A Study of the Artificial Vegetation Restoration Technology in the Wenchuan Earthquake Area

Yu WANG[1], Xingliang LIU[1], Anmin MIN[1], Li WANG[1*], Wenbao MA[1], Hongli PAN[1], Hongxia LI[1], Li ZHANG[2]

1. Sichuan Academy of Forestry Sciences, Chengdu 610081, China; 2. Aba Academy of Science and Technology, Wenchuan 62300, China

Abstract The situation of plants on the slope can reflect the effect of vegetation restoration during the process of artificial vegetation recovery. Taking the typical damaged slope of Wenchuan earthquake area as the research object, through observing the vegetation situation of deserted slope, the results show that compositae plants and gramineous plants are suitable for being pioneer plants and dominant in community; during the vegetation succession, many compositae and gramineous species invade, but there is no magaphanerophytes invading; as time goes by, the herbaceous species and diversity increase gradually, so the ecosystem becomes more stable and the gradient is important for the vegetation restoration.

Key words Wenchuan earthquake, Vegetation restoration, Species diversity

The "5 · 12" Wenchuan earthquake triggered the landslides in varying degrees with the amount initially estimated to be as many as tens of thousands. A large number of mountain landslides changed the appearance of mountains and rivers, causing broken mottled mountain, damaged roads, and blockage of rivers. In the rainy season, it is easy to form new landslides and generate mudslides, so the ecological reconstruction of the disaster area and acceleration of the vegetation restoration are strategic and practical issues to be urgently solved, playing a particularly urgent and important role in promoting the rapid and healthy development of the area[1-3]. As of May 2011, the reconstruction projects completed accounted for 95% of the planned projects, which means that the Wenchuan earthquake area basically completes the reconstruction task, and is about to enter the phase of rapid development[4-7].

However, the follow-up study on the vegetation restoration after the end of the relevant ecological project of vegetation restoration is rarely reported, so based on the damaged slope characteristics in the Wenchuan earthquake area, we choose the representative vegetation restoration mode in this study to research the vegetation community structure and ecological situation after 2 years of artificial vegetation restoration, in order to provide a theoretical basis for the future ecological restoration and reconstruction of plant community in the earthquake-stricken area.

1 Experimental materials

1.1 Overview of the study area The experimental site is located in Laohuzui of Yinxiu Town in Wenchuan County, featuring a humid climate. It is influenced by the southeast and southwest monsoons in summer, and due to the location at the windward slope, the temperature is high and there is a lot of rain. It is affected by the northwest monsoons in winter, with an average annual temperature of 14.1 oC. The frost-free period is 247 - 269 d, the rainfall is 528.7 - 1332.2 mm, and the sunshine hours are 1693.9 - 1042.2 h, suitable for the growth of all kinds of plants and animals.

The mountains are severely damaged by the earthquake in the study area, and through the field survey of the earthquake-stricken area, it is found that the soil degradation mainly occurs in the surface of wound and debris arising from the earthquake-induced landslides, and the original surface soil and the vegetation are destroyed and covered, with poor land occupation conditions, so the natural soil repair and natural vegetation restoration are very difficult.

1.2 Design of vegetation restoration mode

1.2.1 The horizontal structure configuration and integrated measures. On the basis of site type investigation, we follow the principle of matching species with the site and establish the ecology - economy type vegetation pattern. The community configuration is mainly based on the mountain site, gradient and biological and ecological characteristics of all plants tested. In order to effectively play the soil and water conservation benefit, the vegetation takes the horizontal ribbon mixed configuration along the contour. Arbor and shrubs (or vine) are planted along the contour in the shape of horizontal strip, and the herbaceous plants are planted along the contour in the shape of strip. According to the site conditions, we conduct the combination of economic and ecological types, and adopt corresponding different management measures.

(i) The upper ring of slopes (slope distance of about 40m). The upper ring soil is the slid mountain surface soil with abundant organic matter, so there is no need to take too many engineering measures in this region. We adopt conventional manual operation, to terrace the slope land along the horizontal contour, and the slope distance is 4m. The width of the transformed terraced land is 1 m, and in order to maintain soil and water, the outer edge of terraced land is 10 cm higher than the inner edge.

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* Corresponding author. E-mail: wyu110@sina.com

(ii) The middle ring of slopes. The soil layer is thin, and the gravel content is high. After simply changing the belt, it is easily collapsed again, so the bamboo basket is used to load the gravel and soil, and it is buried 30cm deep in the ground, and laid along the horizontal line of contour. The slope distance is 6 – 8m. A total of 10 slope protection belts are set. The seedlings are planted inside the bamboo basket. The grass and flower seeds are sown on the protection edge of bamboo basket to form a ribbon vegetation belt.

(iii) The lower ring of slopes (slope distance of about 30m). The lower ring is the gravel accumulation zone arising from landslides occasioned by earthquake, and there is a need to collect a portion of gravel into the wire cage during this control, and use the wire cage as the retaining wall. The seedlings are planted inside the retaining wall. The slope distance is 8 – 10m, and the belt width is 1.8 – 2.0m. The specification of wire cage is 2.0 × 1.0m × 1.0m, and three retaining walls are set. The soil is embedded in the retaining wall, and the grass and flower seeds are sown to form a unique biological retaining wall.

1.2.2 Vegetation restoration measures. According to the natural site conditions in the restoration area and the principle of matching species with the site, it is dominated by the native trees, and the specific vegetation restoration measures are as follows:

(i) The upper ring of slopes (slope distance of about 40m). The plants within the horizontal terraces are mixed bushes and trees, and the grass seeds are sown on the outer slope terraces.

Plant species are chosen as follows:

Arbor species: *Eucalyptus camaldulensis* Dehnh., *Liquidambar formosana* Hance, and *Ligustrum lucidum* Ait.

Shrub species: *Pyracantha fortuneana* (Maxim.) Li.

Herbaceous species: *Poa annua* L., *Festuca rubra* L., and *Cynodondactylon* (Linn.) Pers.

(ii) The middle ring of slopes. The plants within the horizontal belt are mixed arbor and shrub, and the grass seeds are sown in the bamboo basket.

Plant species are chosen as follows:

Arbor species: *Eucalyptus camaldulensis* Dehnh., *Liquidambar formosana* Hance, and *Ligustrum lucidum* Ait.

Shrub species: *Pyracantha fortuneana* (Maxim.) Li.

Herbaceous species: *Poa annua* L., *Festuca rubra* L., *Cynodondactylon* (Linn.) Pers., *Tagetes patula* L., and *Medicago sativa* L.

(iii) The lower ring of slopes (slope distance of about 30m). The plants within the horizontal belt are mixed arbor and shrub, and the grass and flower seeds are sown in the wire cage retaining wall.

Plant species are chosen as follows:

Arbor species: *Argentina willows*, *Litsea cubeba* (Lour) Pers., and *Ligustrum lucidum* Ait.

Shrub species: *Armeniaca sibirica* (L.) Lam.

Herbaceous species: *Poa annua* L., *Festuca rubra* L., *Cynodondactylon* (Linn.) Pers., *Tagetes patula* L., and *Medicago sativa* L.

2 Research methods

2.1 Sample plot setting and survey The stratified sampling method and systematic sampling method are used for the entire artificial restoration slope. According to the difference in the artificial slope gradient, the artificial vegetation restoration slope is roughly divided into three parts: upper slope, middle slope and lower slope. Then in each part, the systematic sampling is conducted in accordance with a certain distance. The plot size is 1 × 1 m^2, and there are a total of 30 plots on the entire slope. Some indicators are recorded within the plots, such as the composition and structure of plant communities, plant diversity, and vegetation cover[8].

2.2 Data processing The species diversity of community refers to the number of all species in the community and the number of each species. It has two meanings: the number or richness of species refers to the amount of species in one community or habitat; the evenness of species refers to the distribution of number of individuals of all species in one community or habitat, which reflects the evenness of distribution of number of individuals of all species[9].

To compare the differences in the diversity between the relevant plants in the community, we use richness index, Simpson index, Shannon – Weiner index, Pielou index and other indices.

The index is calculated according to the following formula:

(i) The richness index of species: Margalef index $R = (s - 1)/\ln(n)$ (1)

(ii) The diversity index of species:

Simpson index $D = 1 - \sum P_i^2$ (2)

Shannon – Wiener index $H = -\sum(P_i \ln P_i)\, i = 1, 2, \cdots, s$ (3)

(iii) The evenness index of species

Pielou index $E = H/\ln s$ (4)

where s is the total number of plant species in the community; n is the total number of individuals of species in the community; P_i is the proportion of the number of individuals of plant species i to the total number of individuals of plants in the community.

3 Results and analysis

3.1 The species composition of the community on slope It is found from the survey that the plants grow well on the artificial restored slope, and the total coverage is up to 98.35%. The major plants are *Ligustrum lucidum* Ait., eucalyptus, *Liquidambar formosana* Hance, walnut, Argentina willow, *Ligustrum lucidum* Ait., *Clematis florida* Thunb., *Akebia trifoliata*, *Poa annua* L., thyme, *Coix lacroyma – jobi* L. var. *ma – yuen* (Roman.) Stapf, *Fallopia multiflora* (Thunb.) Harald, *Polygonum chinense* L., *etc*. There are 27 plant species found in the plots, belonging to 26 genera and 18 families, including 16 herbaceous plant species, accounting for 59.26% of the total number of species, and 3 shrub species and 5 arbor species, accounting for 10.7% and 18.52% of the total number of species, respectively. The composition of plant families on the slope is dispersed. In terms of the

community structure, the herbaceous plant is the dominant group, and it is dominated by leguminous plants and gramineous plants. The leguminous plants and Gramineae plants play an important role in the early period of soil and water conservation and community succession on the artificial restored slope.

As can be seen from Table 1, there are obvious differences in the composition of plant communities in different slope positions. The lower slope has the most abundant plant families, genera and species; the middle slope is slightly different from the lower slope; the upper slope has few families, genera and species than the lower slope.

3.2 Analysis of vegetation diversity From Table 1 and Table 2, it can be found that after two years of artificial vegetation restoration, the form and structure of communities on the restored slope have been basically formed, and the indices related to the species diversity have been well improved; the density matching of herbaceous and shrub plants is more reasonable, it has formed a lot of grass and shrub communities on the slope, and the community function is relatively stable.

As for the composition of species on the slope, the number of species is increased from initial 12 to current 27, and the increased 15 invading plants are shrubs and herbs (Table 2), and the invasion by arbor is not found.

Table 1 The composition of plant communities on the restored slope

Slope position	Number of families	Number of genera	Number of species	Coverage//%
Upper	11	17	18	96.42
Middle	16	24	24	98.76
Lower	17	25	26	99.88

Table 2 New plants on the slope

No.	Species name	Family name	Plant type
1	*Clematis florida* Thunb	*Ranunculaceae*	Perennial herbs or woody vine
2	*Akebia trifoliata*	*Lardizabalaceae*	Deciduous woody vine
3	*Debregeasia edulis*	Urticaceae	Shrub
4	*Thymus mongolicus*	*Lamiaceae*	Perennial herb
5	*Coix lacroyma – jobi* L. var. *ma – yuen* (Roman.) Stapf	VGramineae	*Perennial herb*
6	Fallopia multiflora (*Thunb.*) *Harald*	*VPolygonaceae*	Perennial twining vine
7	*Polygonum chinense* L	*Polygonaceae*	Perennial herb
8	*Centaurea cyanus*	*Asteraceae*	Annual or biennial herb
9	*Argyranthemum frutescens*	*Asteraceae*	Perennial herb
10	*GasTCMLIBodiaelata* Bl.	*OrchidaceaeV*	*Perennial parasitic herb*
11	Cymbopogon citrat	*VAsteraceaeV*	*Biennial herb*
12	Leonurus heterophyllus *Sweet*	*VLamiaceaeV*	*Annual or biennial herb*
13	Artemisia argyi	Asteraceae	*A perennial herb*
14	Setaira viridis(*L.*)*Beauv*	Gramineae	*Annual herb*
15	O. japonicus (*L. f.*)*Ker – Gawl*	Liliaceae	*Evergreen perennial herb*

The herbaceous plants on the slope are still the previously artificially sown *Poa annua* L., *Festuca rubra* L., and *Cynodondactylon* (Linn.) Pers., but they have degenerated to some extent, and there are a variety of surrounding local grasses invading and gradually getting stable. The major invading plants are *Poa annua* L., thyme, *Coix lacroyma – jobi* L. var. *ma – yuen* (Roman.) Stapf, *Fallopia multiflora* (Thunb.) Harald and *Polygonum chinense* L.

Table 3 The vegetation diversity index in different slope positions

Slope Position	Richness Margalef	Dominance Simpson	Diversity Shannon – Wiener	Evenness Pielou
Upper	3.12	0.61	2.01	0.96
Middle	3.56	0.68	2.34	0.87
Lower	3.78	0.71	2.77	0.83

As can be seen from Table 3, the indices related to the diversity of plant community species are also affected by the slope position. The Marglef richness index, Simpson dominance index and Shannon diversity of plant community show the feature of lower slope > middle slope > upper slope, while the Pielou evenness index shows the feature of upper slope > middle slope > lower slope. As for the diversity index, there are no significant differences between the middle slope and lower slope, while there are great differences between the middle slope and upper slope, possibly because the soil conditions on the upper slope are poorer than the soil conditions on the middle and lower slopes. There are no dense shrubs and trees covering the top of the slope, and there is one gutter, so the top of the slope is seriously eroded when there is heavy rain. The emphasis on upper slope is not enough during the artificial maintenance.

3.3 Characteristics of community structure After 2 years of vegetation restoration, it is no longer the herb community dominated by herbaceous plants on the slope, and the herbaceous layer is gradually changed from a even state to a mosaic state. All kinds of communities cluster, the proportion of shrubs is increased significantly, and the shrub and grass community is formed on the slope. The herbaceous layer is mainly occupied by *Setaria viridis* (L.) Beauv., *Cynodondactylon* (Linn.) Pers., *Poa annua* L., *Festuca rubra* L., thyme, *Coix lacroyma – jobi* L. var. *ma – yuen* (Roman.) Stapf, *Fallopia multiflora* (Thunb.) Harald, *Polygonum chinense* L. And *Cynodondactylon* (Linn.) Pers., *Poa annua* L., *Coix lacroyma – jobi* L. var. *ma – yuen* (Roman.) Stapf, *Festuca rubra* L. are the main species, and the average height of herb layer is about 45 cm. The dominant species of shrub layer is *Ligustrum lucidum* Ait., D. Orientalis, and *Akebia trifoliata*. *Ligustrum lucidum* Ait. is the main species, and the height of shrub

layer is about 120cm. The arbor layer is mainly occupied by *Ligustrum lucidum* Ait., *Liquidambar formosana* Hance, walnut, and eucalyptus, which are all artificially planted trees. The survival rate of artificially planted arbor is high, and the average height of arbor is 150 cm.

There are some differences in the structure of vegetation community, and the middle slope is similar to the lower slope, but both of them are significantly different from the upper slope (Table 4). The height of herbaceous layer on the upper slope is similar to that on the middle slope and lower slope, but its coverage is significantly higher than that of other two slopes, and the main herbaceous plant is also simple. The height of shrub layer on the upper slope is slightly lower than that on the middle and lower slopes, and its coverage is significantly low. The main shrub is also simple. The main arbor plants on the upper slope are the same as those on other slopes, but its height and coverage are lower than those of the middle and lower slopes.

Table 4 The vegetation community structure in different slope positions

Slope position	Vertical structure	Height cm	Coverage %	The main plants	Vegetation type
Upper	Herb layer	50	82	*Poa annua* L., *Festuca rubra* L., *Cynodondactylon* (Linn.) Pers.	Perennial herb
	Shrub layer	120	17	*Clematis florida* Thunb., *Akebia trifoliata*, *Pyracantha fortuneana* (Maxim.) Li.	Shrub or small arbor
	Arbor layer	125	1	*Ligustrum lucidum* Ait., *Liquidambar formosana* Hance, walnut	Evergreen or deciduous arbor
Middle	Herb layer	40	81	*Poa annua* L., *Festuca rubra* L., *Cynodondactylon* (Linn.) Pers., *Thymus mongolicus*	Perennial herb
	Shrub layer	120	42	*Debregeasia orientalis* C. J. Chen, *Pyracantha fortuneana* (Maxim.) Li.	Shrub or small arbor
	Arbor layer	155	4	*Ligustrum lucidum* Ait., *Liquidambar formosana* Hance, walnut	Evergreen or deciduous arbor
Lower	Herb layer	45	86	*Poa annua* L., *Festuca rubra* L., *Cynodondactylon* (Linn.) Pers., *Tagetes patula* L., *Setaria viridis* (L.) Beauv., *Coix lacroyma – jobi* L. var. *ma – yuen* (Roman.) Stapf, *Fallopia multiflora* (Thunb.) Harald	Perennial herb
	Shrub layer	140	38	*Armeniaca sibirica* (L.) Lam., *Pyracantha fortuneana* (Maxim.) Li., *Debregeasia orientalis* C. J. Chen, *Akebia trifoliata*	Shrub or small arbor
	Arbor layer	150	5	*Ligustrum lucidum* Ait., *Liquidambar formosana* Hance, walnut, eucalyptus	Evergreen or deciduous arbor

3.4 Analysis of vegetation slope protection in different slope positions After the implementation of vegetation restoration project on the damaged slope, the slope is well protected due to good vegetation effect. There are differences in the vegetation slope protection between different slope positions (Table 5), and there are no significant differences in the slope protection effect between the middle and lower slopes, but the slope protection effect is better than on the upper slope. The whole slope has high vegetation coverage, mostly close to 100%. The vegetation coverage on the middle slope is 99.42%, and the vegetation coverage on the lower slope is 99.88%, slightly higher than the vegetation coverage on the upper slope (98.54%). In terms of the plant diversity, the middle and lower slopes are also better than the upper slope.

Table 5 Analysis of vegetation slope protection in different slope positions

Slope position	Gradient	Coverage	Diversity	Bulk density g/cm^3	Moisture %	Thickness cm
Upper	55	98.54	1.91	1.28	15.68	15.01
Middle	45	99.42	2.23	1.18	18.98	17.01
Lower	35	99.88	2.86	1.20	17.87	16.98

The soil moisture of slope is in the range suitable for plant growth, but the middle slope occupies 18.98% and the lower slope occupies 17.87%, significantly higher than the soil moisture of the upper slope (15.68%). The soil bulk density on the slope is also suitable for plant growth. The soil bulk density on the middle and lower slopes is 1.18g/cm^3 and 1.20 g/cm^3, respectively, lower than the soil bulk density on the upper slope (1.28 g/cm^3). The vegetation on the slope plays a good role in soil and water conservation. The thickness of the middle and lower slopes is 17.01 cm and 16.98cm, respectively, significantly better than the thickness of the upper slope (15.01cm).

As can be seen from Table 5, the vegetation coverage, diversity, soil moisture, bulk density and thickness are closely related to each other. On the slope with good soil conditions, the vegetation restoration effect is also good, and such difference is greatly correlated with the gradient.

Due to differences in gradient, there are significant differences in the water and fertilizer conditions between different slope positions, and there are also differences in the vegetation growth and soil thickness.

4 Conclusions

After the artificial vegetation restoration on the damaged slope in the earthquake disaster area, all the initial artificially planted species have shown adaptation to the climate and environment of the Wenchuan earthquake area; the richness, dominance and diversity indices of community have increased and the community structure is increasingly stable. The artificially sown *Poa annua* L., *Festuca rubra* L. and *Cynodondactylon* (Linn.) Pers. can grow rapidly on the slope, play a good role in soil and water conservation, and provide an environment for future vegetation succession. The sur-

vival rate of artificially planted *Ligustrum lucidum* Ait. , *Liquidambar formosana* Hance and *Ligustrum lucidum* Ait. is high, and they can quickly grow, playing an important role in promoting the vertical development and stability of community.

The major invading plant is herb, and it is based on Asteraceae and Gramineae. The invading shrub species are *Clematis florida* Thunb. , *Akebia trifoliata* and D. orientalis, and the arbor is difficult to invade, possibly because the herb density is too large on the slope, and the indigenous shrub and arbor species are poorly tolerant of poor, acid soils. The artificial planting of seedlings can be used to introduce indigenous shrub and arbor species. The gradient plays an important role in promoting the artificial vegetation restoration. When the gradient is about 45°, in order to ensure the soil thickness of the slope and provide better conditions for the future vegetation restoration, it is necessary to take some additional process to stabilize the slope, and conserve soil and water.

There are no obvious differences in the indicators related to vegetation and soil between the middle and lower slopes, but better than on the upper slope, so it is necessary to artificially plant more seedlings on the upper slope, increase more inputs to the upper slope conservation, and plant more trees and shrubs at top of upper slope to resist rain and other natural disasters, or when conditions permit, appropriately reduce the gradient of the upper slope.

References

[1] TANG J. Pay attention to the social evaluation of the reconstruction work after the disaster[J]. Chinese Cadres Tribune, 2008(6): 10 - 11. (in Chinese).

[2] DENG WJ. The effectiveness and social evaluation of the reconstruction work after the disaster[J]. Sichuan Provincial Conditions, 2008(9): 14 - 15. (in Chinese).

[3] GUO H, YANG N. Review of social evaluation seminar of the reconstruction work after the disaster[J]. Social Science Research, 2008(5): 196. (in Chinese).

[4] LI XY. Pay attention to the social evaluation after the disaster [J]. Sichuan Provincial Conditions, 2008(9): 6 -7. (in Chinese).

[5] Rules of the restoration and reconstruction after Wenchuan earthquake disasters[DB/OL]. (2008 - 06 - 09) . [2011 - 05 - 12]. http: / /www. gov. cn/zwgk /2008 -06 /09/content_1010710. htm. (in Chinese).

[6] WANG QZ, GU B. Preliminary analysis on vegetation restoration scheme in Qingfeng abandoned stone pit of Zhoushan City[J]. Soil and Water Conservation In China, 2006(6): 34 -36. (in Chinese).

[7] ZHOU ST, GU B, CAI S, *et al*. Application of soil protecting wing technics in restoration of lithoid slope [J]. Bulletin of Soil and Water Conservation, 2009, 29(2): 190. (in Chinese).

[8] SONG YC. Vegetation ecology[M]. Shanghai: East China Normal University Press, 2001. (in Chinese).

[9] YU YH, GU B, AI YW. Analysis of plant diversity of railway cutting slopes in Sichuan Province[J]. Science of Soil and Water Conservation, 2006, 4 (B12): 27 -30. (in Chinese).

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takes empirical test and analysis with the influence factors on the WTP of farmers for reducing agricultural non-point source pollution.

This survey study finds that farmers have had a fundamental understanding on the harm of agricultural non-point source pollution, and show high enthusiasm in improving water and soil quality. In survey, we also learn that farmers have a lot of confusion with government and related organizations, they think it is difficult to rely on government in this respect, actually, they hope that government will make achievement in control of agricultural non-point source pollution. At the same time, farmers are very practical, they don't believe their donation can be used reasonably, thus they take voluntary work to express their willingness to pay.

In terms of the influence factors on the WTP of farmers for reducing agricultural non-point source pollution, there is positive correlation between the age and culture degree of householder, farmers' income per year, cultivated land area of farmers and the WTP of farmers, that is to say, when the age of farmer householder is older, the education level and farmers' income per year is higher, the cultivated land area of farmers is bigger, the WTP of farmers for reducing agricultural non-point source pollution tend to be much stronger.

The conclusions that come from the statistical analysis of farmers' cognitive degree on agricultural non-point source pollution and the empirical test on the WTP of farmers for reducing agricultural non-point source pollution, provide the support in theory and practice for optimizing the behavior of farmers, promoting the management of agricultural non-point source pollution and implementing the new rural construction goal.

References

[1] Whittington D. Administering contingent valuation surveys in developing countries[J]. World Development, 1998(26): 21 -30.

[2] Venkatachalam L. The contingent valuation method: a review. Environmental Impact Assessment Review, 2004, 24(1): 89 -124.

[3] HU XL, XIA PH, HU JW, *et al*. Current status and countermeasures of agricultural non-point pollution[J]. Guizhou Agricultural Sciences, 2011, 39 (6): 211 -215. (in Chinese).

[4] YAN C, MA T, LUAN JD, *et al*. Analysis on farmers' environmental awareness in Anhui[J]. Journal of Shanxi Agricultural University (Social Science Edition), 2013, 12(5): 453 -456. (in Chinese).

[5] Li HP. The agricultural non-point source pollution in China: an economic analysis and policy studies[D] . WU HAN: Huazhong agricultural university, 2007. (in Chinese).

[6] LIANG S, JIANG N, GU SZ. The analysis of the WTP of farmers in city water source and its influencing factors: as Miyun reservoir for example [J]. Chinese Rural Economy, 2005(2): 55 -60. (in Chinese).

[7] ZONG MX, XIA CP. Farmers' willingness to pay for ecological effects and influencing factors——Based on the data from field research in Zhangwan District of Shiyan and Danjiangkou Area[J]. Journal of Huazhong Agricultural University (Social Sciences Edition), 2013(4): 70 -76. (in Chinese).