

Species diversity and interspecific association in development sequence of *Hippophae rhamnoides* plantations in the Loess Hilly Region, China

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Abstract Based on our field investigation, we analyzed the characteristics of species diversity and interspecific association at different development stages of *Hippophae rhamnoides* plantations. The results show that the species diversities of the shrub layer, grass layer and the whole community of the *H. rhamnoides* plantations all fluctuated in an “S” shape pattern. At different development stages, the species richness and diversity were higher in the grass layer than in the shrub layer. The shrub species diversity was lower on bare land, but increased gradually with development of the community. The shrub evenness index was higher in 13-year forest stand, while the grass diversity index was higher in the 3-year and 25-year plantations and lower in the 8-year plantation. The positive and negative absolute values of interspecific association between *H. rhamnoides* and other principal species changed in a parabolic pattern. The significance level and intensity of interspecific association were lower or weaker in the 13-year plantation, indicating that the species substitution rate slowed down, competition became less intense and community composition and its structure reached a relatively stable state. Therefore, to improve the ecological environment, priority should be given to the protection of the *H. rhamnoides* plantations younger than 13 years, while for those of 25 year plantations, moderate thinning should be made to promote their regeneration.

Keywords species importance value, similarity index, α -diversity, interspecific association, plantation

1 Introduction

Species diversity of the plant community is an important index reflecting its composition, structure and stability. Interspecific association is the main quantitative characteristic of community formation, evolution and stability (Cai, 2004; Feng, 2003; Guo et al., 1997, 2004; Janson and Vegelius, 1981). Studies on species diversity and interspecific association of different development stages can help us understand the relationship between community composition, structure, stability and environment, and provide important references to community management (Greig-Smith, 1983; Huang et al., 2000; Zhang et al., 2006).

Hippophae rhamnoides is one of the important shrubs with soil and water conservation functions and economic value in the Loess Plateau. *H. rhamnoides* plantations, which have broad cultivation areas and can regenerate itself in the Loess Plateau, are ideal species in the Loess Hilly Region. After the *H. rhamnoides* are afforested and local plants intrude, the interspecific association has a series of changes in these plantations. Research on the changes of species diversity, species relation and interspecific association in the development sequence of *H. rhamnoides* plantations can provide important information for their long term management and sustainable utilization and for making full use of their ecological functions of soil and water conservation in the long run (Li et al., 2001). Previously, research of *H. rhamnoides* plantations mainly focused on their benefit of soil and water conservation, community structure and classification (Cheng et al., 2003; Li et al., 2000; Ruan and Li, 2001, 2002). Only few studies on the species diversity and change of interspecific association were reported. We studied the species composition, the diversity and the change in the trends of interspecific association in the development sequence of these plantations in an effort to establish the species

importance value, the diversity index and the dynamic change of interspecific association. The study provides the basis for management and sustainable use of the *H. rhamnoides* plantations in the Loess Plateau.

2 Study area and methods

2.1 Natural condition

We chose the Zhifanggou and Xiannangou river valleys as the research area, which is located in the Ansai County, Shaanxi Province (36°51'N, 109°19'E). This area lies in the hinterlands of the Loess Plateau and is characterized by typical hilly and ravine areas with an altitude of 1010–1431 m above sea level. Climatically, it belongs to a warm temperate zone with a semiarid climate and an average rainfall of 535 mm annually, an average annual air temperature of 8.8°C and an average annual accumulated temperature $\geq 10^\circ\text{C}$ of 3113.9°C. On vegetation regionalization, it was classified as forest-steppe area and the soil type is loess soil (Ruan and Li, 2002; Zhang et al., 2006).

After the 1970s, comprehensive treatments in the Zhifanggou river valley were carried out by the Water and Soil Conservation Institute of the Chinese Academy of Sciences and the Ministry of Water Resources. Some vegetation restoration measures, such as enclosure, building plantations and artificial pastures were taken. The *H. rhamnoides* plantations had the largest afforestation area in this river valley and good ecological benefits were obtained. The goals of self-renewal and sustained development have been basically achieved (Cheng et al., 2003; Li et al., 2000, 2001; Ruan and Li, 2001). We made an investigation into the well preserved *H. rhamnoides* communities. The afforestation land was prepared by adopting cave shapes and planting the seedlings. The row spacing was 1.5 m \times 1.5 m. Average height of the seedlings was 0.27 m and the average basic diameter was 0.16 cm. Prohibition of cutting and browsing was commenced in 2000 in the Xiannangou river valley where there were large areas of abandoned grassland slopes (Zhang et al., 2005). We concluded that it took 8-years' development for the community to reach a mostly closed canopy state, 13 years to develop into mature stages and 25 years for the old individuals to die, renewal of young individuals (the seedlings sprouting from roots) to grow and the community to develop towards a more complex one.

2.2 Methods

2.2.1 Plot investigation

The *H. rhamnoides* plantations at different stages were selected in Zhifanggou and Xiannangou, respectively, after a thorough investigation. Barren plots were aban-

doned grassland slopes with no management or protection. The overall cover rate of the shrub and herb was about 27% and the average plant height was 0.20 m. The barren plots and 3-year plantations were selected in the Xiannangou river valley, while the other three stages of plantations were selected in the Zhifanggou river valley. In order to select plots at different development stages to be comparable and representative, the slope aspects of plots were all east-west directions, the slopes and positions and other habitat situations were basically identical (Table 1). In addition, the management measures were the same. That was to say, there were no irrigation, no weeding or other upbringing measures. A ban on felling trees and grazing on grasses was basically implemented. Three plots were selected in each development stage and there were 15 plots in total. Each plot area was 20 m \times 20 m. Five shrub quadrats (5 m \times 5 m) and 5 herb quadrats (1 m \times 1 m) were set up in one plot, respectively. The investigation included two aspects. The first one included landform and physiognomy, human disturbance, slope aspect, slope position, illumination of the community insides and outsides and relative humidity. The second one was the plant community characteristics, including the whole vegetation cover, average height and cover of the shrub layer and herb layer in each plot, the coordinate value, height, basic diameter and crown width of each shrub species, the number, height, cover and crown width of each grass species and the frequency of each species in the plot was investigated at the same time.

2.2.2 Important value and similarity calculation

The important values of all species at different stages within the 3 plots were calculated respectively (Cao et al., 2000; Guo et al., 2004; Ma and Liu, 1994; Zhang et al., 2005). Using the Sorensen similarity index (C), the similarity was calculated between different development stages (Cao et al., 2000; Zhang et al., 2003, 2004).

$$C = Z_j / (a + b)$$

where Z_j is the sum of important value of common species in two communities, and the letters a and b are the sum of the important value of the whole species in the two communities respectively.

2.2.3 Biodiversity index calculation

The species richness index (S), Simpson index (D), Shannon-Wiener index (H'), Pielou evenness index (J_w), and weighted parameter (W_i) of the shrub layer and herb layer at different stages, based on the species important value of the three plots in each stage were calculated (Cao et al., 2000; Guo et al., 2004; Huang et al., 2000; Ma and Liu, 1994).

2.2.4 Interspecific association index calculation

Seven common plants that had higher important values were selected from each development stage after important value re-evaluation. The matrix of appearance (1) and disappearance (0) for the seven populations in each quadrat at the four stages were built and then the indices of interspecific associations and intensities between the seven populations and *H. rhamnoides* population were calculated using 2×2 contingency table, χ^2 test and Jaccard index (Greig-Smith, 1983; Guo et al., 1997; Janson and Vegelius, 1981; Liu and Cheng, 2000; Peng et al., 1999; Zhang, 1998).

2.2.5 Data processing

Based on the data collected from field investigations, regression analysis and correlation test were carried out with the SPSS13.0 software.

3 Results and analyses

3.1 Species biodiversity evolution

3.1.1 Dynamic characteristics of species composition

After forestation, the *H. rhamnoides* community crown density increased speedily along with the invasion of native plants. The community crown density could reach 80%–90% from 30%–40% (abandoned land) after 4–5 years' development. The important value of the *H. rhamnoides* population was the largest in the community after 8 years' development. The old and feeble *H. rhamnoides* individuals began to appear in 13 year's community and in the community after 25 years' development, the number of buds increased and old ones markedly decayed. The species diversity increased again. As shown in Table 2, the composition and number of the *H. rhamnoides* community from the abandoned land to the 25-year development community shows the following trend: 4 new species appeared in the shrub layer, with an increase rate of 200%, 7 new species grew in the herb layer and 3 prior species disappeared as time went by, with an overall increase rate of 22.7%. Although the mass plants were drought-resistant and light-loving in the *H. rhamnoides* community, the important value of some deflection mesad grasses or

mesad grasses (such as *Artemisia anethoides* and *Agropyron cristatum*) increased as they gradually appeared, while the typical light-loving grasses (such as *Gueldenstaedtia stenophylla*, *Melica scabrosa* and *Viola yedoensis*) disappeared with time. The important value of the species tended to gradually balance out except for the constructive species (*H. rhamnoides*).

3.1.2 Comparability

The common connection of the species at different development stages, which is an important index indicating community stability, can reflect the species composition substitution with time (Zhang, 1998). As can be seen from Table 3, the comparability coefficient of the adjacent stages rose gradually with the development of the communities. The least one was 0.854 between the abandoned land and the 3-year *H. rhamnoides* community, suggesting that the community structure and composition had acutely changed. After 3 years, the stage-adjacent comparability coefficient increased, being 0.899 (3–8 a), 0.882 (8–13 a) and 0.938 (13–25 a), respectively, suggesting that the species substitution speed in the community was diminished and the community tended to stabilize gradually with its development.

3.1.3 Species diversity

Regular changes of species diversity of plantations at different developing stages suggest community stability (Greig-Smith, 1983; Li and Shao, 2004; Yan et al., 2005). The species diversities of the shrub layer and grass layer of the *H. rhamnoides* plantations all fluctuated in an "S" shape from abandoned land to 25-year plantations, and they decreased slightly after the plantations had developed for 20 years. It can be seen from the development course of the community diversity that the species diversities of the grass layer were notably higher than those of the shrub layer, especially the richness. However the evenness differences of the two layers were less, which might be due to the interaction and restriction between the two layers.

Regressive equations between the species diversity indices (y) and developing stages (x) of *H. rhamnoides* plantations show that their correlation reached an extremely significant level ($P < 0.01$) (Table 4), suggesting that the development course of the *H. rhamnoides* community in the Loess Region was a course of native plant invasion, accompanied

Table 1 Habitat information for *H. rhamnoides* plantations at different development stages

location	altitude/m	slope position	slope/°	slope aspect	developing time/a
Yayaogou	1130	middle and lower sites	15–24	ES	0
Laolingou	1120	lower site	12–40	EN	3
Xiaofanjiagou	1068	lower site	16–39	ES	8
Litagou	1160	lower site	16–26	WS	13
Hougou	1190	lower site	15–29	ES	25

Table 2 Important values of the species in the *H. rhamnoides* plantations at different development stages

layer	species	developing stages/a				
		S ₀	S ₃	S ₈	S ₁₃	S ₂₅
A	<i>Lespedeza davurica</i>	269.8	140.90	51.33	57.12	31.44
	<i>Periploca sepium</i>	30.20	14.14	43.07	51.21	48.16
	<i>Hippophae rhamnoides</i>	–	144.96	205.60	162.89	180.97
	<i>Rubus coreanus</i>	–	–	–	28.78	25.96
	<i>Lonicera ferdinandii</i>	–	–	–	–	13.47
B	<i>Artemisia sacrorum</i>	62.76	60.22	53.76	15.33	44.07
	<i>Stipa bungeana</i>	27.90	25.72	5.09	11.23	18.32
	<i>Taraxacum mongolicum</i>	26.75	6.23	–	–	7.88
	<i>Geranium sibiricum</i>	24.58	15.60	–	20.30	57.09
	<i>Ixeris denticulata</i>	21.51	6.94	9.16	26.99	14.61
	<i>Melica scabrosa</i>	14.52	2.80	–	–	–
	<i>Cephalanoplos segetum</i>	13.28	11.18	3.84	19.86	4.59
	<i>Cynodon dactylon</i>	13.20	11.11	–	7.90	2.75
	<i>Cleistogenes chinensis</i>	13.10	26.75	–	5.08	6.15
	<i>Gueldenstaedtia stenophylla</i>	12.79	1.45	–	–	–
	<i>Setaria viridis</i>	11.71	4.61	–	9.47	9.18
	<i>Artemisia argyi</i>	11.33	1.98	–	–	4.72
	<i>Phlomis umbrosa</i>	9.69	6.36	4.25	15.97	5.53
	<i>Viola yedoensis</i>	7.77	2.36	4.52	–	–
	<i>Potentilla anserina</i>	7.53	45.98	8.47	12.50	12.41
	<i>Heteropappus altaicus</i>	7.30	10.11	11.01	20.56	10.79
	<i>Artemisia capillaris</i>	6.29	24.62	28.13	45.08	12.10
	<i>Bothriochloa ischaemum</i>	6.07	2.00	–	–	9.49
	<i>Patrinia heterophylla</i>	1.92	1.88	–	7.10	2.79
	<i>Hemistepta lyrata</i>	–	12.72	50.54	–	–
<i>Potentilla bifurca</i>	–	8.72	2.63	14.76	12.07	
<i>Artemisia anethoides</i>	–	5.14	9.10	15.56	14.93	
<i>Rubia truppeliana</i>	–	2.74	63.46	21.73	–	
<i>Agropyron cristatum</i>	–	–	46.04	23.056	27.40	
<i>Ixeris chinensis</i>	–	–	–	7.53	6.15	
<i>Thermopsis lanceolata</i>	–	–	–	–	16.98	

A: Shrub layer, B: Herb layer; S₀: Barren plot; S₃: Developed for 3 years; S₈: Developed for 8 years; S₁₃: Developed for 13 years; S₂₅: Developed for 25 years.

Table 3 Similarity index between communities of the *H. rhamnoides* plantations at different development stages

development time/a	S ₀ –S ₃	S ₀ –S ₈	S ₀ –S ₁₃	S ₀ –S ₂₅	S ₃ –S ₈	S ₃ –S ₁₃	S ₃ –S ₂₅	S ₈ –S ₁₃	S ₈ –S ₂₅	S ₁₃ –S ₂₅
similarity index	0.854	0.572	0.705	0.693	0.899	0.923	0.904	0.882	0.765	0.938

Table 4 Regressive equations between species diversity indices (y) and development stages (x) of *H. rhamnoides* plantations (n = 5)

layer	diversity indices	regressive equation	R ²	T _{max}
A	S	y = 0.0001x ³ – 0.0058x ² + 0.1873x + 2.1448	0.9482**	–
	D	y = 0.0001x ³ – 0.0056x ² + 0.0822x + 0.2191	0.859**	–
	H'	y = 0.0001x ³ – 0.0065x ² + 0.1196x + 0.3923	0.8876**	–
	J _w	y = –0.0002x ³ + 0.0057x ² – 0.0425x + 0.7840	0.8345**	18
	E _a	y = –0.0002x ³ + 0.0073x ² – 0.0553x + 0.7995	0.9710**	18
B	S	y = –0.0100x ³ + 0.3877x ² – 3.2867x + 23.082	0.8568**	20
	D	y = –0.00005x ³ + 0.0021x ² – 0.0171x + 0.9166	0.9697**	20
	H'	y = –0.0005x ³ + 0.0172x ² – 0.1440x + 2.7024	0.954**	18
	J _w	y = –0.0002x ³ + 0.0059x ² – 0.0471x + 0.9165	0.9665**	18
	E _a	y = –0.0002x ³ + 0.0076x ² – 0.0543x + 0.7641	0.9213**	17
C	S	y = –0.0036x ³ + 0.1410x ² – 1.1953x + 14.0500	0.8179**	21
	D	y = –0.0001x ³ + 0.0050x ² – 0.0284x + 1.0055	0.7123**	21
	H'	y = –0.0004x ³ + 0.0161x ² – 0.1012x + 1.9089	0.9215**	21
	J _w	y = –0.0002x ³ + 0.0062x ² – 0.0399x + 1.3306	0.6908**	18
	E _a	y = –0.0002x ³ + 0.0077x ² – 0.0794x + 1.4707	0.7072**	18

* P < 0.05, ** P < 0.01; y: Diversity indices, x: Developing stages; T_{max}: The development time of *H. rhamnoides* community when its species diversity reached the maximum value.

by a gradual increase of species diversities and evenness and a development trend towards community stability.

It was similar between the change trend of species diversity of the whole *H. rhamnoides* community (C) and that of the grass layer (B) at different stages, indicating that the grass layer played an important role in the *H. rhamnoides* plantations (Fig. 1).

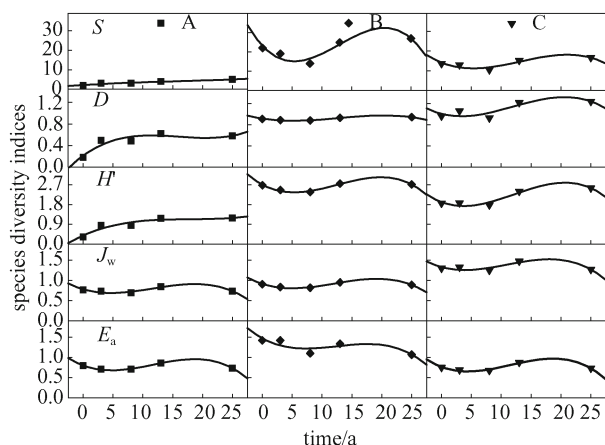


Fig. 1 Dynamics of the species diversity indices in the development sequence of *H. rhamnoides* plantations. A: Shrub layer; B: Herb layer; C: Whole community; S: Species richness; D: Simpson diversity index; H' : Shannon diversity index; J_w : Pielou evenness index; E_a : Alatalo evenness index.

3.2 Interspecific association

Seven populations were selected whose important values were bigger than those of the others in the *H. rhamnoides* plantations. The significance level and intensities of interspecific association between *H. rhamnoides* population and the 7 principal populations were examined, respectively. The χ^2 tests and Jaccard indices of interspecific association shows a parabola shape (Fig. 2) and the correlation coefficients were significant at the level of $P < 0.01$ (Table 5). The significance level of interspecific association between *H. rhamnoides* and most of the 7 principal species in 13-year plantation was decreased and the intensities were weaker. There was no significant positive or negative correlations (the absolute values of χ^2 test were both < 3.841), suggesting relative independence between the different populations and species. This implied that the competition for resources was relatively lower among populations in 13-year plantation.

4 Discussion

4.1 Evolvement course between species diversity and interspecific association

The ideal conditions for the natural development of plantations are that given trees or shrubs grow healthily, have

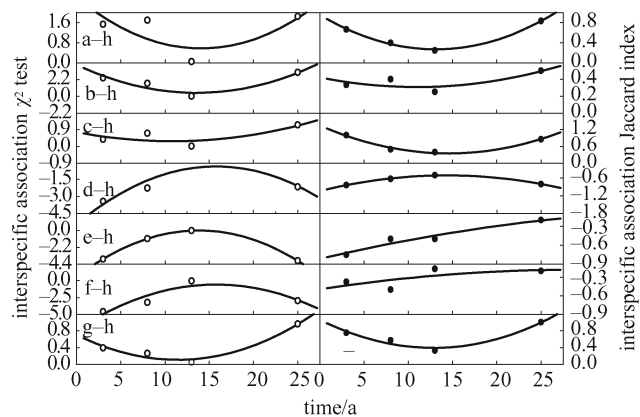


Fig. 2 Changes in interspecific association between *H. rhamnoides* and 7 species in *H. rhamnoides* plantations at different development stages. a: *Lespedeza davurica*; b: *Periploca sepium*; c: *Artemisia capillaries*; d: *Artemisia sacrorum*; e: *Ixeris denticulate*; f: *Cephalanoplos segetum*; g: *Stipa bungeana*; h: *Hippophae rhamnoides*.

self-renewal abilities, abundant species diversity and there are little disease or insect damage. Although the condition was very harsh in the Loess Region, the *H. rhamnoides* plantation developed well and this species could regenerate itself in naturalized development (Cheng et al., 2003; Li et al., 2001). The comparability coefficient of the *H. rhamnoides* plantation increased. However, biodiversity indices were fluctuating in an “S” shape at different stages. And it stayed in a relatively stable state at around 13 years. The significance level and intensity of interspecific associations between *H. rhamnoides* and the 7 principal species changed in parabolic pattern, and they were decreased or became weaker in the 13-year plantation, indicating that the remaining species were not influenced significantly by the lost species in the community (Cai, 2004). The study result is similar to that of plant community diversity in Dinghushan Nature Reserve (Huang et al., 2000). There was some relation between the stability and the evolvement of *H. rhamnoides* plantations' diversity and interspecific association and this relationship reached a higher level at around the 13-year development period, showing that the plantation was at a relatively stable stage. The natural development of the 13-year plantation produced good effects. Therefore, the *H. rhamnoides* was a suitable plantation type which can grow healthily in the Loess Region.

4.2 Comparability and species diversity at different development stages and interspecific association between constructive species and others

As is well known, the stability of climax community is higher than the succession community (Cai, 2004; Huang et al., 2000). The community comparability at different stages is an important index of the species substitution speed. Although the diversity cannot stand for the

Table 5 Regressive equations of the interspecific association index between 7 populations and *H. rhamnoides* in *H. rhamnoides* plantations ($n = 5$)

interspecific association index	species pair	regressive equation	R^2	T_{\min}
χ^2 -test	<i>Lespedeza davurica</i> - <i>Hippophae rhamnoides</i>	$y = 0.0101x^2 - 0.2861x + 2.5898$	0.5468**	14
	<i>Periploca sepium</i> - <i>Hippophae rhamnoides</i>	$y = 0.0040x^2 - 0.1045x + 0.9548$	0.9943**	13
	<i>Artemisia capillaris</i> - <i>Hippophae rhamnoides</i>	$y = 0.0200x^2 - 0.5421x + 4.1323$	0.8793**	13
	<i>Artemisia sacrorum</i> - <i>Hippophae rhamnoides</i>	$y = 0.0009x^2 - 0.0207x + 0.4197$	0.6405**	10
	<i>Ixeris denticulata</i> - <i>Hippophae rhamnoides</i>	$y = 0.0041x^2 - 0.0892x + 0.7622$	0.6326**	10
	<i>Cephalanoplos segetum</i> - <i>Hippophae rhamnoides</i>	$y = 0.0047x^2 - 0.1369x + 1.3478$	0.9807**	14
	<i>Stipa bungeana</i> - <i>Hippophae rhamnoides</i>	$y = -0.0203x^2 + 0.6410x - 5.4266$	0.8759**	16
Jaccard index	<i>Lespedeza davurica</i> - <i>Hippophae rhamnoides</i>	$y = -0.0026x^2 + 0.0742x - 1.0384$	0.995**	14
	<i>Periploca sepium</i> - <i>Hippophae rhamnoides</i>	$y = -0.0319x^2 + 0.8812x - 6.0824$	0.9999**	13
	<i>Artemisia capillaris</i> - <i>Hippophae rhamnoides</i>	$y = -0.0003x^2 + 0.0329x - 0.8164$	0.938**	–
	<i>Artemisia sacrorum</i> - <i>Hippophae rhamnoides</i>	$y = -0.0270x^2 + 0.8505x - 7.2737$	0.8409**	17
	<i>Ixeris denticulata</i> - <i>Hippophae rhamnoides</i>	$y = -0.0004x^2 + 0.0219x - 0.4969$	0.459**	–
	<i>Cephalanoplos segetum</i> - <i>Hippophae rhamnoides</i>	$y = 0.0046x^2 - 0.1039x + 0.7041$	0.964**	11
	<i>Stipa bungeana</i> - <i>Hippophae rhamnoides</i>	$y = 0.0040x^2 - 0.1036x + 1.0572$	0.9502**	13

** $P < 0.01$, * $P < 0.05$; y: Interspecific association index; x: Developing stages. T_{\min} : The development time of *H. rhamnoides* community when the absolute value of its interspecific association index reached the minimum.

stability, the former is the prerequisite of the latter (Li and Shao, 2004). When the community evolved to a certain level, the species substitution speed slowed down and the interspecific association between constructive species and the others became weaker, showing that the community was relatively stable at the time. The community comparability, the species diversity index and interspecific relation of the shrub layer and grass layer in the 13-year *H. rhamnoides* plantation all reached a higher level by interspecific correlation analysis. This was because some species were eliminated due to the fierce competition and selection in the early development stage and the remaining species found their comfortable places, respectively. Interspecific relationships reached a relative stabilized state as they gained mutual benefit from their coexistence.

4.3 Proper cultivation and management for community stability and persistent development

The *H. rhamnoides* population possesses an intense sprouting capability consistently during the community development course, which was the basis for population renewal and sustainable utilization. The species richness kept increasing and the diversity changed in an “S” shape pattern with the invasion of local species. The complex composition was formed and interspecific associations between constructive species and the others were relatively weaker in the 13-year plantation. Therefore, for the communities younger than 13 years, protection should be reinforced and disturbance from human beings should be reduced. However, after a 13-year development, proper selective cutting and the dense clusters of *H. rhamnoides* clone thinning should be carried out in order to create favorable conditions for seedlings growth and local species invasion in this community. In the 25-year old community, the original individuals were already aging. The diversity increased again and the interspecific associations between *H. rhamnoides* and

other species were intensified. The old individuals should be cut selectively at this time, which can further stimulate sprouting and the regeneration of young seedlings. Thus, the *H. rhamnoides* can regenerate itself stably, bringing its ecological function into full play constantly.

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