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APPLICATION OF DISTANCE BASED INDICES TO MEASURE PATTERN OF FUNCTIONAL DIVERSITY OF *GENTIANA MACROPHYLLA* PALL. COMMUNITIES: A CASE STUDY FROM DONGLING MOUNTAIN MEADOW, BEIJING, CHINA

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Abstract

Functional diversity changes with the change of environmental variables' values in *Gentiana macrophylla* communities in Dongling Mountain. Seventy-five quadrats of 1m*1m around 15 sampling zones separated by 50m in meadow elevation were fixed. Functional traits, community composition and various environmental factors were measured, observed and recorded in each quadrat. Soil samples were also collected and then analyzed in laboratory for five soil nutrients' contents. Ten functional diversity indices based on functional distances (FAD1, MFAD, FDp, FDc, wFDp, wFDc, Rao, rRao, FDiv, FDis) were used to find out functional diversity. Functional diversity was found to be significantly affected by variation in elevation. Besides elevation, slope aspect, soil type, soil pH, disturbance, total phosphorus, magnesium and zinc also proved to be significantly important for functional diversity change of *G. macrophylla* communities. Rank-order correlation coefficient between/among species diversity and functional diversity indices indicated that changes in functional diversity were significantly correlated to species richness and heterogeneity while no significant correlation was observed for species evenness. Principle component analysis showed that all the indices were correlated to each other. Criteria defined by these results will prove helpful for management and conservation of *G. macrophylla* communities and other medicinal plant species in Dongling Mountain meadow.

Key words: Biodversity, Conservation, Medicinal plants, Meadow, PCA, Ecology

Introduction

Variation of plant community function is known as functional diversity. Functional traits and their changes is representative of functional diversity at any place (Petchey & Gastron, 2002; Zhang *et al.*, 2015). Ecosystem processes, services and their change with the change of environmental variables is well depicted by functional diversity (Laliberte & Legendre, 2010). Phytosociological studies present an overview of current and future prospectus of vegetation (Naz *et al.*, 2019). Functional diversity is more sensitive to disturbance as compared to species diversity (Zhang *et al.*, 2015). Quantitative methods to determine functional diversity indices are developed in many previous investigations (Suding *et al.*, 2008; Ackerly & Cornwell, 2007; Zhang *et al.*, 2013; Laliberte & Legendre, 2010; Zhang *et al.*, 2012). These researchers also depicted the importance of comparison studies of diversity indices to rectify the confusion of researchers to select the best method.

In the past few decades, with the extinction acceleration of global species, the impact of vegetation scarcity on ecosystem has become the topic of major concern in ecology (Sun *et al.*, 2003). Functional diversity points out suitable environmental conditions and strength of habitat factors for plant communities. Hence, it can be used as an indicator for the proper conservation of highly demanded and threatened plant species (Cornwell *et al.*, 2006; Song & Zhang, 2003). Changes in functional diversity can be related to environmental gradients. Therefore, variation pattern of functional diversity should also be given importance along with species diversity variation (Mason *et al.*, 2005; Butterfield & Suding, 2013).

In China, Mountain meadows are mainly distributed in the west (Zhou, 2001). Northern part of country has limited meadows areas among which largest area is occupied by Dongling Mountain nature reserve. It is 125Km far from the center of main city (He, 1992). Previously, Zhang *et al.*, 2015 conducted a comprehensive research of FD along an anthropogenic interference in Dongling Mountain Meadow.

G. macrophylla Pall., Qin Jiao in Chinese, is effectively used Traditional Chinese medicine. Its roots, the most important part which constitute Qin Jiao, are used to cure hepatitis, constipation, pains, rheumatism, bone fever, heat deficiency syndrome and strokes (Jian-Bin *et al.*, 2008; Cai *et al.*, 2010). Digging of its roots leads to the destruction of its wild habitat and population. Recently, a Himalayan species of the same genus (*G. kurroo* Royle) has been declared as critically endangered species due to roots digging, climate changes and disturbance to its natural habitats (Ved *et al.*, 2015). As Dongling mountain is the sole habitat of *G. macrophylla* in Beijing, here its conservation and management is highly needed due to potent and possible risk to its communities.

Correlation studies on pattern and fluctuations of functional diversity in specific habitats, lead to define certain criteria which prove to be helpful for the management and conservation of medicinal plant communities. Until now very few case studies have been found on functional diversity of medicinal plant communities. Research hypotheses of this research were the presence of variation in functional diversity of *G. macrophylla* communities in Dongling Mountain meadow, effect of environmental factors especially elevation on functional diversity of *G. macrophylla* communities and Correlation between functional diversity and species diversity of *G. macrophylla* communities.

Materials and Methods

Study site: Beijing, the capital city of People Republic of China, is located in the North of the country. Xiaowutai Mountain in Hebei extends up to Dongling Mountain located in the West of Beijing. The Dongling Mountain is situated at 40°00'-40°05' N and 115°26'-115°40' E coordinates (Fig. 1). Its altitude varies from 800 to 2303m (highest mountain in Beijing). Meadow area starts from 1600m and continues up to summit of Mountain. It has temperate humid climate and annual temperature of 7°C (Zhang *et al.*, 2015). Being the nature reserve, it is main tourists' attraction in Beijing (Zhang *et al.*, 2012).

Data collection: Fifteen patches of *Gentiana macrophylla* were located along an elevation gradient between 800-2303m, so 15 sampling zones at distance of 50m in elevation were set up. Five quadrates in each sampling zone were set. Plants and environmental data were collected in each quadrat. Quadrate size was 1m*1m. Species name, cover, height was noted in each quadrat. Three soil samples were also collected from each point and then mixed together to from one sample per point so total 15 samples were obtained. Concentration of magnesium, zinc, total nitrogen, total phosphorus and total potassium was found by using visible spectrophotometer (Schmid, 2001), inductively coupled plasma emission spectrophotometer (Philips Innovation Services, 2013; Hou, 2000), and Atomic absorption spectrophotometer (Ata, 2015). These were measured as soil variables because these are the most important nutrients of soil. Total 85 plant species were obsrved in 75 quadrats.

Eight functional traits (Table 1) were chosen to represent the function of plant species in the communities of *G. macrophylla.* Photosynthetic pathway, seed dispersal, Nitrogen-fixing capability and the way of pollination were researched from local flora (He, 1992), whereas Life cycle, leaf shape, date and period of flowering were recorded and measured in field. Total 75 data matrices for 75 quadrats were generated for the calculation of functional diversity. Each data source consisted of functional traits × plants in a quadrat. Before calculation of functional diversity indices, standardization of all the traits was carried out to minimize scale errors (Casanoves *et al.*, 2011).

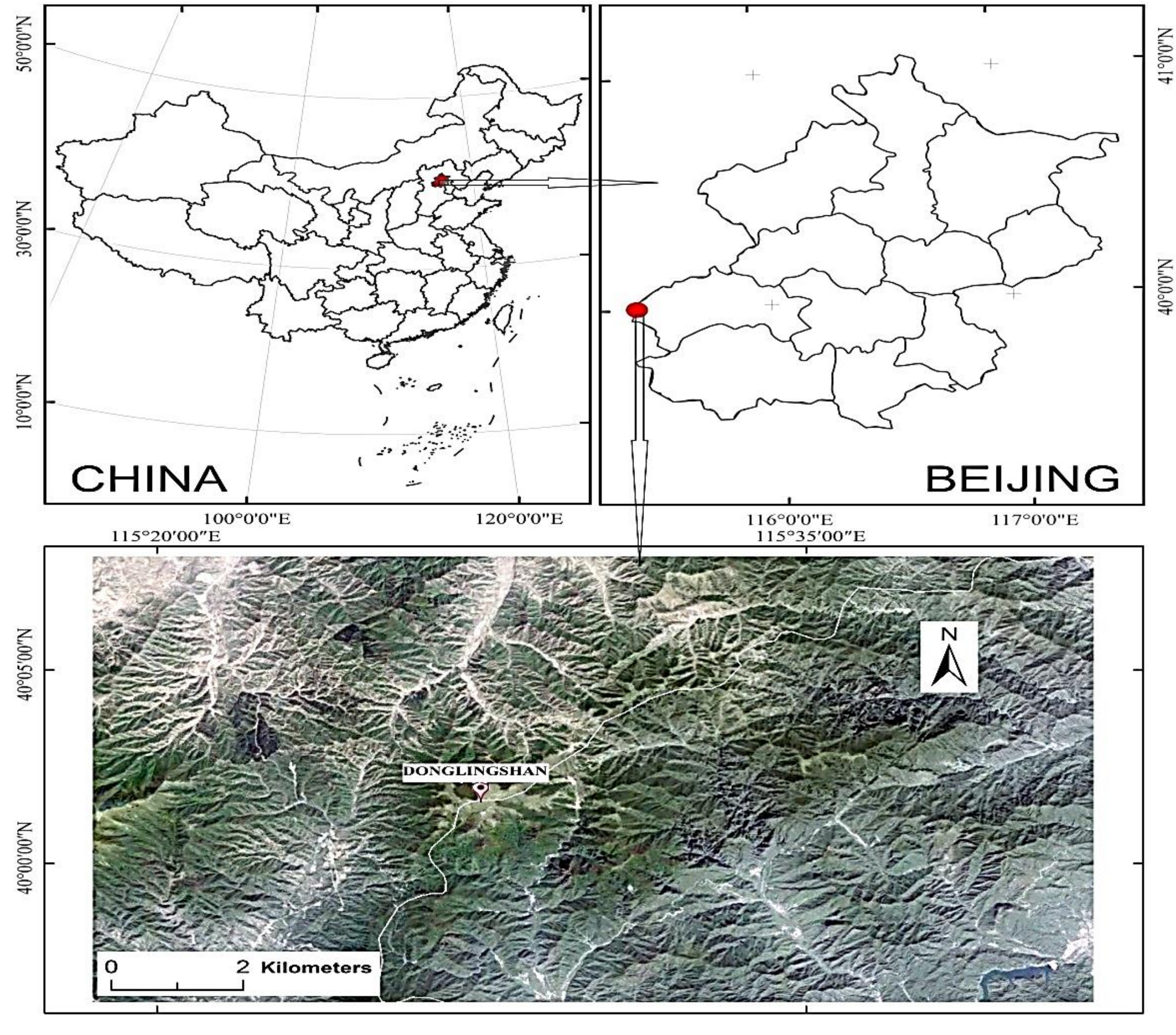

Fig. 1. Geographical location of Dongling Mountain, Beijing, China.

Table 1. Plant functional traits and their values in mountain meadows communities in the Dongling Mountain, Beijing.

Functional trait type	Data type	Functional traits and values
Photosynthesis pathway	Categorical data	1Crassulacean pathway, 2 C3 pathway, C4 pathway
Nitrogen fixing	Categorical data	0 No nitrogen fixing, 1 Elaegnaceae nitrogen fixing, 2 Leguminosae nitrogen fixing
Seed dispersal	Categorical data	1Automatic spreading, 2 gravity spreading, 3 wind spreading, 4 animals spreading
Pollination method	Categorical data	1 Anemophilous, 2 entomophilous
Life cycle	Categorical data	1 Annual, 2 biennial, 3 perennial
Leaf form	Categorical data	1 Coniferous, 2 broadleaf
Flowering date	Quantitative data	Beginning month of flowering
Flowering period	Quantitative data	Flowering months

Elevation, slope, slope aspect, soil pH, soil temperature and disturbance for each quadrate were noted. GPS and Compass were used to quantify the elevation, the slope and aspect. Soil pH and temperature were found by pH meter and hygrometer, respectively. Eight classes of slope aspect were made in following ways; Greater the value, more the sunshine is. Five classes of disturbance intensity were used for evaluation on the basis of visitors' number, distance from human population, litter and waste material, trampling and grazing: 1 (minute interference), 2(less interference), 3 (moderate interference), 4 (extensive interference), 5 (very extensive interference). In this way, standardization of qualitative environmental variables was done before the calculations of functional diversity.

Analysis of data: Importance value (IV) of each plant species was used to carry out multivariate analysis of plant communities and species diversity (Zhang *et al.*, 2013):

$$IV_{herbs} = (\text{relative cover} + \text{relative height})/2$$

Functional diversity of plant traits can be finding out by using different measurement available in Plant ecology. The following indices were used in our study:

Functional attribute diversity (FAD): The basic aim of FAD is estimation of plants dispersion in trait area as an addition of the pairwise species lengths (Leps *et al.*, 2006):

$$\text{FAD} = \sum_{i,j} dij$$

where *dij* is the functional length between species *i* and *j* in functional trait area; *dij* is Gower's distance between species *i* and *j* and is computed on the basis of functional traits matrix (*N*) by species (*S*).

Modified FAD (MFAD): Functional species were defined for a provided source of S species and N traits. The set of functional species is resulted from joining the species with the similar entities in all the features into barely one functional species. The amount of units in the data source will be decreased from S to M (M≤S), and correspondingly the pairwise disparities are decreased from an S ×S to an M ×M matrix.

MFAD is computed as;

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

where d_{ij} is the length between functional entities "*i*"and "*j*", and *M* is the quantity of functional entities (Schmera *et al.*, 2009).

Functional diversity based on dendrogram (FDp and FDc): Dendrogram based indices are the plot based indices that recapitulates the dendrogram for every quadrat, but by this practice, the required attribute of 'set monotonicity' does not carried. Monotonicity points to disappearance of reverse branch present in a dendrogram. As compared to FDp, FDc is an index that rectifies the absence of monotonicity aroused when there is a specific dendrogram for every quadrat (Casanoves *et al.*, 2011).

Weighted functional diversity (wFDp and wFDc): In this type of diversity, Symmetric matrix is used to derive the total branch length of the functional dendrogram. In the pool based functional diversity (wFDp), the dendrogram is calculated only with the species set existing in each plot. While in community based functional diversity (wFDc), the index is from one dendrogram inclusive of the species community pole, with equi-abundance wFD equals FD/S^2 and wFDc equals FDc/S^2 (Pla *et al.*, 2008).

Rao's index

$$\text{Rao} = \sum_{i=1}^{s}\sum_{j=1}^{s} d_{ij}\, p_i p_j$$

where Rao is the index for a plot (community), dij is the functional length between species i and j, pi and pj are the relative importance values of species i and species j, and S is the total number of plant species per community (Lepš *et al.*, 2006).

Relative Rao index (rRao): The rRao index constitutes the relative values got from ratio between observed R values and maximum value of R. If the rRao is higher, closer the community is to the basal area (biomass) among the species or frequency (the best distribution of individual).

$$rRao = Rao/Rao_{max}$$

If the distance matrix between species is ultrametric, then interpretation of the ratio Rao/Rao_{max} becomes very easy. In some cases, the Value of R reaches to maximum when there are only two species of opposite traits due to use of continuous factors (Pavoine *et al.*, 2005).

Functional divergence (FDiv): Functional divergence is connected to distribution of abundance within the capacity of functional trait space (Ville´ger *et al.*, 2008). FDiv is:

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

dGi is the functional length from species i to the gravity core of species that constitute the peaks of the convex hull, dG is the average length of the S species to the gravity center, and wi is the relative abundance of species i.

Functional dispersion (FDis): It is the average distance of individual species to the centroid of all species in the community trait space, taking into account the relative abundance of species by calculating the weighted centroid (Laliberte and Legendre, 2010):

$$\text{FDis} = \sum_{i=1}^{s} wd_i$$

where wi is the relative abundance of species i and di is the length of species i to the weighted centroid C.

Species diversity indices: Species richness (species number), heterogeneity (Shannon-Wiener index), and species evenness (Pielou index) were used as species diversity indices to compute species diversity values (Zhang, 2011).

Species richness: D =S

Shannon Weiner index: $H = -\sum P_i \ln P_i$

Pielou index: $E = \frac{H}{\ln(S)}$

where Pi is the relative abundance of species i, *Pi = Ni*/*N*, *Ni* the importance value of species *i*, *N* the total of importance values for all species in a quadrat, and S the species number found in a quadrat.

Statistical analysis

The functional diversity indices were computed by the FDivrsity software (Casanoves *et al.*, 2011).

The associations of functional diversity, environmental variables, and species diversity was found by spearman correlations. Polynomial regression by SPSS was used to analyze the variation patterns of functional diversity along the elevation gradient.

Results and Discussion

Variation in functional diversity: Functional diversity indices (build on Eucladian distances) were measured in functional trait space in this research. Distance between species was computed by using functional traits × species matrix directly (Song & Zhang, 2013). A large variation of functional diversity was observed in *G. macrophylla* communities of Dongling mountain meadow. FAD1 varies from 0.34 to 0.94, MFAD varies from 0.03 to 8.00, FDp varies from 18 to 49.64, FDc varies from 20.58 to 49.53, wFDp from 15.76 to 51.08, wFDc from 18.12 to 47.99, Rao's index from 4.01 to 13.21, rRao from 0.34 to 0.94, FDiv from 0.72 to 0.92, FDis from 1.94 to 3.16. Variation of functional diversity is a good indicator to quantify the relationship of community composition, its structure, its function, suitable environment and disturbance impact (De Bello *et al.*, 2006).

Functional diversity and environmental factors: Functional diversity variation usually depends upon changes of environmental factors (Zhang, 2011). As phenology related traits are related to elevation and nutrients related traits are mostly affected by soil properties (Molina-venegas *et al.*, 2016). Similar trends of change along elevation gradient were observed for almost all the functional diversity indices because they are significantly correlated to each other (Fig. 2). Low functional diversity was observed at high elevation points. Significant correlation between elevation and functional diversity indicates that elevation is a key factor affecting the structure, composition, distribution and diversity of *G. macrophylla* communities in Dongling mountain meadows (Pavoine & Bonsall, 2011). Effect of elevation gradient on functional diversity was consistent with previous literature (Xu & Zhang, 2008: Zhang, 2011). Besides elevation, slope aspect, soil type, soil pH and disturbance also proved to be significantly important for functional diversity change of *G. macrophylla* communities (Table 2). Slope aspect was positively and significantly correlated to FAD1, Rao's index and FDiv. Soil pH was significantly correlated to rRao, FDiv and FDis. Soil type was significantly correlated to all indices except Rao and FDiv. Disturbance was significantly but positively correlated to all indices except wFDp, wFDc, Rao and FDis.

Soil type was also found to be significantly correlated to functional diversity. Among three classes of soil type i.e. Sandy soil, loamy soil and clay soil, result indicated that clay soil leads to low functional diversity of *G. macrophylla* communities while sandy soil has a reverse effect. High functional diversity in the presence of low clay contents in soil is consistent with the idea of low nutrient conditions lead to increased niche dimensionality (Harpole & Tilman, 2007). It is an explanatory mechanism for coexistence of many species in nutrient-poor patches (Von Felton & Schmid, 2008). This result was consistent with Silva *et al.*, (2013), which depicted presence of fewer species and low FDis values for high proportion of clay in soil. Other topographic factors did not show significant correlation with functional diversity. A positive correlation between disturbance and functional diversity was observed which is conflicting with the "hump" pattern that medium disturbance leads to maximum diversity (Zhang *et al.*, 2012). Reason behind this result may lies on the nature of disturbance in Dongling mountain meadow i.e. main disturbance source is tourists rather than natural processes (Attorre *et al.*, 2013). Mayfield *et al.*, (2010) proposed a model which describes that disturbance can help to release the environmentally compatible species from their dominant and strong competitor which lead to increased functional diversity. According to Grime (2006), disturbance has a great potential to create and sustain variation of traits in plant communities. However, in some cases, disturbance is also proved to be driver of divergence (Pakeman, 2011). Other environmental factors like aspect, soil pH and soil minerals (phosphorus, magnesium and zinc) also showed somewhat significant effects on the pattern of functional diversity. Phosphorus and magnesium are significantly correlated to MFAD, rRao and FDiv. Zinc is significantly correlated to all indices except FDiv. Aspect, magnesium and zinc were independent of elevation but soil pH and phosphorus were significantly correlated to elevation so they may illustrate its effect on functional diversity (Duivenvoorden & Cuello, 2012).

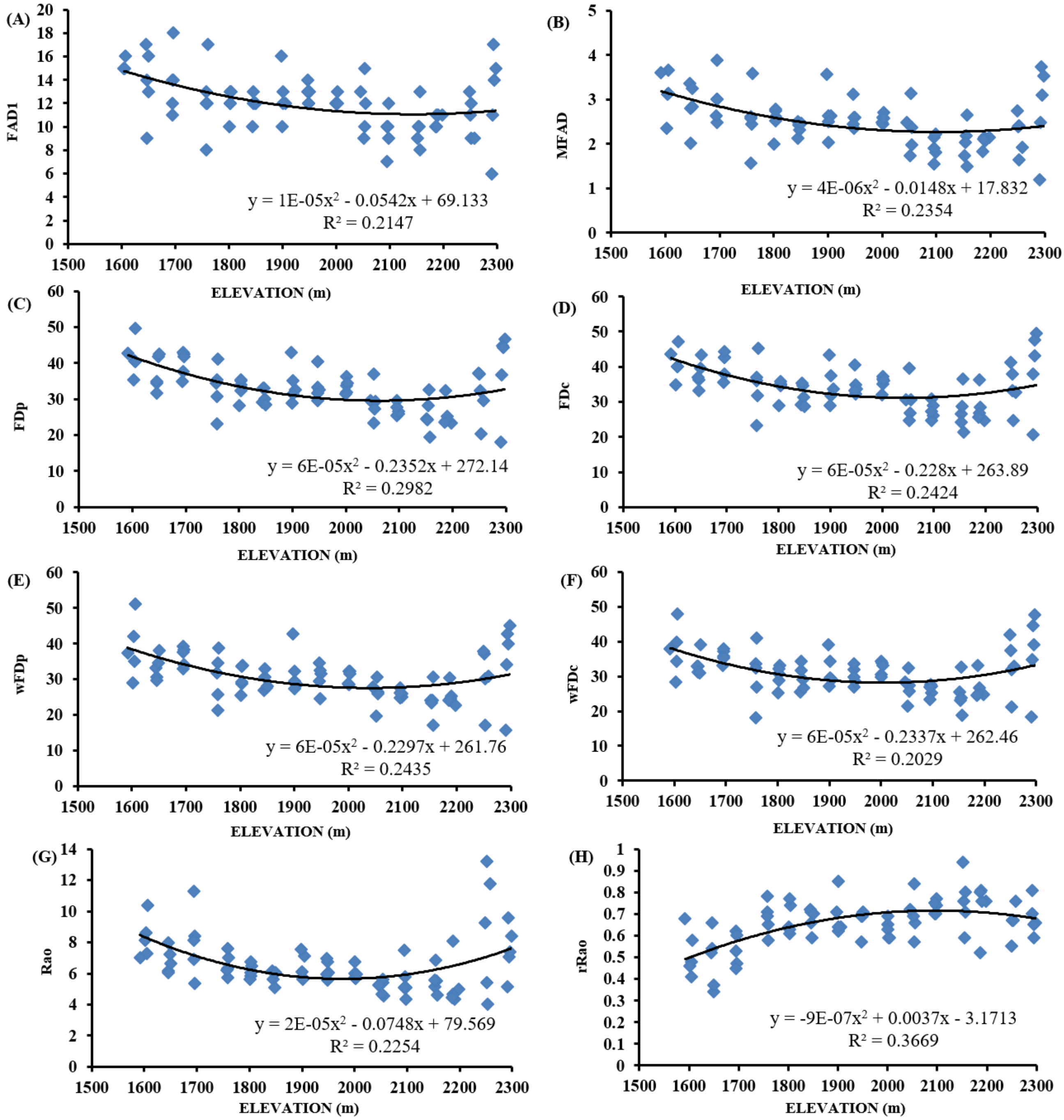

Fig. 2. Changes in functional diversity of *G. macrophylla* communities along elevation gradient in Dongling mountain meadow, Beijing, China. FAD, MFAD, FDp, FDc, wFDp, wFDc, Rao and rRao refer to functional attribute diversity, modified functional attribute diversity, plot based functional diversity, community based functional diversity, weighted FDp, weighted FDc, Rao's index and relative Rao's index respectively.

Table 2. Spearman correlation between environmental variables and functional diversity indices.

	FAD1	MFAD	FDp	FDc	wFDp	wFDc	Rao	rRao	FDiv	FDis
Altitude	-0.339**	-0.442***	-0.484***	-0.511**	-0.364***	-0.353**	-0.495**	0.616***	0.140	-0.359***
Slope	0.139	0.174	0.086	0.051	0.067	0.054	-0.046	-0.052	0.237*	0.008
Aspect	0.033**	0.007	-0.130	-0.040	-0.059	0.042	-0.219*	-0.053	-0.296**	-0.200
Soil pH	-0.052	-0.094	-0.015	-0.034	0.112	0.165	0.084	0.316**	0.542***	0.221*
Soil temp.	-0.034	-0.071	-0.180	-0.215	-0.150	-0.139	-0.192	0.195	0.174	-0.085
Soil type	-0.499***	-0.407***	-0.310**	-0.358***	-0.351**	-0.419***	-0.148	0.231*	-0.033	-0.078
Disturbance	0.341**	0.365*	0.231*	0.326*	0.211	0.193	0.168	-0.595***	-0.340**	0.026
Total N	-0.038	-0.089	-0.058	-0.104	0.009	0.031	-0.084	-0.092	-0.055	-0.094
Total P	0.187	0.264*	0.073	0.093	-0.004	-0.060	-0.006	-0.402***	-0.292**	-0.117
Total K	0.020	0.006	-0.026	0.054	-0.061	-0.076	-0.085	0.123	-0.102	-0.123
Mg	-0.154	-0.220*	-0.141	-0.111	-0.117	-0.076	-0.140	0.532***	0.238*	-0.036
Zn	0.235*	0.307**	0.328**	0.334**	0.300**	0.255*	0.346**	-0.722***	-0.344**	0.171

Note: *p<0.05, **p<0.01, ***p<0.001

Table 3. Spearman correlation between species diversity and functional diversity indices.

	FAD1	MFAD	FDp	FDc	wFDp	wFDc	Rao	rRao	FDiv	FDis
S	0.960***	0.911***	0.776***	0.781***	0.734***	0.715***	0.296**	O.486***	.194	0.259*
H	0.81***	0.814**	0.664***	0.685***	0.661***	0.682***	0.167	-.386***	-.181	.134
E	.075	.020	-.028	-.013	.034	.105	-.162	.065	-.076	-.172

Note: *p<0.05, **p<0.01, ***p<0.001

Table 4. Correlation coefficient among functional diversity indices.

	FAD1	MFAD	FDp	FDc	wFDp	wFDc	Rao	rRao	FDiv	FDis
FAD1	1.000									
MFAD	0.954***	1.000								
FDp	0.811***	0.893***	1.000							
FDc	0.815***	0.890***	0.979***	1.000						
wFDp	0.777***	0.846***	0.963***	0.951***	1.000					
wFDc	0.757***	0.820***	0.935***	0.956***	0.967***	1.000				
Rao	0.320**	0.477***	0.695***	0.653***	0.717***	0.659***	1.000			
rRao	-0.483***	-0.544***	-0.620***	-0.624***	-0.529***	-0.539***	-0.465***	1.000		
FDiv	-0.194	-0.216*	-0.337**	-0.357***	-0.282*	-0.311**	-0.253*	0.685***	1.000	
FDis	0.283**	0.436***	0.652***	0.610***	0.686***	0.635***	0.976***	-0.335**	-0.117	1.000

Note: *p<0.05, **p<0.01, ***p<0.001

Functional diversity and species diversity: Correlation coefficient between functional diversity and species diversity indices indicated that changes in functional diversity were significantly related to heterogeneity (Fig. 3) and species richness (Fig. 4) while no significant correlation was observed for species evenness (Table 3).

Relationship between functional diversity and species richness opposes the idea of those scientists who say these two should be independent of each other (Mason *et al.*, 2005). But as no two species can have exactly the same functional traits in a community especially when there are several traits under consideration, so greater number of plants will lead to higher functional diversity (Casanoves *et al.*, 2011). Bisvas & Malik (2011) pointed out a naïve philosophy in conservation ecology that high species diversity causes greater functional diversity that is necessary to maintain ecosystem functioning stability. Combination of functional diversity and species evenness is considered as a best predictor of risk of disease in multi-host communities (Chen & Zhou, 2015).

Principle component analysis: Principle component analysis (Fig. 5) depicted that eigenvalue for first axis was 0.8120 and total variation was 20.66 which are very low, it represents the close relationship of all the indices with each other. All ten indices successfully illustrated the variation pattern of functional diversity in *G. macrophylla* communities. However, effectiveness of functional diversity indices was distinct (Mason *et al.*, 2005). Keeping in view the significant relation with elevation all indices except FDiv, were efficient in functional diversity analysis (Petchey & Gaston, 2006). There was a significant correlation among nine indices (Table 4) as theoretically they were similar due to being established on functional distances between plant species (Zhang *et al.*, 2012).

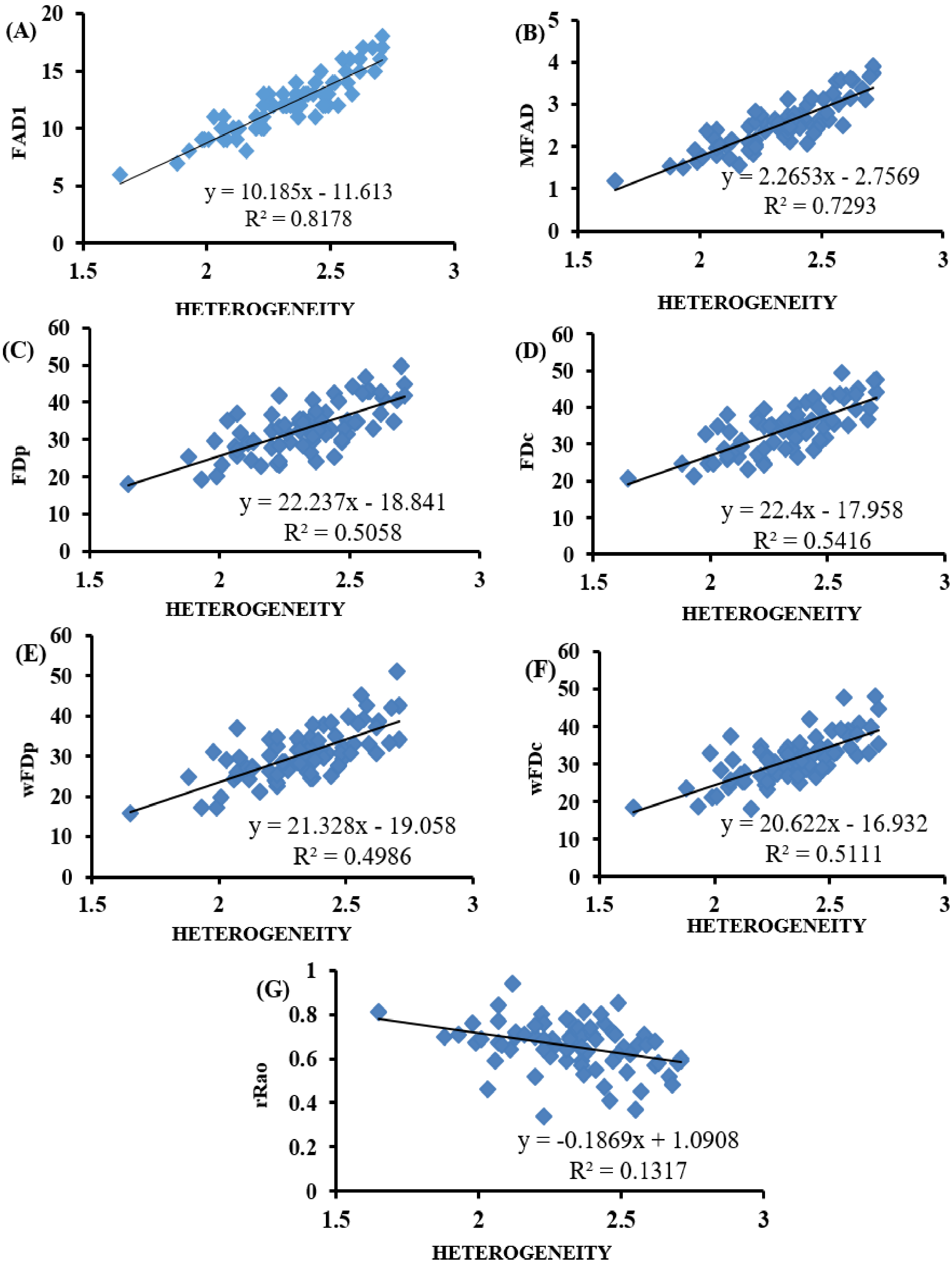

Fig. 3. Relationships between species' heterogeneity and functional diversity of *G. macrophylla* communities along elevation gradient in Dongling mountain meadow, Beijing, China. FAD, MFAD, FDp, FDc, wFDp, wFDc, Rao and rRao refer to functional attribute diversity, modified functional attribute diversity, plot based functional diversity, community based functional diversity, weighted FDp, weighted FDc, Rao's index and relative Rao's index respectively.

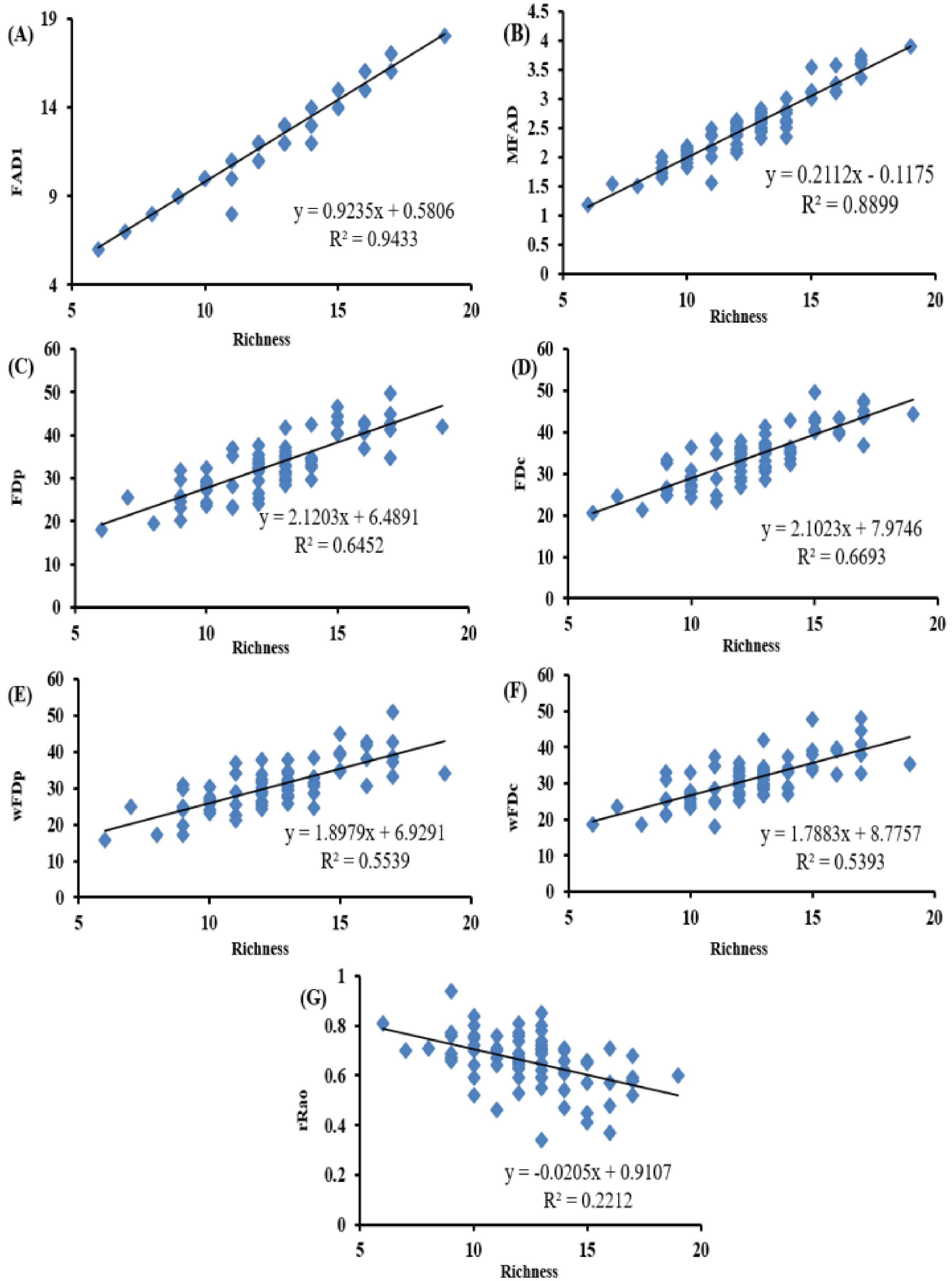

Fig. 4. Relationships between species' richness and functional diversity of *G. macrophylla* communities along elevation gradient in Dongling mountain meadow, Beijing, China. FAD, MFAD, FDp, FDc, wFDp, wFDc, Rao and rRao refer to functional attribute diversity, modified functional attribute diversity, plot based functional diversity, community based functional diversity, weighted FDp, weighted FDc, Rao's index and relative Rao's index respectively.

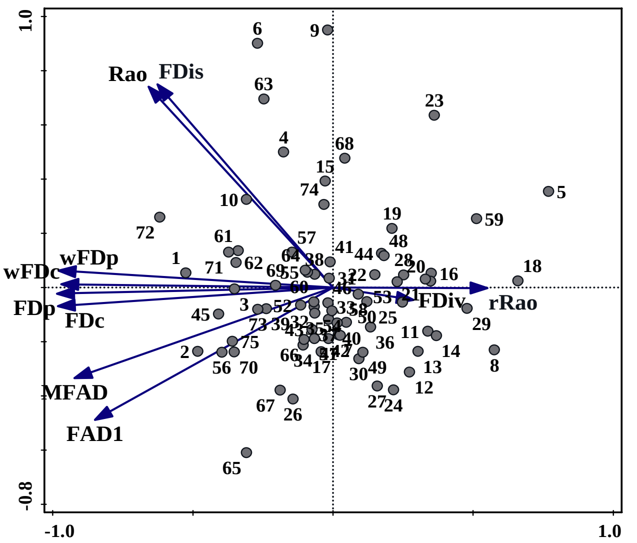

Fig. 5. PCA ordination diagram of ten measures of functional diversity in 75 quadrats of G. macrophylla communities in Dongling Mountain meadow, Beijing, China.

Conclusion

Use of different indices to study the pattern and fluctuation of functional diversity along elevation gradient of Dongling mountain meadow defined certain criteria which will prove helpful for management and conservation of *G. macrophylla* communities. Comparison analysis of different components of diversity leads to complete understanding of diversity and functioning of these communities.

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