 2009). Soil drying results in the allocation of more tree biomass to root systems to increase water availability, while aboveground growth may decrease or stop (Hacke and Sauter, 1996; Frensch, 1997). Soil loosening increases aerobic microorganism growth and activity, thus accelerating organic matter decomposition and nutrient loss (Walker and Shiels, 2008; Walker et al., 2009; Pupin et al., 2009). Nutrient-poor soils also promote a similar allocation of tree biomass to roots, primarily promoting the growth of small fine roots (≤2.0 mm in diameter) (Mencuccini, 2003; Bernstein et al., 2004) for the uptake of soil resources (water and mineral nutrients) because the membranes of small fine roots are permeable to water and chemical elements (McCully, 1990). Root architectural parameters (e.g., root length, surface area, volume, tips and branches) show much higher values in small fine roots than in coarse fine roots (2.0–5.0 mm in diameter) and coarse roots (>5.0 mm in diameter) of trees (Cheng, 2007). Higher values of these root parameters (length, area, tips and branches) promote greater soil resource availability by increasing the root absorptive area (Mencuccini, 2003; Bernstein et al., 2004). Therefore, small fine root growth may play a critical role in tree survival after earthquake-induced landslides.

Cupressus funebris and *Cryptomeria fortunei* are two of dominant conifer species in the Wenchuan Earthquake area. Compared to *Cr. fortunei*, *Cu. funebris* is a slower-growing and more drought-tolerant species with a relatively deep root system. These tree species differ in their physiological and morphological characteristics, including root architecture, and exhibit different responses to the environment (Bauhus and Messier, 1999; Cheng, 2007; Song and Cheng, 2010) due to genetic controls. To acclimate to a stressful soil environment, trees must effectively adjust both root architecture and growth; otherwise, they will die (Bauhus and Messier, 1999). The underlying mechanisms of the changes in fine root architecture that allow trees to survive in earthquake-induced landslides where many physical properties of the soils have been altered in a complex manner are poorly understood. The objectives of this study are to examine how the soil physical properties and root parameters of *Cu. funebris* and *Cr. fortunei* have been affected by Wenchuan Earthquake-induced landslides and how the impacted soil and root variables influence plant organ water contents. Understanding these relationships will shed light on the present growth of both species and will enable us to estimate their growth rate and to shed light on future trajectories of vegetation recovery.

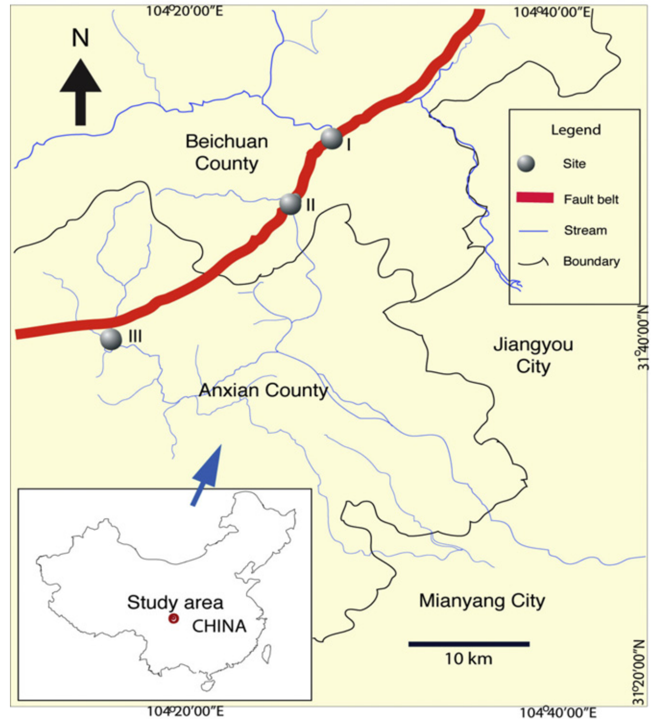

Fig. 1. Study area with three research sites (dots) in the northern section of the fault belt caused by the Wenchuan Earthquake of China on May 12, 2008.

2. Materials and methods

2.1. Study area

The study area (N31°38′-31°49′ and E104°16′-104°27′) is located in one of the most severely impacted disaster areas. Its elevation and mean annual rainfall range from 650 to 1400 m and from 800 to 1400 mm, respectively. Air temperature ranges from −6.2 °C in January to 35.3 °C in July. The research was conducted at three sites in the area, including landslide-impacted and non-impacted stands, along the northern section of the Wenchuan Earthquake fault belt (Fig. 1). The soils are generally loamy to >70 cm depth. The focal species, *Cu. funebris* and *Cr. fortunei*, were widely planted in the past two to three decades and are two of the dominant trees in the area. Some bamboo (*Phyllostachys bambussoides* cv. *tanakae* and *Cunninghamia lanceolata*) forests also grow in the area but were not included in this study.

2.2. Experimental design

Between June and July of 2009, four, six and five 20 m × 20 m plots were established at sites I–III, respectively. These sites were located 1.3, 0.5 and 2.3 km perpendicularly from the fault belt. The plots were dominated by 23- to 27-year-old *Cu. funebris* and *Cr. fortunei* stands with a tree density (1 per m^2). At site I, two plots of each species were established in non-impacted stands. At site II, three plots of *Cu. funebris* were established in non-impacted stands and another three plots were placed in landslide-impacted stands. At site III, three plots of *Cr. fortunei* were placed in non-impacted stands, while two plots of this species were placed in impacted stands. In impacted stands (landslide areas), whole forest floors had shifted 20–60 m downward from higher elevations along the mountain slopes. At each plot, we measured the tree height and diameter at breast height (1.3 m high) of every tree and used the mean values of these two variables to select five trees representing