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Wenchuan 512 earthquake and giant panda habitat in Wolong, China: A review of strong earthquake effects

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Abstract In May 12, 2008, a strong earthquake occurred in Wenchuan County in the northern Sichuan Province of China. It registered 8.0 on the Richter scale with an 11-degree quake intensity, killing a large number of people, and causing extensive damage to the local environment. Wolong National Nature Reserve is about 30 km away from the epicenter and is one of the most important giant panda (*Ailuropoda melanoleuca*) habitats in China. Based on the impacts of the Wenchuan 512 earthquake and those of other strong earthquakes in the world, this paper reviews and discusses effects of strong earthquakes on geomorphology, soil chemical and physical properties, forests, bamboo growth, biodiversity, and giant panda habitat. This information may be useful for scientists when undertaking research projects on natural geography, ecological restoration, and habitat restoration in the Reserve and the disaster area.

Keywords China, ecological restoration, environmental change, giant panda habitat, Wenchuan earthquake, Wolong National Nature Reserve

1 Introduction

At 2:28 pm on May 12, 2008, a catastrophic earthquake with an 8.0 magnitude and 11-degree earthquake intensity occurred in Wenchuan County in the northern Sichuan Province in southwestern China. This was one of the most destructive earthquakes in China over the last 100 years (CMCA, 2008). The Wenchuan 512 earthquake impacted a 300000 km² area. The most intensively affected area was 132596 km² located in a part of Sichuan, Gansu, and Shanxi provinces, involving a total of 51 counties (CMCA,

2008). Approximately 80% of this area was within Sichuan Province, a mostly mountainous region where more than 19 million people lived. Based on the official government announcement of August 7, 2008, the earthquake killed 69222 people, injured 374638, and 18176 were missing. In addition, it also destroyed a large number of buildings, houses, bridges, and 43125 km of roadways. The earthquake not only led to a loss of human life and \$US124 billion in damages (CMCA, 2008), but it also had immediate and long-term effects on the natural environment. The earthquake caused 2394 mountain collapses, 4314 large-scale landslides, 2273 huge debris flows and soil movements (CMSLR, 2008). While the immediate effects were apparent, the long-term effects were not well known.

While strong earthquakes lead to enormous disasters, they also generate many scientific questions and provide an extraordinary opportunity for scientists to do research on natural geography and ecology. So far, there has not been enough data showing the long-term effects of strong earthquakes on the local ecology, thus revealing how these local environments will be further degraded and how these areas can be restored. The objective of this paper is to summarize how strong earthquakes change the environment and its ecological processes, which may help scientists in conducting research projects on ecological restoration for disaster areas. Of interest here is giant panda habitat restoration in China's Wolong National Nature Reserve near the epicenter of the Wenchuan 512 earthquake.

2 Environmental impacts of strong earthquakes

Earthquakes above 7.0 and above 8.0 on the Richter scale are considered strong and severe quakes (Noij, 1997; Prager, 1999; Briggs, 2006), having vast effects on terrain. Keefer (1984) estimated an 8.0 magnitude earthquake may induce landslides totaling 100000 km². The Wenchuan 512 earthquake in China triggered at least 25 million m³ in

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mass movements over a 130000 km² area within one week (CMSLR, 2008). It also caused 30% to 60% of the total land cover to become denuded while loosening the upper soil layer (CMSLR, 2008). A large number of frequent mass movements will significantly modify local geomorphology (Small and Clark, 1982). These can vary from extremely large and rapid movements to frequently slow micro-displacements along transport paths, eventually leading to a deposition in valleys.

Changes in the area from mass movements not only impact the terrain, but also disturbed existing ecosystems (Geertsma, 2006). The Wenchuan 512 earthquake immediately created 34 earthquake-induced lakes attributed to large mountain collapses and landslides, and altered water systems. Ecosystems will subsequently experience more drastic changes, since the disaster area will now be in a tectonically active period for at least 10 years. During this time, soil erosions, debris flows, landslides and windthrow will create additional damages, in particular during rainy seasons (Rapp et al., 1972). These secondary disasters will continuously destroy vegetative cover, farmlands, and change watershed hydrology by increasing run-off, flooding, and turbidity of river water.

2.1 Changes in soil physical properties

Generally, a strong earthquake (magnitude > 7.0) results in large-scale soil losses, including slope-recession, and mass movements (Schuster and Highland, 2007) in many mountainous regions. The slope-recession value is generally 1 mm/year, and the lowest value appears in forested slopes in temperate climates (Schuster and Highland, 2007). Rapp et al. (1972) estimated that soil loss in the Mogoro River Valley of Tanzania was between 5000 and 10000 m³/a. Temple and Rapp (1972) noted the Mgeta area of the western Uluguru Mountains in Tanzania lost 270000 m³ of soil within 3 hours in February 1970, with a concurrent loss of soil nutrients. In many large mountainous regions, soil losses can expose the bedrock (Rapp et al., 1972). This accounted for completely bare rocky ridges in the Torricelli Range on the north coast of Papua New Guinea (Montgomery and Eve, 1935; Marshall, 1937). Within one month after the Wenchuan 512 earthquake, soil loss and mass movements in the severe disaster area were 4.1 billion m³ from mountain collapses, 1.8 billion m³ from landslides, 5.4 billion m³ from huge debris flows, and 2.6 billion m³ from soil movements (CMSLR, 2008). These changes significantly altered soil texture (Vittoz et al., 2001; Liu and Sheu, 2007).

Additionally, strong earthquakes significantly change soil physical properties due to the loosening of the upper soil layer. Liu and Sheu (2007) demonstrated that strong earthquakes increase soil aeration, drainage, and temperature, especially at the 50 cm deep soil but did not change air temperatures. These changes enhance the exchange of water, air and heat energy between soil and atmosphere,

which can cause drought conditions (Vittoz et al., 2001; Liu and Sheu, 2007) for more forests to die.

2.2 Changes in soil chemical properties

Strong earthquakes change soil chemistry (Bussmann et al., 2008; Wilcke et al., 2008). In September 12, 1999, a 7.3 magnitude earthquake created permanent physiogeographic changes over 112.8 km² of a forested watershed in central Taiwan. Stream waters experienced significant increases in NH₄, Mg, Na, NO₃, and SO₄ concentrations, and conductivity; conversely, Ca and K concentrations decreased 4 years after the earthquake (Liu and Sheu, 2007). Similarly, Ca, K, Na, S, Cl, SO₄ concentrations in river water increased by 12% to 19% within 10 days after the occurrence of a 6.8 magnitude earthquake in Iceland (Claesson et al., 2004). These results implied that these changes were likely the result of changing soil chemistry in the region. Schruppf et al. (2001) postulated that landslides improved soil fertility because they brought deeper, less-weathered, nutrient-richer material to the surface in southern Ecuador. Bussmann et al. (2008) also reported that landslides caused nutrient-poor topsoil to be removed, and nutrient-richer subsoil to be exposed to the surface. However, many studies found different results that indicated fewer N and P in soils after landslides due to slower soil mineralization when compared to undisturbed areas (Guariguata, 1990; Dalling and Tanner, 1995; Wilcke et al., 2008).

Around 300 km² (60%) of the epicenter of the Wenchuan 512 earthquake was denuded with a large amount of organic and inorganic nutrients in the upper soil layer lost with the mass flows. The losses suggested that the soil chemistry likely changed; however, no details on these changes have presented themselves.

After the Wenchuan 512 earthquake, water chemicals were examined in the river systems of the disaster area. Primary results showed water chemicals did not change within 3 months (Wang and Cheng, 2008). Potential changes in soil chemistry may involve some complicated processes, and need time. For instance, a large number of dead plants in the disaster area will gradually decompose and release inorganic chemicals to soil and water systems. Strong earthquakes change many abiotic factors in soils, including soil temperature, moisture, and aeration (Vittoz et al., 2001; Liu and Sheu, 2007). These changes influence soil microbial activity that will gradually change nutrient cycling and soil mineralization (McCully, 1990), and sequentially change forest growth. Strong earthquakes have long-term effects on soil chemicals.

2.3 Impacts on vegetation

Generally, strong earthquakes devastate large forested areas. In September 1935, the hillsides in the Torricelli Range of Papua New Guinea, impacted by 7.9 and 7.0

magnitude earthquakes, carried away millions of tons of earth and timber (Montgomery and Eve, 1935; Marshall, 1937). Afterward, 60% of the tropical forests were found to be destroyed. In November 1970, a 7.9 magnitude earthquake in the Adelbert Range in Papua New Guinea removed 25% of the vegetation from a sloped surface area 240 km² in size (Pain and Bowler, 1973). In 1976, on the southeast coast of Panama, 6.7 and 7.0 magnitude earthquakes razed about 54 km² of jungle cover from a 450 km² region (Garwood et al., 1979). In 1987, a strong earthquake removed 230 km² subtropical forests in Ecuador (Schuster and Highland, 2007). In 2008, the Wenchuan 512 earthquake destroyed 3308 km² forests in the northern Sichuan Province.

Vittoz et al. (2001) stated that along with the direct effects of a strong earthquake on forest removal, many trees eventually die of pathogenic attacks, soil drought, or disturbances of root system development in decades that follow. For example, in June 1994, a 6.7 magnitude earthquake occurred in the Southern Alps of New Zealand. Allen et al. (1999) found that in 1995, tree mortality and injury were 24.0% and 22.5%, respectively, and stem biomass declined by 35 mg/hm² in a mountain beech (*Nothofagus solandri* var. *cliffordides*) forest 10 km southeast of the epicenter, and tree mortality was up to 75% several years later. In 1976, a 7.3 magnitude earthquake occurred in Songpan County, China. More than 80% of bamboo forests died in a mountainous area near the epicenter 5 years later (Schaller et al., 1985).

On the one hand, strong earthquakes are an important factor for driving vegetation dynamics in this tectonically active region. The resulting environmental diversity increases plant species diversity in a region. Changes occur in both macro- and micro-environments, and soil properties on landslides will also vary unsystematically on a small-scale (Guariguata, 1990; Dalling and Tanner, 1995; Wilcke et al., 2008). The environmental differences are major sources of heterogeneity in forest structure and vegetation regeneration (Vittoz et al., 2001). On less than 1-year-old landslides from 350 to 850 m elevation in the Luquillo Experimental Forest in northeastern Puerto Rico, soil organic carbon, nutrients, and germinable buried seeds were more prevalent in the lower zone than the upper. This caused light-demanding and fast-growing pioneer species, including *Calycogonium squamulosum* Cogn., *Cyrtilla racemiflora* L., *Micropholis garciniaefolia* (Guariguata, 1990) to regenerate in the lower zone, and light-demanding ferns to occur in the upper zone (Guariguata, 1990). Similar results were found by Stern (1995), Kessler (1999), Ohl (2000), and Ohl and Bussmann (2004), which suggested greater forest diversity, for example *Gleicheniaceae*, *Chusquea*, had increased as a result of the landslides in Bolivia and Ecuador. However, there is an argument on the diversity changes. Some studies revealed a decrease in diversity due to a large amount of plants being destroyed by strong earthquakes (Garwood et al.,

1979; Geertsma, 2006; Schuster and Highland, 2007). The issue needs more studies in the future.

In natural plant succession after strong earthquakes, natural post-landslide temperate forest restoration requires at least 50 years (Guariguata, 1990). However, Lin (2008) found that in 7 years, 53.8% of the vegetation, including bush, bamboo, betel nut, and orchard and grass species, recovered on 209.50 hm² of a denuded area caused by a 7.3 magnitude earthquake at Chi-Chi area of Nantou County, Taiwan in September 21, 1999. Lin et al. (2004) stated a vegetative restoration rate of 47.1% in natural plant succession one year after the earthquake. On the Jou-Jou Mountain in Nantou County, 17.4% of 822.97 hm² landslides from 123 to 776 m in elevation recovered with *Arundo formosana* Hack., *Pinus taiwanensis* Hayata., *Pinus morrisonicola* Hayata. over 6 years (Lin et al., 2006), and the vegetative recovery rate reached up to 86% (Chou et al., 2008). Various periods of vegetative recovery depended on climate, soil loss intensity, seed bank, and the micro- and macro-environments resulting from landslides. Generally, mountain ridges and acidic surface soils were more difficult to restore (Lin et al., 2004), and frequent occurrence of typhoons accelerated the ecological restoration in coastal areas (Chou et al., 2008).

2.4 Influences on wildlife

Strong earthquakes impact wildlife in a multitude of ways. Large-scale landslides immediately, and severely, damage wildlife habitat due to the removal of vegetation (Schuster and Highland, 2007). However, Schuster and Highland (2007) documented that after strong earthquakes, habitat quality may likely be improved, as the vegetation diversity increases in the long-term (Ohl, 2000; Ohl and Bussmann, 2004). Rozell (1998) reported snow avalanche chutes in British Columbia and Montana produced an abundance of vegetative food for grizzly bears (*Ursus arctos horribilis*), such as avalanche lilies (*Erythronium montanum*), whereby the bears were known to increase in population. Whether the Wenchuan 512 earthquake will improve wildlife habitat in the disaster area is unclear at present, and only future research efforts will document this.

3 China's Wolong National Nature Reserve

3.1 Wolong Reserve's importance for biodiversity

The Reserve's flora was estimated to be in excess of 5000 species, including more than 4000 flowering plants (Chen et al., 2002). Higher level plants consisted of more than 4000 species, including bryophytes (46 families, 102 genera), pteridophytes (30 families, 70 genera), gymnosperms (9 families, 24 genera), and angiosperms (147 families, 794 genera). These represented 65% of the total dicotyledons, and 15% of total monocotyledons in China. The Reserve

contained some ancient trees called living fossils, including *Davidia involucreta*, *Kingdonia uniflora*, *Dipteronia sinensis*, *Bretschneidera sinensis*, *Cercidiphyllum japonicum*, *Tetracentron sinensis* and *Gingko biloba*. The faunal component was also rich with 365 avian species (45 families), 109 mammals (25 families), 14 fish species (5 families), 22 amphibians (8 families), 32 reptiles (9 families), and more than 1700 insects. Among the 86 species of protected animals in China, 17 species existed in the Reserve and were listed in the First-Class category for national protection. Notable species were golden monkey (*Pygathrix roxellanae*), clouded leopard (*Neofelis nebulosa*), snow leopard (*Panthera unica*), leopard (*Panthera pardus*), takin (*Budorcas taxicolor*), Chinese hazel grouse (*Tetrastes sewerzowi*) as well as the giant panda (Chen et al., 2002).

3.2 Bamboo forest's importance for giant panda survival

The giant panda mainly consumes various bamboo species found on the subalpine and middle-altitude mountains. In the Reserve, there were about 30 species of bamboo such as, *Bashania*, *B. fangiana*, *B. faberi*; *Chimonobambusa*, *Ch. pachystachys*, *Ch. quadrangularis*, *Ch. rivularis*, *Ch. szechanensis*; *Fargesia*, *F. angustissima*, *F. nitide*, *F. robusta*, *F. spathacea*; *Phyllostachys*, *Ph. heteroclada*, *Ph. nidularia*, *Ph. nigra*; *Pseudosasa*, *P. japonica*; *Qiongzhueta*, *Q. tumidinoda*; *Yushania*, *Y. chungii*, and *Y. brevipaniculata*. Bamboo grows within evergreen broad-leaf forests, evergreen and deciduous mixed forests, and coniferous and broad-leaf mixed forests in subalpine areas. *Fargesia nitide*, *Pseudosasa japonica*, and *Fargesia robusta* were the most preferred food species for the giant panda. In primitive forests, giant pandas mainly consumed bamboo between 2600 and 3000 m in elevation. Natural coniferous forests with more than 50% of bamboo cover were more favorable than natural broad-leaf forests and plantations. Giant pandas preferred coniferous forests located in mountain ridges and south-facing slopes in middle-altitude mountain areas. Tree height, bush height, slope degree, and vegetative density did not influence the giant panda activity in these forests (Ran et al., 2004). In secondary forests, giant panda activity expanded to broad-leaf forests (Liu et al., 2003).

3.3 Important giant panda habitat

The giant panda is one of the world's most endangered species and is listed by the Convention on International Trade of Endangered Species (CITES), the International Union for the Conservation of Nature and Nature Resources (IUCN), and the World Wildlife Fund (WWF).

Based on the 3rd national survey of giant pandas in 2004, about 2000 live in a very narrow belt around the Wolong National Nature Reserve. Within Sichuan province, the area of giant panda habitat is 17743.92 km². The Reserve was an important giant panda habitat, and was the first and

largest reserve covering a 2000 km² area at 1800 to 6250 m in elevation (Chen et al., 2002). Around 200 giant pandas lived near and in the Reserve.

3.4 Earthquake impacts on giant panda habitat

Within Wenchuan Country, the 512 earthquake-induced 79 large-scale landslides with 75.42 million m³ in mass movements, 168 debris flows of 1.6 billion m³ materials, 163 mountain collapses with 47.49 million m³ in mass movements, and 113 large-scale soil movements with 28.36 million m³ washed out within one week (unpublished data).

The Wolong National Nature Reserve is about 30 km away from the epicenter. The Wenchuan 512 earthquake critically destroyed the Giant Panda Research Center, buildings, communication and road systems in the Reserve, and killed many of the Reserve's employees. Hundreds of people were rescued from the Reserve after one week. There were originally 64 pandas kept in 32 breeding houses at the Research Center. Fourteen of the houses were lost, and the remaining 22 were severely damaged. One panda died, one injured, and six went missing. Later, five were found in the mountains, but one is still missing. The earthquake completely destroyed 533.3 km² of the giant panda habitat. It is unclear how many wild giant pandas and other wildlife were killed.

Giant pandas are sensitive to a changing environment and this may affect their chances for survival. Before the Wenchuan 512 earthquake, disturbances from human activities, such as logging, grazing, herbal medicine collection, and road construction, were primarily responsible for impacting the giant panda habitat (Ran et al., 2004). The natural disturbance of the earthquake was, at present, more serious than the above disturbances of human activities, as the earthquake splits vegetation by landslides and mountainous collapses in the Reserve, which obstructs the exchange of giant panda populations, and affects their propagation. As a possible reason, the Wenchuan 512 earthquake enhanced the threat to the giant panda's survival.

3.5 Earthquake impacts on bamboo growth

Generally, the lifespan of bamboo is around 50–70 years. However, bamboo growth is sensitive to a changing environment. When experiencing senescence, or growing in a stressful environment, bamboo blooms produce seeds, and eventually wilt. The reduction of bamboo habitat threatens the survival of the giant panda. In 1976, a 7.3 magnitude earthquake occurred in Songpan County of Sichuan Province near the Reserve, and large swaths of bamboo suddenly flowered and died. In the early 1980s in the Reserve, 80 to 90% of *Fargesia nitide* and *Pseudosasa japonica* at 2300 to 3500 m in elevation withered after blooming (Schaller et al., 1985), resulting in 183 giant

pandas starving to death (Johnson et al., 1988). The large-scale die-off was a serious threat to the endangered giant panda. Whether the Wenchuan 512 earthquake will trigger a bamboo flowering, and how the earthquake will potentially threaten the giant panda are currently unknown.

Generally, bamboo grows well in deep, moist, well-drained, well-aerated, and nutrient-rich soils, such as sandy loam, but it can also grow in a more stressful environment, such as sandy soils (Chen et al., 2002; Huang et al., 2007). Soil nutrients, light intensity, and soil and air temperature can significantly affect bamboo growth in the Reserve (Huang et al., 2007). Nutrient-poor soil, resulting from debris flows, or soil erosion, reduces bamboo growth (Huang et al., 2007). Light has a linear relationship with bamboo growth. Song et al. (2006) showed that bamboo density, height, base diameter, and biomass were greatest in large canopy gaps (400 to 500 m²), followed by medium gaps (100 to 200 m²), and small gaps (< 50 m²). Soil temperature increased root respiration, and fine root production of bamboos (Wei et al., 2005; Fukuzawa et al., 2007), and promoted total bamboo growth. However, soil moisture had no effect on respiration (Wei et al., 2005). Generally, the optimum monthly mean air temperature is 14 to 17°C for bamboo growth. Bamboo originating from a temperate climate was most sensitive to high air temperature. After the temperature rises above 30°C, bamboo growth declined rapidly (Gratani et al., 2008). Little information can be found on the optimum soil temperature for bamboo growth.

The Wenchuan 512 earthquake damaged a large-scale area of bamboo in the Reserve. For example, approximately 15000 hm² of bamboo forests in Tangjiahe Mountain located in the northwestern part of the Reserve were destroyed by landslides. However, the exact total of destroyed vegetation, heavily and lightly damaged forests, and bamboo losses are currently difficult to obtain. The earthquake created widespread destruction of forests, and increased the large number of canopy gaps in the Reserve. In the forest floor, light intensity, soil temperature, and soil aeration increased, and soil organic matter, soil moisture most likely decreased. These changes complicated both the immediate and potential bamboo growth in the Reserve. How earthquakes damaged the growing environment of bamboo forests, and changed light and soil physical and chemical properties interactively to influence bamboo diversity, distribution, and growth in the Reserve were not known. However, this information was critical for understanding how a strong earthquake impacts giant panda survival in the Reserve.

4 Summary

Strong earthquakes induce large-scale landslides and debris flows in mountainous areas. Large massive movements cause soil loss, eventually leading to changes in soil

physical and chemical properties, disturbance of the root development of forests, and destruction or major damage to large areas of vegetation, including forests and bamboo habitat. After strong earthquakes, increases in canopy gaps of forests changed the understory environment. Soil temperature and aeration increased, soil moisture and organic matter declined, and many trees gradually died of pathogenic attacks, root disturbance, and soil drying.

The Wenchuan 512 earthquake severely impacted the ecology of the environment in the disaster area, and will have long-term interactive effects on environmental factors in bamboo forests and other giant panda habitats in the Wolong National Nature Reserve. However, these effects are currently unknown, and further research is warranted to understand the future dynamics of this disturbed area.

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