Changes in species diversity and above-ground biomass of shrubland over long-term natural restoration process in the Taihang Mountain in North China

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ABSTRACT

In order to restore the impaired forest ecosystem in China, great efforts including the banning of the animal grazing and cutting woods for fuel, and implementation of the 'Grain for Green' program have been made by the central and local government of China. The objective of this research was to investigate the changes in above-ground biomass and species diversity after 22 years of vegetation recovery efforts in the lower Taihang Mountain of China. The results indicated that over the natural restoration process shrubs became the dominant species in 2008, while herbs were the dominant species back in 1986. Community coverage, height and above-ground biomass showed significant increases in 2008 compared to 1986. Shrubs showed significant increases in coverage, height, and above-ground biomass, whereas herbs significantly increased in height, but decreased in above-ground biomass. Over the 22-year natural restoration process, the species richness index and the Shannon-Wiener's index had been significantly decreased, whereas the Simpson's predominance index and the Pielou's evenness index had been significantly increased. Long-term vegetation recovery efforts improved the impaired forest ecosystem in lower Taihang Mountain to some extent: significant increases in both community coverage and above-ground biomass. The significant increase in community coverage can reduce the soil loss by wind and water erosion, and increase in the above-ground biomass will improve the soil chemical properties and physical structure. A comprehensive assessment of the success of vegetation recovery should include the evaluation of the changes in ecological process such as soil biological activities in the future research.

Keywords: shrub-herb community; vegetation recovery; community succession; species composition

As human activities keep escalating with ever-increasing population, forest ecosystems near human settlements are made fragile; it caused the severe vegetation degeneration (Chittbabu and Parthasarathy 2000, Cadotte et al. 2002). Understanding and quantifying the vegetation recovery after human disturbances is the major topic of research in basic and applied plant ecology in part due to its important implications for vegetation management, conservation, and community restoration (Bakker et al. 1998). Direct consequence of vegetation degeneration by these anthropogenic activities could be the change in the vegetation composition, biodiversity, and community biomass (Drayton and Primack 1996, Thompson and Jones 1999), which are often used to assess the restoration success (Yang et al. 2002, Ruiz-Jaén and Aide 2005).

During the past decade, primary or old-growth forests in the hilly area of Taihang Mountain in China have already disappeared or diminished considerably because of deforestation, cutting, tilling, logging, grazing, and so on (Yang et al. 2009). Most forests turned into shrubs or herbs with

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worsening habitats, or even rocky desertification in some zones. Great vegetation recovery efforts were exerted by the local and central government of China, such as banning of animal grazing and cutting woods. In 1999, the Chinese government launched the 'Grain for Green' (GfG) program in order to recover the vegetation and reduce soil erosion (Zhou et al. 2009). The GfG requires that all cropland cultivated on the mountainous area with a slope greater than 25° be returned to forest or pastureland. The farmers participating in the GfG program will be compensated with free grain and cash, and the seedlings were also provided by the government (Zhou et al. 2009).

In 1986, in order to better understand the characteristics of the impaired forest ecosystem and provide information in support of vegetation recovery in the lower Taihang Mountain areas, the Hilly Ecological Experimental Station (HEES), was established by the Chinese Academy of Sciences. A survey of soil chemical properties, vegetation type, above-ground biomass (AGB), and species diversity in 144 permanent sample plots of Niujiazhuang watershed was conducted in 1986 by the researchers of HEES. In 2008, the survey was done again in these 144 permanent sampling plots. Year 1986 represents the impaired soil and vegetation condition impaired by human activities. During 1986 and 2008, the major vegetation recovery efforts near the experiment site banned the animal grazing and cutting woods for fuel, which essentially eliminate the impacts of human activities. Hence, the comparison of soil and vegetation data between 1986 and 2008 can reveal the impacts of the 22-year natural restoration process.

Liu et al. (2010) compared the soil chemical properties between 1986 and 2008, and found that these vegetation recovery efforts had resulted in positive impacts on soil chemistry. The soil organic matter content stopped decreasing, and the collected N in B horizon and K, Na, Fe, Mg, and Zn in both A and B horizons showed significantly higher level in 2008 compared with 1986. The objective of this research was to further investigate the changes in AGB and species diversity after 22 years of vegetation recovery efforts in the lower Taihang Mountain of China.

MATERIAL AND METHODS

Study site. The survey was conducted in the lower Taihang Mountain by the researchers of the Hilly Ecological Experimental Station (with geographical coordinates of 114°15'50''E and 37°52'44''N), Chinese Academy of Sciences. The experiment site is located in the Niujiazhuang Catchment (with the drainage area of 9.3 km^2), approximately 50 km southwest of Shijiazhuang, capital city of Hebei Province, China. The elevation ranges from 247 to 1040 m a.s.l. The long-term annual average temperature is 13°C with the lowest monthly average temperature of –1.6°C in January and the highest of 26.3°C in July. The average annual precipitation is 560 mm, with 67.8% of that available from June to September.

The vegetation in the catchment is a mosaic of shrubs, herbs, plantation, agricultural crops, deciduous and coniferous forests. In this manuscript, the names of plant species are based on the Flora Reipublicae Popularis Sinicae (Hu et al. 1959–2004). The shrub-herb community is dominated by *Vitex negundo* var. *heterophylla*, *Leptodermis oblonga,* and *Ziziphus jujuba* var. *spinosa*, *Artemisia sacrorum*, *Bothriochloa ischcemum*, and *Themeda japonica*. The planted species were *Z. jujuba*, *Punica granatum*, *Diospyros kaki*, *Juglans regia,* and *Armeniaca sibirica*.

Field study. Vegetation and soil surveys of the Niujiazhuang Catchment in the lower Taihang Mountain were taken in both 1986 and 2008. Field measurements of vegetation community in the Niujiazhuang Catchment were conducted in 42 permanent belt transects with the size of 30 m in length and 2 m in width (Figure 1). There were a total of 144 permanent sampling plots (2 m in length and 2 m in width) taken from these transects. At each sampling plot, the community coverage and plant species were recorded. For each species, the coverage, abundance, height, and AGB were measured. The elevation and slope aspect were also recorded for each sampling plot. The AGB of herbs and shrubs were measured after harvest. The plant samples were put into oven at a constant temperature of 80°C until completely dry.

Species diversity indexes. The species diversity was evaluated using species richness (S), Shannon-Wiener's (H), Simpson's predominance index (D), and evenness index (J_{sw}) (Pielou 1966). The diversity index H expresses heterogeneity while the D is sensitive to changes in common species and is determined by the relative concentration of dominance (Dörgeloh 1999). Because determining the degree to which each factor contributes to species diversity is impossible from the calculated value of H alone (Christensen and Peet 1984), a separate measurement of J_{sw} is calculated based

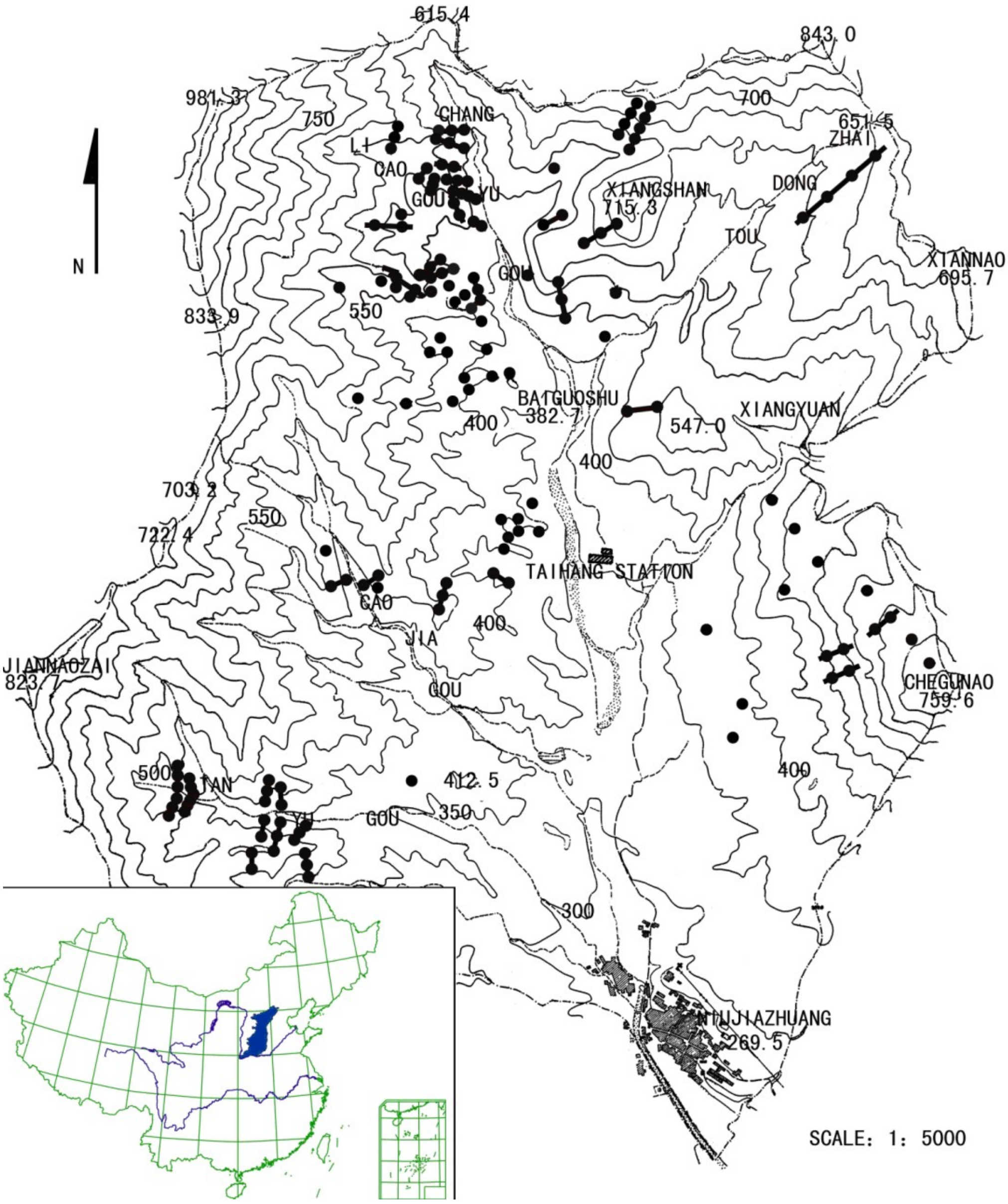

Figure 1. The transect and permanent sampling plots in the study area

on *H*. Diversity indexes of *H* and J_{sw} are calculated based on density and percent cover.

The species importance values (IV) for shrub-herb species are calculated as follows:

$$IV = (\text{relative density} + \text{relative percent cover})/2 \quad (1)$$

Where: relative density is the percentage of the individuals of a shrub or herb species to the total individuals of all plant species per plot; relative percent cover is percentage of the cover of a species to the total cover of all species. The IV is used to calculate species diversity at each plot.

The plant density data are used to calculate the H of the plant communities as follows:

$$H = -\Sigma P_i \ln P_i \quad (2)$$

Where: P_i is the proportional IV of the i^{th} species at a plot, and is calculated as follows:

$$p_i = N_i/N \quad (3)$$

Where: N_i is the IV of the i^{th} species at a plot; *N* is the summation of IV values of all species.

The calculation of *D* is shown as follows:

$$D = 1 - \Sigma p_i^2 \quad (4)$$

J_{sw} is calculated according to the following equation:

$$J_{sw} = (-\Sigma P_i \ln P_i)/\ln S \quad (5)$$

Statistical analysis. Analysis of variance (ANOVA) was conducted using SPSS13.0 procedure. Duncan's test at $P < 0.05$ was used to investigate whether there are significant differences in plant AGB and species diversity between 1986 and 2008.

RESULTS AND DISCUSSION

Change of species composition. The species richness decreased during natural vegetation recovery process. In the 1986 field survey, there were a total of 58 plant species belonging to 27 families and 51 genera, whereas there were 48 recorded species belonging to 24 families and 41 genera in the 2008 survey (Tables 1 and 2). In both 1986 and 2008 surveys, Asteraceae, Poaceae and Fabaceae are the major families. There were a total of 25 and 20 species recorded from the above three families in the 1986 and 2008 surveys, respectively (Table 2). The species from these three families accounted for 43.10 and 41.67% of the total species in the 1986 and 2008 surveys, respectively (Table 2). The species from Asteraceae, Poaceae and Fabaceae families have a much wider range of climatic adaptation than other families, which is likely the reason explaining their relatively higher percentage in the plant community composition in the lower Taihang Mountain (Yang et al. 2009).

The dominant species of community changed during the natural succession of vegetation: the perennial herbs were the dominant and main companion species in 1986, while in 2008 perennial shrubs were the dominant and main companion species in the majority of communities (Table 3). In 1986, the dominant and main companion species were *V. negundo* var. *heterophylla*, *L. oblonga*, *Gleditsia sinensis*, *Z. jujuba* var. *spinosa*, *Lespedeza floribunda*, *Selaginella sinensis*, *T. japonica*, *B. ischcemum*, *A. sacrorum*, *Cleistogenes chinensis*, *Pennisetum centrasiaticum*, and *Dendranthema indicum*, the majority of which are perennial herbs. Nowadays, *V. negundo* var. *heterophylla*, *Z. jujuba* var. *spinosa*, *G. sinensis*, *L. oblonga*, *L. floribunda*, *B. ischcemum*, *A. sacrorum*, and *D. indicum* are the dominant and main companion species. Similarly, Zhao (2007) studied the vegetation restoration of degraded ecosystem in the hilly areas of the Taihang Mountain, and found that vegetation succession process show the trend from herbs to shrubs and trees.

Change of AGB. Based on the results of statistical analysis, there were significant differences in the coverage, height, and AGB for both shrubs and herbs between 2008 and 1986 with the exception of herb coverage (Table 4). Over the 22-year natural succession of vegetation, the mean community coverage was significantly increased from 76.72 to 93.85% (Table 4). In 2008, the community coverage at the majority of sampling plots was over 90%, and at some plots the community coverage can even reach 100%. The increased coverage of soil surface will effectively prevent or ease the incidence of wind and water erosion, and reduce the soil loss (Liu et al. 2010).

Community, shrubs and herbs showed significantly higher heights in 2008 than in 1986: the mean heights of them were increased from 0.47, 0.47, and 0.45 m in 1986 to 1.21, 1.64, and 0.84 m, respectively (Table 4). Community and shrubs had significantly higher coverage in 2008 than in 1986, but there were no significant differences in the mean coverage of herbs between 1986 and 2008 (Table 4). The average coverages of community and shrubs were significantly increased from 76.72 and 33.66% to 93.85 and 59.08%, respectively (Table 4). There was a significant increase in the AGB of community and shrubs, while AGB of herbs in 2008 was significantly lower than in 1986. The average AGB of community and shrubs were significantly increased from 0.37 and 0.15 kg/m^2 to 0.44 and 0.35 kg/m^2, respectively, and the average AGB of herbs was significantly decreased from 0.23 to 0.10 kg/m^2 (Table 4).

The coverage, height, and AGB of the major communities in 1986 and 2008 are given in Table 3. Clearly the majority of plant communities in 2008 had relatively higher coverage, height, and AGB than the plant communities in 1986. The increased community AGB might result in positive impacts on the impaired ecosystem because the vegetation plays a key role in maintaining the soils in which they grow (Liu et al. 2010). The increased litter falls resulting from increased community AGB can improve the soil chemical properties and physical structure, and increase the biological activities within the soil (Mishra et al. 2003, Liu et al. 2010).

The species richness decrease while community AGB increase might suggest that the functional group and dominant species may play more important role in the function of the ecosystem of ecological restoration. After 22 years of vegetation restoration, the roles of dominant species became more and more significant: few dominant species made the greatest contribution to the AGB. The AGB distribution among species during early secondary succession primarily depends on light availability and nitrogen supply, the total species number, and cover of dominant species (Luzuriaga et al. 2002).

Change of species diversity. Over the 22-year natural restoration process, the diversity indexes of *S* and *H* had been significantly decreased, whereas the *D* and J_{sw} had been significantly increased (Figure 2). The reason that the *S* and J_{sw} responded

Table 1. Recorded plant species in 1986 and 2008 surveys

Family	Species	1986	2008	Family	Species	1986	2008
Fabaceae	*Robinia pseudoacacia*	A	A	Caryophyllaceae	*Dianthus chinensis*	A	A
	Lespedeza bicolor	A	A		*Dianthus superbus*	NA	A
	Lespedeza tomentosa	A	NA	Crassulaceae	*Orostachys fimbriatus*	A	A
	Lespedeza floribunda	A	NA		*Hylotelephium tatarinowii*	A	NA
	Lespedeza caraganae	A	A	Rosaceae	*Potentilla anserina*	A	A
	Medicago lupulina	A	NA		*Sanguisorba officinalis*	NA	A
	Gleditsia sinensis	NA	A	Simaroubaceae	*Ailanthus altissima*	A	A
	Campylotropis macrocarpa	NA	A	Rhamnaceae	*Ziziphus jujuba* var. *spinosa*	A	A
Asteraceae	*Artemisia sacrorum*	A	A	Umbelliferae	*Ziziphus jujuba*	NA	A
	Artemisia capillaris	A	NA		*Rhamnus parvifolia*	NA	A
	Artemisia hedinii	NA	A		*Bupleurum chinense*	A	A
	Artemisia lavandulaefolia	NA	A	Asclepiadaceae	*Cynanchum thesioides*	A	A
	Bidens pilosa	A	A		*Periploca sepium*	A	NA
	Aster tataricus	A	A	Rubiaceae	*Rubia cordifolia*	A	A
	Scorzonera austriaca	A	A		*Leptodermis oblonga*	A	NA
	Dendranthema zawadskii	A	NA	Verbenaceae	*Vitex negundo* var. *heterophylla*	A	A
	Dendranthema indicum	A	A	Euphorbiaceae	*Leptopus chinensis*	A	NA
	Saussurea japonica	A	NA		*Euphorbia pekinensis*	NA	A
	Cirsium setosum	NA	A	Vitaceae	*Parthenocissus tricuspidata*	A	NA
	Lagedium sibiricum	NA	A		*Ampelopsis japonica*	A	NA
Poaceae	*Setaria viridis*	A	A		*Vitis amurensis*	NA	A
	Festuca ovina	A	A	Valerianaceae	*Patrinia rupestris*	A	NA
	Cleistogenes chinensis	A	A	Liliaceae	*Allium chrysanthum*	A	NA
	Themeda japonica	A	A		*Allium ramosum*	NA	A
	Bothriochloa ischcemum	A	A		*Anemarrhena asphodeloides*	A	NA
	Achnatherum extremiorientale	A	NA		*Lilium pumilum*	A	NA
	Arundinella anomala	A	NA	Iridaceae	*Iris dichotoma*	A	NA
	Pennisetum centrasiaticum	A	NA		*Belamcanda chinensis*	NA	A
	Poa nemoralis	A	NA	Violaceae	*Viola verecunda*	A	NA
	Arthraxon hispidus	A	NA	Campanulaceae	*Adenophora tetraphylla*	A	NA
	Stipa bungeana	A	NA		*Wahlenbergia marginata*	A	NA
	Stipa capillata	NA	A	Cyperaceae	*Carex humilis*	A	NA
Pinaceae	*Pinus tabulaeformis*	A	NA	Gesneriaceae	*Boea clarkeana*	A	NA
Selaginellaceae	*Selaginella sinensis*	A	NA	Labiatae	*Perilla frutescens*	A	NA
	Selaginella tamariscina	A	NA		*Elsholtzia ciliata*	NA	A
	Selaginella sanguinolenta	A	NA	Tiliaceae	*Grewia biloba*	A	NA
Chenopodiaceae	*Salsola collina*	A	A	Juglandaceae	*Juglans regia*	NA	A
	Chenopodium glaucum	NA	A	Scrophulariaceae	*Rehmannia glutinosa*	NA	A
	Chenopodium album	NA	A		*Digitalis purpurea*	NA	A
Ranunculaceae	*Clematis kirilowii*	NA	A	Caprifoliaceae	*Lonicera tatarinowii*	NA	A
Zygophyllaceae	*Tribulus terrester*	A	A	Ulmaceae	*Ulmus pumila*	NA	A

A – represents that the species was found in the survey; NA – the species was not found in the survey. Names of plant species are based on the Flora Reipublicae Popularis Sinicae (Hu et al. 1959–2004)

Table 2. Summary of recorded plant species in 1986 and 2008 survey

Year	Family	Genera	Species	Asteraceae		Poaceae		Fabaceae	
				species	(%)	species	(%)	species	(%)
1986	27	51	58	8	13.79	11	18.97	6	10.34
2008	24	41	48	9	18.75	6	12.50	5	10.42

differently may be because S is the absolute density of community while J_{sw} is relative density (Ma et al. 1995). The *S* was directly proportional to the amount of species in the particular community and was independent of individual distribution in the community, while the J_{sw} increased when having well-distribution of individual in the community. The community with higher *D* had a better

Table 3. The coverage, height and AGB of the main plant communities in the study area

Year	Community types	Community coverage (%)	Shrub			Herb		
			height (m)	coverage (%)	AGB (kg/m²)	height (m)	coverage (%)	AGB (kg/m²)
2008	*Vitex negundo* var. *heterophylla-Artemisia sacrorum*	85.00	0.67	43.33	0.23	0.40	43.33	0.21
	Vitex negundo var. *heterophylla-Carex humilis*	85.00	0.58	30.00	0.06	0.25	80.00	0.23
	Vitex negundo var. *heterophylla-Pennisetum centrasiaticum*	66.67	0.53	26.67	0.09	0.40	40.00	0.22
	Vitex negundo var. *heterophylla-Themeda japonica*	50.00	0.55	15.00	0.06	0.60	35.00	0.18
	Leptodermis oblonga-Themeda japonica	70.00	0.35	60.00	0.20	0.60	10.00	0.10
	Lespedeza floribunda-Carex humilis	95.00	0.38	30.00	0.15	0.28	65.00	0.45
	Ziziphus jujuba var. *spinosa*	80.00	0.30	20.00	0.37	0.60	60.00	0.06
	Themeda japonica-Bothriochloa ischcemum	40.00	0.60	10.00	0.03	0.40	30.00	0.12
	Themeda japonica-Pennisetum centrasiaticum	50.00	0.50	10.00	0.13	0.40	45.00	0.11
	Themeda japonica-Artemisia sacrorum	87.50	0.30	25.00	0.10	0.55	45.00	0.22
	Artemisia sacrorum-Carex humilis	80.00	0.40	50.00	0.43	0.20	20.00	0.11
	Cleistogenes chinensis	85.00	0.40	20.00	0.04	0.55	76.67	0.38
	Mean value	72.85	0.46	28.33	0.16	0.44	45.83	0.20
1986	*Vitex negundo* var. *heterophylla-Pennisetum centrasiaticum*	91.65	1.45	70.59	0.44	0.80	41.76	0.09
	Vitex negundo var. *heterophylla-Artemisia sacrorum*	96.30	1.79	74.57	0.39	0.98	42.61	0.11
	Ziziphus jujuba var. *spinosa-Pennisetum centrasiaticum*	95.00	1.59	50.00	0.53	0.78	55.00	0.05
	Ziziphus jujuba var. *spinosa-Artemisia sacrorum*	100.00	1.70	60.00	0.46	1.30	15.00	0.04
	Gleditsia sinensis-Artemisia sacrorum	99.00	5.50	85.00	0.51	1.23	60.00	0.05
	Gleditsia sinensis-Pennisetum centrasiaticum	96.67	4.17	83.33	0.26	0.87	38.33	0.09
	Leptodermis oblonga-Pennisetum centrasiaticum	75.00	0.40	60.00	0.38	0.90	40.00	0.36
	Leptodermis oblonga-Artemisia sacrorum	99.58	0.61	76.25	0.26	0.94	43.00	0.07
	Leptodermis oblonga-Festuca ovina	98.00	0.45	85.00	0.10	0.40	60.00	0.08
	Leptodermis oblonga-Dendranthema indicum	100.00	0.58	60.00	0.16	0.81	24.00	0.07
	Artemisia sacrorum	100.00	0.60	5.00	0.21	0.67	61.67	0.10
	Pennisetum centrasiaticum	100.00	0.42	4.50	0.20	0.97	70.00	0.05
	Mean value	95.93	1.61	59.52	0.32	0.89	45.95	0.09

AGB – the above-ground biomass. Names of plant species are based on the Flora Reipublicae Popularis Sinicae (Hu et al. 1959–2004)

Table 4. Comparison of plant AGB

Year	Aspect	Community			Shrub			Herb		
		height (m)	coverage (%)	AGB (kg/m^2)	height (m)	coverage (%)	AGB (kg/m^2)	height (m)	coverage (%)	AGB (kg/m^2)
1986	overall	0.47^a	76.72^a	0.37^a	0.47^a	33.66^a	0.15^a	0.45^a	44.84^a	0.23^a
2008	overall	1.21^b	93.85^b	0.44^b	1.64^b	59.08^b	0.35^b	0.84^b	46.50^a	0.10^b
1986	south-facing	0.53^a	69.66^a	0.37^a	0.53^a	25.23^a	0.11^a	0.53^a	48.52^a	0.28^a
	north-facing	0.43^b	82.57^b	0.36^a	0.44^b	39.83^b	0.18^b	0.38^b	47.50^a	0.19^a
2008	south-facing	1.29^a	93.48^a	0.46^a	1.71^a	62.15^a	0.39^a	0.90^a	38.18^a	0.08^a
	north-facing	1.15^a	96.79^b	0.42^a	1.59^a	57.07^a	0.33^a	0.80^a	50.20^b	0.12^b

Different letters in the same column mean significant difference at 0.05 level; AGB – the above-ground biomass

function of absorbing resources of domination species and lower species diversity. On the contrary, the lower *D*, the weaker function of species in the community. Compared with the perennial herbs, the important value of shrubs increased gradually after 22 years' natural restoration in Taihang Mountain. Temporal stability increased with dominance by *V. negundo* var. *heterophylla* and *L. oblonga*, because these species exhibited exceptionally stable AGB production. In poor-species nature plant communities, species traits (such as ability to respond to higher nutrient levels) as well as competitive interaction may determine the ecosystem processes (e.g. productivity) by which dominant species affect relationships between diversity and productivity.

In order to maintain and restore the impaired forest ecosystems and halt the land degradation, the Government of China has launched three large-scale nation-wide land conservation projects: 'The three-north forest shelter belt project', 'Natural forest resources protection project', and 'Returning farmland to forest and grasslands – grain for green (GfG) project' (Yang 2004). The conservation effects of these vegetation recovery efforts varied regionally. For example, the GfG project resulted in a significant increase in vegetation cover on the farmland in the northern part of the Shanxi Province, but no significant changes in vegetation cover on the farmland in the southern part (Zhou et al. 2009). On the Chinese Loess Plateau, afforestation efforts even had significant negative effects on soil desiccation, which impaired the long-term sustainability of these ecosystems (Jiao et al. 2010). After 22 years' vegetation recovery efforts in the Niujiazhuang Catchment of the lower Taihang Mountain in China based on the comparison results of two surveys of 144 permanent sampling plots in 1986 and 2008, shrubs replaced herbs to be the dominant species and played more important role in the function of the ecosystem by contributing the majority of AGB.

Long-term vegetation recovery efforts in the study area have led to positive impacts on the impaired forest ecosystem: significant increases in community coverage and AGB, which can in turn prevent soil loss by wind and water erosion, improve soil chemical properties and physical structure, and increase biological activities within the soil. It is expected that the community coverage and AGB will continue to increase with the establishment of dominant shrub communities.

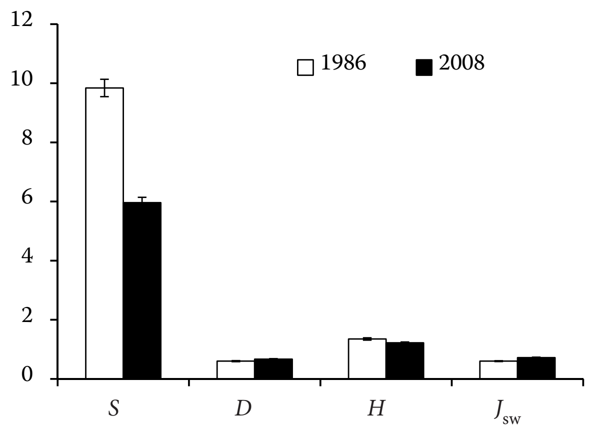

Figure 2. Comparison of calculated mean species diversity indexes of the permanent plots between 1986 and 2008

S – species richness; *D* – the Simpson's predominance index; *H* is the Shannon-Wiener's index; and J_{sw} is the Pielou's evenness index. Each plot is 2 m in length and 2 m in width. Error bars represent stand errors

But further monitoring should be conducted to confirm the trend found in this study. In addition, the measures of restoration success should include vegetation structure, species diversity, and ecological processes (Ruiz-Jaén and Aide 2005). The ecological parameters considered in this study were AGB and the soil nutrient contents in a previous research (Liu et al. 2010). It is suggested that more ecological process parameters such as quantity of earthworms be included as a part of vegetation restoration assessment in the future research.

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