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云南北部泥石流多发干旱河谷区不同干扰对土壤种子库的影响*

沈有信 张彦东 张 萍 刘文耀

(中国科学院西双版纳热带植物园, 昆明 650223)

摘 要 对云南北部的泥石流多发干旱河谷区不同干扰状况下的土壤种子库特征进行了研究。结果表明不同形式的干扰对土壤种子库特征产生不同形式的影响。人工种植合欢(*Leucaena glauca*)并屏除人和家养动物的影响使土壤种子库的种子密度增大, 同时种子组成也由原来的耐旱型为主变为耐荫型为主; 马桑(*Coriaria sinica*)种植并实行年度砍伐降低了种子密度并减少了种子种类, 但主成分的性质未发生改变; 滑坡与水土流失将很多种子带入其坡积物中, 从而降低土壤种子库密度与组成种类; 泥石流是破坏地表土壤层和土壤种子库的最主要因素。

关键词 土壤种子库 干扰 泥石流干旱河谷

EFFECTS OF DISTURBANCE TYPE ON SOIL SEED BANKS IN A DEBRIS-FLOW PRONE DRY VALLEY OF NORTHERN YUNNAN

SHEN You-Xin ZHANG Yan-Dong ZHANG Ping and LIU Wen-Yao

(*Xishuangbanna Tropical Botanic Garden, the Chinese Academy of Sciences, Kunming* 650223)

Abstract Soil seed banks of different ecosystems subject to different disturbances were studied in a dry valley prone to debris flow in Northern Yunnan. It was found that variation in the type of disturbance had a strong effect on the density and composition of the soil seed bank. Restoration with a *Leucaena glauca* plantation (with over 6 years free of disturbance from humans or domestic animals) increased the seed bank density and the dominant species changed from aridity-tolerant to shade-tolerant species. Seed bank density and the variety of species was reduced in an annually cut *Coriaria sinica* plantation, though the composition of the seed bank remained constant. Landslides and soil erosion had a negative effect on seed bank density and species types as many seeds were removed from the soil. Debris flow created the greatest disturbance as it destroying both the soil surface and seed bank.

Key words Soil seed bank, Disturbance type, Debris flow prone dry valley

Along some rivers and their tributaries in the Hengduan Mountain Region in the Southern China, the phenomena of "local dryness", that is, increased heat and aridity in the valley can be found (Zhang, 1992). Due to their comparative advantage in agricultural development, these hot and dry valleys are highly exploited and it is now almost impossible to find a natural ecosystem (Zhang, 1992). In fact, soil erosion, debris flows and landslides are very common (Du & Kang, 1987). Restoration and rehabilitation of these valley systems is of significant and urgent need for both economic and ecological reasons

Soil seed bank is an important component of any plant community or ecosystem. Persistence of seeds in the soil have important implications for

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E-mail: yxshen@xtbg.ac.cn

the restoration and conservation of plant species and communities (Akinola *et al.*, 1998). In recent decades much research has been carried out on soil seed banks, including such aspects as their density, composition, relationship with standing vegetation, dormancy, persistence and viability (Michael, 1992; Xiong *et al.*, 1992; Tang *et al.*, 1999; Zhou *et al.*, 2000). Since the 1990's, with increasing attention to environmental restoration and rehabilitation, some research has begun to be undertaken to directly serve restoration purposes (Hester *et al.*, 1991; Shaw, 1996; Akinola *et al.*, 1998). However, to date no research on seed banks in dry valleys in Southern China has been undertaken.

This study focuses on soil seed banks of ecosystems subject to different disturbances in one typical dry valley, the Xiaojiang River in Northeastern Yunnan. The study analyzes the effects of disturbances on soil seed banks, with a view to providing knowledge that can be useful in the restoration of those ecosystems.

1 Material and methods

1.1 Study area and sample sites

Flowing from south to north in Northeast Yunnan, the Xiaojiang River is one of the tributaries of the Jinsha River (the upper reaches of the Yangtze River). The section between 700-1600 meters above sea level has been identified as dry valley area (Du & Kang, 1987). Within this area, grass species constitute the dominant vegetation cover. Due to special geographical features (namely Great Xiaojiang Faults) and the huge impact of human activities, this area is becoming one of the major areas of debris flow activity areas in China. Some geologists have spoken of the area as a 'natural museum' of debris flows. There are 107 debris flow trails in the 123 gullies that lie along the 90 km stretch of the lower part of the Xiaojiang River. Therefore, debris control and vegetation cover restoration is a very urgent need in this area.

This study was carried out at Jiangjiagou (26 °N, 103 °E), one of the major debris flow watersheds of the Xiaojiang River. The watershed is 13.9 km long and covers an area of 48.6 km^2. The altitude ranges from 1042 m at the bottom to 3269 m at the top. The climate is hot and dry in the lower portion of the valley, with a mean annual temperature of 18℃ and lowest mean temperature of more than 10℃. Frost is rare and there are more than 300 frost-free days each year. Annual precipitation is around 600-700 mm, but the potential evaporation exceeds as much as five times this number. On average, there are 15 debris flow occurrences each year in this small valley. As a result, along the lower part (i.e. the dry valley portion), slopes are unstable and land surfaces are rocky. Grass is the major vegetation cover. Because the local farmers heavily depend on grass for animal fodder and fuel, the grass is cut annually throughout the valley. In recent years, efforts have been put into tree and shrub planting, in an effort to solve fuel shortages, reduce landslides and erosion, and ultimately reduce the material available for accumulation in debris flows.

Five typical ecosystems were selected for this study. These are 1) grassland, 2) shrub + grass, 3) tree plantation, 4) new slope deposit, and 5) new debris flow materials. Each of these systems is the result of some kind of disturbance. The characteristics of each site are as follows.

1) Grassland (GL): This is the main land cover type in the Jiangjiagou area. The major species are aridity tolerant species, such as *Eriophorum comosum*, *Heteropogen contortus*, and *Eulaliopsis binata*. Grazing and cutting of grass for fodder or fuel occur annually.

2) Shrubs (*Coriaria sinica*) + grass (CG): On some unstable slopes, seeds of *C. sinica* were sown in 1995, and coverage of *C. sinica* is now around 60%. Other land is covered by herbal species, such as *Eriophorum comosum*, *H. contortus* and *Eulaliopsis binata*. Grazing and annual cutting of *C. sinica* for fuel are major disturbances. There is no production of *C. sinica* seeds.

3) Tree plantation (LG): *Leucaena glauca* were planted around 1993-1994 at some slopes. Now most trees are 3-4 meters tall and the cover

rate is 100%. *Peristrophe japonica* and *Rabdosia sculponeata* are the major species occupying the under story. No cutting and other human disturbances take place.

4) New slope deposits (NSD): These were formed during the recent rainy season by landslides and soil erosion. The surface is rocky and with sparse vegetation.

5) New debris flow materials (NDFM): Formed by the latest debris flows. They are rocky and bare.

Since it is impossible to find a primary ecosystem as the reference site, we took grassland (GL) as the control for comparisons.

1.2 Soil sampling and treatment

A site of about 100 m × 50 m was selected in each of the *L. glauca* plantation, *C. sinica* plantation, and grass types. Two transects were designed along the river banks to sample for NSDs and NDFMs. The altitude of the five sites varied within 50 meters.

In December 1999, 15 soil samples (10 cm × 20 cm × 10 cm) were collected from random points within each of the five sites. Soils were sterilized with 5 mm mesh and the top ones were carefully checked and weighted. After weighting, the remains were transported to the laboratory and stored to protect from the cold winter.

When winter was over, each stored soil sample was mixed and evenly spread to an approximate depth of 2 cm in a plastic tray filled with 2 cm of seed-killed sand (8 hours at 105℃). This was then placed in a large germination house constructed of translucent fiberglass roof and glass walls. Starting from March 6, 2000, all samples were kept moist by mist spraying. Records were taken at one-week intervals until there were no more seedlings emerging within a period of a week (August 18). Seedlings were removed and recorded as they were identified. For several uncertain species, seedlings were transplanted until they were identified.

The mean numbers of seeds of each species from each site were calculated and transformed into individuals/m^2. The Shannon-Weiner index and Simpson's index (Rico-gray & Garcia-Franco, 1992) was used to describe the diversity of the five communities.

Surveys on species composition of vegetation were carried out in August 2000. Two 20 m × 20 m sites for *L. glauca*, three 10 m × 10 m sites for *C. sinica* and two transects for grass land were designed and surveyed.

2 Results

2.1 Characteristics of germination

From March 6 to August 18 2000, 1358 seedlings emerged from all of the soil samples. Seeds started to emerge one week after trays were watered. About 50% of seedlings emerged after 30 days of wetting (Fig. 1).

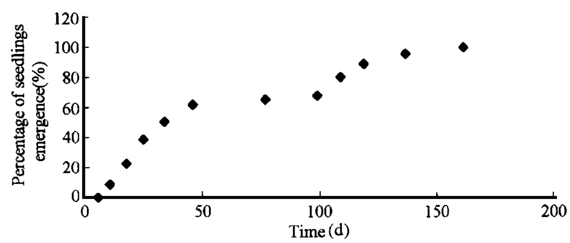

Fig. 1 Seedlings emerged from all of the soil samples of debris prone dry valley

2.2 Density and composition of seed banks

The total numbers of seedlings that emerged from the soil samples are shown in Table 1. Density of per square meter was calculated. To quantify the effects of each species and species groups, the proportion of individuals was also calculated.

The density of seed banks in the sampled sites ranged from 90 at the NDFM to 1397 individuals/m^2 at the *L. glauca* forest. The density of the tree covered community (LG, 1397) was higher than that of the grassland (GL, 1213) and shrub (CG, 810) communities. Landslides and soil erosion caused the redistribution of surface materials but there were still about 290 individuals/m^2 of seeds inside the NSD samples. Pioneer-species seeds had already occupied the NDFM.

Table 1 Density and species composition of different seed banks in a debris flow prone dry valley

Community types	*Coriaria sinica* grass (CG)		*Leucaena glauca* (LG)		Grass land (GL)		New slope deposit (NSD)		New debris flow materials (NDFM)	
Species groups and species name	A *	B #	A	B	A	B	A	B	A	B
Herb species										
Artemisia codonocephala	14	5.8	102	24.3	80	21.9	2	2.3		
Oxalis corniculata	5	2.1	39	9.3	2	0.5	14	16.1		
Chenopodium album					6	1.6				
Polygonum capitatum			3	0.7	8	2.2	3	3.5		
Gnaphalium affine	2	0.8	2	0.5	18	4.9	1	1.1		
Amaranthes spirosus			5	1.2	3	0.9				
Carpesium nepalense var. *lanatum*			1	0.2	16	4.5	3	3.5		
Stellaria media					1	0.3				
Ixeris gracille			2	0.5	3	0.9	1	1.1		
Cardamine flexuosa			1	0.2						
Heteropogen contortus	149	61.3	8	2.0	44	12.0	22	25.4		
Arthraxon jispidus			4	1.0	21	5.8	4	4.6		
Peristrophe japonica			99	23.6	2	0.5				
Solanum nigrum	4	1.7	4	1.0	2	0.5				
Elsholtzia ciliata			10	2.4			3	3.4		
Origanum vulgare	2	0.8	21	5.0	10	2.7	5	5.7		
Eriophorum camosum	21	8.6	3	0.7	85	23.3				
Rabdosia sculponeata			55	13.1						
Eupatirium adenophorum	20	8.2	28	6.7	25	6.7	14	16.1	27	100
Oxyria digyna			2	0.5	2	0.5				
Eulaliopsis binata	4	1.7	1	0.2	30	8.3	15	17.2		
Senecio chrysanthemoides			5	1.2						
Themeda triandra var. *japonica*	2	0.8	1	0.2	2	0.5				
Subtotal	223	91.8	396	94.5	360	98.5	87	100	27	100
Shrubs species										
Campylotropis polyantha	11	4.5	1	0.2	3	0.9				
Viburnum cylindricum	9	3.7	2	0.5						
Coriaria sinica			6	1.4						
Sida acuta			5	1.2						
Subtotal	20	8.2	14	3.4	3	0.9				
Liana species										
Atylosia scarabaeoides					1	0.3				
Subtotal					1	0.3				
Other species			9	2.1	1	0.3				
Total	243	100	419	100	365	100	87	100	27	100
Density (individuals/m^2)	810		1397		1213		290		90	

*: Number of seeds #: Ratio of individual

Soil seed banks in all sample sites were dominated by herbs, both in terms of the quantity of seedlings emerged and number of herb species identified. The ratio of individual herbs ranged from 91.6% in the CG land to 100% at NSD and NDFM. Shrub, liana and tree species were few. The dominant seedlings that emerged from each of the soil samples were:

CG: *H. contortus* (61.3%), *Eriophorum camosum* (8.6%), *Eupatirium adenophorum* (8.2%), *Artemisia codonocephala* (5.8%), *Campylotropis polyantha* (4.5%), *Viburnum cylindricum* (3.7%).

LG: *A. codonocephala* (24.3%), *Peristrophe japonica* (23.6%), *R. sculponeata* (13.1%), *Oxalis corniculata* (9.3%), *Eupatirium adenophorum* (6.7%), *Origanum vulgare* (5.0%).

GL: *Eriophorum. camosum* (23.3%), *A. codonocephala* (21.9%), *H. contortus* (12%), *Eulaliopsis binata* (8.3%), *Eupatirium adenophorum* (6.7%), *Arthraxon jispidus* (5.8%), *Gnaphalium affine* (4.9%), *Carpesium nepalense* var. *lanatum* (4.5%).

NSP: *H. contortus* (25.4%), *Eulaliopsis binata* (17.2%), *Eupatirium adenophorum* (16.1%), *O.*

corniculata (16.1%).

NDFM: *Eupatirum adenophorum* (100%).

The dominant species in CG, GL, and NSD seed banks were similar. Aridity-tolerant Gramineae species (*H. contortus*, *Eriophorum comosum*, *Eulaliopsis binata*) accounted for high proportions (71.5%, 43.6% and 42.6% respectively). Under LG communities, species in the soil seed bank were dominated by species from Compositae, Acanthaceae and Labiatae, most of which are relatively shade tolerant.

Taking the dominant community type, grassland (GL), as the control site, we can see that 11 species among the 12 CG species were found in GL. There were 18 common seeds between GL and LG. Three GL species were not found in LG and nine LG species were not found in GL. Only one species of NSD was not found in GL. These results suggest that disturbances can lead to changes in the species composition of seed banks, and that seeds of some species persist in the seed banks for a long time.

2.3 Diversity

Thirty four species were identified during the germination period, of which 27 were found in LG, 22 in GL, and 12 each in CG and NSD (Table 2). On the basis of individual numbers of each species, both Shannon-Weiner index and Simpson's index (Rico-Gray & Garica-Franco, 1992) were calculated for the five community types (Table 2). Although 5 species differ between LG and GL, the two diversity indexes are almost the same. CG and NSD have the same numbers of species, but the diversity indexes are quite different. This is due to the different composition of seed banks, since one species (*H. contortus*) dominated in CG and two species (*P. japonica*, *A. codonocephala*) dominated in LG.

Table 2 Species diversity of seed banks in a debris flow prone dry valley

Community types	*C. sinica* + grass (CG)	*L. glauca* (LG)	Grass land (GL)	New slope deposit (NSD)	New debris flow materials (NDFM)
No. of species identified	12	27	22	12	1
Shannon-Weiner index	2.19	3.40	3.37	2.9	0
Simpson's index	0.61	0.86	0.88	0.86	0

2.4 Vegetation cover and seed banks

Vegetation surveys in CG, LG and GL communities showed that 21 species were identified in the established vegetation of CG (12 in the seed bank), 24 in GL (22 in the seed bank), and only 17 in the LG community (27 in the seed bank). Other than 60% *C. sinica* cover, CG is dominated by Gramineae species (*Cymbopogen distans*, *H. contortus*, *T. triandra* var. *japonica*, *Eulaliopsis binata*), most of which are also found in GL. The vegetation composition of the LG site had totally changed compared with the GL, except for the *L. glauca* that occupied the upper layer, and *P. japonica* and *R. sculponeata* that dominated the ground layer.

There was a sharp dissimilarity between the species found in the seed banks and in the established vegetation among the three surveyed ecosystems. Only a few species were found both at the seed bank and in the established vegetation (Table 3).

Table 3 Numbers of species in the seed bank and in vegetation communities in a debris flow prone dry valley

Communities	*C. sinica* + grass (CG)			*L. glauca* (LG)			Grass land (GL)		
	Seed banks	Vegetation	Common species	Seed banks	Vegetation	Common species	Seed banks	Vegetation	Common species
Herb	10	20	6	21	12	6	19	20	10
Shrub	2	1	0	4	2		1	2	
Liana					1		1	2	1
Tree					2				
Others				2			1		
Total	12	21	6	27	17	6	22	24	11

The species composition of seed banks also differed from that of vegetation. The ten densest species from the seed bank and vegetation were taken out and their relative abundance is shown in Fig. 2. This shows that there were only two in common in *C. sinica* grass, and four each in common under *L. glauca* and in grass land. The densest species in the seed banks were not the same as those in the established vegetation.

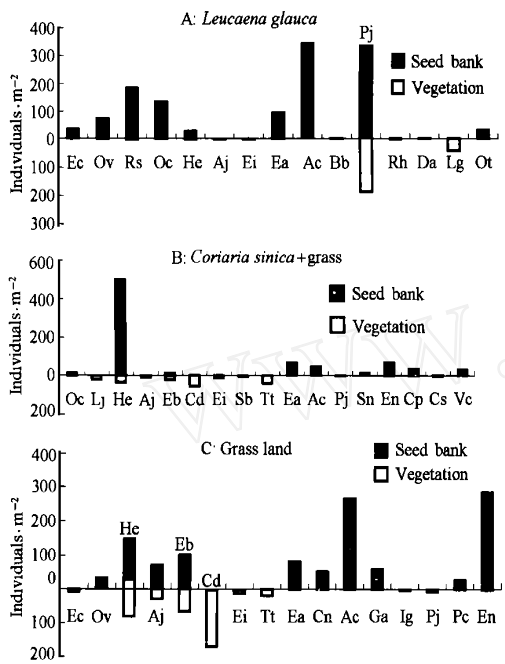

Fig. 2 The ten densest species in both seed bank and stand vegetation in communities in a debris flow prone dry valley

Ac: *Artemisia codonocephala* Aj: *Arthraxon jispidus* Bb: *Bidens bipinnata* Cd: *Cymbopogen distans* Cn: *Carpesium nepalense* var. *lanatum* Cp: *Campylotropis polyantha* Cs: *Coriaria sinica* DA: *Dodonea angustifolia* Ea: *Eupatirium adenophorum* Eb: *Eulaliopsis binata* Ec: *Elsholtzia ciliata* Ei: *Elensine indica* En: *Eriophorum comosum* Ga: *Gnaphalium affine* Hc: *Heteropogen contortus* Ig: *Ixeris gracille* Lg: *Leaucaena glauca* Lj: *Lespedeza juncea* Oc: *Oxalis corniculata* Ot: others Ov: *Origanum valgare* Pc: *Polygonum capitatum.* Pj: *Peristrophe japonica* Rh: *Rumex hastatus* Rs: *Rabdosia sculponeata* Sb: *Spodiopogon bambusoides* Sn: *Solanum nigru* Tt: *Themeda triandr* var. *japonica* Vc: *Viburnum cylindricum*

3 Discussion and conclusion

Disturbances are the major threat to the stability of ecosystems in dry and hot valley areas of the Xiaojiang River (Du & Kang, 1987; Zhang, 1992). These disturbances are caused by both natural factors, such as debris flow, landslides and soil erosion, and human induced activities, such as restoration, annual cutting and grazing of grass. Since it is impossible to find a primary and undisturbed site, we took grassland, the typical ecological type of the study area, as the control site to compare ecosystems within the valley. Thus the CG and LG sites can be considered as communities with different restoration efforts, and NSD and NDFM as different natural disturbance sites. Debris flow is the strongest natural disturbance that changes land surface cover. Soil erosion and small landslides caused the redistribution of grassland surface soil and formed NSD.

The size of soil seed banks have this sequence: LG (1397 individuals/m^2) > GL (1213) > CG (810) > NSD (290) > NDFM (90). Obviously, these numbers suggest that different disturbances bring different changes to seed banks. Compared with GL, tree (*L. glauca*) plantation increases the seed density of soil seed banks, while shrub (*C. sinica*) plantation depletes some seeds from the soil seed bank. Natural disturbance, redistribution of surface material by soil erosion and landslides deplete soil seed bank sharply (NSD) since a lot of seeds are brought to the deposit site. Debris flow destroys the soil surface and the seed bank (NDFM).

It is commonly suggested that the density of buried seeds declines along the successional sere, and that seed density of seed bank of grassland is usually higher than that of shrubs which are in turn higher than that of forest (Xiong *et al.*, 1992; Baskin & Baskin, 1998). The result found in this study was the inverse. The density of grassland is lower than that under tree cover. Three possible reasons are as follows: 1) Disturbance had been eliminated for 6 to 7 years in the tree plantation site. 2) *L. glauca* grows rapidly and the land surface is covered, so that the dry and hot condition is modified, thus partly changing seed storage conditions. 3) The area of plantation is not large and seed from grassland is still accessible. This result also suggests that stable conditions without disturbance can lead to increase in soil seed bank size in this area.

Disturbances can lead to changes in species composition of seed banks, but seeds of some species persist in the seed banks for long time. Compared with GL: 1) *L. glauca* plantation increases the number of species (22 in GL to 27 in LG) and the dominant species changes from aridity-tolerant Gramineae species (*H. contortus*, *Eriophorum comosum*, *Eulaliopsis binata*) to shade-tolerant species (*P. japonica*, *A. codonocephala*, *R. sculponeata*) after several years. But there are still 18 species in common with GL even though their densities are low. 2) Shrub (*C. sinica*, 60% of cover rate) plantation with annual cutting reduces the number (22 in GL to 12 in CG) of species in the seed bank, but the dominant species are still aridity-tolerant and 11 of the 12 species were found in GL. 3) The number of species is reduced sharply from GL (22) to NSD (12), but only one species of NSD cannot be found in the soil seed bank of GL. 4) Only one type of seed was found in the NDFMs.

After a study of 38 different grasslands across the Europe, Bekker *et al.* (1997) concluded that there is poor correlation between floristic composition of established vegetation and the seed bank. Zhou *et al.* (2000) found that only 10%-50% of floristic species were found across five communities representing a serial of secondary succession in Guangdong. In comparing the seed banks with the established vegetation of this study, we have also found this dissimilarity between the two components of CG, LG, and GL communities.

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