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ARTICLE

Human Disturbance Reduces Plant Species Diversity and Stability of *Phyllostachys pubescens* Forests

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ABSTRACT

Plant species diversity is an important index reflecting the functional complexity and stability of ecosystems. Human activity can completely alter plant species diversity and cause serious degradation of ecosystems but its impact on bamboo forest still lacks of systematic evaluation. In this study, we performed a field investigation to reveal the influences of human disturbances on the plant diversity and stability of Moso bamboo forests at Southern China. The selected bamboo fields contained different intensities of human activities that could be classified as slight, moderate and severe disturbance level. Species richness index S, Shannon-Wienner index H, Simpson index D, Pielou index Jsw, community similarity index IS and community stability index were employed to quantitatively evaluate the plant species diversity and stability. The survey revealed that there were 203 species belonging to 83 families and 108 genera in Moso bamboo forests. The number of plant species in the Moso bamboo forests decreased with the increasing of disturbance intensity. The species diversity indexes generally followed the order of slight > moderate > severe disturbance, as well as the richness index S, Shannon-Wienner index H and Pielou index Jsw. The similarity and species stability of the bamboo forest communities also decreased with the increase of the disturbance intensity. Under the severe disturbance, plant species replacement occurred strongly. The obtained results provide some a guideline for the sustainable management of bamboo forest.

1. Introduction

Disturbance frequently alters spatial patterns of species diversity and its influence on ecological system has become a widely concerned subject for research [1-3]. Disturbance generally includes natural and human activities that destroy the ecosystem, community or species structure, and significantly change the effectiveness of the matrix substance and the physical environments [4]. Human disturbances such as logging [5,6], burning [5,7,8], livestock grazing [9,10], urban development [11-13] have had a marked influence on vegetation composition and dynamics, as well as terrestrial and aquatic ecosystem processes [14-18]. In particular, several studies have shown that regional vegetation patterns at the time of European settlement were related to climate, physiography, or natu-

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ral disturbance regime, and that these patterns have been altered or obscured by human disturbance since settlement [19-24]. Although human activity can completely change the original forest landscape, destroy ecosystem stability and plant community species diversity, and even cause serious degradation of ecosystems [25-28], its impact on ecological system, especially on the species diversity and the stability of forest communities is still poorly understood and lacks of systematic evaluation. It is generally recognized that the community with a high diversity, which affected by low human disturbance, can increase the productivity of the plant community, the retention of nutrients in the ecosystem, and the stability of the ecosystem [29-31]. However, many examples of research practice do not meet this point. Some scholars argued that diversity can lead to the stability of the community and the process of the system, but it will not lead to the stability of population level [32-34].

Phyllostachys pubescens (Moso bamboo) is an important economic plant and widely distributed in China. It has characteristics of fast growth, short harvesting period and sustainable management [35, 36]. As an important material resource and ecological barrier, it also contributes to regional economic development. However, in some of the major bamboo producing areas, bamboo farmers have planted large area of pure bamboo forest with frequent reclamation of the forestland. Together with excessive application of chemical fertilizers, long-term use of chemical herbicides, these have caused a fragile bamboo forest ecosystem. Declines of biodiversity and site productivity, as well as the deterioration of regional ecological environment have been reported in the main producing areas [36-38]. Long-term over-management also caused significant deduction in both quantity and quality of bamboo shoot production [39,40]. All of these call for an urgent need of scientific management strategy through maintaining integrity of bamboo forest ecological system. Therefore, the objective of this study was to evaluate the impact of human disturbance on the species diversity and the stability of bamboo forest communities.

2. Materials and methods

2.1 Profile of the Experimental Area

The experimental area located in Anji County (30°27'13"-30°28'45" N, 119°40'33"-119°40'54" E), Huzhou City, Zhejiang Province of China. It is characterized by subtropical monsoon climate with considerable amount of sun and four distinct seasons. The average annual temperature is 16.6 °C with a lowest temperature in January (- 5.5 °C) and a highest temperature in July (30.8 °C). The annual sunshine hours are in the range of 1613 to 2430 h and precipitation 761-1780 mm. Average frost-free period in the site is about 231 d and relative humidity above 70%. The soil type is yellow soil and yellow brow soil. Among the 563.73 hectare (ha) of testing land, bamboo forest covered 309.27 ha, accounting for 54.86% of the total area. Bamboo cultivation and bamboo shoot processing are important part of the mainstay industries in the region.

2.2 Selection of the Bamboo Forest

In the experimental area, we selected three test sites with same soil type and similar landform. Each site has different intensity of human disturbance, classified as slight (A), moderate (B) and severe disturbance (C). Slight disturbance site A was mixed forest, distributed in the edge of natural forest. The vertical bamboo density in this site was 3600 ± 55 plants/ha with 9.20 ± 0.34 cm of average diameter at breast height (DBH). The ratio of number of plants between age structures (named as grades, grade I refers 1-2 years; grade II refers 3-4 years; and so on) was 31: 34: 17: 18 for grade I:II:III:IV, respectively. No removal of weeds, neither leveling off hilltops nor fertilization was applied in this site. Moderate disturbance B site was also mixed forest but had a higher bamboo density of 3920 ± 52 plants/ha and DBH of 10.04 ± 0.56 cm. The ratio of number of culms between was 33:32:22:13 for grade I:II:III:IV, respectively. Removal of weeds and leveling off hilltops were conducted once every year but no fertilization was applied. The severe disturbance C site was mainly bamboo, mixed with a small amount of arbor species. The bamboo density was 4500 ± 61 plants/ha with a ratio of 25:44:20:11 for number of culms between grades. Manually removal of weeds and leveling off hilltops were conducted 1 to 2 times every year. Besides, compound fertilizer was applied during June-July or September-October through ditch application method. For all the sites, the management also included retaining the shoots and cutting the forests only seasonally. Each site was at least 1.2 ha in area.

2.3 Plot Setup and Survey

Three plots of 20 m × 20 m were set up in each type of test sites (Table 1). Each plot was equally divided into four 10 m × 10 m survey areas for arbors. Along the diagonal of each plot, we arranged six 5 m × 5 m survey areas for shrubs and twelve 1 m × 1 m quadrats for herbaceous. The total number of areas for tree layer, shrub layer and herbage layer were 36, 54 and 108 respectively.

In the tree layer, the type of tree species, DBH, height and the crown width were recorded for the all plants higher than 3 m. In the shrub layer, the type of plant species,

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height and crown width were recorded for all the woody individuals with height less than 3 m, including tree seedlings and saplings. Survey in the herbaceous layer included the type of species, number of plants (number of clusters), height, coverage of herbaceous vines and ferns. According to the DBH, large woody vines were included in the tree layer or shrub layer, respectively.

Soil was sampled in three layers (0-20 cm, 20-40 cm and 40-60 cm) at five positions randomly picked from a zigzag line. Soil fertility was measured by standard soil chemical analysis. These parameters were used to evaluate the community stability.

Table 1. General information of the selected Moso bamboo forests

Sample Plot No.	Slope (°)	Aspect	Elevation/ m	Average diameter /cm	Density/ (Plant/ha)	Canopy
A-1	32°	E	251.5	9.5	3541	0.8
A-2	39°	E	259	8.9	3623	0.7
A-3	35°	SW	252.6	9.3	3645	0.7
B-1	24°	E	240.5	10.7	3856	0.8
B-2	37°	SE	234.9	11.2	4026	0.8
B-3	28°	SE	237.5	10.9	3886	0.8
C-1	28°	W	306.8	11.8	4568	0.9
C-2	18°	NW	301.9	12.3	4452	0.9
C-3	20°	NW	303.5	12.0	4476	0.9

Note: A: Slight disturbance; B: Medium disturbance; C: Severe disturbance. The same below.

2.4 Data Processing and Analysis

According to the survey data, relative density, relative significance (relative coverage) and relative frequency of the tested species were calculated. The importance values (IV) of the species in each plot were also calculated. Based on the IVs, diversity index of species was further evaluated. This included species richness index S value, Shannon-Wiener's diversity index H value, Simpson's dominance index D value, Pielou's evenness index Jsw value and Alatalo's evenness index Ea value. The species diversity in bamboo stands was then evaluated based on the species diversity index [41-45]. The related definitions were listed as:

Relative density = number of plants per species / total plant number of all species;

Relative density = number of plants per species / total plant number of all species;

Relative frequency = number of occurrences of a species in a quadrat/ total number of occurrences of all species in the quadrat;

Relative coverage = coverage of a species / coverage of all species;

IV for tree layer = (relative density + relative significance + relative frequency) / 3;

IV for shrub layer or herbaceous layer = (relative density + relative coverage + relative frequency) / 3;

Richness index S = number of species present in the quadrat.

Simpson's dominance index: $D = 1 - \sum_{i=1}^{S} P_i^2$

Shannon-Wiener diversity index: $H = -\sum_{i=1}^{S} P_i \ln P_i$

Pielou's evenness index: $Jsw = \dfrac{-\sum P_i \ln P_i}{\ln S}$

Alatalo's evenness index: $E = \dfrac{\left(\sum_{i=1}^{S} P_i^2\right)^{-1} - 1}{\exp\left(-\sum_{i=1}^{S} P_i \ln P_i\right) - 1}$

where P_i is the ratio of the number of individuals n_i in the i^{th} species to the total number n of all species, that is, $P_i = n_i / n$; i=1,2, 3, ..., S, and S is the number of species.

Sorensen's index was used to compare the community similarity IS=[2C/ (A + B)] × 100%, where A (B) is the number of species in plot A (B), C is the number of species shared between plot A and B.

We applied 11 factors including soil fertility, species diversity and human disturbance intensity to the membership function of fuzzy mathematics to evaluate plant community stability, i.e: $P(X_{ijk}) = P_{ijk} / P_{kmax}$, where $P(X_{ijk})$ is the standardized value of k-th index of the j-th attribute of the i-th community, Pijk is the original k-th index of j-th attribute of the i-th community, and P_{kmax} is the maximum value of the k-th index of all communities [46].

Community stability indicators included (1) soil fertility: Participation factors are soil organic matter, total nitrogen, total phosphorus, available nitrogen and available phosphorus contents; (2) species diversity: Participation factors include species richness index, species diversity index (Simpson index and Shannon index), evenness index (Pielou index and Alatalo index); and (3) human interference intensity: according to the actual survey results, we artificially assigned 1 for the slight grade, 0 for the Medium grade, and -1 for the severe grade [46].

Data were analyzed in SPSS 22.0 and DPS 9.5 software using one-way ANOVA method with least significant difference (LSD) P <0.05.

3. Results

3.1 Secies Composition in the Bamboo Plant Community

In the 9 bamboo plots with a total area of 3600 m^2, we recorded 203 plant species. They belong to 108 genera of 83 families, mainly include *Rosaceae, Gramineae, Liliaceae, Compositae, Lauraceae, Pteridiaceae, Labiatae, Leguminosae, Theaceae, Rubiaceae, Orchidaceae, Fagaceae,* and *Ericaceae*. As shown in Table 2, there are obvious species diversity differences among the plant layers in the species composition. The herb layer contributes most to the species diversity of the *Phyllostachys pubescens* forest with arbor layer the least. In detail, there were 34 species in the arbor layer, belonging to 28 genera in 22 families. They mainly consisted of *Lauraceae, Fagaceae, Leguminosae* and *Juglandaceae*. The 72 species in the shrub layer were classified into 37 families and 50 genera. They were mainly *Rosaceae, Camelliaceae, Lauraceae, Leguminosae*, and *Euphorbiaceae*. The herbaceous layer had 95 species, belonging to 48 family and 79 genera. They were mainly *Gramineae, Compositae, Lepidoptera, Lupus, Euphorbiaceae, Shaped flowers*, and *Lily*. The species composition of bamboo plant community also varied with human disturbance (Table 2). In the slight-disturbed bamboo forest, we found 142 species belonging to 72 family and 89 genera; in the moderate-disturbed plots, 125 species belonging to 83 genera and 64 families; in the severe disturbed plots, 103 species belonging to 80 genera and 61 families. Clearly, both numbers of species and families decrease with the increase of human disturbance.

Table 2. The species composition of Moso bamboo forests

Items	Layer			Disturbance intensity		
	Herb	Shrub	Arbor	A	B	C
Species number	95	72	34	142	125	103
Genus number	79	50	28	89	83	80
Family number	48	37	22	72	64	61

3.2 Species Important Value in the Bamboo Community

Table 3 shows that the number of species in the arbor layer of bamboo stands follows the order of slight disturbance> moderate disturbance> severe disturbance. In this layer, 19 species were found under the slight disturbance, mainly including bamboo, *Cunninghamia lanceolata, Chinese fir, Sassafras tzumu*, and *Pinus massoniana*. Among them, bamboo has the maximal IV of 0.6018, followed by *Cunninghamia lanceolata* (0.1142). The moderate disturbance left 15 species mainly consisting of bamboo, *Sassafras tzumu, Holly, Lindera erythrocarpa, Chinese fir*. Bamboo has the maximal IV of 0.6611, followed by *Sassafras tzumu* (0.0620). The severe disturbance survived only 12 species, they were mainly bamboo, *Holly, Palm*, and *Lindera erythrocarpa*. The absolute dominant species was bamboo with IV of 0.7461, followed by holly (0.0607). Compared with the slight disturbed plots, the IVs for many arbor species in the severe disturbance group drop tens of folds, indicating that severe disturbance causes the bamboo forest composition to decay drastically.

The number of species in the shrub layer followed the order of moderate disturbance> slight disturbance> severe disturbance. In detail, there were 46 species under moderate disturbance, including *Ardisia japonica* Blume, *Trachelospermum jasminoides* Lem, *Rubus reflexus* Ker, *Camellia sinensis* O. Ktze, and *Euscaphis japonica* Dippel. There were 43 species under slight disturbance, including *Eurya muricata* Dunn, *Rubus idaeus* L, *Litsea cubeba* Pers, *Rubus corchorifolius* L. f, and *Smilax china* L. The severe disturbance left over only 35 species, including *Rubus hirsutus* Thunb, *Trachelospermum jasminoides* Lem, *Smilax davidiana* A. DC, *Ardisia japonica* Blume, and *Symplocos paniculata* Miq (Table 4).

The number of species in the herb layer followed the order of serious disturbance> slight disturbance> moderate disturbance. Briefly, there were 48 species under severe disturbance, including *Polygonum persocar* L, *Hedyotis Chrysotricha* Merr, *Oxalis corniculata* L, *Polygonum dissitiforum,* and *Achyranthes bidentata* Blume. The slight disturbance contained 45 species, including *Dicranopteris dichotoma* Bernh, *Lophatherum gracile, Hedyotis Chrysotricha* Merr, *Diplopterygium laevissima* Naka, and *Parathelypteris glanduligera*. The moderate disturbance left 43 species, including *Parathelypteris glanduligera*, *Hedyotis Chrysotricha* Merr, *Lophatherum gracile, Carex breviculmis* R. Br (Table 5).

3.3 Comparison of Species Diversity in the Bamboo Community

As shown in Table 6, the values of S, H, D, Jsw and Ea in the tree layer of bamboo showed a decreasing tendency with the increase of disturbance intensity. Despite the difference between the slight and moderate disturbances are not significant ($p > 0.05$), the difference between the moderate and severe disturbances are significant ($p<0.05$). In the shrub layer, these values were higher in the moderate disturbed plots than in the slight and severe disturbed forests with S value at the significance level ($p <0.05$). In the herb layer with severe disturbance, all the values were

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Table 3. IV of species in tree layer of Moso bamboo forests

Species name	Relative density			Relative frequency			Relative superiority			*IV*		
	A	B	C	A	B	C	A	B	C	A	B	C
Phyllostachys pubescens	0.7035	0.8136	0.8882	0.2419	0.2586	0.3659	0.8599	0.9112	0.9852	0.6018	0.6611	0.7461
Cunninghamia lanceolata	0.1357	0.0271	0.0016	0.1452	0.0862	0.0244	0.0618	0.0038	0.0004	0.1142	0.0390	0.0088
***Quercus glandulifera* Bl**	0.0518	0.0085	0.0033	0.1290	0.0345	0.0244	0.0143	0.0011	0.0003	0.0651	0.0147	0.0093
Phyllostachys glauca		0.0356			0.0172			0.0071			0.0200	
Sassafras tzmum	0.0251	0.0322		0.1290	0.1207		0.0282	0.0332		0.0608	0.062	
***Ilex chinensis* Sims**		0.0186	0.0526		0.1207	0.1220		0.0159	0.0077		0.0517	0.0607
***Pinus massoniana* Lamb**	0.0285			0.0968			0.0042			0.0431		
Albizzia kalkora	0.0084			0.0645			0.0039			0.0256		
***Lindera erythrocarpa* Makino**	0.0100	0.0169	0.0016	0.0484	0.1207	0.0244	0.0044	0.0037	0.0005	0.0209	0.0471	0.0101
***Betula luminifera* H.Winkl**	0.0084			0.0323			0.0087			0.0164		
***Trachycarpusfortunei* H.Wend**			0.0132			0.1220			0.0012			0.0454
***Quercus fabri* Hance**	0.0084	0.0068	0.0082	0.0322	0.0345	0.0732	0.0013	0.0036	0.0010	0.0140	0.0150	0.0027
The other belongs to B	0.0202			0.0807			0.0133			0.0381		
The other belongs to B		0.0407			0.2069			0.0204			0.0894	
The other belongs to B			0.0313			0.2437			0.0037			0.1169
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 4. IV of species in shrub layer of Moso bamboo forests

Species name	Relative density			Relative frequency			Relative superiority			*IV*		
	A	B	C	A	B	C	A	B	C	A	B	C
***Eurya muricata* Dunn**	0.1905	0.0109		0.0592	0.0182		0.2032	0.0224		0.1510	0.0172	
***Rubus hirsutus* Thunb**		0.0148	0.1755		0.0091	0.1154		0.0048	0.1285		0.0096	0.1398
***Trachelospermum jasminoides* Lem**	0.0207	0.1544	0.2201	0.1183	0.0454	0.0769	0.0058	0.0718	0.1144	0.0128	0.0896	0.1371
***Rubus idaeus* L**	0.1216	0.0078	0.0028	0.0710	0.0182	0.0096	0.1875	0.0105	0.0028	0.1267	0.0122	0.0051
***Litsea cubeba* Pers**	0.0449		0.0139	0.0770		0.0192	0.1778		0.0537	0.0998		0.0289
***Rubus corchorifolius* L. f**	0.0793	0.1046	0.0446	0.0651	0.0636	0.0577	0.0337	0.1152	0.0367	0.0594	0.0945	0.0463
Kadsura longipedunculate	0.0448	0.0016	0.0362	0.0769	0.0045	0.0385	0.0232	0.0075	0.0210	0.0132	0.0045	0.0329
***Hydrangea chinensis* Maxim**			0.0223			0.0096			0.0565			0.0295
***Camellia sinensis* O. Ktze**	0.0017	0.0523	0.0167	0.0059	0.0500	0.0288	0.0029	0.0651	0.0311	0.0035	0.0558	0.0255
***Smilax china* L**	0.0750	0.0226	0.0195	0.0473	0.0500	0.0288	0.0505	0.0284	0.0424	0.0576	0.0337	0.0302
Stephanandra chinensis		0.0328			0.0227			0.0546			0.0367	
***Serissa serissoides* Druce**		0.0210	0.0251		0.0273	0.0385		0.0213	0.0254		0.0230	0.0297
***Lindera reflexa* Hemsl**		0.0141	0.0111		0.0318	0.0192		0.0277	0.0452		0.0245	0.0252
***Rubus reflexus* Ker**	0.0595	0.0804		0.0592	0.0401		0.0462	0.0909		0.0549	0.0707	
***Symplocos paniculata* Miq**	0.0026	0.0219	0.0473	0.0059	0.0409	0.0673	0.0012	0.0329	0.0847	0.0032	0.0319	0.0665
***Loropetalum chinense* Oliver**	0.0672	0.0055		0.0592	0.0182		0.0297	0.0071		0.0520	0.0102	
***Ardisia japonica* Blume**	0.0785	0.1561	0.1003	0.0355	0.0500	0.0769	0.0107	0.0711	0.0508	0.0416	0.0924	0.0760
***Smilax davidiana* A. DC**	0.0500	0.0156	0.0919	0.0355	0.0227	0.0962	0.0293	0.0142	0.0720	0.0383	0.0175	0.0867
***Glochidion puberum* L**	0.0060	0.0031		0.0059	0.0364		0.0140	0.0094		0.0086	0.0163	
***Mallotus paxii* Pamp**		0.0055	0.0028		0.0227	0.0096		0.0232	0.0042		0.0171	0.0055
***Eurya hebeclados* Ling**	0.0103	0.0258	0.0028	0.0118	0.0273	0.0096	0.0046	0.0337	0.0141	0.0089	0.0289	0.0088
***Vaccinium bracteatum* Thunb**	0.0035	0.0125	0.0028	0.0118	0.0227	0.0096	0.0087	0.0157	0.0151	0.0080	0.0170	0.0088
***Euscaphis japonica* Dippel**	0.0259	0.0640	0.0028	0.0473	0.0500	0.0096	0.0154	0.0483	0.0028	0.0295	0.0541	0.0051
***Camellia fraterna* Hance**	0.0129			0.0592			0.0104			0.0275		
***Clerodendrum cyrtophyllum* Turcz**	0.0121	0.0031		0.0355	0.0091		0.0180	0.0060		0.0219	0.0061	
***Rubus buergeri* Miq**	0.0224	0.0726	0.0251	0.0178	0.0409	0.0192	0.0081	0.0441	0.0438	0.0161	0.0526	0.0293
Rhaphiolepis indica	0.0043			0.0296			0.0023			0.0121		
***Smilax glabra* Roxb**	0.0095	0.0133	0.0223	0.0178	0.0409	0.0385	0.0058	0.0101	0.0155	0.0110	0.0214	0.0254
The other belongs to A	0.0568			0.0473			0.1110			0.1424		
The other belongs to B		0.0837			0.2373			0.1640			0.1625	
The other belongs to C			0.1141			0.2213			0.1393			0.1577
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

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Table 5. IV of species in herb layer of Moso bamboo forests

Species name	Relative density			Relative frequency			Relative superiority			IV		
	A	B	C	A	B	C	A	B	C	A	B	C
Dicranopteris dichotoma **Bernh**	0.4256	0.0023		0.0803	0.0074		0.6228	0.0012		0.3763	0.0036	
Polygonum persocar **L**	0.0043	0.0083	0.3953	0.0073	0.0074	0.0833	0.0005	0.0020	0.3585	0.0040	0.0059	0.2791
Lophatherum gracile	0.1254	0.0544	0.0060	0.1095	0.0741	0.0139	0.0437	0.0353	0.0055	0.0929	0.0546	0.0085
Hedyotis Chrysotricha **Merr**	0.1369	0.2623	0.1188	0.0730	0.1038	0.0417	0.0375	0.1639	0.0587	0.0825	0.1767	0.0731
Oxalis corniculata **L**		0.0011	0.0508		0.0074	0.0625		0.0004	0.0287		0.0030	0.0473
Polygonum dissitiforum	0.0040		0.0501	0.0146		0.0208	0.0008		0.0489	0.0064		0.0399
Achyranthes bidentata **Blume**	0.0011	0.0011	0.0209	0.0073	0.0074	0.0556	0.0005	0.0008	0.0404	0.0030	0.0031	0.0390
Houttuynia cordata **Thunb**	0.0029	0.0072	0.0389	0.0073	0.0074	0.0278	0.0013	0.0039	0.0447	0.0038	0.0062	0.0371
Liriope spicata **Lour**			0.0172			0.0417			0.0489			0.0359
Lysimachia fortunei **Maxim**	0.0014	0.0079	0.0224	0.0073	0.0148	0.0417	0.0010	0.0043	0.0220	0.0032	0.0090	0.0287
Liriope graminifolia		0.0026	0.0105		0.0148	0.0347		0.0014	0.0098		0.0063	0.0183
Diplopterygium laevissima **Nakai**	0.0273			0.0219			0.1550			0.0681		
Carex breviculmis **R. Br**		0.0193	0.0112		0.0593	0.0278		0.0226	0.0139		0.0337	0.0176
Melothria ndica **Lour**			0.0067			0.0208			0.0208			0.0161
Parathelypteris glanduligera	0.0690	0.5076		0.0876	0.1111		0.0354	0.6596		0.0640	0.4261	
Gynostemma pentaphyllum **Makino**			0.0067			0.0208			0.0147			0.0141
Paedria scandens		0.0143	0.0097		0.0519	0.0208		0.0082	0.0165		0.0248	0.0157
Woodwardia japonica **Sm**	0.0233	0.0019		0.0584	0.0074		0.0200	0.0001		0.0339	0.0034	
Smilax riparia **A.DC**		0.0034			0.0519			0.0037			0.0197	
Triarrhena sacchariflora **Nakai**	0.0147	0.0079		0.0511	0.0222		0.0100	0.0049		0.0253	0.0117	
Liriope platyphlla **Wang et Lang**			0.0067			0.0139			0.0367			0.0191
Stemona japonica		0.0019	0.0105		0.0222	0.0417		0.0035	0.0153		0.0092	0.0225
Smilax nipponica **Miq**		0.0045	0.0082		0.0371	0.0417		0.0035	0.0153		0.0150	0.0217
Osmunda japonica **Thunb**	0.0104	0.0042		0.0511	0.0297		0.0139	0.0051		0.0251	0.0130	
Oplismentls undulatifolius folius	0.0273	0.0174	0.0120	0.0219	0.0148	0.0208	0.0037	0.0157	0.0092	0.0176	0.0160	0.0140
Syneliesis aconitifolia		0.0015	0.0037		0.0149	0.0208		0.0014	0.0061		0.0059	0.0102
Dioscorea japonica	0.0022	0.0034	0.0008	0.0219	0.0296	0.0070	0.0008	0.0016	0.0012	0.0083	0.0115	0.0030
Rabdosia amethystoides **Hara**	0.0083		0.0015	0.0292		0.0070	0.0029		0.0012	0.0134		0.0032
Miscanthus floridulus **Warb**	0.0054	0.0004		0.0292	0.0074		0.0021	0.0008		0.0122	0.0029	
Microstegium vimineum **A.Camus**	0.0345	0.0140	0.0374	0.0146	0.0148	0.0208	0.0060	0.0086	0.0220	0.0184	0.0125	0.0267
Viola verecunda		0.0019	0.0217		0.0296	0.0208		0.0004	0.0122		0.0106	0.0182
Mosla dianthera **Maxim**	0.0068	0.0004	0.0127	0.0219	0.0074	0.0139	0.0031	0.0020	0.0086	0.0106	0.0033	0.0117
Carex doniana **Spreng**	0.0029	0.0083	0.0008	0.0219	0.0296	0.0070	0.0022	0.0067	0.0024	0.0090	0.0149	0.0034
Paederia cavaleriei Levl	0.0011	0.0113		0.0073	0.0296		0.0005	0.0082		0.0030	0.0164	
Viola grypoceras	0.0007	0.0094	0.0270	0.0073	0.0222	0.0139	0.0015	0.0024	0.0208	0.0032	0.0113	0.0205
Arundinella anomala	0.0007	0.0026		0.0073	0.0222		0.0050	0.0079		0.0043	0.0109	
The other belongs to A	0.0638			0.2408			0.0298			0.1115		
The other belongs to B		0.0172			0.1406			0.0199			0.0588	
The other belongs to C			0.0918			0.2568			0.1170			0.1554
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

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Table 6. Species diversity of Moso bamboo community under different level of disturbance

Plant layer	Disturbance intensity	S	D	H	Jsw	Ea
Arbor layer	A	12.6667±1.1547a	0.7309±0.0764a	1.8218±0.1218a	0.7200±0.0718a	0.6397±0.0384ab
	B	10.3333±0.5774a	0.7405±0.0723a	1.7067±0.1874a	0.7326±0.0718a	0.6896±0.0795a
	C	7.3333±1.1547b	0.4917±0.0731b	1.0656±0.1404b	0.5182±0.0619b	0.4991±0.0922b
Shrub layer	A	30.6667±1.5275b	0.9085±0.0199a	2.7475±0.1784a	0.8025±0.0432a	0.6988±0.0255a
	B	35.0000±1.0000a	0.9144±0.0249a	2.8536±0.2179a	0.8026±0.0594a	0.7112±0.0726a
	C	19.0000±2.0000b	0.8669±0.0465a	2.4161±0.2738a	0.8203±0.0689a	0.7268±0.0378a
Herb layer	A	20.6667±0.5774b	0.9031±0.0381a	2.7721±0.3688ab	0.9003±0.1039a	0.8324±0.0244a
	B	21.6667±1.1547b	0.8856±0.0077a	2.5808±0.0380b	0.8523±0.0206a	0.8041±0.0156a
	C	35.3333±0.5774a	0.9299±0.0183a	3.2462±0.2014a	0.9105±0.0522a	0.8443±0.0486a

Table 7. Similarity index values of Moso bamboo forests under various disturbance levels

Disturbance intensity	Arbor layer			Shrub layer			Herb layer		
	A	B	C	A	B	C	A	B	C
A		48.48	41.67		63.74	39.51		58.43	28.85
B	8.00		25.81	29.00		48.78	26.00		49.50
C	5.00	4.00		16.00	20.00		15.00	25.00	

Table 8. Characteristics of soil fertility of Moso bamboo forests under various disturbance levels

Soil layer /cm	Disturbance intensity	Total N /(g·kg $^{-1}$)	Total P /(g·kg-^{1})	Available N /(mg·kg^{-1})	Available P /(mg·kg $^{-1}$)	Organic matter /(g·kg $^{-1}$)
0-20	A	3.2853±0.1305a	0.2720±0.0237b	131.9111±16.8345c	3.1131±0.4310b	45.0171±3.1768a
	B	2.0193±0.1774c	0.3257±0.0434b	166.7556±12.0010b	5.0847±0.6128a	37.9150±1.2532b
	C	2.5841±0.2093b	0.5908±0.0444a	196.7111±7.9211a	5.6271±0.3971a	40.6772±4.9026ab
20-40	A	1.5556±0.2418ab	0.2337±0.0301b	101.3556±10.8239b	2.9561±0.2422c	28.9080±1.6496a
	B	1.4795±0.1031b	0.2576±0.0225b	133.0667±15.1108a	3.7116±0.1964b	27.6943±1.6496a
	C	1.8618±0.1937a	0.3849±0.0336a	152.8000±12.8879a	4.6111±0.5227a	30.5557±1.6679a
40-60	A	1.2227±0.2237ab	0.1914±0.0219b	83.3778±4.3109b	2.7462±0.3129b	22.4756±2.3179a
	B	1.1430±0.0397b	0.2177±0.0183b	104.5333±3.7333a	3.4617±0.5755ab	20.1915±1.4428a
	C	1.5112±0.1513a	0.3054±0.0268a	115.6889±11.1334a	4.2817±0.4881a	23.6487±1.9374a

Table 9 Evaluation on Moso bamboo community stability

Item	Disturbance types		
	Slight disturbance	Medium disturbance	Severe disturbance
Organic matter	1.0000	0.8900	0.9842
Total N	1.0000	0.7655	0.9824
Total P	0.5399	0.6252	1.0000
Available N	0.6807	0.8692	1.0000
Available P	0.6074	0.8447	1.0000
S	0.9552	1.0000	0.9204
D	1.0000	0.9992	0.9000
H	1.0000	0.9136	0.9164
Jsw	1.0000	0.9854	0.9282
Ea	0.9846	1.0000	0.9389
Artificial disturbance	1.0000	0.0000	-1.0000
Subordinate function value	0.8880	0.8084	0.7791

higher where S and H values were at a significance level ($p < 0.05$) while other indexes were not.

3.4 Comparison of Plant Community Similarity in the Bamboo Fields

Plant community similarity was quantified using Sorensen's index and summarized in Table 7, where a higher value indicates a higher similarity. It is clear that human disturbance has shown a great influence on the community similarity within each of the layers, especially within the shrub and herb layers. The similarity decreased with the increase of disturbance intensity. Between different levels of disturbances, species substitution occurred strongly while composition changed gradually, evidenced by the gradual decline of the sun-loving plants and the strong invasion of shade loving plants. All these together reduced the similarity among communities.

3.5 Comparison of Soil Fertility Characteristics in the Bamboo Community

In terms of total P, available N and P, soil fertility follows the order of slight < moderate < severe disturbance, regardless of the soil depth. However, the total nitrogen and content of organic matter showed varied trends but were least in the moderately disturbed bamboo community. In general, the relative fertility distribution among different disturbances remains unchanged with soil depth.

3.6 Comparison of the Stability of *Phyllostachys pubescens* Community

Stability of Moso bamboo community was estimated using the membership function method in fuzzy mathematics. Eleven factors from three types of indices (soil fertility, species diversity and disturbance) were included in the evaluation. The stability result was summarized in Table 9, which showed an obvious decrease from 0.8880 to 0.7791 with increase of disturbance from slight to severe. Indicating that human activities greatly affect the stability of the bamboo plant community, and the near-natural management is beneficial to the stability of the community.

4. Discussion and Conclusion

Species diversity changes are closely related to species habitat, therefore more studies of environmental factors on the effects of species diversity are conducted [47]. However, biological factors, especially human activities, have shown a significant impact on species diversity of plant community [48-50]. Here we demonstrated that increase of human disturbance not only significantly reduces the species diversity in the bamboo forest, but also affects the species composition and distributions of the dominant species. There are most tree layer species and shrub layer species under the slight and moderate disturbances, respectively. While under the severe disturbance, there appear more herb layer species. The number of tree layer species and its change are likely related to the selective removal of arbor species in the process of man's activities (such as leveling of hilltops, reclamation). The number of shrub layer species is related to the competition with the dominant bamboo forest for the light, nutrient and water content, so that part of the shrub species is eliminated and suitable ones developed. Numbers of species in the herb layer seems to benefit from human activities, which improve the growth conditions (space, light, water and fertilizer, etc.) of the herbs under the bamboo forest. All these indicate that persistent human disturbance change the plant community structure, vegetation type, community succession direction. In the bamboo dominated forests, many studies have revealed that bamboo species have been observed to flourish following human disturbances, resulting in a decrease in woody species abundance, richness, diversity, regeneration, and basal area [51-54] through their competitive superiority in terms of the capture of light and other resources [55-62].

In terms of species diversity index (S), H value, D value, Jsw value and Ea value, they decrease with the increase of human disturbance intensity. Consistent with previous findings [37,53,54], the severe disturbance shows obvious negative effect on the species diversity of the bamboo plant community (table 6). However, on the plant layer level, human activities show diverse effects on species diversity. For *Phoebe zhennan* communities, human disturbances such as selective logging and high intensity of tourism activities will have a greatest negative impact on the shrub and herbaceous layers [63]. To the same layers, however, moderate disturbance is found to promote the species diversity for *pinus taiwanensis* communities [64]. In the shrub layer of our bamboo forest, the S and H values are the highest under the moderate disturbance, while in the herb layer, the values are highest under the severe disturbance. The mixed effects on species diversity by human activity may be related to the ecological behaviors of the species at the layer of the plant community, such as their different tolerances to disturbance and the utilized breeding strategies, but on the other hand, it may be related to the length of disturbances and the geographical position of the forest. Surely, human disturbance also affects the similarity and stability of the bamboo plant community. Our results show that the similarity and stability indexes decrease with the increase of human disturbance. Especially under the severe disturbance, plant species replacement

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occurs strongly in the bamboo plant community, and the community stability reduces apparently. Thus, our results may provide guidelines for a sustainable management of bamboo forest.

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