Botanical Sciences 91 (4): 505-513, 2013

Functional diversity and conservation of *Phellodendron amurense* communities in the Dongling Mountain of Beijing, China

Jin-Tun Zhang[1,4], Bin Zhang[1], Min Li[2] and Xunzhi Zhu[3]

[1]College of Life Sciences, Beijing Normal University, Beijing, China
[2]Institute of Loess Plateau, Shanxi University, Taiyuan, China
[3]School of Biology and Chemical Engineering, Jiangsu University of Science and Technology, Zhenjiang, China
[4]Corresponding author: zhangjt@bnu.edu.cn

Abstract: Functional diversity is important to ecological processes and functioning of plant communities. The interaction of functional diversity with environmental variables in *Phellodendron amurense* (an endangered species) communities in the Dongling Mountain was analyzed. Twenty-five 10 m × 20 m-plots were established in *P. amurense* communities and species composition, traits and environmental variables were measured and recorded. A new index based on Self-Organized Feature Map theory (SOFM index) for measuring functional diversity was introduced, and other six common indices were used in the analysis of functional diversity. The results showed that Self-Organized Feature Map index was an effective method in functional diversity studies. Functional diversity in *P. amurense* communities varied greatly; functional diversity increased linearly with elevation; it was negatively correlated with aspect, litter and slope position, and positively correlated with species richness. Functional diversity showed significant, negative effects on the importance values of *P. amurense*, which suggested that functional diversity should be maintained in a suitable extent for conservation purpose.
Key words: conservation, environmental variable, functional distance, functional diversity, functional traits, species diversity.

Resumen: La diversidad funcional es importante para los procesos ecológicos y el funcionamiento de las comunidades vegetales. Se analizó la interacción de la diversidad funcional con las variables ambientales en comunidades de *Phellodendron amurense*, una especie en peligro de extinción, de la montaña Dongling en China. Se establecieron 25 parcelas de 10 m × 20 m en las comunidades de *P. amurense*, se midieron y registraron la composición de especies, los rasgos y las variables ambientales. Se empleó un nuevo índice basado en la teoría del mapa de características autorganizadas, así como otros seis índices generalmente usados en el análisis de la diversidad funcional. Los resultados mostraron que el índice del mapa de características autorganizadas fue un método eficaz en estudios de diversidad funcional. La diversidad funcional en comunidades de *P. amurense* resultó muy variable, se incrementó linealmente con la altitud y se correlacionó negativamente con el aspecto, el mantillo y la posición de la pendiente, pero positivamente con la riqueza de especies. La diversidad funcional mostró efectos negativos para los valores de importancia de *P. amurense*, lo que sugiere que la diversidad funcional se debe mantener en un nivel adecuado con propósitos de conservación.
Palabras clave: características funcionales, conservación, distancia funcional, diversidad de especies, diversidad funcional, variables ambientales.

Functional diversity refers to the value and scope of species functional traits in a plant community (Díaz *et al.*, 2007; de Bello, 2012). This concept emphasizes differences of functions among species in ecosystems, and it is related to ecosystem processes and functioning (Tilman *et al.*, 2001; Petchey and Gaston, 2002). Therefore, it is relevant to conservation of endangered species and their communities (Zhang *et al.*, 2012a). Study on functional diversity becomes a hotspot in plant ecology in the last two decades (Villéger *et al.*, 2008).

Recently, methods for measuring functional diversity based on species traits have attracted much attention, and there are several techniques available for quantifying functional diversity of communities (Suding *et al.*, 2008; Laliberté and Legendre, 2010). These methods differ in mathematical properties, the features they capture, their emphasis on location or dispersion measures, the consideration of single or multiple traits and the inclusion of abundances of the trait values. Casanoves *et al*. (2011) developed a software (FDivesity) for these methods. However, the insufficient effective methods for measuring functional diversity are still limits in practical studies (Casanoves *et al*., 2011; de Bello, 2012). The Self-Organizing Feature Map (SOFM) is one of the best-known neural networks with unsupervised learning rules (Chon, 1996; Giraudel and Lek, 2001; Zhang *et al*., 2010), and it performs a topology-preserving projection of the data space onto a regular two-dimensional space. SOFM has been successfully used in classification and ordination of plant communities (Zhang *et al*., 2008; 2010). Because of its theoretical advantages, the application of Self-Organizing Feature Map to functional diversity analysis is expectant.

Phellodendron amurense is an endangered and national-protected species in China, and its geographical range is extremely limited. This tree species became endangered due to heavily disturbance of its habitat for economical uses in industry and medicine (Zhang *et al*., 2009). The conservation for this species is urgent. The change of functional diversity and its related factors may be important in the conservation of *P. amurense* population and communities (Petchey and Gaston, 2002). Patterns of change of plant diversity provide the basis of conservation of natural reserves and have been studied many times in ecology (Muhumuza and Byarugaba, 2009). Changes in species diversity along altitudinal gradients have been the subject of numerous studies (Lomolino, 2001; Austrheim, 2002; Fetene *et al*., 2006) and most of them found a “humped” distribution pattern; i.e. the greatest species diversity appeared near the middle of the gradient (Austrheim, 2002). Conversely, the patterns of change of functional diversity along such gradients have not been sufficiently studied (Zhang *et al*., 2012b).

The aims of this study were: (1) to apply a new method for measuring functional diversity, namely the SOFM index, to quantify functional diversity of plant communities; (2) to assess the pattern of change of functional diversity of *Phellodendron amurense* communities along an elevation gradient; (3) to analyze the relationships between functional diversity and conservation of endangered species.

Materials and methods

Study site. The study site lies within the main distribution area of *Phellodendron amurense* communities in the Dongling mountain of Beijing, China. The Dongling mountain is located at 115º 26’ - 115º 40’ E, 40º 00’ - 40º 05’ N, it is an extension of the Xiaowutai Mountain Range, and it belongs to the broader Taihang Mountain Range (Figure 1). This area has a typical warm temperate continental monsoon climate with an average annual precipitation of 500-

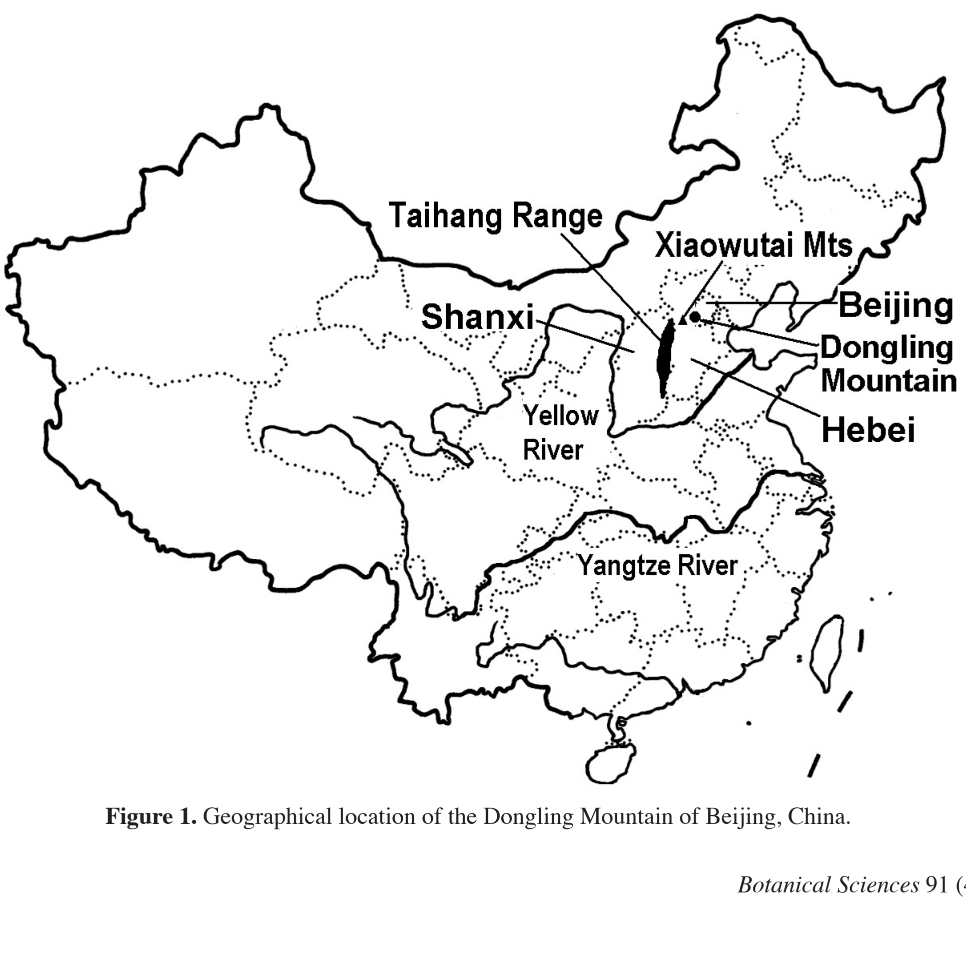

Figure 1. Geographical location of the Dongling Mountain of Beijing, China.

650 mm. Annual mean temperature is 7 °C, with the monthly mean temperatures of January and July being -7.8 °C and 21.1 °C, respectively. Elevation varies from 800 m to 2,301 m. Several soil types, such as cinnamon soil, mountain cinnamon soil, brown forest soil and mountain meadow soil can be found in this mountain (Huo, 1989). Vegetation mainly includes secondary scrublands from 800 m to 1,200 m, secondary forests from 1,000 to 1,800 m, and mountain meadows from 1,600 to the mountain summit. This study mainly concerned the area from 950 m to 1,300 m where *P. amurense* and its communities occur.

Sampling.Through a comprehensive survey, twentyfive communities or patches of *Phellodendron amurense* forest were located in the study area. One standard plot in each community or patch was set up and totally there were twenty-five sampling plots of *P. amurense* communities. Species data were recorded in each plot. The plot size was 10 m × 20 m, in which three 5 m × 5 m and three 2 m × 2 m small quadrats were used to record shrubs and herbs, respectively. Species name, cover, height, basal area and individual abundance for tree species, and name, cover, abundance and height for shrubs and herbs were recorded in each plot (Zhang *et al*., 2008). Plant heights were measured by using a height-meter (CHM6000, Huajingshun Co.) for trees and shrubs over 2 m, and using a steel tape ruler for saplings for shrubs under 2 m, and herbs. The basal diameter of trees was measured by using a caliper and was used to calculate the basal area. A total of 105 plant species were recorded in the 25 plots.

Nine functional traits were selected to illustrate plant species functions in the community (Table 1) (Zhang *et al*., 2012a). Photosynthetic pathway, seed dispersal, pollination syndrome, and nitrogen-fixing capacity were identified from a local flora (He, 1992), whilst life-form and growth type, leaf shape, plant height, starting flowering date, and flowering period length were observed and measured *in situ*. To calculate functional diversity, a data matrix of functional traits × species in a plot was constructed, and there were in total 25 data matrices for 25 plots. All functional traits data were standardized before calculation of functional diversity to avoid scale effects (Casanoves *et al*., 2011).

Elevation, slope, aspect, slope position, litter thickness, and soil depth for each plot were also recorded. Elevation was measured by using a GPS, the slope and aspect were measured by using a compass meter, the litter thickness was measured by using a ruler directly and soil depth was measured with a soil depth instrument (Zhang *et al*., 2006). Elevation, slope, litter thickness, and soil depth were reading values, while the aspect measurements were coded from 1 to 8 in the following way: 1 (337.6° - 22.5°), 2 (22.6° - 67.5°), 3 (292.6° - 337.5°), 4 (67.6° - 112.5°), 5 (247.6° - 292.5°), 6 (112.6° - 157.5°), 7 (202.6° - 247.5°), and 8 (157.6° - 202.5°). The greater values corresponds the plot where more sunlight is received. The slope position was recorded as 1 for mountain ridge, 2 for upper position, 3 for middle position, 4 for lower position, and 5 for valley bottom. Environmental data were also standardized before analysis.

Table 1. Plant functional traits and their values in *Phellodendron amurense* communities in the Dongling mountain of Beijing, China.

Functional trait type	Functional traits and values
Photosynthesis pathway	1 Crassulacean Acid Metabolism (CAM) pathway, 2 C3 pathway, 3 between C3 and C4 pathway, 4 C4 pathway
Nitrogen-fixing	0 No nitrogen-fixing, 1 Elaeagnaceae nitrogen-fixing, 2 Leguminosae nitrogen-fixing
Seed dispersal	1 Authochory (self dispersal), 2 barochory (dispersal by gravity), 3 anemochory (wind dispersal), 4 zoochory (animal dispersal)
Pollination syndrome	1 Anemophilous, 2 entomophilous
Life-form and growth type	1 Tree, 2 shrubs, 3 woody vine, 4 perennial herb, 5 biennial herb, 6 annual herb
Leaf shape	1 Needle, 2 broad
Plant height	Measured value in meter
Start flowering date	First month of flowering
Flowering period length	Number of flowering months

Data analysis

The SOFM index and other six common indices were applied and their results were compared.

SOFM functional diversity index. SOFM neural network uses unsupervised learning and produces a topologically ordered output that displays the similarity between the species presented to it (Schalkoff, 1992; Foody, 1999). The network consists of two layers, the input layer and the output layer. The input layer contains a unit (neuron) for each variable (species functional trait) in the data set. The input units operate in a similar way to those in other neural networks, presenting the data for each species to the network in an appropriate format. The input units are connected directly to units in the output layer or competitive layer. The output layer is also a two-dimensional array of units, and each of these units is connected to every unit in the input layer by a weighted connection. Species similar to each other should be associated with units that are close together in the output layer, while a pair of dissimilar species would be associated with a distant unit elsewhere in the output layer.

Let the input data vector be:

$$P_k = (P_1^k, P_2^k, ..., P_N^k), \quad (k = 1, 2, \ldots, M)$$

and the associated weight vector be:
$W_{ij} = (W_{j1}, W_{j2},\ldots, W_{ji},\ldots, W_{jN})$ $i = 1, 2,\ldots, N; j = 1, 2,\ldots, M$.
Then, the procedure of the SOFM functional diversity measure is:

(1) Initializing. Giving initial values of W_{ij} within [0, 1] randomly ($i = 1, 2, \ldots, N; j = 1, 2, \ldots, M$), initial values of learning rate $\eta(0)$ and neighborhood $Ng(0)$, and determining total learning times T.

(2) Inputting a random species unit drawn from the input dataset P_k into the network and calculating $\overline{P}_k$:

$$\overline{P}_k = \frac{P_k}{\| P_k \|} = \frac{(P_1^{\,k} + P_2^{\,k}, \ldots .. P_N^{\,k})}{[(P_1^{\,k})^2 + (P_2^{\,k})^2 + \ldots . + (P_N^{\,k})^2]^{\,1/2}}$$

(3) Calculating $\overline{w}_j$:

$$\overline{W}_j = \frac{W_j}{\| W_j \|} = \frac{(W_{j1}, W_{j2}, \ldots .. W_{jN})}{[(W_{j1})^2 + (W_{j2})^2 + \ldots . + (W_{jN})^2]^{\,1/2}},$$

(4) Defining Euclidean distance between $\overline{w}_j$ and $\overline{P}_k$:

$$d_j = [\sum_{i=1}^{N} = (\overline{P_i^{\,k}} - \overline{W_{ji}})^2]^{1/2}, \quad (j = 1, 2, \ldots, M)$$

(5) Determining the minimum distance d_g; g is chosen as the winning neuron, called the Best Matching Unit (BMU).

$$d_g = \min[d_j], \quad j = 1, 2, \ldots, M$$

(6) Adjusting the weights (W_{ij})

$$\overline{W_{ji}(t + 1)} = \overline{W_{ji}(t\,)} + \eta(t)[\overline{P_i^{\,k}} - \overline{W_{jt}(t)}], \ (j = 1, 2, \ldots, M)$$

Where $\eta(t)$ is the learning rate at t time; here we defined it as follows:

$$\eta(t) = \eta(0)(1 - t/T) \qquad (0 < \eta(0) < 1)$$

The neighborhood $N_g(t)$ is defined:

$$N_g(t) = \mathrm{INT}\,[N_g(0)(1 - t/T)]$$

$Ng(0)$ is the initial value of $Ng(t)$.

(7) Increasing time t to t+1. If $t < T$, then go to step (2), else stop the training.

When the learning process is finished, a topological map of small squares is obtained and species units can be mapped into the corresponding squares. This map reflects the distribution of species in the functional trait space.

(8) Scaling the two dimensional axes, considering the topological map of small squares of 6 × 6 is a diagram with coordinate scores of 0.0-0.6, and each species has its two-dimensional scores.

(9) Calculating functional distances between species,

$$d_{jk} = \sqrt{(x_j - x_k)^2 + (y_j - y_k)^2}$$

Where d_{jk} is functional distance between species j and k in topological space, x_j and x_k are scores of species j and k on x axis, and y_j and y_k are scores of species j and k on y axis.

(10) Calculating SOFM functional diversity

$$SOFM = \frac{1}{2}\sum d_{jk} \quad (j = k = 1, 2, \ldots, S = \text{species number in a plot})$$

The parameterization of the SOFM used was that the learning rate was 0.1 for the ordinating phase and 0.02 for adjusting phase; the learning phase was broken down into 5,000 steps for the ordinating phase and 50,000 steps for the tuning phase.

Functional attribute diversity (FAD). FAD aimed at estimating the dispersion of species in trait space as the sum of the pairwise species distances (Walker *et al*., 1999):

$$FAD = -\sum_{i,j} d_{ij}$$

Where d_{ij} is the functional distance between species i and j in the functional trait space; $D = \{d_{ij}\}$ is the Euclidean distance matrix, which is calculated based on the matrix of functional traits (N) by species (S).

Modified FAD (MFAD). For a given set of data of S species and N traits, the functional species were defined. The set of functional species results from combining the species with the same values in all the traits into only one functional species. The number of entities in the data matrix will be reduced from S to M ($M \leq S$), and accordingly the pairwise dissimilarities are reduced from an $S \times S$ to an $M \times M$ matrix. MFAD is calculated as:

$$MFAD = \frac{\sum_{i,j}^{N} d_{ij}}{N}$$

Where d_{ij} is the distance between functional units i and j, and N is the number of functional units.

Functional diversity based on dendrogram. The functional diversity index based on dendrogram is the total branch length of the functional dendrogram that can be constructed from information about species functional traits (Petchey and Gaston, 2006). There were two choices: *FDp* is a plot-based index which recalculates the dendrogram for each plot, but in doing so the desirable property of 'set monotonicity' does not hold. Monotonicity here refers to no reverse branch existing in a dendrogram. *FDc* is a community-based index which corrects for the lack of monotonicity that arises when there is a particular dendrogram for each plot.

Functional richness (FRic). FRic represents the trait space filled by the community. In the one trait case it is represented by the range (maximum–minimum), but with more than one trait it is represented by the volume filled by the community in the trait space. The procedure is similar to the convex hull hyper-volume. The algorithm identifies the

Table 2. Spearman correlation coefficients between functional diversity indices and environmental variables in *Phellodendron amurense* communities in the Dongling Mountain of Beijing, China (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$).

Functional trait index	Soil thickness	Litters thickness	Slope	Elevation	Aspect	Slope position
SOFM	-0.168	-0.397*	0.341	0.655***	-0.461*	-0.564**
FAD	-0.160	-0.395*	0.350	0.670***	-0.452*	-0.561**
MFAD	-0.157	-0.412*	0.303	0.613***	-0.460*	-0.548**
FDp	-0.127	-0.420*	0.34	0.597***	-0.471*	-0.606***
FDc	-0.155	-0.366	0.312	0.614***	-0.471*	-0.602***
Fric	-0.241	-0.593**	0.055	0.352	-0.262	-0.568**
Fdiv	0.272	-0.351	0.117	0.042	0.070	0.169

extreme species and then estimates the volume of the trait space. The maximum value of FRic in a T dimensional trait space is attained with 2^T species with a combination of extreme values of the traits values.

Functional divergence (FDiv). Functional divergence is related to how abundance is distributed within the volume of the functional trait space. The functional divergence index is calculated as follows:

$$FDiv = \frac{\sum_{i=1}^{S} w_i (dG_i - \overline{dG}) + \overline{dG}}{\sum_{i=1}^{S} w_i |dG_i - \overline{dG}| + \overline{dG}}$$

dG_i is the functional distance from species i to the gravity center of species that form the vertices of the convex hull, $\overline{dG}$ and is the mean distance of the S species to the gravity center. w_i is the relative abundance of species i.

Results

The SOFM index was calculated by using the neural network toolbox in MATLAB. Other functional diversity indices, namely FAD, MFAD, FDp, FDc, FRic and FDdiv, were calculated with the FDiversity software (Casanoves *et al.*, 2011). Euclidean distance was used in the analyses. All functional diversity indices, except FDiv, varied greatly in *Phellodendron amurense* communities in the Dongling

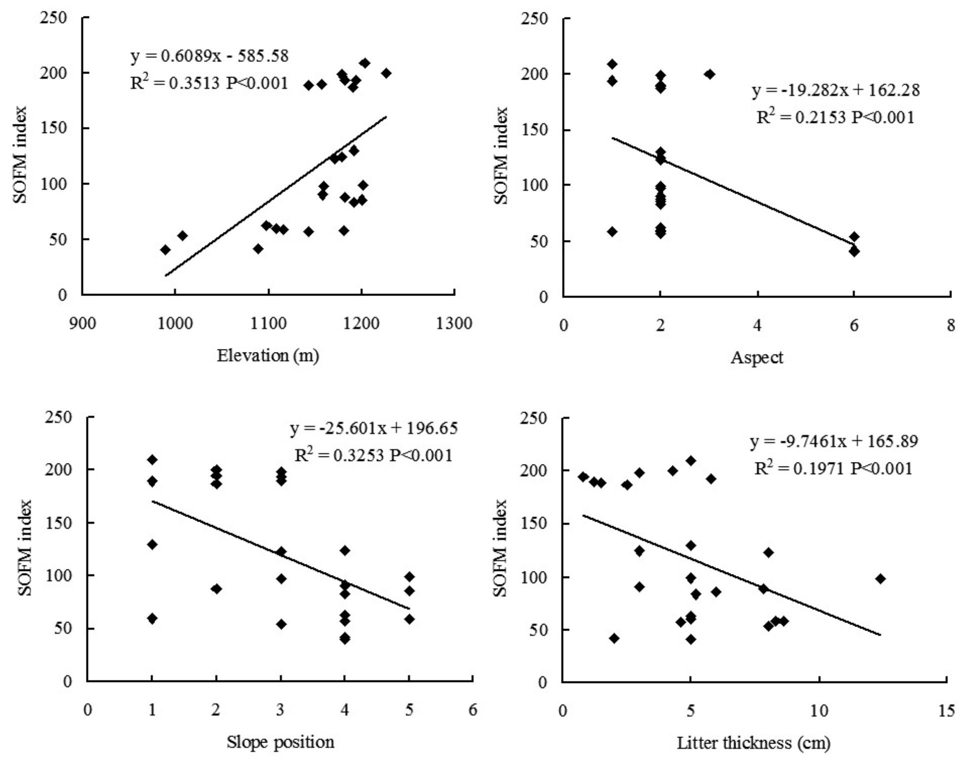

Figure 2. Regression analysis between SOFM functional diversity index and environmental variables in *Phellodendron amurense* communities in the Dongling Mountain of Beijing, China.

Table 3. Spearman correlation coefficients between functional diversity indices in *Phellodendron amurense* communities in the Dongling Mountain of Beijing, China (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$).

Indices	SOFM	FAD	MFAD	FDp	FDc	FRic	FDiv
SOFM	-						
FAD	0.905***	-					
MFAD	0.790***	0.973***	-				
FDp	0.869***	0.961***	0.984***	-			
FDc	0.831***	0.951***	0.982***	0.988***	-		
FRic	0.756***	0.740***	0.731***	0.727***	0.703***	-	
FDiv	0.341	0.280	0.334	0.259	0.249	0.074	-

Mountain, such as SOFM varied from 40.7 to 209.5, FAD from 46.18 to 328.62, MFAD from 3.11 to 8.23, FDp from 5.61 to 12.44, and FDc from 5.57 to 13.05. These indices showed that functional diversity was rich in *P. amurense* communities compared to that in other forests in this area (Zhang, 2011).

The variability of functional diversity was usually dependent on the variation of environmental variables (Zhang, 2011; de Bello, 2012). This also was true in this study. SOFM functional diversity index was significantly correlated with elevation, aspect, slope position, and litter thickness in *Phellodendron amurense* communities in the Dongling Mountain (Figure 2), but its correlation with soil thickness and slope were not significant. Other indices, FAD, MFAD, FDp, FDc, and FRic showed the similar correlations with these variables as that of SOFM and only FDdiv had no significant correlation with environmental variables (Table 2). Although, different indices showed different significance on relations between functional diversity and environmental variables, the positive or negative relations were consistent. Functional diversity showed a positive and linear correla-

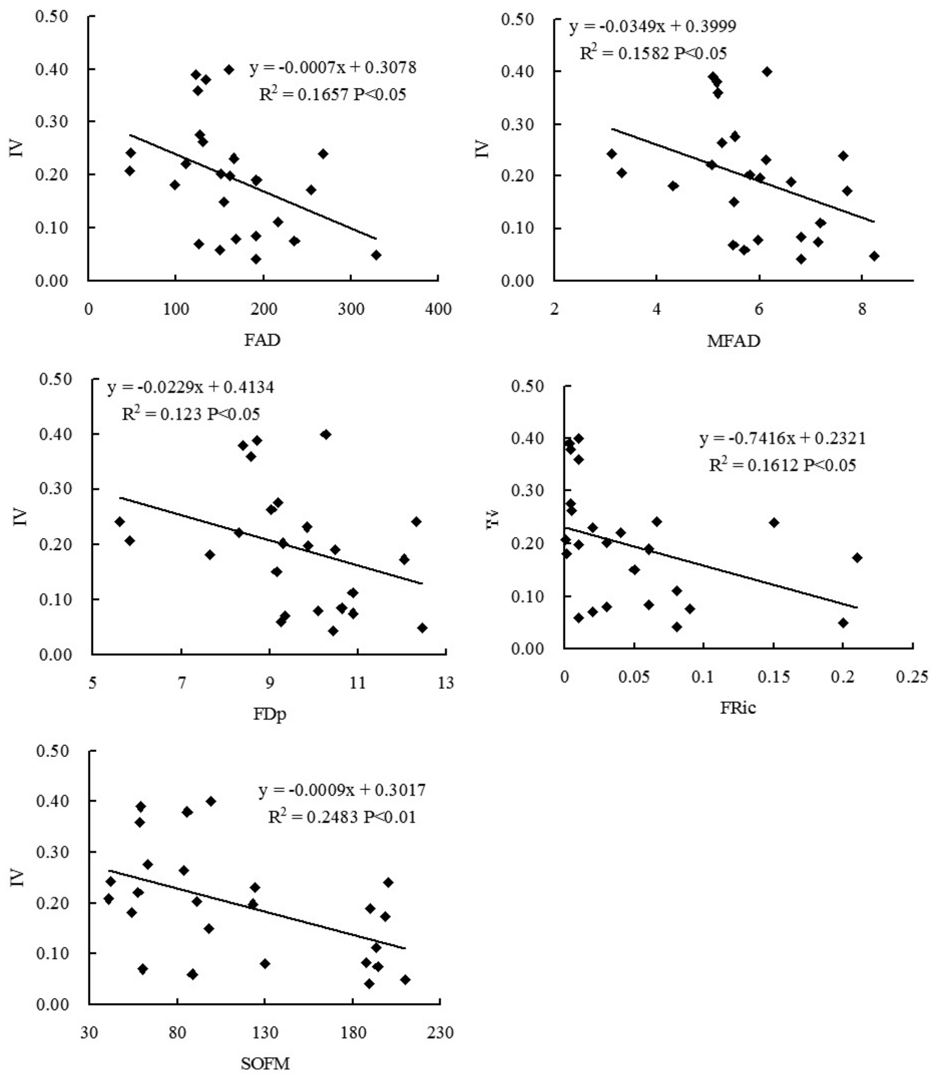

Figure 3. Regression analysis between importance value of *Phellodendron amurense* and functional diversity in *Phellodendron amurense* communities in the Dongling Mountain of Beijing, China.

Table 4. Spearman correlation coefficients between species diversity with environmental variables in *Phellodendron amurense* communities in the Dongling Mountain of Beijing, China. (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$)

Diversity index	Soil thickness	Litter thickness	Slope	Elevation	Aspect	Slope position
S	-0.006	-0.177	0.324	0.733***	-0.680***	-0.502**
H'	0.233	0.389*	0.236	0.306	-0.479*	-0.342
E	0.091	0.446*	-0.034	-0.113	0.034	-0.144

tion with elevation. Elevation was the most important factor affecting functional diversity in *Phellodendron amurense* communities (Table 2). Functional diversity had negative correlations with aspect, litter thickness and slope position (Figure 2, Table 2). These three variables were also significant for functional diversity in communities. Six of the seven indices (SOFM, FAD, MFAD, FDp, FDc, FRic) showed the same pattern with environmental variables because they were significantly correlated with each other (Table 3).

As a new method, SOFM index could complete functional diversity analysis and provide reasonable results, i.e. describing the functional diversity and its change in *Phellodendron amurense* communities (Zhang and Li, 2010). Furthermore, SOFM results were significantly correlated with other common methods. This suggested that SOFM index is an effective technique in functional diversity analysis in plant communities.

Species diversity also correlated with environmental variables. Species richness (S) was significantly correlated with elevation, aspect, and slope position; species heterogeneity (H') and evenness (E) were significantly correlated with litter thickness (Table 4). All the functional diversity indices were significantly related to species richness, four out of the seven indices were related to species heterogeneity, and only one index (FDiv) related to evenness (Table 5). All correlations of functional diversity with community diversities were positive (Table 5).

The Importance Value [IV = (relative cover + relative height + relative basal area)/3] of *Phellodendron amurense* was significantly correlated with functional diversity of communities (Figure 3). Their correlations were negative, i.e. importance values of this species decreased as functional diversity increased. This may provide useful information for conservation of endangered species, *P. amurense*, and its communities.

Discussion

Functional diversity has become an increasing body of work in plant community studies demonstrating its importance (Suding *et al*., 2008). Several studies have attempted to develop methods to measure functional diversity (Mason *et al*., 2005; Zhang *et al*., 2012a). SOFM index successfully described the magnitude and change of functional diversity of *Phellodendron amurense* communities, which suggested that SOFM index was fully usable in functional diversity studies. Significant correlations of SOFM index with common methods, namely FAD, MFAD, FDc, FDp, FRric, and FDiv indices, also proved that SOFM index was an useful method in quantifying functional diversity in plant communities (Petchey and Gaston, 2006; Suding *et al*., 2008). SOFM index was measured in neural network topological space of functional traits. It is theoretically different from other indices, it can deal with much imprecise and incomplete fuzzy information and has advantages in solving non-linear problem and in studying complex systems. Theoretically, SOFM can describe natural phenomena and rules better than other indices (Lek and Guegan, 2000; Zhang *et al*., 2008). However, the advantages of the SOFM index need to be tested by more case studies in various vegetation types (Zhang *et al*., 2012a).

Functional diversity in *Phellodendron amurense* communities in the Dongling mountain varied significantly, which suggested that functional diversity is a suitable indicator for quantifying relationships of composition, structure, function and environment in communities (Zhang, 2011). Functional diversity was significantly correlated with elevation, which was consistent with the conclusion that elevation was the key environmental variable affecting vegetation structure, diversity and distribution in this reserve (Zhang *et al*., 2012b). Among the environmental variables measured in this study, the same conclusion that elevation was key environmental factor affecting functional diversity can be obtained. Functional diversities increased linearly with elevation increase, which did not follow the "humped" pattern that peak diversity appears near the middle of the gradient (Austrheim, 2002). This may be explained by the fact that the elevation range of 950-1,300 m where *P. amurense* communities distributed was shorter than the whole elevation gradient of 800-2,303 m in this mountain (Zhang *et al*., 2009). The increase of functional diversity with elevation seems to be due to the increasing precipitation along elevation gradient, and water conditions and precipitation are the

Table 5. Spearman correlation coefficients of functional diversity with community diversity indices in *Phellodendron amurense* communities in the Dongling Mountain of Beijing, China. (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$)

Functional diversity index	*S*	*H'*	*E*
SOFM	0.883***	0.268	0.215
FAD	0.960***	0.529**	0.055
MFAD	0.986***	0.537**	0.140
FDp	0.983***	0.570**	0.114
FDc	0.978***	0.590**	0.354
FRic	0.569**	0.240	0.072
FDiv	0.491**	0.046	0.471*

key factors for plant communities in this mountain (Zhang *et al*., 2012a). Functional diversity was negatively correlated with aspect, litter thickness, and slope position, because these factors affected heat and water-conditions in communities, i.e. shady-slope, thin litters, and low slope position representing comparatively rich soil water-condition which was a key factor for plant growth and microbial decomposition in soils in this area (Zhang, 2005; de Bello *et al*., 2009).

Species diversity and functional diversity of *Phellodendron amurense* communities showed the same pattern in response to environmental variables, as they were significantly correlated with each other. All functional diversity indices were correlated with species richness, and four out seven correlated with heterogeneity, and only FDiv was also correlated with evenness. These results are consistent with other studies (e.g. Casanoves *et al*., 2011; de Bello, 2012; Zhang *et al*., 2012a). Some authors have argued that functional diversity and species richness should be independent of each other (Ricotta and Moretti, 2008; Zhang, 2011), thus further studies will support this assertion (Mouillot *et al*., 2005; Zhang *et al*., 2012a).

The Importance Value of a species including its relative cover, relative height, and relative basal area can reflect species growing status, position and likely roles in communities, and is an indicator of conservation effects for an endangered and protected species (Peet and Loucks, 1977; Mouillot *et al*., 2005; Zhang, 2011). The negative correlations of the importance value of *Phellodendron amurense* with functional diversity indices showed that communities with greater functional diversity were not certainly beneficial for the conservation of *P. amurense* and its communities, which was similar to the effects of species diversity on conservation of some endangered species (Lomolino, 2001; Zhang *et al*., 2009). Therefore, functional diversity should be maintained in a suitable extent for conservation purpose of the studied species (Lomolino 2001; Fetene *et al*., 2006). This point needs further tested by more case studies of functional diversity and conservation of endangered species for different species in different regions (de Bello, 2012).

Acknowledgments

The study was financially supported by the Specialized Research Fund for the Doctoral Program of Higher Education (Grant No. 20120003110024) and the National Natural Science Foundation of China (Grant No. 31170494). We thank two anonymous reviewers for their constructive comments and suggestions on the manuscript.

Literature cited

Austrheim G. 2002. Plant diversity patterns in semi-natural grasslands along an elevational gradient in southern Norway. *Plant Ecology* **161**:193-205.

Casanoves F., Pla L., Di Rienzo J.A. and Díaz S. 2011. FDiversity: a software package for the integrated analysis of functional diversity. *Methods in Ecology and Evolution* **2**:233-237.

Chon T.S., Park Y.S., Moon K.H. and Cha E.Y. 1996. Patternizing communities by using an artificial neural network. *Ecological Modelling* **90**:69-78.

de Bello F., Thuiller W., Lepš J., Choler P., Clement J., Macek P., Sebastia M.-T. and Lavorel S. 2009. Partitioning of functional diversity reveals the scale and extent of trait convergence and divergence. *Journal of Vegetation Science* **20:475–486**

de Bello F. 2012. The quest for trait convergence and divergence in community assembly: are null-models the magic wand? *Global Ecology and Biogeography* **21**:312-317.

Díaz S., Lavorel S., de Bello F., Quétier F., Grigulis K. and Robson T.M. 2007. Incorporating plant functional diversity effects in ecosystem service assessments. *Proceedings of the National Academy of Sciences USA* **104**:20684-20689.

Fetene M., Assefa Y., Gashaw M., Woldu Z. and Beck E. 2006. Diversity of afroalpine vegetation and ecology of treeline species in the Bale Mountains, Ethiopia, and the influence of fire. In: Spehn E.M., Liberman M. and Korner C. Ed. *Land Use Change and Mountain Biodiversity*, pp. 25-38, CRC Press, Boca Raton.

Foody G.M. 1999. Applications of the self-organising feature map neural network in community data analysis. *Ecological Modelling* **120**:97-107.

Giraudel J.L. and Lek S. 2001. A comparison of self-organizing map algorithm and some conventional statistical methods for ecological community ordination. *Ecological Modelling* **146**:329-339.

He S.Y. 1992. *Flora of Beijing*, Beijing People's Press, Beijing.

Huo Y.Z. 1989. *Beijing Physical Geography*. Beijing Normal University Press, Beijing.

Laliberté E. and Legendre P. 2010. A distance-based framework for measuring functional diversity from multiple traits. *Ecology* **91**:299-305.

Lek S. and Guégan J.F. 2000. *Artificial Neuronal Networks Application to Ecology and Evolution*. Springer, Berlin.

Lomolino M.V. 2001. Elevation gradients of species-density: historical and prospective views. *Global Ecology and Biogeography* **10**:3-13.

Mason N.W.H., Mouillot D., Lee W.G. and Wilson J.B. 2005. Functional richness, functional evenness and functional divergence: the primary components of functional diversity. *Oikos* **111**:112-118.

Mouillot D., Mason W.H.N., Dumay O. and Wilson J.B. 2005. Functional regularity: a neglected aspect of functional diversity. *Oecologia* **142**:353-359.

Muhumuza M. and Byarugaba D. 2009. Impact of land use on the ecology of uncultivated plant species in the Rwenzori mountain range, mid western Uganda. *African Journal of Ecology* **47**:614-621.

Peet R.K. and Loucks O.L. 1977. A gradient analysis of southern Wisconsin forests. *Ecology* **58**:485-499.

Petchey O.L. and Gaston K.J. 2002. Functional diversity (FD), species richness and community composition. *Ecology Letters* **5**:402-411.

Petchey O.L. and Gaston K.J. 2006. Functional diversity: back to basics and looking forward. *Ecology Letters* **9**:741-758.

Ricotta C. and Moretti M. 2008. Quantifying functional diversity with graph-theoretical measures: advantages and pitfalls. *Community Ecology* **9**:11-16.

Schalkoff R.J. 1992. *Pattern Recognition: Statistical Structural and Neural Approaches*. Wiley, New York.

Suding K.N., Lavorel S., Chapin III F.S., Cornelissen J.H.C., Díaz S., Garnier E., Goldberg D., Hooper D.U., Jackson S.T. and Navas M.L. 2008. Scaling environmental change through the community-level: a trait-based response-and-effect framework for plants. *Global Change Biology* **14**:1125-1140.

Tilman D., Reich P.B., Knops J., Wedin D., Mielke T. and Lehman C. 2001. Diversity and productivity in a long-term grassland experiment. *Science* **294**:843-845.

Villéger S., Mason N.W.H. and Mouillot D. 2008. New multidimensional functional diversity indices for a multifaceted framework in functional ecology. *Ecology* **89**:2290-2301.

Walker B., Kinzig A. and Langridge J. 1999. Plant attribute diversity, resilience, and ecosystem function: the nature and significance of dominant and minor species. *Ecosystems* **2**:95-113.

Zhang J.T. 2005. Succession analysis of plant communities in abandoned croplands in the Eastern Loess Plateau of China. *Journal of Arid Environments* **63**:458-474.

Zhang J.T. 2011. *Quantitative Ecology*. 2nd edition, Science Press, Beijing. (In Chinese).

Zhang J.T. and Li M. 2010. Application of self-organizing feature map clustering and ordination to the analysis of subalpine meadows in North China. *Proceedings of 2010 Sixth International Conference on Natural Computation*, Vol. 3, pp. 1564-1568, IEEE & CAS, Yantai.

Zhang J.-T., Dong Y. and Xi Y. 2008. A comparison of SOFM ordination with DCA and PCA in gradient analysis of plant communities in the midst of Taihang Mountains, China. *Ecological Informatics* **3**:367-374.

Zhang J.T., Fan L. and Li M. 2012a. Functional diversity in plant communities: theory and analysis methods. *African Journal of Biotechnology* **11**:1014-1022.

Zhang J.T., Li S. and Li M. 2010. A comparison of self-organizing feature map clustering with TWINSPAN and fuzzy C-means clustering in the analysis of woodland communities in the Guancen Mts, China. *Community Ecology* **11**:120-126.

Zhang J.T., Ru W. and Li B. 2006. Relationships between vegetation and climate on the Loess Plateau in China. *Folia Geobotanica* **41**:151-163.

Zhang J.T., Song N. and Li M. 2012b. Application of fuzzy equivalence clustering to the analysis of functional diversity in plant communities. Proceedings of 2012 9th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD), Vol. 2, pp. 545-549, IEEE & CAS, Sichuan.

Zhang B., Zhang J.T., Suriguga, Zhang Q.D., Cheng J.J. and Tian S.G. 2009. A comparison of co-intertia analysis and canonical correspondence analysis in plant community ordination. *Chinese Journal of Plant Ecology* **33**:842-851.

Received December 2nd, 2012
Accepted April 25th, 2013