Pakistan J. Zool., vol. 54(5), pp 2039-2045, 2022 DOI: https://dx.doi.org/10.17582/journal.pjz/20210911030917

Natural Recovery and Impaction of Landslide and Debris Flow within Habitat of Yunnan Snub-nosed Monkeys in Baimaxueshan Nature Reserve

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Article Information
Received 11 September 2021
Revised 15 October 2021
Accepted 06 November 2021
Available online 25 February 2022 (early access)
Published 23 May 2022

Authors' Contribution
DW, YZ, MZ and DL designed the research. DW, YZ and WX conducted research. CY and WX prepared figures and tables. DL Wrote and revised the draft.

Key words
Landslide and debris flow, Natural recovery, Habitat, Vegetation restoration, Yunnan snub-nosed monkeys, *Rhinopithecus bieti*

ABSTRACT

Landslide and debris flows, a serious geological disaster, are common at the edge of the Tibetan Plateau, and damage the surface vegetation. Like other natural disasters, landslide and debris flows cause a shift in local ecological conditions, which can have profound impacts on the habitat of non-human primates. This study investigated the characteristics of surface vegetation found within the debris field of a landslide and debris flow that occurred in 2008 at Gehuaqing in Baimaxueshan Nature Reserve ten years later. We calculated the surface area of the debris field to be 71672.96 m2, affecting around 312500 m2 of the known home range of a resident Yunnan snub-nosed monkey group. A field survey was conducted to sample the vegetation within the area of the landslide and debris flow after it had been allowed to grow for ten years. In total, 27 plant species were observed within the debris field, all classified as either shrubs or herbaceous plants. *Gnaphalium hypoleucum* had the highest importance value of the herbs (27.48%), while *Leycesteria formosa* had the highest importance value of the shrubs (17.33%). The Shannon-Wiener diversity index was significantly higher in the lower section and the Bray-Curtis distance was significantly lower, suggesting vegetation recovery has progressed faster on the lower end of the debris field. The speed of restoration within the landslide and debris flow area is important for the protection of Yunnan snub-nosed monkeys living at Gehuaqing. A reasonable plan for vegetation restoration according to the composition of the surrounding community could mitigate population reductions in the monkeys and other local wildlife.

INTRODUCTION

Landslide and debris flows, a common geological disaster, dump large amounts of mud and rocks onto lower-lying areas (Blahut *et al.*, 2010). They can permanently change landscapes, for instance by flattening mountains (Wang *et al.*, 2005). The landscape of Yunnan is comprised of the southeast edge of the Tibetan Plateau. Due to its unique geographic structure and complex local geologic processes, the area has a long history of landslide and debris flows (Chen *et al.*, 2016). According to the National Bureau of Statistics of the People's Republic of China, from 2010-2017 natural disasters such as landslide and debris flows and mudslides in Yunnan Province affected 1777.5 thousand hectares, impacted 135.19 million people, killed 2,056 people and caused 165.79 billion RMB of direct economic losses (http://data.stats.gov.cn/easyquery.htm?cn=E0103). Due to Yunnan Province has a high incidence of landslide and debris flows and mudslides, making it a natural laboratory for studying vegetation recovery after these destructive events.

Yunnan is also one of the most biodiverse regions in China, with a variety of ecosystems characteristic of the province (Pu *et al.*, 2007). Baimaxueshan Nature Reserve is located in Yunnan Province, and this reserve is an important habitat for Yunnan snub-nosed monkeys (*Rhinopithecus bieti*), an endangered species (Ren *et al.*, 2016; Xia *et al.*, 2020), and about 407 individuals of Yunnan snub-nosed monkeys inhabited Gehuaqing in

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0030-9923/2022/0005-2039 $ 9.00/0

2007 (Grueter *et al*., 2017). Endemic to China, this primate lives at high altitudes under difficult, strongly seasonal conditions (Long *et al*., 1994; Li *et al*., 2006). *R. bieti* occupy a certain area for a long time to ensure their daily activities, including foraging, breeding, concealment and rearing (Li *et al*., 2010a). If enough habitat is destroyed within their home range, such that they can no longer survive there, *R. bieti* groups will migrate to seek out other suitable habitat (Li *et al*., 2010b). The destruction characteristic of landslide and debris flows can increase habitat fragmentation within the monkeys' territory. The total geographic distribution of *R. bieti* is restricted to a long and narrow section of the Hengduan Mountains, between the Jinsha River and the Lancang River, and during 1994 and 2016 population surveys estimated that only 3,000 individuals remain across 17 groups (Zhao *et al*., 2019; Xia *et al*., 2020). Despite recovery in the total population since the millennium, the long-term survival of *R. bieti* is still at risk due to forest fragmentation and anthropogenic disturbance (Zhao *et al*., 2019). The declining habitat quality and resource availability of *R. bieti* also have negative effects on the long-term viability of other primate species (Wahungu *et al*., 2005; Arroyo-Rodriguez *et al*., 2014), increasing the risk of global primate extinction (Li *et al*., 2018).

The effects of other natural disasters on animals have been studied both in China and abroad; for instance, the impact of snowstorms on *R. bieti* (Li *et al*., 2012) and changes to wildlife behavior brought on by earthquakes (Ge *et al*., 2011). However, the interaction between landslide and debris flows and primate habitat quality has not yet been explored, and this phenomenon could affect the protection of species such as *R. bieti*. In this study, we analyzed the composition of vegetation re-growing over a landslide and debris flow that occurred at Gehuaqing in 2008. We examined site characteristics in 2018, ten years after the disaster, and calculated several measures of species diversity with the goal of helping administrator to build a reasonable vegetation restoration plan in Baimaxueshan Nature Reserve.

MATERIALS AND METHODS

Study site and species

The study site is located at Gehuaqing in the southernmost part of Baimaxueshan Nature Reserve (27° 34′N, 99° 17′E), in Yunnan Province (Grueter *et al*., 2017). The study site belongs to the Hengduan Mountains, a high-altitude region without basins or valley plains.

Yunnan snub-nosed monkeys living at Gehuaqing numbered about 407 in 2007 (Grueter *et al*., 2017). Their home range occurs entirely within the reserve, and the edge of their territory is less than 1 km away from the nearest human dwellings (Grueter *et al*., 2008). In 2008, a landslide and debris flow occurred within the monkey group's range. We investigated the range of landslide and debris flow in 2008, and we also surveyed natural recovery at the site of the slide in 2018.

Data collection

Field sampling was conducted on the width and altitude of the debris area from the landslide and debris flow at 46 sample points. SPSS 17.0 was used to calculate the correlation between altitude and the width of the landslide and debris flow at that point. Spatial analysis in ArcGIS10.2 was used to calculate the surface area of the debris field from the landslide and debris flow. Finally, the area of the debris field was compared to the rest of the resident monkey group's home range of (Grueter *et al*., 2008) results to assess its impacts on their habitat.

We conducted a quadrat survey of vegetation within the debris field in order to investigate its natural recovery after ten years. In order to compare differences in the distribution of vegetation in different parts of the landslide and debris flow's debris field, we divided it into an upper and a lower section. ArcGIS 10.2 was used to randomly divide the study area into 10m×10m grids, randomly select the grids of 20 points in the study area as survey zones (Fig. 1), and record all species in each sample. Species identification was done using Flora of Yunnan (Wu, 2006). We also calculated relative density, coverage and frequency for each quadrat.

Data analysis

To determine the distribution characteristics of plant species, we calculated species importance value (IV), to determine the diversity characteristics of plant species, the Shannon-Wiener diversity index was calculated to study species diversity and evenness (Oksanen *et al*., 2010). The Bray-Curtis distance index was used to indicate the similarity of plant species composition in different parts of the area impacted by the landslide and debris flow after natural recovery (Mi *et al*., 2019). The equations follow:

Importance value (IV) = (Relative Density + Relative Coverage + Relative Frequency)/ 3

The Shannon-Wiener diversity index

$$H = -\sum_{i=1}^{S} P_i \ln P_i$$

Where; P_i represents the proportion of importance values of species i to the sum of importance values of all species in the community. S is the total number of plant species in each sample plot.

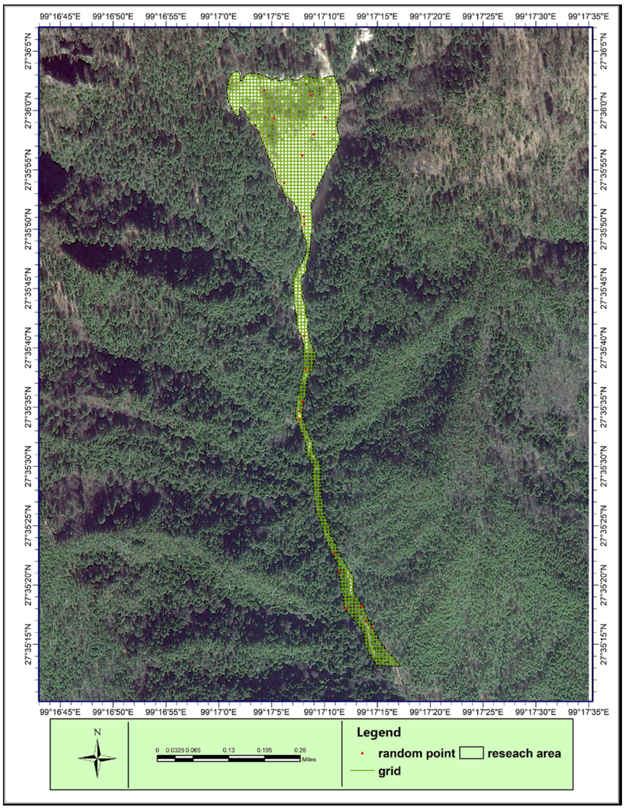

Fig. 1. Diagram of the study area grid.

The Bray-Curtis distance index is calculated as:

$$\text{Bray - Curtis: } d_{jk} = \frac{\sum_{i=1}^{n} |x_j - x_k|}{\sum_{i=1}^{n} |x_j + x_k|}$$

Where x_i is the importance value of each species, and j and k are the number of quadrats.

In order to more clearly and intuitively express species abundance, we tested a series of ranked abundance distribution models and selected the best model to compare species abundance distribution between the upper and the lower section of the debris field (Whittaker, 1965). The model used is as follows:

$$\hat{a}_r = \frac{N}{S}\sum_{k=r}^{S}\frac{1}{k} \text{ Null model}$$

$$\hat{a}_r = N\alpha(1-\alpha)^{r-1} \text{ Preemption model}$$

$$\hat{a}_r = \exp[\log(\mu)+\log(\sigma)\phi] \text{ The log-normal model}$$

$$\hat{a}_r = N\,\hat{p}_i\, r^{\gamma} \text{ Zipf model}$$

$$\hat{a}_r = N_c(\gamma+\beta)^{\gamma} \text{ Zipf-Mandelbrot model}$$

T-tests were used to compare the Shannon-Wiener diversity index, the Bray-Curtis distance between the upper and lower sections of the landslide and debris flow area. All statistical analyses were two-tailed and the significant alpha level was set at 0.05. SPSS 19.0 and R 3.6.1 were used for the statistical analyses, and ArcGIS 10.2 was used for drawing maps and graphs.

RESULTS

Distribution characteristics of landslide and debris flow at Gehuaqing in 2008

According to the Chinese geographical classification of animals, there are 9 orders, 23 families, 70 genera and 100 species of mammals in the reserve, accounting for 16.8% of the total mammal species in China and 33.3% in Yunnan. 246 species of birds have also been spotted in the reserve, belonging to 17 orders, 43 families and 4 subfamilies, accounting for 30.7% of the recorded bird species in Yunnan province (Li, 2007).

The average altitude and the average width of landslide and debris flow are 2665.96±183.32 m and 91.39±93.06 m, respectively (Table I). The development stage of debris flow width is divided into two parts: the upper section is the altitude range of 2875 m to 3168 m with a total of 7 points, and the lower section is the altitude range of 2454 m to 2842 m, with a total of 39 points. There is a clear monotonic relationship that the upper section mudslides altitude and width were positively correlated relationship, namely, with the loss of the altitude, the width of the debris flow is gradually reduced (Spearman correlation analysis: r=0.883, $p<0.01$). The lower section debris flow is a negative linear relationship, namely, with the decrease of the altitude, the debris flow width increases gradually (Spearman correlation analysis: r=0.604, $p<0.01$).

Table I. The distribution characteristics of landslide and debris flow.

Name	N	M±SD (Range)	N	correlation coefficient	P
Altitude (m)	46	2665.96±183.32 (2454.00-3168.00)			
Width (m)	46	91.39± 93.06 (30.00- 520.00)			
Upper section			7	.8830**	.008
Lower section			39	-0.604**	.000

**indicates the correlation is highly significant (p<0.01).

Influence of landslide and debris flow for monkeys' home range

The landslide and debris flow occurred within the home range of the *R. bieti* group. Using ArcGIS 10.2 the surface area of the landslide and debris flow's debris field was found to be 71672.96 m^2. The area affected by the landslide and debris flow is nearly in the center of the monkeys' range, running through five 250 m×250 m grid cells of 184 occupied habitat (312500 m^2 total) (Grueter *et al*., 2008) (Fig. 2). The landslide and debris flow ran through a river valley that is an important water source for the monkeys. Four fresh segments of monkey feces were found in the lower section of the debris field, which shows that *R. bieti* is still active in the area of the landslide and debris flow, but in fewer numbers (Supplementary Fig. 1).

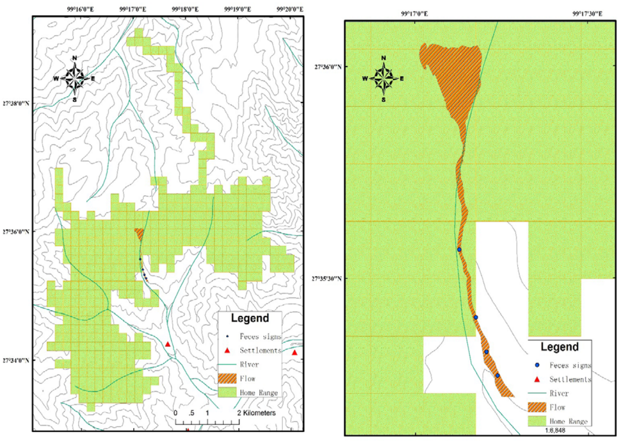

Fig. 2. Influence of the landslide and debris flow for *Rhinopithecus bieti*'s home range.

Species composition for natural recovery of vegetation in the debris field

A total of 27 species of plants were found in the debris field (Table II). The species were divided into shrubs and herbs, with small trees less than 3 m tall also classified as shrubs. The highest importance value for a shrub in the upper section was for *Alnus nepalensis* (10.56%), followed by *Pinus massoniana* (10.13%) and *Pinus massoniana* (9.26%). The herb with the highest importance value was *Gnaphalium hypoleucum* (18.49%), followed by *Artemisia argyi* (6.19%) and *Polygonum viviparum* (4.52%). In the lower section, the shrub with the highest importance value was *Aralia elata* (15.28%), followed by *Leycesteria formosa* and *Pinus massoniana*. The highest importance value for an herb was *Lobelia sessilifolia* (11.34%), followed by *Gnaphalium hypoleucum* (8.99%). Within the entire debris field, *Gnaphalium hypoleucum* had the highest overall importance value, 27.48%, among the herbs while *Leycesteria formosa* had the highest importance value among the shrubs, 17.33%. Three of the recorded plant species are edible by *R. bieti*; they are *Salix radinostachya*, *Aralia elata* and *Holboellia latifolia*.

Table II. Species composition within the landslide and debris flow area.

Number	Species	Upper	Lower	IV*
	Shrubs			
1	*Pinus massoniana*	10.13%	6.36%	16.49%
2	*Alnus nepalensis*	10.56%	0	10.56%
3	*Salixradinostachya*	9.26%	0	9.26%
4	*Leycesteria formosa*	7.17%	10.16%	17.33%
5	*Tsuga chinensis*	4.79%	4.74%	9.53%
6	*Aralia elata*	0	15.28%	15.28%
7	*Coriaria nepalensis*	0	1.63%	1.63%
8	*Dioscorea deltoidea*	0	1.69%	1.69%
9	*Sorbaria arborea*	2.96%	0	2.96%
10	*Hypericum monogynum*	1.62%	3.86%	5.48%
11	*Coriaria nepalensis*	1.02%	0	1.02%
12	*Sarcococca hookeriana*	8.49%	0	8.49%
13	*Streptolirion volubile*	0	6.30%	6.30%
14	*Holboellia latifolia*	0	1.70%	1.70%
15	*Clethra delavayi*	0	2.79%	2.79%
16	*Hedera nepalensis*	0	1.89%	1.89%
	Herbs			
17	*Lobelia sessilifolia*	0	11.34%	11.34%
18	*Nasturtium officinale*	1.54%	0	1.54%
19	*Rubus lutescens*	1.14%	0	1.14%
20	*Aletris pauciflora*	1.14%	0	1.14%
21	*Gnaphalium hypoleucum*	18.49%	8.99%	27.48%
22	*Carextaliensis franch*	4.00%	0	4.00%
23	*Duchesnea indica*	0.32%	1.40%	1.72%
24	*Polygonum viviparum*	4.52%	0	4.52%
25	*Diphylleia sinensis*	2.75%	4.74%	7.49%
26	*Artemisia argyi*	6.19%	0	6.19%
27	*Chamerion angustifolium*	3.92%	0	3.92%

*IV, importance value.

With respect to the recovery of vegetation in the upper vs. the lower section of the landslide and debris flow area, the Shannon-Wiener diversity index had higher values for the lower section of the debris field (Fig. 3). This indicated greater diversity in the lower section. During the collection of field samples, numerous tree seedlings were observed in the shrub layer, suggesting that the community is actively regenerating through the growth of these seedlings. The Bray-Curtis index reflects the dissimilarity in species composition between patches (Fig. 3). It was significantly smaller in the lower section than in the upper, indicating that patches there have become more similar to each other as the vegetation has regrown.

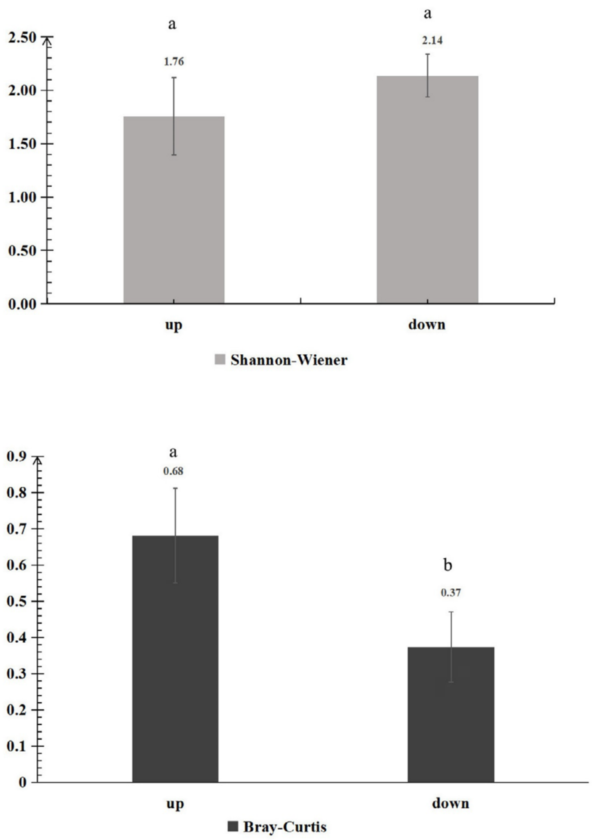

Fig. 3. The Shannon-Wiener index, the Bray-Curtis index in the upper and lower sections of the landslide and debris flow.

Ranked abundance distribution model

The ranked abundance distribution model plots in descending order. Five models commonly used in R were chosen, and the best-fit model was selected. For the upper section of the landslide and debris flow, the AIC value of preemption was the lowest, indicating that the model best fit the data. In contrast, for the lower section of the landslide and debris flow, Mandelbrot is the optimal model. Both models indicate the same general trend of increased vegetation recovery in the lower section of the debris field (Fig. 4).

DISCUSSION

Impact of landslide and debris flows for Yunnan snub-nosed monkeys

Snub-nosed monkeys tend to thrive in the world that are Pleistocene refugia (Jablonski, 1998), suggesting that they do best when the landscape remains relatively unchanged. Landslide and debris flows are often sudden and destructive, and the occurrence of this natural disaster within the home range of an *R. bieti* group could force them to alter their ranging patterns and seek out alternative areas to occupy and forage (Li *et al*., 2012). The width of the debris field created by a landslide and debris flow varies with the influence of soil type and compaction, slope angle, and various other factors. The group of 407 Yunnan snub-nosed monkeys distributed in Gehuaqing, where is one of the most densely distributed areas of Yunnan snub-nosed monkeys (Grueter *et al*., 2017). With respect to the landslide and debris flow at Gehuaqing, the resident monkey group was greatly affected because of its location in the center of their range. It likely contributed to fragmentation of their habitat (Laurance *et al*., 2000), but most importantly, the landslide and debris flow destroyed the old-growth forest within the debris field, which is the monkeys' preferred habitat type for feeding (Grueter *et al*., 2009). This could increase nutritional stress, especially during the winter. Under normal conditions, monkeys travel along relatively stable routes within their territory (Ren *et al*., 2012). Only three species of plants *R. bieti* finds edible were found in the area affected by the landslide and debris flow. The destruction of a section of the forest may force the resident *R. bieti* group to alter movement patterns for several years. Larger trees are also preferred as sleep sites (Li *et al*., 2006), so the loss of many large trees in the area of the landslide and debris flow could affect the choice of sleep sites for these monkeys. The ecological impact of this landslide and debris flow on Gehuaqing's monkeys can be felt along several dimensions (Guo *et al*., 2008).

Natural recovery of vegetation in the landslide and debris flows field

The progress of vegetation regrowth within the debris field shows that though there is the potential to restore native plant cover, natural recovery is limited. After ten years of undisturbed regrowth, the landslide and debris flow is dominated by a shrubby-herbaceous community. Under natural restoration conditions, the sequence of community succession is typically annuals, perennials, short root clusters and subshrubs (Kou *et al*., 2016). Trees, in contrast, usually take decades or even hundreds of years to recover after a landslide and debris flow or a mudslide (Salmo *et al*., 2013). In this study, we found that although the species list at the bottom and the top of the landslide and debris flow area were different, comparisons of the Shannon-Wiener diversity index between the upper and lower region were not significant, and species composition was only slightly different. Active human intervention in an ecosystem after a natural disaster can help to rebuild native communities faster (Finnegan *et al*., 2019). Baimaxueshan is located at the southeast edge of the Tibetan Plateau, where has undergone an uplift since the early Pleistocene. The climate is also mild and humid, providing favorable terrain and climate conditions for landslide and debris flows (Chen *et al*., 2005). Without human intervention and management, natural vegetation may be difficult to recover, especially in the initial stage of restoration (Chen *et al*., 2016).

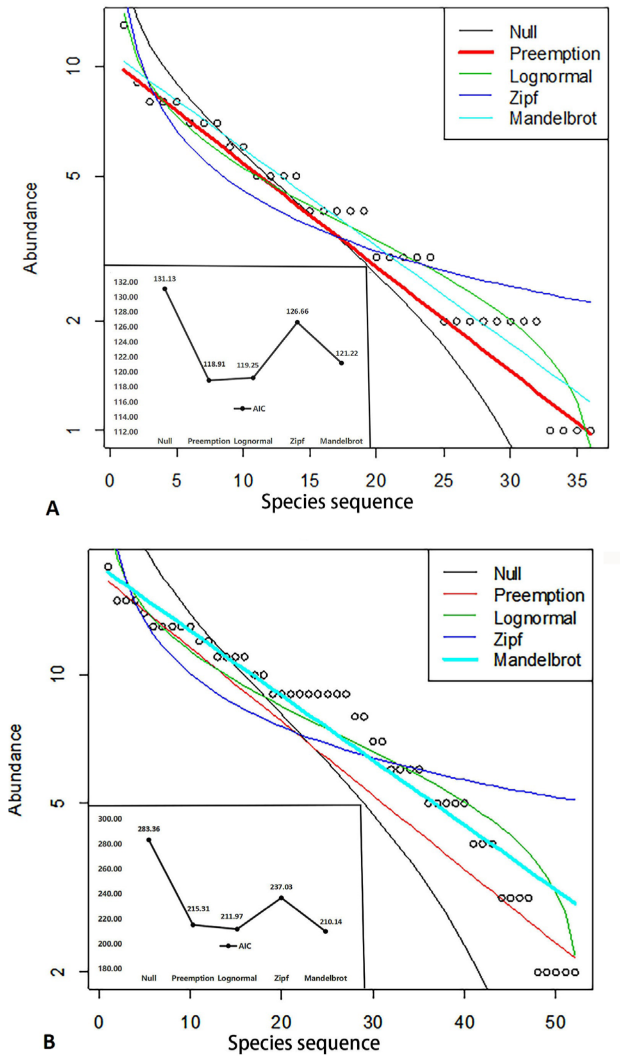

Fig. 4. Model of the upper section and lower section (red line is the best model).

CONCLUSIONS

In summary, the speed of ecological restoration in the area affected by the landslide and debris flow at Gehuaqing has a profound impact on the local *R. bieti* population. Forest fragmentation spatially isolates subpopulations and impedes gene flow. In addition, fragmentation can reduce the availability of large food patches by changing tree species composition and diversity. Vegetation restoration may not happen quickly enough under natural conditions to prevent negative impacts on wildlife vegetation. From 2008 to 2018, no trees have grown to more than 3m tall in the debris field, reflecting the slow pace of recolonization by ecologically important species. A reasonable vegetation restoration plan, based on the community characteristics of the area surrounding the damage and the criteria for suitable monkey habitat, can help improve habitat quality and mitigate losses of Yunnan snub-nosed monkeys as well as other wildlife within the reserve.

ACKNOWLEDGEMENTS

We are grateful to our field assistants Nisha A, Shunkai Feng, Xuewen Feng. We thank Baimaxueshan Nature Reserve for our work permit. We also thank that Ali Krtzon revise English for this manuscript.

Funding

Financial support was provided by National Natural Science Foundation of China (No. 32070454), the Second Tibetan Plateau Scientific Expedition and Research Program (No. 2019QZKK0501), the Biodiversity Survey and Assessment Project of the Ministry of Ecology and Environment, China (No. 2019HJ2096001006), the Sichuan Science and Technology Program (No. 2021JDRC0024).

Field study permissions

This field experiments were approved by State Forestry Administration of China (the Second National Survey on Terrestrial Wildlife Resources in China).

Supplementary material

There is supplementary material associated with this article. Access the material online at: https://dx.doi.org/10.17582/journal.pjz/20210911030917

Statement of conflict interest

The authors have declared no conflict of interest.

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