

SHI Juan, LUO Youqing, SONG Jiying, YAN Xiaosu, JIANG Ping, WANG Yijiao

# Impact of the invasion of pinewood nematode and the following different removal disturbance intensities on the plant diversity of Masson pine community

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**Abstract** Reported in this paper are our findings of the study on changes in species diversity of different Masson pine communities after the invasion of *Bursaphelenchus xylophilus* (Steiner and Buhren) Nickle and subsequent and different removal disturbance management approaches. Based on the results, the species diversity indices for the arbor layers of the different communities can be arranged in the following order (from high to low): 1) broad-leaved stand after the removal of all infected pine trees in the pure pine stand in Fuyang; 2) lightly infected Masson pine and *Schima superba* mixed stand in Fuyang; 3) uninfected stand mixture of Masson pine and *Castanopsis fargesii* as a control; 4) lightly infested pure Masson pine stand in Fuyang; 5) *Quercus variabilis* stand formed following the selective removal of infected pine trees from a mixed Masson pine and *Q. variabilis* stand in Zhoushan Islands; 6) pure young Masson pine stand formed following the removal of all infected pine trees from a pure Masson pine stand; 7) pure *Liquidambar formosana* stand after the removal of infected pine trees from a pure pine stand in Zhoushan Islands; 8) a mixed stand consisting of *Pinus thunbergii* and the Masson pine in Zhoushan Island; and 9) moderately infected Masson pine stand in Zhoushan Islands.

All the three diversity indices ( $R_0$  = richness,  $H'$  = Shannon-Wiener index, and  $E$  = evenness) for the shrub layer did not show any significant differences among the various

communities except for the pure pine stand in Zhoushan Island, which had the lowest diversity. The three indices for the herb layer of the pure young Masson pine, *Q. variabilis* stand, and *L. formosana* stand were higher than that of other stands.

The integrated analysis showed that the Masson pine forest in different geographical situations and extent of damage had distinct disparity, just as in different disturbance degrees and restoring manners.

We created the “index of disturbing intensity of stump and fallen woods” (IDISFW) to represent the degree of disturbance of tree removal to plant diversity. We found that the relationship between the species diversity index and the IDISFW shows both a lower and higher degree of removal disturbance that follows the “mid-altitude bulge” theory. Specifically, both excessive and insufficient removal of infected trees will cause a decline of plant species diversity to a certain degree. Covariance analysis indicated that different IDISFW had no significant effects on the species diversity of the arbor layer, but had different impacts on that of the shrub and herb layers, and therefore can be used to assess changes in species diversity of different Masson pine communities after the invasion of pine wood nematode.

**Keywords** *Bursaphelenchus xylophilus* (Steiner and Buhner) Nickle, disturbing intensity of stump and fallen woods, plant diversity, disturbance

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SHI Juan (✉), LUO Youqing, SONG Jiying  
The Key Laboratory for Silviculture and Conservation of Ministry of Education, Beijing 100083, China  
E-mail: shi\_juan@263.net

YAN Xiaosu, JIANG Ping  
Forest Pest Control & Quarantine Station of Zhejiang Province, Hangzhou 310002, China

WANG Yijiao  
Forest Pest Control & Quarantine Station, Dinghai District, Zhoushan 316000, China

## 1 Introduction

With the increasing disturbance from human activity on natural ecosystems, biological invasion has become a question of national concern. Such invasion has changed the original biological geography distribution, structure and function of natural ecosystems, bringing a great impact on the environment (Curnutt, 2000). Since the pine wilt disease was first found in China in 1982, it has become one of the most destructive forest calamities. Once infected by this disease,

the host plant will die in 40 days, and only 3–5 years from occurrence before the destruction of the whole pine forest. Consequently, the pine wilt disease was called “the cancer of pines” (Chai and Jiang, 2003).

The area of pine forest in Zhejiang Province is  $2.57 \times 10^6$  hm<sup>2</sup>, which occupies 49.7% of forested land, and 59.2% of growing stock. The pine tree not only was the main timber species, but also the primary sightseeing resource (Department of Forestry, Anhui Agricultural College, 1980). It was in Xiangshan County where Zhejiang Province officials first discovered the pine wilt disease. In recent years, the damage has extended to  $2.7 \times 10^4$  hm<sup>2</sup>, occupying about 60% of the whole country’s affected area (Chai and Jiang, 2003). Pine wilt disease not only caused economic damage, but also destroyed the environment. As a result, the Forest Pest Control & Quarantine Station of Zhejiang Province adopted disturbance measures such as clearing-cutting and thinning to remove the infected trees and prevent the further spread of pinewood nematode (Jiang et al., 2001). However, human removal of infected trees brought a certain disturbance to the structural variation of forest vegetation. Given the recent study on the relationship between disturbance and vegetation, and the shortage of effective measurement to different disturbance intensity, it is hard to quantitatively analyze the vegetation change after the disturbance (Liu et al., 2002).

In August and October of 2003, while carrying on the overall on-the-spot survey of forest, we found varying degrees of damage to Masson pine forests across different forest types, species constitution, altitude, gradient and slope direction. Measures such as the human removal of infected trees and allowing them to naturally restore and regenerate were also taken. The formed forest type has continued to change significantly. Considering all the above, the paper considered the infected *Pinus massoniana* community after taking the different removal disturbance measures as the research objective and comparing the variation discipline of plant diversity of the Masson pine community in different restoration phases after the attack. Through the “index of disturbing intensity of stump and fallen woods” (IDISFW), further research was conducted on the variation discipline of plant diversity of the Masson pine community in different infecting phases under different disturbing intensities.

## 2 Research area and methods

### 2.1 Natural general situation

The research area is located at Fuyang and Zhoushan cities of Zhejiang Province. Fuyang city, which is situated northwest of the province, comprises part of 17 towns and 8 counties with an area of 1,830 km<sup>2</sup> (29°44′–30°12′ N, 119°25′–120°09′ E). The area is exposed to invasion of north cold wind and is a section with a rather lower temperature in winter. The city also has a subtropical monsoon

climate with sufficient sunlight, moderate temperature, superior natural conditions and rich soil. The mean annual precipitation is above 1,400 mm. The main vegetation is formed with *P. massoniana*, *Quercus* sp. and *Castanopsis sclerophylla*, accompanied by *Schima superba*, *Cinnamomum chekiangensis* and *Ilex purpurea*, etc.

Zhoushan city, which belongs to a hill physiognomy located in the shore islands of Zhejiang, comprises part of 98 islands, with an area of 22,200 km<sup>2</sup> (29°32′–31°04′ N, 121°30′–123°25′ E). The area has a northern subtropical monsoon ocean climate with high air temperatures and abundant heat. The mean annual precipitation and relative humidity is about 1,500 mm and above 80%, respectively. The forest vegetation is much different from that inland. There are *P. massoniana* and *P. thunbergii* forests on hilly country, most of which have low growth because of the strong winds on the island (Regionalization Office of Forestry Department in Zhejiang Province, 1991).

### 2.2 Research method

#### 2.2.1 Field investigation

In August and October of 2003, based upon the most consistent principle of site conditions and environmental factors, we set nine sample plots of 30 m × 30 m in size in Fuyang and Zhoushan. The Masson pines in the plots all originated from manual afforestation at the end of the 60th year or the beginning of 70th year in the 20th century. Moreover, except for the control group, the other plots applied the removal measures in 1997 after the attacks of 1996; the damage and management situation are listed in Table 1.

To obtain data from the arbor, shrub and herbage, we use the fundamental methods of investigating each individual tree and the quadrant method. According to the sampling plot of 5 m × 5 m, the diameter at breast height (including basal diameter of stump), height and crown width of the trees were measured, and the name of each tree species was individually labeled. For every plot, 25 sampling plots of shrub and herbage with 2 m × 2 m size was investigated, and the indices of species, number, cover degree, average height and growth situation, and the environmental factors of geographical position, altitude, gradient and slope direction were recorded (Department of Forestry, Anhui Agricultural College, 1980).

#### 2.2.2 Species diversity index

The richness degree index:  $R_0 = S$ . The species diversity index (Shannon-Wiener index):  $H' = -\sum_{i=1}^s \frac{N_i}{N} \ln\left(\frac{N_i}{N}\right)$ . The evenness index:  $E = \frac{H'}{\ln S}$ . In the formulas,  $S$  is the species sum of sampling plots in every standard site,  $N$  is the sum of all the importance values of  $S$  species, and  $N_i$  is the

**Table 1** General condition of standard sites

Sample site No.	Community type	Place	Situation of damage and management on <i>P. massoniana</i>	Altitude /m	Gradient /°	Slope direction	Crown density
1	<i>P. massoniana</i> pure forest	Fuyang	Slight damage	98	22	SW	0.9
2	<i>Quercus fabric</i> forest	Fuyang	<sup>1)</sup>	107	17	NW	1.0
3	Young <i>P. massoniana</i> pure forest	Fuyang	<sup>2)</sup>	86	16	NE	0.3
4	<i>P. massoniana</i> & <i>S. superba</i> mixed forest	Fuyang	Slight damage	117	30	S	0.8
5	<i>Q. variables</i> forest	Zhoushan	<sup>3)</sup>	59	27	NW	0.81
6	<i>Liquidambar formosana</i> forest	Zhoushan	<sup>4)</sup>	90	7	SW	0.3
7	<i>P. massoniana</i> pure forest	Zhoushan	Medium damage	36	17	NE	0.4
8	Mixed <i>P. thunbergii</i> and <i>P. massoniana</i> forest	Zhoushan	Selected cutting the damaged trees in 1997	24	23	SW	0.3
CK	<i>P. massoniana</i> & <i>Castanopsis fargesii</i> mixed forest	Fuyang	No damage	131	28	SE	0.75

<sup>1)</sup> *P. massoniana* pure forest—Clear cutting in 1997—Broad-leaved forest; <sup>2)</sup> *P. massoniana* pure forest—Clear cutting in 1997—Young *P. massoniana* pure forest; <sup>3)</sup> *P. massoniana* and broadleaf tree mixed forest—Selected cutting in 1997—Broad-leaved forest; <sup>4)</sup> *P. massoniana* pure forest—Selected cutting in 1997—Broad-leaved forest

importance value of *i*th species. The above formulae and *S* are used to measure species diversity.

### 2.2.3 The establishment of “index of disturbing intensity of stump and fallen woods”

Because the Masson pine of plots 1–8 were all formed after the pinewood nematode (PWN) damage of 1996 and 1997, and considering the stumps left by removal measures and fallen wood that died naturally after the Masson pine attacks, continuous removal in the main community has included the two species through natural removal and falling from a natural disturbance. Additionally, in practical production when fostering and thinning the plantation, the percentage of the original forest total number with cutting wood number each time is often taken to represent the cutting intensity (Deng et al., 1995; Hu, 1998). According to these, an “index of disturbing intensity of stump and fallen woods” (IDISFW) was created, defined as the percentage of the original forest total number with the number of stumps and fallen woods in the community. The index represents the disturbance degree of the community which suffered from the “removal of affected wood” and “the falling down of withered stumpage”, with the formula

$$\text{IDISFW} = \frac{n_s + n_f}{N} \times 100\%$$

where IDISFW represents the “index of disturbing intensity of stump and fallen woods”;  $n_s$  is the stump number in the community;  $n_f$  is the fallen wood number in the community; and  $N$  is the total number in original forest stand.

### 2.2.4 The effect check of “index of disturbing intensity of stump and fallen woods”

Using the IDISFW as the control variant and the crown density as the covariate, the covariance analysis of richness, species diversity and evenness indices on arbor, shrub and herb layers were carried on.

## 3 Results and analysis

### 3.1 The plant community appearance and vertical structure in different sample plots

Plot 1: dominant species in the arbor layer were *P. massoniana*. Dominant species in the shrub layer were *Phyllostachys nidularia*, *Loropetalum chinensis*, *Eurya hebeclados*, etc. Main species in the herb layer were *Dicranopteris dichotoma*. Concomitant lianas include *Smilax china* and *Millettia dielsiana*.

Plot 2: the original stand was pure Masson pine forest, and later a broadleaved one (Masson pine has been clear-cut after the damage). Dominant species in the arbor layer include *Q. fabric* and *Castanopsis sclerophylla*. Dominant species in the shrub layer were *Pleioblastus amarus*, *Q. fabric* and *C. sclerophylla*. Main species in the herb layer were *D. dichotoma*. Concomitant lianas include *S. china* and *M. dielsiana*.

Plot 3: the original stand was pure Masson pine forest; after natural regeneration and removal, the dominant species in the arbor layer became practically renewed young *P. massoniana*. Dominant species in the shrub layer were *Q. glandulifera* var. *brevipetiolata*, *Gardenia jasminoides* and *L. chinensis*. Main species in the herb layer were *D. dichotoma*, *Carex doniana*, *Calamagrostis epigejos* and *Lophatherum gracile*. Concomitant lianas include *S. china* and *Rosa laevigata*.

Plot 4: dominant species in the arbor layer include *P. massoniana* and *S. superba*. Dominant species in the shrub layer were *S. superba*, *C. sclerophylla* and *Q. glandulifera* var. *brevipetiolata*. Main species in the herb layer were *Dicranopteris dichotoma*. Concomitant lianas include *S. china*, *S. nervo-marginata* and *M. dielsiana*.

Plot 5: the original stand was *P. massoniana* and *Q. variables* mixed forest. After the damage and thinning, it regenerated naturally into a *Q. variables* broad-leaved

forest, and Masson pine featuring fallen wood and stumps. Dominant species in the arbor layer were *Q. variables* and *I. purpurea*. Dominant species in the shrub layer were *Callicarpa pedunculata*, *Eurya muricata* and *I. purpurea*. Main species in the herb layer were *Dryopteris atrata*, *D. dichotoma*, *Farfugium japonicum* and *Imperata cylindrical* var. *major*. Concomitant lianas include *S. china*, *Millettia reticulata* and *Gardneria multiflora*.

Plot 6: the original stand was pure *P. massoniana* forest. After the damage and thinning, it regenerated naturally into a sparse forest. Many of the Masson pines featured stumps, fallen wood and withered stumpage. Dominant renewed species in the arbor layer were *Liquidambar formosana*. Dominant species in the shrub layer were *Q. fabric*, *Camellia oleifera* and *Cunninghamia lanceolata*, etc. Main species in the herb layer were *D. dichotoma*, *I. cylindrical* var. *major* and *Woodwardia japonica*. Concomitant liana includes *S. china*.

Plot 7: dominant species in the arbor layer was *P. massoniana*. Dominant species in the shrub layer were *Q. fabric*, *L. chinensis* and young Masson pine. Main species in the herb layer were *I. cylindrical* var. *major*. Concomitant lianas include *S. china*.

Plot 8: dominant species in the arbor layer were *P. massoniana* and *P. thunbergii*. Dominant species in the shrub layer were *I. purpurea*, *Eurya japonica* and *L. chinensis*. Main species in the herb layer were *D. dichotoma*. Concomitant liana includes *S. china*.

Plot 9 (Control): dominant species in the arbor layer were *P. massoniana* and *Castanopsis fargesii*. Dominant species in the shrub layer were *Pistacia chinensis* and *L. chinensis*. Main species in the herb layer were *D. dichotoma*.

### 3.2 The species diversity of Masson pine community in different infecting phases

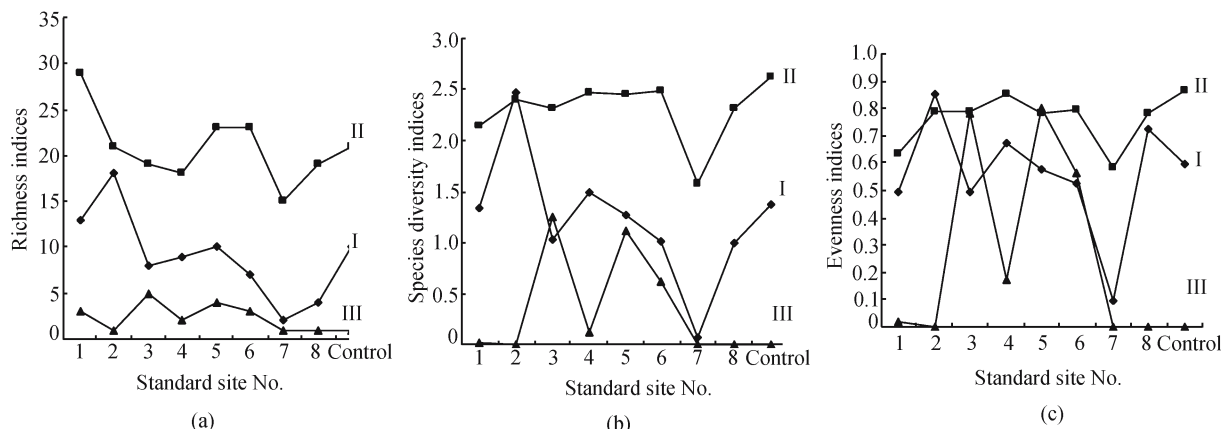
#### 3.2.1 The arbor layer

From Fig. 1, we can see that except for evenness indices, the changing trend of richness, species diversity indices of arbor

layer are almost the same. The species diversity indices for the arbor layers of the nine Masson pine communities can be arranged in the following orders (from high to low): 1) sample plot 2; 2) sample plot 4; 3) control; 4) sample plot 1; 5) sample plot 5; 6) sample plot 3; 7) sample plot 6; 8) sample plot 8; 9) sample plot 7. According to the community type, the order is 1) broad-leaved stand after the removal of all infected pine trees in the pure pine stand in Fuyang; 2) lightly infected Masson pine and *Schima superba* mixed stand in Fuyang; 3) uninfected stand mixture of Masson pine and *Castanopsis fargesii* as a control; 4) lightly infested pure Masson pine stand in Fuyang; 5) *Quercus variables* stand formed following selective removal of infected pine trees from a mixed Masson pine and *Q. variables* stand in Zhoushan Islands; 6) pure young Masson pine stand formed following the removal of all infected pine trees from a pure Masson pine stand; 7) pure *Liquidambar formosana* stand after the removal of infected pine trees from a pure pine stand in Zhoushan Islands; 8) a mixed stand of *Pinus thunbergii* and the Masson pine in Zhoushan Island; and 9) moderately infected Masson pine stand in Zhoushan Islands.

Compared with the control, sample plots 1 and 4 were all lightly (nearly zero) attacked by the PWN, and the disturbance from PWN damage and human removal were all rather minimal. The richness and species diversity indices are rather higher, but because sample plot 4 is Masson pine and *S. superba* mixed stand, diversity is higher than the pure Masson pine forest of sample plot 1.

Sample plot 2 is a *Q. fabric* broad-leaved stand after the damage and clear-cutting of pure Masson pine forest, and sample plot 5 is a *Q. variables* forest that originated from thinning 3/5 of infected trees in *P. massoniana* and *Q. variables* mixed forest in 1997. Some experts think that the mono-dominant and pioneer community of Masson pine is instable, but will finally succeed to the stable community of Masson pine and broad-leaved mixed stand and broad-leaved forest (Zan et al., 2000; Yang et al., 2003). The field investigation showed that sample plots 2 and 5 are in the higher succession phase, with rather higher richness and species diversity indices. The species structure of sample plot 2 is



**Fig. 1** Change of richness (a), species diversity (b) and evenness (c) indices of the arbor (I), shrub (II) and herb (III) layers of different plant communities

very abundant, while the diversity indices also reached the peak value for distribution in the north facing slope with better soil and water conditions. From the above, we can see that after the damage if the restored and formed forest is a broad-leaved one, community plant diversity will increase.

Sample plot 7 is the most damaged Masson pine forest at present, with major disturbance caused by the PWN. Additionally, it is located in the Zhoushan Island, which has the worst growth of Masson pine with a high number of “small-old pines”. Consequently, the richness and species diversity indices are the lowest. Sample plots 1–4 are all located in Fuyang, belonging to the inland area. Sample plots 5–8 are all located in Zhoushan, belonging to the island, and the idioplasmatic resource and vegetation species are all fewer than that in inland area. Thus, the richness and species diversity indices in sample plots 5–8 are generally lower than those of sample plots 1–4.

Sample plots 2 and 3 are all located in the inland area, which all originated from the pure Masson pine forest after clear-cutting, while water and fertilizer conditions in sample plot 2 are better, which has succeeded to a *Q. fabric* broad-leaved stand. The eco-niche of Masson pine has been occupied by broad-leaved trees and dominant shrub—*P. amarus*, but sample plot 3 is in the flat upland on a transverse section with barren soil. The pioneer tree species of Masson pine often formed the pure forest, and after an eight-year restoration, the Masson pine young trees of second generation have formed a mono-dominant population. At this time, the stand is still not entirely covered, and the shade-tolerant broad-leaved trees have not been permanently planted, so the diversity indices are rather lower in sample plot 3. From the above, we can see that after the damage, if the restored and formed forest is the second generation Masson pine, community plant diversity will decrease.

Given all the data above, nine sample plots were divided into the following three types: different geographical situation (inland and island), different forest type (Masson pine pure forest and mixed forest) and different restored forest type (after damage and restoration into the second generation Masson pine and broad-leaved forest). Applying one-factor variance analysis on the species diversity index of the arbor layer, the following results are obtained. Masson pine forest inland and island:  $F = 5.602^*$ ,  $F_{0.05}(1,7) = 5.59$ ; Masson pine pure forest and mixed forest:  $F = 6.046^*$ ,  $F_{0.05}(1,6) = 5.99$ ; The second generation Masson pine and broad-leaved forest after damage and restoration:  $F = 7.765^*$ ,  $F_{0.05}(1,4) = 7.71$ . These results show that the plant diversity of the Masson pine forest in different geographical situations and forest types had distinct disparities; similar to that in different restored forest types after damage.

### 3.2.2 The shrub layer

From Fig. 1, we can see that the three diversity indices showed almost similar variety. All the three diversity indices for sample plot 7 were the lowest, which did not show any

significant differences among the other plots and were all lower than the control. Thus, regardless of the extent of harm from pine wood nematode, the diversity indices for the shrub layer in Masson pine community after the invasion all decreased to some extent. The diversity indices for sample plot 7 was attributed to the fact that the Masson pine community had barren soil and faced to the south, where only the pioneer tree species—Masson pine can survive, making the species of the shrub and herb layer the lowest one.

### 3.2.3 The herb layer

From Fig. 1, we can see that all the three diversity indices for sample plots 3 and 7 were rather higher, which was related to their small crown density. Sample plot 3 was a second generation Masson pine stand formed following the removal of all infected pine trees from a pure Masson pine stand, which belong to a young Masson pine stand, where the height many young trees is less than 3 m. Sample plot 6 was a broad-leaved stand after the removal of infected pine trees from a pure and damaged pine stand, where surviving Masson pine featured withered stumpages and stumps, and have lost dominant status. On the other hand, the concomitant tree species—*L. formosana*—was derived from the shrub or subarbor layer after the removal of infected pines, where the present stand has not wholly closed. Consequently, sample plots 3 and 6 featured sparse forests and had abundant sunlight, leading to rather higher richness and species diversity indices of the herb layer. The three indices in sample plot 5 are also rather higher; the land offered alkaline soil and good water and fertilizer conditions, enabling a favorable growth situation for the indication plants—*D. dichotoma* and *F. japonicum*.

## 3.3 The impact of removal disturbance on the species diversity

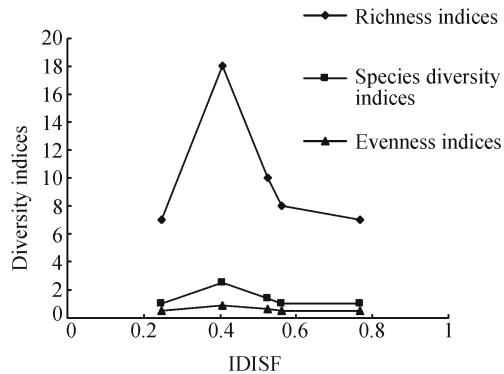
### 3.3.1 The establishment of Masson pine community type in different infecting phases

Using the extent of damage and harm by the PWN as basis, Masson pine was divided into five types: healthy wood, feeble wood, withered stumpages and stumps. The Masson pine number of five types in eight sample plots was computed respectively, with the dominant type regarded as the infecting phase of Masson pine in sample plots. Based on this method, the eight sample plots were divided into five phases: healthy wood, feeble wood, withered stumpages, stumps and second-generation Masson pine.

### 3.3.2 Species diversity in different intensities of stump and fallen woods

Given the eight communities belonging to five infecting phases, and according to the different infecting phase types, figures of the changes of diversity indices (richness index,

species diversity index and evenness index) with the IDISFW index of the arbor layers of different communities were established (Fig. 2).



**Fig. 2** Change of diversity indices according to the IDISF index of arbor layers of different communities in different damage phase

From a general analysis in Fig. 2, with the species indices of arbor layer as an example, we can see that the species diversity indices according to the IDISFW index will first increase and then decrease. Thus, for a lower or higher intensity of stump and fallen woods, the community diversity indices were rather lower; for a middle intensity of stump and fallen woods, the community diversity indices were rather higher, in accord with the mid-altitude bulge theory provided by Gentry (1988). That study noted that with moderate disturbance, ecosystems have higher species diversity. Under the disturbance function with lower and higher frequency, the species diversity of an ecosystem keeps decreasing. For a habitat subjected to uninterrupted disturbance, some new or invasive species that had not completed growth will eventually be affected by the disturbance. Consequently,

higher species diversity is maintained in the community when the new dominant species have not completely formed. Under the disturbance condition with lower frequency, some dominant species will grow in small spurts for the long-term stable development of the ecosystem, with some inferior species gradually washed out and making species diversity decrease (Chen et al., 2004; Miao et al., 2004). Kleyer's (1999) research also showed that the diversity of plant group (function type) possessed with the similar biological characteristics reached the highest when in "middle disturbance" intensity.

### 3.3.3 The effect check of intensity index of stump and fallen woods

Covariance analysis showed that the different removal disturbance measures imposed on the community will produce a major and distinct effect on the evenness indices of herb layers (namely the frequency of the herb species in each spot of the community), a distinct effect on the species diversity indices of the herb layer (the result not shown) and evenness indices of the shrub layer (Table 2).

The different crown densities produce a distinct effect on the species diversity of arbor layer (Table 3). The species diversity index  $H'$  reflects the disturbance characteristic among species of the species number and individuals included in the arbor layer, while the value of crown density depended on the cover degree of arbor layer crown.

Generally speaking, different disturbance degrees will produce a distinct impact on the species indices of the shrub and herb layers, but will not affect the species index of the arbor layer. Different crown densities only produce the distinct impact on the species indices of the arbor layer. Therefore, the established IDISFW can be used to assess changes in species diversity of different Masson pine

**Table 2** Covariance analysis of evenness indices of different layers and the disturbing intensity of stump and fallen woods using the crown density as the covariate

Layer	Error source	Sum of squares	df	Mean square	F value	Significance
Herb	Model	0.870	3	0.290	25.184	0.005**
	Crown density	0.007,49	1	0.007,49	0.650	0.465
	IDISFW	0.809	2	0.405	35.139	0.003**
Shrub	Error	0.046,1	4	0.011,5		
	Model	0.057,6	3	0.019,2	6.878	0.047*
	Crown density	0.018,9	1	0.018,9	6.774	0.060
	IDISFW	0.050,6	2	0.025,3	9.062	0.033*
	Error	0.011,2	4	0.002,79		

**Table 3** Covariance analysis of species diversity indices of arbor layers and the disturbing intensity of stump and fallen woods using the crown density as the covariate

Error source	Sum of squares	df	Mean square	F value	Significance
Model	2.596	3	0.865	6.726	0.048*
Crown density	1.798	1	1.798	13.978	0.020*
IDISFW	1.020	2	0.510	3.965	0.112
Error	0.515	4	0.129		

communities after the invasion of pine wood nematode, and the effect is remarkable.

## 4 Discussion

After PWN invaded Masson pine forest, if the formed community after resilience tends to be mixed or broad-leaved forest, the species diversity in the forest would increase. On the contrary, if the formed community after resilience succeeded conversely to become the second generation's young Masson pine forest, the species diversity in the forest would decline. Wang and Duan (2003) studied the restoration effects of some typical natural vegetation in middle Yunnan area, and found that the restoration of plant diversity centered in the "pioneer" situation on realizing the ecosystem's function. Under most conditions, the augmentation of plant diversity can also induce a decreasing population number of some pests (Hou and Sheng, 1999). Other research also showed that compared with the pure forest, the mixed forest could more easily prevent/deter/be shielded from insect pests and diseases, increase the stand productivity and wood output, and improve the soil condition and fertility (Li et al., 2004). To prevent the degradation of plantation soil, we can increase the forest transparency and reduce the stand crown density through thinning measures, which not only will increase the shrub and herb species under the forest, but also accordingly advance each species' height, cover degree and numbers, and finally boost the soil fertility (Sheng and Yang, 1997).

Consequently, when the undamaged but overly dense or newly damaged pine forests are concerned, moderated thinning should be applied. After that, the formed forest type can maintain rather high species diversity and enhance the resistance of pine forests to PWN. However, for a seriously damaged pine forest, measures such as removing the affected trees and supplementing a certain number of broadleaf trees could also be taken—this transforms the forest into a mixed one, which not only maintains the stability of the community structure and function, but also increases the pine forest resistance.

It has been reported that resistance was a direct anti-disturbance ability of the ecosystem on environment, but resilience referred to the ability of restoring the original state of the system after a disturbance (Holling, 1973; Ma, 1990). The above two concepts quantitatively described the anti-disturbance ability of the ecosystem on environment. As for the invasion of PWN, some pine forests immediately showed their resistance ability. Other forest ecosystems could not directly resist the pathogen. However, when subjected to self adjustment and human disturbance measures, if the forest can be restored to a moderate type and maintain some pine trees, this would embody a resistance ability of the pine forest ecosystem to the invasion of PWN.

When PWN invades the pine forest, both excessive and insufficient removal of infected trees will cause a decline of plant species diversity to a certain degree. Moderate human disturbance will maintain or promote the natural regeneration

and plant species diversity in thin Masson pine forests. The augment of community species diversity is a kind of benign reaction of the ecosystem to foreign disturbance, which could be a response to the environmental change. If the foreign disturbance exceeded the self-adjusting ability of the system, then the community will succeed conversely to become a forest that is difficult to restore (Kong and Mo, 2002; Odum, 1969). Thus, taking only the moderating disturbance measures will maintain higher species diversity of Masson pine forest and the stability of the community structure and function.

## 5 Conclusions

1) Evaluation of plant diversity of formed different community types after the invasion of PWN on Masson pine forest and removal of affected trees showed that diversity of the Masson pine forest in different geographical situations and forest type had a distinct disparity, similar to results for different restored forest types after damage. The Masson pine mixed with broad-leaved forest is higher than the pure Masson pine one, the inland Masson pine forest is higher than the island Masson pine one, and after removal, the formed broad-leaved forest is higher than the regenerated second generation Masson pine one.

2) The "index of disturbing intensity of stump and fallen woods" (IDISFW) was created to represent the degree of disturbance of tree removal to plant diversity. Given a specific harmed stand, the species diversity obeyed the principle of "mid-altitude bulge" as the change of IDISFW. Specifically, both excessive and insufficient removal of infected trees will cause a decline of plant species diversity to a certain degree. For moderate disturbance intensity, the community species diversity is rather higher. Covariance analysis of IDISFW indicated that different IDISFW had different impacts on the species diversity of the shrub and herb layers in community, and therefore can be used to assess changes in species diversity of different Masson pine communities after the invasion of pine wood nematode.

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## References

- Chai X M, Jiang P (2003). The Breakout and Control of Pine Wilt Disease. Beijing: China Agricultural Press, 3–7 (in Chinese)
- Chen R, Hong W, Wu C Z (2004). Analysis of the evergreen broad-leaf forest through the change of elevation gradient in the north of Fujian. *J Fujian Coll For*, 24(1): 12–16 (in Chinese)
- Curnutt J L (2000). Host-area specific climatic-matching: Similarity breeds exotics. *Biol Conserv*, 94: 341–351

- Deng S J, Zhang J W, Chen C Y (1995). Effect of thinning intensity on the growth of *Cunninghamia lanceolata* and *Michelia maclurei* mixed forests. *Chin J Appl Ecol*, 6(3): 231–236 (in Chinese)
- Department of Forestry, Anhui Agricultural College (1980). *Masson Pine*. Beijing: China Forestry Publishing House, 1–20 (in Chinese)
- Ge F (2002). *Modern Ecology*. Beijing: Science Press, 244 (in Chinese)
- Gentry A H (1988). Changes in plant community diversity and floristic composition on environmental and geographical gradients. *Ann Missouri Bot Gard*, 75: 1–34
- Holling C S (1973). Resilience and stability of ecological systems. *Ann Rev Ecol Syst*, 4: 1–24
- Hou M L, Sheng C F (1999). Effect of plant diversity in agroecosystems on insect pest populations. *Chin J Appl Ecol*, 10(2): 245–250 (in Chinese)
- Hu J W (1998). The confirming of tending thinning intensity. *For Eng*, 14(1): 4–6 (in Chinese)
- Jiang P, Zhao J N, Chai X M (2001). Integrated control techniques of *Bursaphelenchus xylophilus*. *J Zhejiang For Sci Technol*, 21(4): 1–6 (in Chinese)
- Kleyer M (1999). Distribution of plant functional types along gradients of disturbance intensity and resource supply in an agricultural landscape. *J Veget Sci*, 10: 697–708
- Kong G H, Mo J M (2002). Population dynamics of a human-impacted Masson pine plantation in Dinghushan. *J Trop Subtrop Bot*, 10(3): 193–200 (in Chinese)
- Li J Y, Zeng X H, Wu G (2004). The regeneration and reconstruct of pure Masson pine forest. *Trop For*, 32(3): 39–40 (in Chinese)
- Liu Z M, Zhao X Y, Liu X M (2002). Relationship between disturbance and vegetation. *Acta Pratac Sin*, 11(4): 1–9 (in Chinese)
- Ma S J (1990). *The Perspective of Modern Ecology*. Beijing: Science Press, 54 (in Chinese)
- Miao L Y, Wang X A, Wang Z G (2004). Relationships between species diversity indices of *Larix chinensis* communities and environmental factors. *Acta Bot Boreal-Occident Sin*, 24(10): 1,888–1,894 (in Chinese)
- Odum E P (1969). The strategy of ecosystem development. *Science*, 164: 262–270
- Regionalization Office of Forestry Department in Zhejiang Province (1991). *Zhejiang Forestry Regionalization*. Beijing: China Forestry Press (in Chinese)
- Sheng W T, Yang C D (1997). Research on effect of ameliorating soil properties by undergrowth vegetation of Chinese fir. *Acta Ecol Sin*, 17(4): 377–385 (in Chinese)
- Wang Z H, Duan C Q (2003). Ecological restoration effects of typical manmade ecosystems and relationships between restoration variables in middle Yunnan area. *Chin J Appl Ecol*, 14(9): 1,439–1,445 (in Chinese)
- Yang Q P, Li M G, Wang B S (2003). Dynamics of biomass and net primary productivity in succession of south subtropical forests in southwest Guangdong. *Chin J Appl Ecol*, 14(12): 2,136–2,140 (in Chinese)
- Zan Q J, Li M G, Wang B S (2000). Dynamics of community structure in successional process of needle and broad-leaved mixed forest in Heishiding of Guangdong. *Chin J Appl Ecol*, 11(1): 1–4 (in Chinese)