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Non-volant Small Mammals in Landslides Caused by the Wenchuan Earthquake in a Fragmented Forest of Sichuan, China

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Abstract.- Landslides caused by the magnitude 8.0 Wenchuan Earthquakes had brought extensive habitat changes in the montane region. Until now, little is known about the non-volant small mammals in landslide disturbed areas. In this study, we compared the non-volant small mammal communities between seismic landslides and undisturbed areas in a broadleaved deciduous forest in the Longxi-Hongkou National Nature Reserve, Sichuan, China. Our goals were to understand the response of non-volant small mammal communities to landslide disturbance, and to explore the effect of vegetation recovery and source populations of non-volant small mammals on the recovery process of small mammal communities in landslides. Pitfall traps were set to capture non-volant small mammals in landslides and control sites from April 2010 to January 2014. Vegetation covers were visually estimated along with each small mammal trapping period. Our results showed that the relative abundance of non-volant small mammal communities in landslides were significantly lower than these in control sites. Shannon-Weiner diversity indices were higher in landslides. The relative abundance and species richness of non-volant small mammal communities in landslides were positively significantly correlated with non-volant small mammal communities in control sites, as well as the herb covers in landslides ($P<0.05$). We concluded that non-volant small mammals could recolonize in landslides soon after seismic landslides, but the communities were highly variable and still need more time to recover. The recovery of herb layer in landslides and source populations in undisturbed areas played important roles in promoting the recovery of non-volant small mammal communities in landslides.

Key words: Non-volant small mammal, landslide, disturbance, vegetation recovery, Wenchuan earthquake.

INTRODUCTION

Disturbances, such as fires, floods, timber harvests, and wind storms, have significant direct effects on wildlife by causing mortality of individuals and indirect effects by destroying or degrading the quality of their habitats (Sousa, 1984; Mena and Medellín, 2010). As a consequence, the habitat changes will undoubtedly impact the ecological processes of forest ecosystems (Mena and Medellín, 2010). Non-volant small mammals, an integral part of the forest ecosystem, are critical to the species diversity and functional diversity of the ecosystem (Carey and Johnson, 1995; Zhang *et al*., 2013). They are known as ecosystem engineers and sensitive to habitat changes (Blois *et al*., 2010). They play crucial role in forest succession (Pauli *et al*., 2006), and can be used as indicators of disturbance response of the ecosystem (Dale and Beyeler 2001; Hurst *et al*., 2014). A well understanding of the response of small mammal communities to habitat alteration and vegetation succession in forests can provide us a better understanding of the ecological processes in forest ecosystems (Pauli *et al*., 2006).

Responses of small mammal communities to different types of disturbance, such as fires, timber harvests, floods, and windstorms, have been well demonstrated (Jacob, 2003; Fisher and Wilkinson, 2005; Pauli *et al*., 2006). Different groups of non-volant small mammals respond to disturbances differently because of their different habits (Fisher and Wilkinson, 2005). For example, rodents are sensitive to the changes of plant community, while insectivores are more sensitive to the changes of forest litter and moisture (Fisher and Wilkinson, 2005; Monroe and Converse, 2006; Matthews *et al*., 2009). Previous studies show that the recovery of vegetation (Carey and Johnson, 1995; Monamy and Fox, 2000, 2010), the accumulation of forest litter

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especially coarse woody debris (Carey and Johnson, 1995; Monroe and Converse, 2006), and the source population (Shenko *et al*., 2012), are decisive factors influencing the recovery of small mammal communities in disturbed areas. However, there is only limited information on how small mammal communities respond to the disturbance of seismic landslides (Zhang *et al*., 2013). So far, little is known about how different groups of non-volant small mammals respond to disturbance of seismic landslides and the vegetation succession in landslides. Moreover, whether vegetation cover, forest litter, and source population, would play critical roles in the recovery of small mammal communities in seismic landslides is not yet clearly discerned.

The magnitude 8.0 Wenchuan Earthquake, which occurred on 12th May 2008 in Sichuan, China, damaged approximately 97,700 ha of standing forest and generated a large number of landslide patches mainly in the Minshan and Qionglai Mountains (Wang *et al*., 2008; Zhang *et al*., 2008). Particularly, the affected area is within a global hotspot for biodiversity conservation, where many endangered animals are concentrated, such as the giant panda (*Ailuropoda melanoleuca*), the golden snub-nosed monkey (*Rhinopithecus roxellana*), and the takin (*Budorcas taxicolor*) (Wang *et al*., 2008). Undoubtedly, the habitat changes caused by seismic landslides will affect small mammal communities in the areas of the landslides. Understanding the information of small mammal communities in disturbed forest is critical to assess the resilience and sustainability of forest ecosystem reserved for biodiversity conservation, and also can help guide forest and mammalian management. Therefore, the objectives of our study were (1) to understand the changes in relative abundance and species richness of non-volant small mammals and the resilience of non-volant small mammal communities in landslides, (2) determine the relationships between non-volant small mammal communities and vegetation covers in seismic landslides, (3) and determine the relationships between non-volant small mammal communities and source population of non-volant small mammals in undisturbed areas.

MATERIALS AND METHODS

Study area

Our study was conducted in the Longxi-Hongkou National Nature Reserve (LHNNR) in Dujiangyan County, Chengdu, Sichuan, China. The LHNNR is established primarily for the conservation of endangered wildlife, especially the giant panda. The LHNNR is located in the south Minshan Mountains, with an area of 31,000 ha and elevation ranges from 820 to 4,582 m. Our study area was approximately 1000 ha (103°34.77′E, 31°9.26′N), between 1800 and 1900 m elevation with gentle to moderate slopes (5-30°). The vegetation is principally secondary broad-leaved deciduous forest. The overstory is dominated by *Acer* spp., *Populus* spp., and *Corylus* spp., and the understory was basically dominated by *Fargesia robusta*, a staple bamboo for the giant panda. The climate is typically subtropical with high rainfall (annual precipitation 1300-1800 mm), high humidity (the annual average relative humidity over 80%), and moderate temperatures (mean annual temperature around 10°) (Chen, 2000; Zhuang and Gao, 2002).

The Wenchuan earthquake of 12th May 2008 was 8.0 in magnitude with the epicenter only 25 kilometers from the LHNNR. The earthquake and accompanying landslides damaged 10,114 ha forest vegetation covering approximately 32.6% of the LHNNR (Wang *et al*., 2008). We located our study area in one of the most damaged area within the LHNNR (Zhang *et al*., 2013; Li *et al*., 2014).

Sites selection

Within the study area, we selected ten landslides covering disturbed areas of about 0.1 ha. We located a control site at least 150 m away from the landslide site at the same elevation within undamaged natural forest, giving a total of ten control sites (Fig. 1). All the 20 sites had gradients of 20° to 30° and elevations between 1800 and 1900 m, and were separated from each other by about 150 meters.

In the landslides, tree layer was absent due to the landslides; shrub layer was dominated by *Buddleja davidii* during 2010-2011, and replaced by

Rubus spp. during 2012-2013; the herb layer was well developed and dominated by *Impatiens* spp., *Pteridium* spp., *Cyperus* spp., *Cardamine* sp., and so on; moss layer was also well developed with the cover 20%-70%; the ground surface was covered with gravel and little forest litter. In control sites, tree layer was primarily dominated by *Acer* spp., *Populus* spp., and *Corylus* spp.; shrub layer was primarily dominated by *Fargesia robusta*, with the cover 60%-90%; herb layer was poor due to the high canopy of upper vegetation; moss layer was poor as well due to the thick ground litter; the ground surface was covered with coarse woody debris and leaves (Li *et al*., 2014).

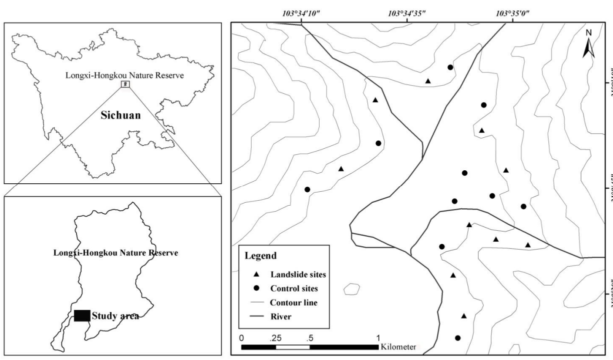

Fig. 1. Location of the study area and the distribution of pitfall traps in the LongXi-Hongkou National Nature Reserve, Sichuan province, China.

Small mammal trapping

We got the permission for small mammal capturing from the Management Office of the Longxi-Hongkou National Nature Reserve. One pair of pitfall traps was placed in each site to capture non-volant small mammals (Fig. 2). Pitfall traps take advantage of the drifting behavior of non-volant small mammals (Sibbald *et al*., 2006), and have a number of advantages over conventional snap traps and live traps (Williams and Braun, 1983). The materials of pitfall traps are simple and cheap, and can work and last for a long time; pitfall traps are easy to set up and require little labor during the operation period, while conventional snap traps and live traps require much labor and might have much negative influence on the vegetation regeneration and matrix stability of the landslide; last but not the least, pitfall traps rarely catch birds (Williams and Braun, 1983; Torre *et al*., 2010). Pitfall traps were mainly made of a drift fence and two pitfalls. Drift fence, consisting of plastic sheeting (100 cm width, 800 cm length), and staked vertically with the bottom buried. The fence was placed paralleled to the contour lines because the landslides were rocky and steep, which made it difficult to place the fence vertically (Fig. 2). Pitfalls, consisting of two plastic buckets (30cm depth, 30 cm internal diameter at the top, 24 cm internal diameter at the bottom, with the handles removed), were placed at the both ends of the drift fence, and were flush with the ground (Hurst *et al*., 2014).

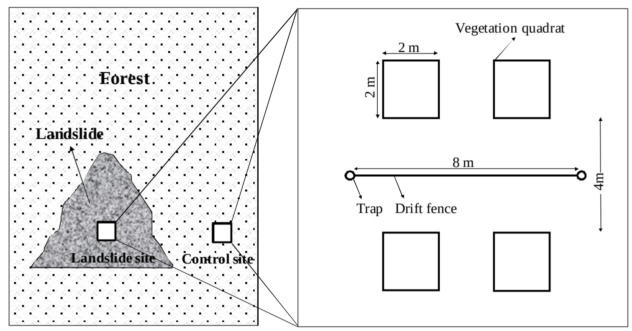

Fig. 2. Schematic of sampling plots for non-volant small mammals trapping and vegetation sampling in landslide and control site.

From April 2010 to January 2014, the pitfall traps were operated for 5 days at the end of each April, July, October, and January. The planned investigation in July 2013 was postponed to late August because of a period of heavy rain. No bait was used for pitfall traps at all. We checked the pitfall traps two times a day, one in the morning and the other at dusk. We closed all the traps at the end of each investigation with the buckets filled with litters and drift fence removed. The body mass, size, and sex of each individual were recorded. The individuals alive were given a unique toe-clip number at first capture and released (Monamy and Fox, 2000), and the dead individuals were labeled and preserved. All the individuals were identified according to Smith *et al*. (2010).

Vegetation data collection

Vegetation data were collected during the same time period as the small mammal trapping.

Two 2 m × 2 m quadrats were set two meters apart and two meters above the drift fence, and a second set two meters below the drift fence (Fig. 2). In each quadrat, the percent (%) of vegetation covers, including shrub cover, herb cover, and moss cover, were visually estimated to the nearest 5%, respectively. These three vegetation covers in four 2 m × 2 m quadrats were averaged for each trap site.

Statistical analyses

Relative abundance, species richness, community evenness, and Shannon-Weiner diversity index were used to describe the non-volant small mammal communities (Monamy and Fox, 2000; Magurran, 2004). Relative abundance was calculated as captures per trapping night to adjust for differences in trap effort. Trapping nights in winters were excluded when performing data analysis because no individual was captured in all the four winters. Mann-Whitney U test was used to compare species richness and relative abundance of small mammal communities between landslides and control sites. Spearman's rho correlation test was used to determine the relationships between small mammal communities in landslides and control sites, and the relationships between small mammal communities and vegetation cover in landslides. Non-volant small mammals were split into two taxonomic groups, insectivore and rodent, to examine whether different species groups had different responses to the changes in vegetation cover.

All data statistics and analyses were implemented in Excel 2007 and R platform (version 2.5.1).

RESULTS

We captured a total of 1,052 non-volant small mammals from 2010 to 2013, including 979 insectivores (shrews and moles; 11 species) and 73 rodents (mice, voles, and pikas; 6 species) with a total effort of 1,116 trap-nights (Table I). None of the marked individuals were recaptured during the study period. Eight captured species represented 97% of our total captures, with Hodgson's red-toothed shrew (*Episoriculus caudatus*) 58%, lesser striped shrew (*Sorex bedfordiae*) 13%, long-tailed mountain shrew (*Episoriculus macrurus*) 8%, strip-blacked shrew (*Sorex cylindricauda*) 6%, south China field mouse (*Apodemus draco*) 4%, Chinese shrew mole (*Uropsilus soricipes*) 3%, Chinese mole shrew (*Anourosorex squamipes*) 2%, and Père David's Chinese vole (*Eothenomys melanogaster*) 2%. The other nine species were captured sporadically, with three of them, Salenski's shrew (*Chodsigoa salenskii*), long-nosed mole (*Euroscaptor longirostris*), and moupin pika (*Ochotona thibetana*), captured only once.

Hodgson's red-toothed shrews (*E. caudatus*) were the most abundant both in landslides (63%) and control sites (51%). They appeared in all investigations (winter excluded) and was the only species in landslides in April 2013. The south China field mice (*A. draco*) were the most abundant rodents both in landslides and control sites.

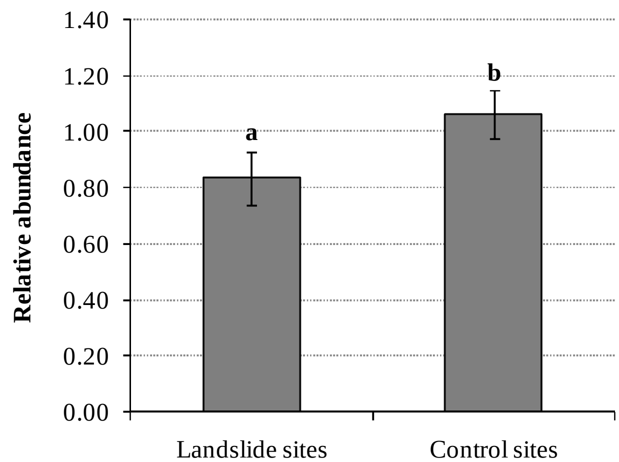

Fig. 3. Relative abundance of non-volant small mammals in landslides and control sites during the four years from 2010 to 2013. The different letters labeled above the columns mean statistically significant (P<0.05) as estimated by Mann-Whitney U test; for landslides sites, n=107, for control sites, n=112.

Mann-Whitney *U* test showed that the overall relative abundance of small mammal communities in landslides were significantly lower than these in control sites (Fig. 3. U=-9.414, P<0.001). The relative abundance and species richness of the small mammal communities in landslides and control sites fluctuated periodically year by year (Fig. 4A, 4B).

Table I.- **Individuals of non-volant small mammals captured in pitfall traps in landslides and control sites from 2010 to 2013 in the Longxi-Hongkou National Nature Reserve (LHNNR), Dujiangyan, Chengdu, Sichuan, China.**

Species	Number of individuals in Landslides				Number of individuals in Controls			
	2010	2011	2012	2013	2010	2011	2012	2013
Soricomorpha								
Episoriculus caudatus	80	46	75	29	93	79	128	80
Sorex bedfordiae	23	14	26	12	13	14	13	22
Episoriculus macrurus	10	8	16	4	7	9	20	14
Sorex cylindricauda	3	5	17	1	4	11	16	5
Uropsilus soricipes	5		6	7	7	6	4	1
Anourosorex squamipes	3	4	3		2	5	3	1
Blarinella quadraticauda		1	2	1	4	3		
Chodsigoa hypsibia			1			2		3
Chodsigoa salenskii						1		
Euroscaptor longirostris	1							
Scaptonyx fusicaudus	2	2						2
Rodentia								
Apodemus draco	2	6	10	7	6	4	4	3
Eothenomys melanogaster	1	2	6	1	1	3	3	3
Niviventer confucianus		1	1	4				
Micromys minutus	1						1	
Vernaya fulva	1						1	
Lagomorpha								
Ochotona thibetana			1					
Total captures	132	89	164	66	137	137	193	134
Trapping nights	129	150	150	135	117	150	150	135

The Shannon-Weiner diversity indices were higher in landslides than these in control sites during the 4 years, and tended to increase in landslides but fluctuated year by year in control sites (Fig. 4C). Community evenness in landslides showed an increasing tendency from 2010 to 2013, but showed an annual fluctuation in control sites (Fig. 4D). The overall dynamics of small mammal communities in landslides, including the species richness and relative abundance, were highly in consistent with these in control sites (Fig. 5).

Spearman test showed that the relative abundance of insectivores and rodents in landslides were positively significantly correlated with these in control sites (r=0.678, P<0.05). The species richness of small mammals in landslides was significantly positively related to that in control sites (r=0.862, P<0.001, Table II), although the correlation was not significant in the species richness of insectivores (r=0.231, P=0.470).

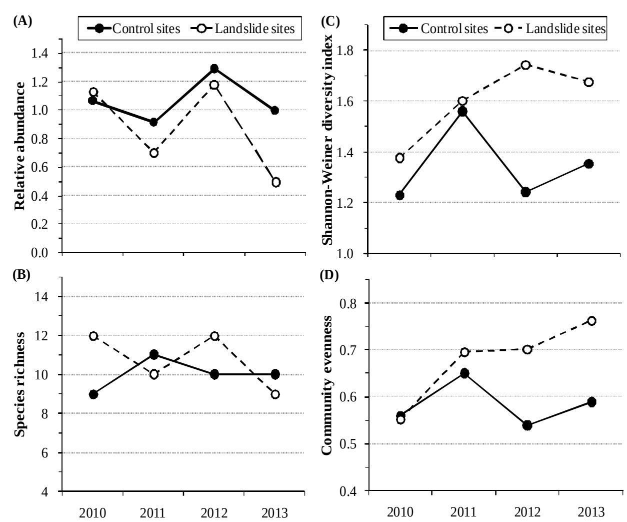

Fig. 4 (A) Relative abundance, (B) species richness, (C) Shannon-Weiner diversity indices, and (D) community evenness of small mammal community in landslides and in control sites from 2010 to 2013.

Table II.- **Spearman correlations of relative abundance and species richness between landslides and control sites.**

		Correlations/*r*	N	P-value
Relative abundance	Insectivores & Rodents	0.678*	12	0.015
	Insectivores	0.805**	12	0.002
	Rodents	0.724**	12	0.008
Species richness	Insectivores & Rodents	0.862**	12	0.000
	Insectivores	0.231	12	0.470
	Rodents	0.791**	12	0.002

Table III.- **Spearman correlations between community indices of non-volant small mammal and vegetation covers in landslides**

		Shrub cover	Herb cover	Moss cover
Species richness	Correlations	-0.050	0.233*	-0.002
	P-value	0.607	0.016	0.984
	N	107	107	107
Total relative abundance	Correlations	-0.101	0.238*	-0.023
	P-value	0.301	0.014	0.817
	N	107	107	107
Relative abundance of rodent	Correlations	-0.017	0.208*	-0.008
	P-value	0.864	0.032	0.933
	N	107	107	107
Relative abundance of insectivore	Correlations	-0.109	0.204*	-0.014
	P-value	0.262	0.035	0.884
	N	107	107	107

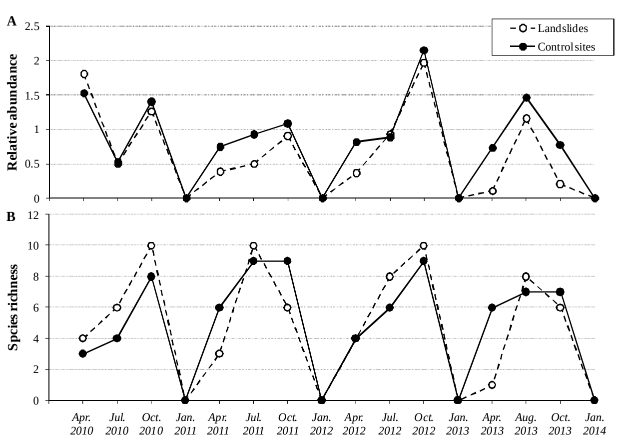

Fig. 5 Dynamics of (A) relative abundance and (B) species richness of non-volant small mammal communities in landslides and control sites in seasons from April 2010 to January 2014.

Spearman correlations between the species richness and relative abundance of small mammal communities in landslides and vegetation covers (shrub cover, herb cover, and moss cover) were shown in Table III. The results showed that the herb cover was positively significantly correlated with the species richness (r=0.233, P<0.05) and the relative abundance of rodents (r=0.208, P<0.05) and insectivores (r=0.204, P<0.05), but with low correlation coefficient.

DISCUSSION

During our 4-year study, Hodgson's red-toothed shrews (*E. caudatus*) were the most abundant among all the species; China field mice (*A. draco*) were the most abundant among the rodents, which was consistent with Zhang *et al*. (2013), who had investigated the small mammal communities in eighteen 3-year-old seismic landslides adjacent to our study area with snap traps in 2011. These results indicated that *E. caudatus* and *A. draco* were two generalist species in this region. In our study, we captured more insectivores than rodents, while Zhang *et al*. (2013) captured more rodents than insectivores. This difference might be the reason of different trapping methods. Any single trapping method has both advantages and disadvantages (Sibbald *et al*., 2006), and cannot be effective for all species. For example, pitfall traps are effective in capturing non-volant small mammals with 'smaller' size and fossorial or semi-fossorial habits, such as shrews and voles (Sibbald *et al*., 2006; Torre *et al*., 2010); snap traps are effective in capturing individuals with 'bigger' size and well ability of climbing and jumping, such as mice and climbing mice (Wilson *et al*., 1996; Torre *et al*., 2010). Therefore, a combination of trapping methods, for example, pitfall traps combined with snap traps, are more effective and strongly recommended in the following studies if the conditions permit. Generally, non-volant small mammals have various strategies to live through the cold winter, such as hibernation, food storage, and migration (Shi *et al*., 2008; Maqbool *et al*., 2011). In our study area, the weather was cold (minimum -5□) and the ground was covered by thick snow all through the winter. Small mammals might reduce their activities to save energy, or migrate to other places, which might be the main reason why no individuals were captured by pitfall traps in all winters in this study.

Our study showed that landslide sites had low relative abundance of non-volant small mammals but high species diversity. Similar findings were also found in other kinds of disturbance such as fires, clearcutting, and floods (Kirkland, 1990; Fisher and Wilkinson, 2005; Raybuck *et al*., 2012). In disturbed areas, the habitat structures (such as vegetation, leaf litter, and woody debris) and food availability would change during the process of regeneration (Hopkins, 2011; Pinotti *et al*., 2012), which would finally lead to the changes of small mammal communities. The limitation of food availability during the early regeneration might be a main reason of the low relative abundance of non-volant small mammals in disturbed area (Fisher and Wilkinson, 2005; Hopkins, 2011). However, the disturbed areas often present a more complex structure (more herbs, more canopy gaps, and more matrix types), which can provide more various microhabitats (Fisher and Wilkinson, 2005, Pinotti *et al*., 2012). Species with special microhabitat requirements may benefit from the habitat changes (Fisher and Wilkinson, 2005). The differences of resource use patterns and niche requirements, allow species to partition certain resources so that coexistence is obtained through the differentiation of their ecological niches (Lancaster and Pillay, 2010). Thus the availability of more microhabitats and niche differentiation would contribute to the high diversity of small mammal community in disturbed areas, which was also shown in seismic landslide disturbed areas in our study.

Generally, non-volant small mammals, especially generalist species which dominated before disturbances, can recolonize soon after disturbances such as forest fire and logging (Williams *et al*., 2002; Fisher and Wilkinson, 2005), but the abundance and species richness of non-volant small mammals remain low over a period of time in disturbed areas (Jacob, 2003; Fisher and Wilkinson, 2005). Studies about non-volant small mammals in burnt areas suggest that the recovery of small mammal communities probably require six to fourteen years after intense forest fires (Fisher and Wilkinson, 2005; Shenko *et al*., 2012). In our study, the relative abundance of small mammal communities in landslides fluctuated dramatically (Fig. 5), and the relative abundance in landslides was significantly lower than these in control sites. Thus, our results suggested that non-volant small mammals from species pool could recolonize soon after seismic landslides happened, but the communities were highly variable during the 4-year study, and the recovery of small mammal communities still need more time.

The responses of non-volant small mammals to disturbance are varied in different species groups (Fisher and Wilkinson, 2005). For example, insectivores, such as shrews, are less directly dependent on the vegetation (Shenko *et al*., 2012). They prefer microhabitats with high moisture and thick forest litter, especially the coarse woody debris which is mainly associated with food availability (Monroe and Converse, 2006; Raybuck *et al*., 2012). Thus shrews may not be present after intense fires with the forest litter burned out, but they can be the primary recolonizers or become more common after clearcutting with much forest litter left (Fisher and

Wilkinson, 2005; Matthews *et al.*, 2009). Compared to insectivores, rodents are more directly dependent on the plant communities. Herbivorous rodents can benefit from the increase of woody plants and herb cover after forest fire or logging as a result of the decrease of canopy cover (Converse *et al*., 2006; Monroe and Converse, 2006). In our study, the relative abundance of both insectivores and rodents responded to the landslide disturbance negatively. However, both of them showed positively responses to the increase of herb cover (Table III). The abundant insectivores in landslides indicated that small mammals might benefit from the changes of habitat characteristics, such as the high moisture, the more canopy gaps, and the availability of more microhabitats, in spite of the rare coarse woody debris.

As direct food resource for rodents and indirect food resource for insectivores, plant communities play important roles in the succession process of non-volant small mammal communities (Carey and Johnson, 1995; Monamy and Fox, 2000). Among the herb layer, shrub layer and tree layer, herb layer has greater effects on the species composition and structures of non-volant small mammal communities (Williams *et al*., 2002; Monroe and Converse, 2006). Herb plants can not only provide food resource for non-volant small mammals but also shelters to avoid the predators (Williams *et al*., 2002). Thus non-volant small mammals can benefit from the increase of herb cover after disturbances (Fisher and Wilkinson, 2005; Monroe and Converse, 2006). In our study, both the insectivores and rodents showed significantly positive relationships with the herb cover (Table III), which suggested that the recovery of herb layer played an important role in promoting the recovery of non-volant small mammal communities in seismic landslides.

Source population is the population which survives well and has high population growth rate in high quality habitat, and can supply individuals for the low quality habitat continuously (Pulliam, 1988). In disturbed areas, the dispersal of individuals from the source populations can promote the utilization of new or depopulated areas and facilitate the persistence of local populations (Roff, 1974), which would finally have profound effects on the reestablishment of non-volant small mammal communities (Santos *et al.*, 2011; Grönroos and Heino, 2012; Gaines and McClenaghan, 1980). In other words, the dynamics of the non-volant small mammal communities in disturbed habitats is highly dependent on the dispersal and colonization of individuals from the source populations (Ulrich and Ollik, 2004; Shenko *et al*., 2012). In our study, we found that the relative abundance and species richness of non-volant small mammal communities in landslides were positively significantly correlated with the control sites, which indicated that the source populations in undisturbed areas might play important roles in promoting the recovery of non-volant small mammal communities in landslides.

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Conflict of interest declaration

The authors declare that there is no conflict of interest.

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