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Review

Dynamics of environmental gradients on plant functional groups composition on the northern slope of the *Fu-Niu* Mountain Nature Reserve

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The dominant and companion species in plant functional groups composition may reflect associations among plant functional groups and species replacement along environmental (elevation) gradients on the northern slope of the *Fu-Niu* Mountain Nature Reserve. Using community ecology techniques, these researchers examined the influences of elevation on plant functional group (PFG) dynamics and population interactions at elevations between 855 and 1920 m on the northern slope of the *Fu-Niu* mountain nature reserve. Importance values (IV) of every dominant and companion species in plant functional groups composition were calculated and the correlation between elevation and species IV was analyzed. We showed that elevation was the most important environmental factor affecting the distribution pattern of plant functional groups composition. IV of dominant and companion species in plant functional groups composition were significantly correlated with elevation gradient (*P<0.05, P<0.01*) on the northern slope of the *Fu-Niu* Mountain. Understanding the changes and their causes in these PFG is essential for further research of local ecosystem functions and the goal of sustainable development in the context of biodiversity conservation. This study may help policy makers formulate better plant biodiversity conservation and restoration plans.

Key words: Plant functional groups, environmental gradients, importance values, elevation, correlation.

INTRODUCTION

The dominant and companion species in plant functional groups composition may reflect associations among plant functional groups and species replacement along environmental gradients from both abiotic factors (soil moisture, nutrients, disturbance, etc) and anthropogenic factors (land-use history, etc) (Liao and Wang, 2010, Liao et al., 2011; Smith et al., 1996; Tilman et al., 1997, 2006; Knapp et al., 2008; Körner and Jeltsch, 2008; Landsberg, 1999; Lenssen et al., 1999). However, ecosystems are typically filled with large numbers of plant species, making species-centered studies of systemic processes and functions extremely difficult, if not outright impossible, to carry out (Liao and Wang, 2010, Liao et al., 2011; Whiteman et al., 2010; Curitst and McIntosh, 1951).

Unfortunately, the plant functional group (PFG) concept is used as a framework for investigating the linkages between ecosystem functions and plant biodiversity (Ustin, 2010; Hooper and Dukes, 2004, Hooper and Vitousek, 1997; Raunkiaer, 1934; Smith et al., 1996; Chapin et al., 1996; Liao et al., 2010, 2011). Moreover, more and more experiments/ models have assessed the relationship between biodiversity and ecosystem processes from PFG perspective, which links plant functional traits (morphological, structural and functional characters) and ecosystem functioning (Liao and Wang, 2010, Liao et

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Abbreviations: **PFG**, Plant functional group; **IV**, importance values.

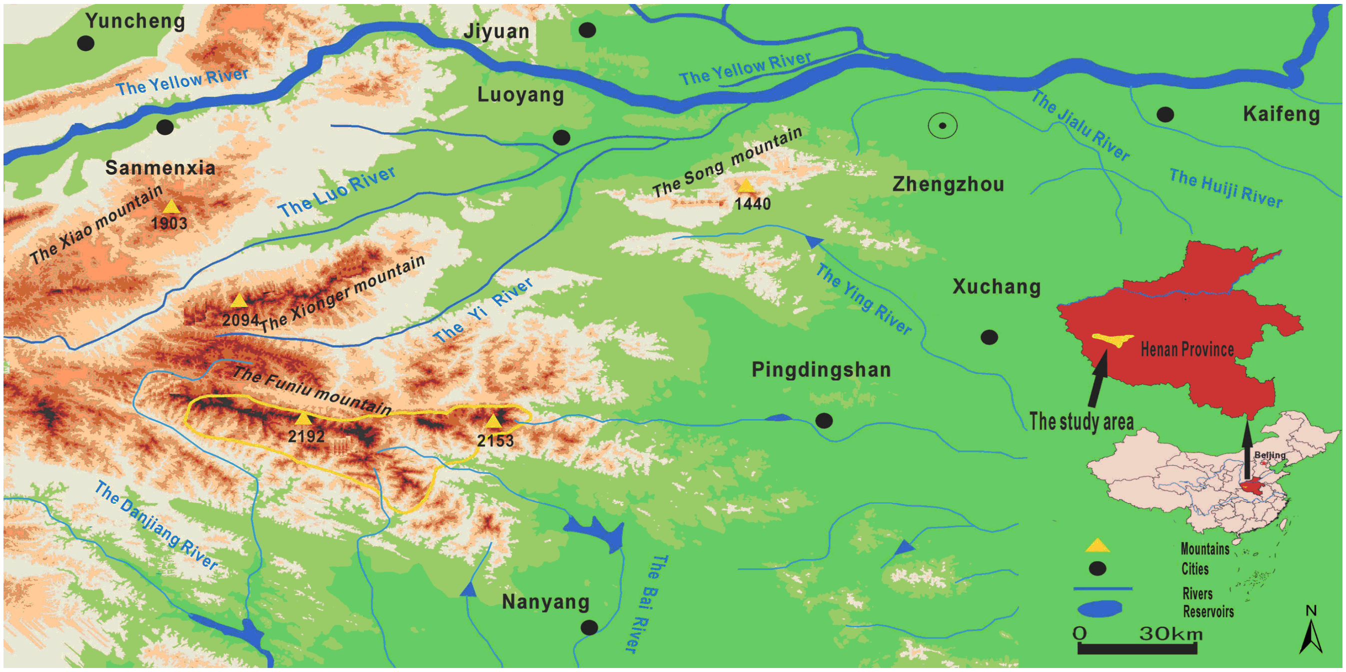

Figure 1. A digital cadastre map in the *Fu-Niu* Mountain Natural Reserve.

al., 2011; Kraft et al., 2008; Ratnam et al., 2008; Bai et al., 2004; Wang et al., 2005; Hooper and Dukes, 2004; Ogle and Reynolds, 2004; Loreau et al., 2001; Symstad et al., 2000; Grime, 1974, 1979, 1988, 2002; Walker et al., 1999; Sandra et al., 1998; Kelly, 1996; Smith et al., 1996; Chapin, 1996; Nobel et al., 1996; Shao et al., 1996; Woodward et al.,1996; Pahl, 1995; Reynolds, 2004; Box, 1981,1996; Root, 1967; Clausen et al., 1948; Raunkiaer, 1934; Schimper, 1903; Von Humboldt, 1849). For example, Von Humboldt (1849) found that there are 16 species-based structural classes having different physiognomies or plant growth forms. Schimper (1903) examined the linkages between the geographical distributions of physiological functions, plant growth forms, life history traits and environmental factors. By using classification knowledge, Raunkiaer (1934) re-organized life forms into plant growth forms. Clausen et al. (1948) also found the relationship between climatic and genetic controls on the distribution of plant growth forms. Root (1967) explained the linkages between ecological groupings of species and environmental resources. In a similar way, Box, (1981) identified 90 plant functional groups in the earth's vegetations. In addition, Nobel et al. (1996) proposed a functional classification based on life history parameters that can be used to predict the dynamics of landscapes and communities.

Studying a grassland ecosystem, Bai et al. (2004) found that community level stability arose from compensatory interactions among major components at both species and PFG levels, and ecosystem stability increased progressively from the species level to the whole community level. Wang et al. (2004) suggested that there are no compensations between species and PFGs in the Leymus chinensis community, and the relative mass of one PFG or species in a community would inevitably rise (or fall) if the relative mass of the other PFG or species fell (or rose), irrespective of whether true compensation exists between them. Therefore, the objective of this study was to define the relationship between elevation gradient and IV of dominant and companion species in plant functional groups composition along environmental (elevation) gradients at elevations between 855 and 1920 m on the northern slope of the *Fu-Niu* Mountain Nature Reserve.

THE PHYSICAL GEOGRAPHIC CONDITIONS OF STUDY AREA AND RESEARCH METHODS

The forest ecosystems in the *Fu-Niu* Mountain Natural Reserve are results of the historical natural activities. Over the past thirty years local people has been involved in a mass exploitation of natural resources, leading to significant changes in the local ecosystem structure, which also means changes in ecosystem functions in means of land uses, biodiversity, and ecosystem stability. A field investigation was conducted in May and November, 2006 to study the distribution patterns and the abundance features of the species in different habitats on the *Fu-Niu* Mountain, investigating the distribution patterns and the abundance features of the species in different habitats along the elevation gradient in the typical area of the *Fu-Niu* Mountain Natural Reserve, which is ideal for studying PFGs (Figures 1 to 3; Tables 1 and 2).

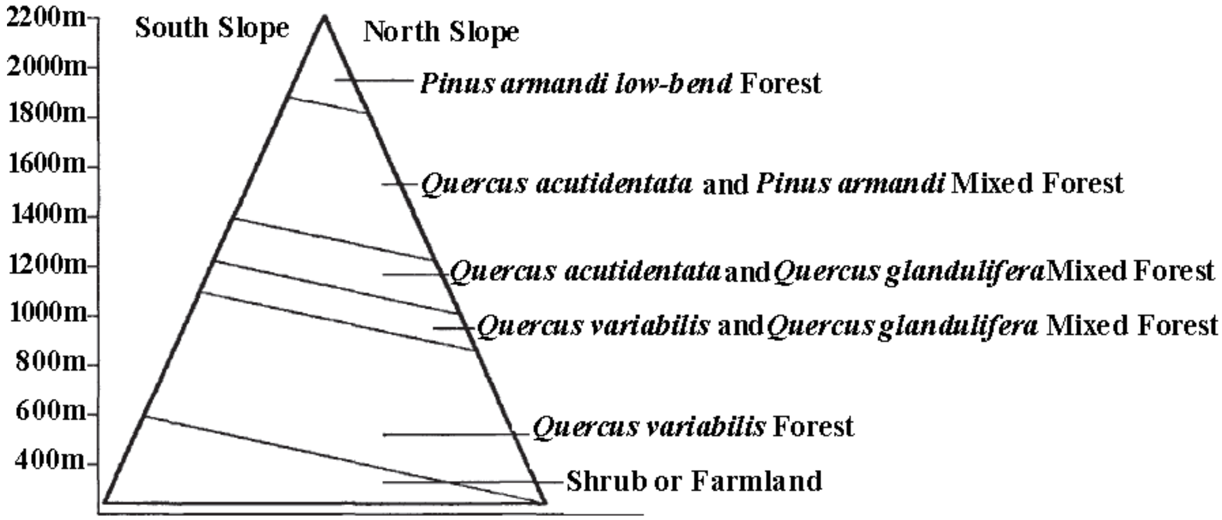

Figure 2. The *Fu-Niu* Mountain Vegetations.

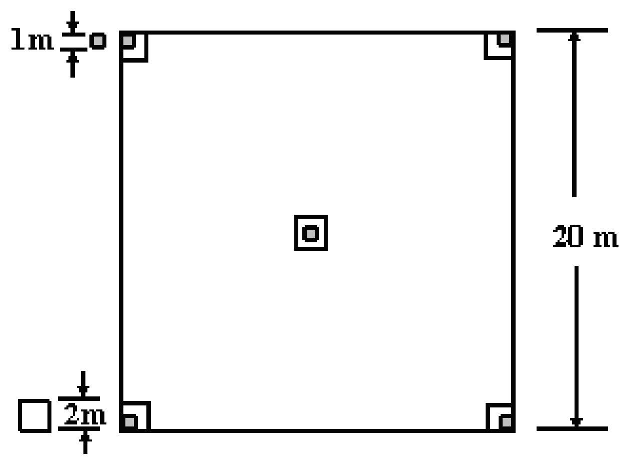

Figure 3. Quadrate settings.

Using community ecology techniques, we investigated all plant species (dominant/companion herbaceous species), along elevation gradients (temperature, moisture, soil, etc.) of the *Fu-Niu* Mountain Natural Reserve in May and November, 2006, at elevations between 855 and 1920 m. Three study plots were established per 100 m elevation. A total of 33 plots were set. Each study plot, consisted of one 20 × 20 m tree layer quadrate, five (the center and four corners of the study plot) 2 × 2 m shrub layer quadrates and five 1 ×1 m herbaceous layer quadrates. There were thus 30 tree layer, 150 shrub layer, and 150 herbaceous layer quadrates all together (Figures 2 and 3; Tables 1 and 2). Plant species identified during this investigation were assigned into three PFGs according to plant life form (Diaz et al., 1999; McIntrye et al., 1995): 1) trees; 2) shrubs and 3) herbaceous species. Importance values of dominant and companion species were calculated using the following formula (Curitst and McIntosh, 1951):

Important Values = Relative dominance + relative density + relative frequency

Where, Relative dominance = (Dominance of a species / Dominance of all species) ×100%; Relative density = (Number of individuals of a species / Total number of individuals) ×100% and Relative frequency = (Frequency of a species / Sum frequency of all species) ×100%

The correlation between elevation and species importance value was then analyzed by SPSS and NTSYS. Importance values of the plant species investigated varied significantly along the elevation gradient at PFGs levels along elevation gradient on the northern slope of the *Fu-Niu* Mountain Natural Reserve (Figures 4 to 8; Table 3).

Table 1. The physical geographic conditions of *Fu-Niu* Mountain nature reserve.

Location	Climatic							Elevation (m) †	Area (hm^2)	Vegetation
	Precipitation (mm)	Mean Temperature (ºC)								
		Annual Mean		Maximum		Minimum				
		South slope	North slope	South slope	North slope	South slope	North slope			
Latitude (º): 32.75 —34.00 Longitude(º): 110.50—113.01	800—1100	14.1 - 15.1	12.1 - 12.7	26.5 - 28.5	26.5 - 28.5	1 - 2	1.5 - 2	640—1920	56000	Straddling mixed vegetation zones of the subtropical and warm-temperate zones of East China, the *Fu-Niu* Mountain National Reserve is representative of north-south climatic transition zones.

†Above sea level.

Table 2. Investigation Index along the elevation gradient variable.

Investigation	Layer	Community	Species	Height	Crow	Diameter
Community investigation	Tree/shrub /herbaceous	Coverage/community's age structure	Species/ individual number	Layer's Height	Crow height/ width	Basal diameter

RESULTS

Dynamics in importance values of the dominant/companion tree species along elevation gradient at PFGs levels

On the one hand, this study has shown that two dominant tree species (*Quercus variabilis* and *Q. glandulifera*) importance value decreases, while five dominant tree species (*Q. acutidentata*, *Pinus tabulaeformis*, *Q. aliena*, *Pinus armandii* and *Platycarya strobilacea*) important value increased along elevation gradients in the *Fu-Niu* Mountain Natural Reserve along elevation gradient (Figure 4; Table 3). On the other hand, this study has shown that there are three companion tree species (*Rhus chinensis*, *Toxicodendron vernicifluum* and *Tilia L.* spp.) important value decreases, while the three companion tree species (*Lindera obtusiloba*, *Carpinus cordata*, *Carpinus turczaninowii*) important value increased along elevation gradients (Figure 4b; Table 3).

Dynamics in importance values of the dominant/companion shrub species along elevation gradient at PFGs levels

dominant shrub species (example *Q. variabilis*, *Tilia chinensis* and *Q. acutidentata*) important value decreases, while five dominant shrub species (example *Crataegus cuneata*, *Q. glandulifera*, *Forsythia suspensa*, *Q. aliena* and *Pinus armandii*) important value increases along elevation gradients (Figure 6; Table 3). On the other hand, this study showed that only two companion shrub species (*Pinus tabulaeformis* and *Rhododendron simsii*) important value decreases, while five companion shrub species (*Acer davidii*, *Carpinus turczaninowii*, *Platycarya strobilacea*, *Acer mono* increases and *Euonymus alatus*) important value increases along elevation gradient (Figure 7; Table 3).

Dynamics in importance values of the dominant/companion herbaceous species along elevation gradient at PFGs levels

On the one hand, this study shows that there is one dominant herbaceous species (*Carex lanceolata*) important value decreases, while there are two dominant herbaceous species (*Miscanthus sinensis* and *Carex siderosticta*) On the one hand, this study shows that three important value increases along elevation gradient (Figure 8a; Table 3). On the other hand, this study also showed that three companion herbaceous species (*Dendranthema indicum*, *Q. variabilis*, *Rodgersia aesculifolia*) important value decreases,

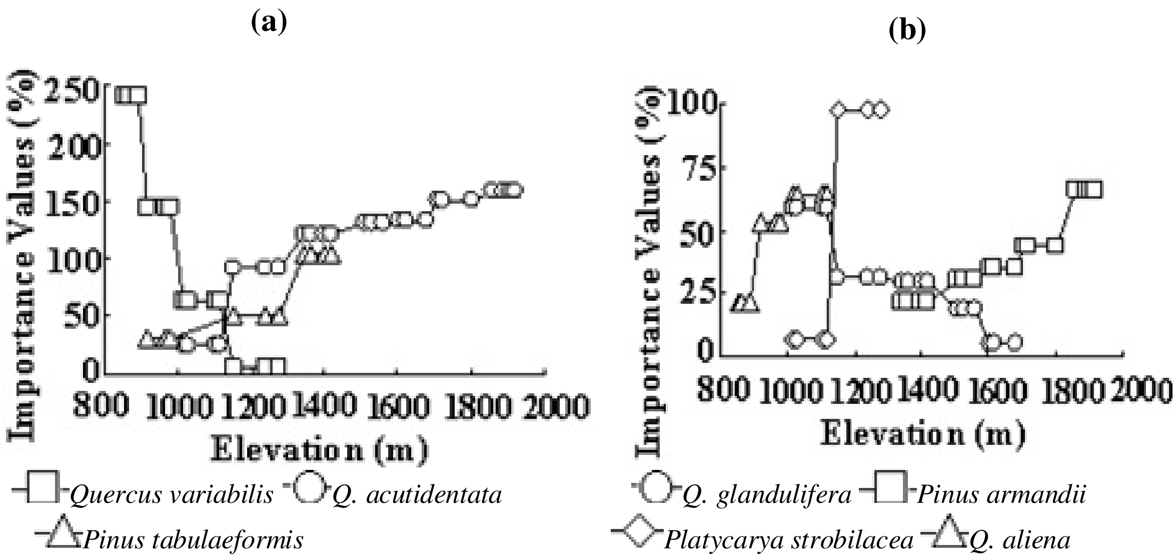

Figure 4. (a) Dynamics in importance values of the dominant tree species (1) and (b) dominant tree species (2).

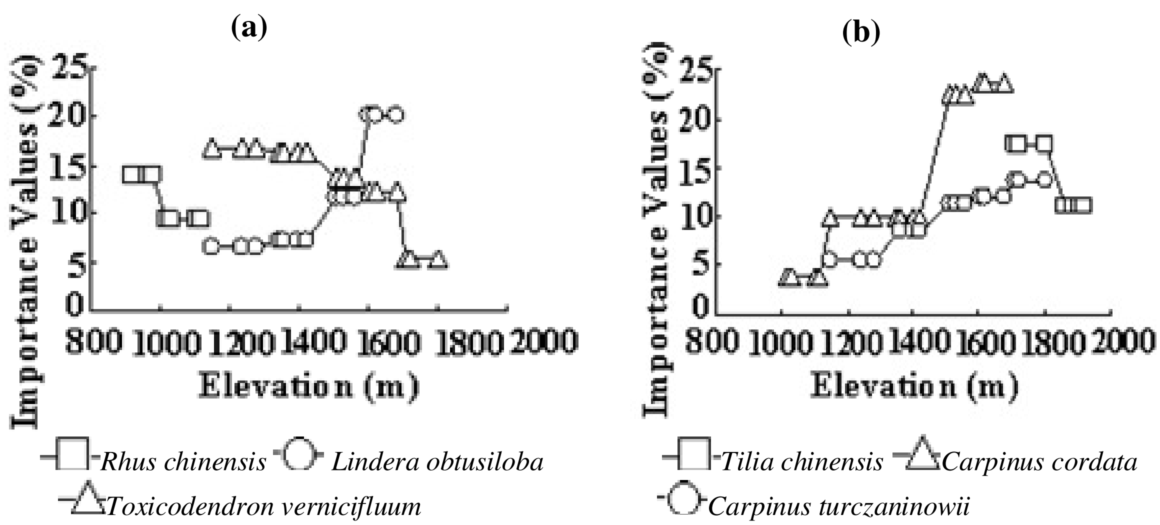

Figure 5. (a) Dynamics in importance values of the companion tree species (1) and (b) companion tree species (2).

while three companion herbaceous species (example *Lespedeza bicolor*, *Forsythia suspense*, *Rubus palmatus*) important value increases along elevation gradient (Figure 8b; Table 3). However, what are the environmental factors drivers contributed greatly to PFGs changes along elevation gradient on the northern slope of the *Fu-Niu* Mountain Natural Reserve? To do this, the correlation between elevation and IV of dominant/ companion species was then analyzed (Table 3).

Importance values of the plant species investigated

This study shows that IV of dominant/companion species in plant functional groups composition in plant functional groups were significantly correlated with elevation gradient (P<0.05, P<0.01) (Table 3).

DISCUSSION

Previous study showed that in shoreline vegetation, the role of plant interactions in determining zonation patterns depends on the environment gradient of both species and PFG levels (Lenssen et al., 1999). By using classification knowledge, Raunkiaer, (1934) reorganized life forms into plant growth forms. Moreover, by analyzing a consistent above ground community biomass of a 24-year data

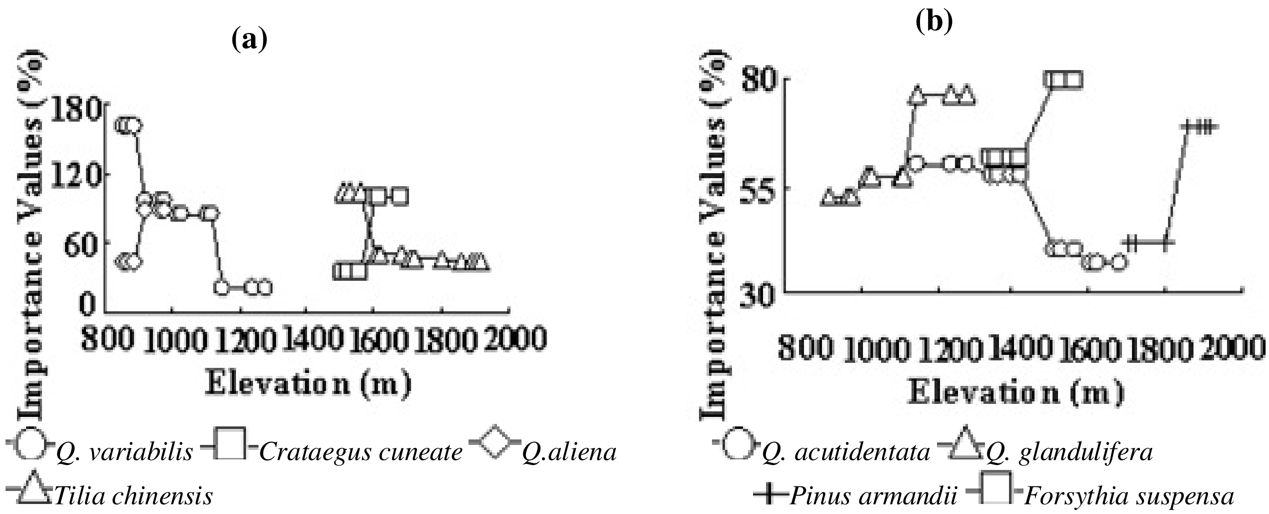

Figure 6. (a) Dynamics in importance values of the dominant shrub species (1) and (b) dominant shrub species (2).

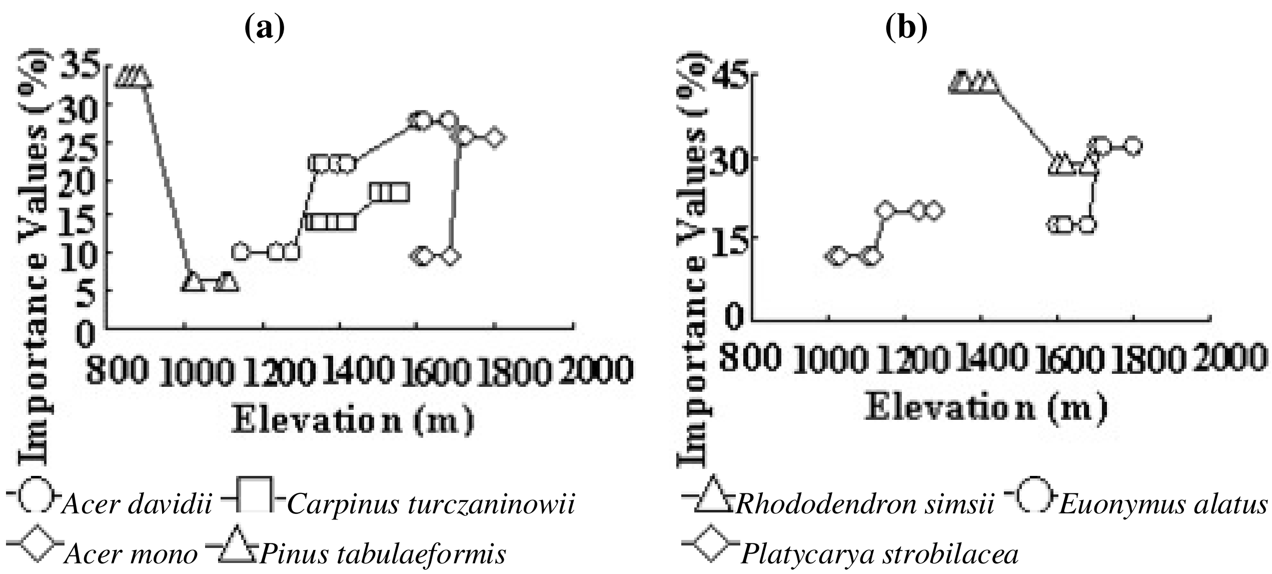

Figure 7. (a) Dynamics in importance values of the companion shrub species (1) and (b) companion shrub species (2).

set of the Inner Mongolia grassland, Bai et al. (2004) found that community level stability arose from compensatory interactions among major components at both species and PFG levels, and ecosystem stabilityincreased progressively from the species level to the whole community level. In addition, Liao et al. (2011) showed that elevation was the most important environmental factor affecting the distribution pattern of biomass of plant functional groups composition. Hence, the forest ecosystems on the northern slope of the *Fu-Niu* Mountain Natural Reserve are results of the historical natural activities.

Therefore, the results indicated that elevation was the most important environmental factor affecting the distribution pattern of the plant functional groups composition (example dominant/companion species). This study supported the hypothesis that environmental (elevation) gradient is a major ecological factor affecting PFG diversity and composition in the natural ecosystems (Smith et al., 1996; Grime, 1974, 1979, 1988, 2002; Kueppers et al., 2004; Lenssen et al., 1999; Walker et al., 1999). Moreover, the relationship between IV of dominant/companion species in PFGs composition and elevation gradient seems important along environmental (elevation) gradient on the northern slope of the *Fu-Niu* Mountain Natural Reserve from PFG perspective.

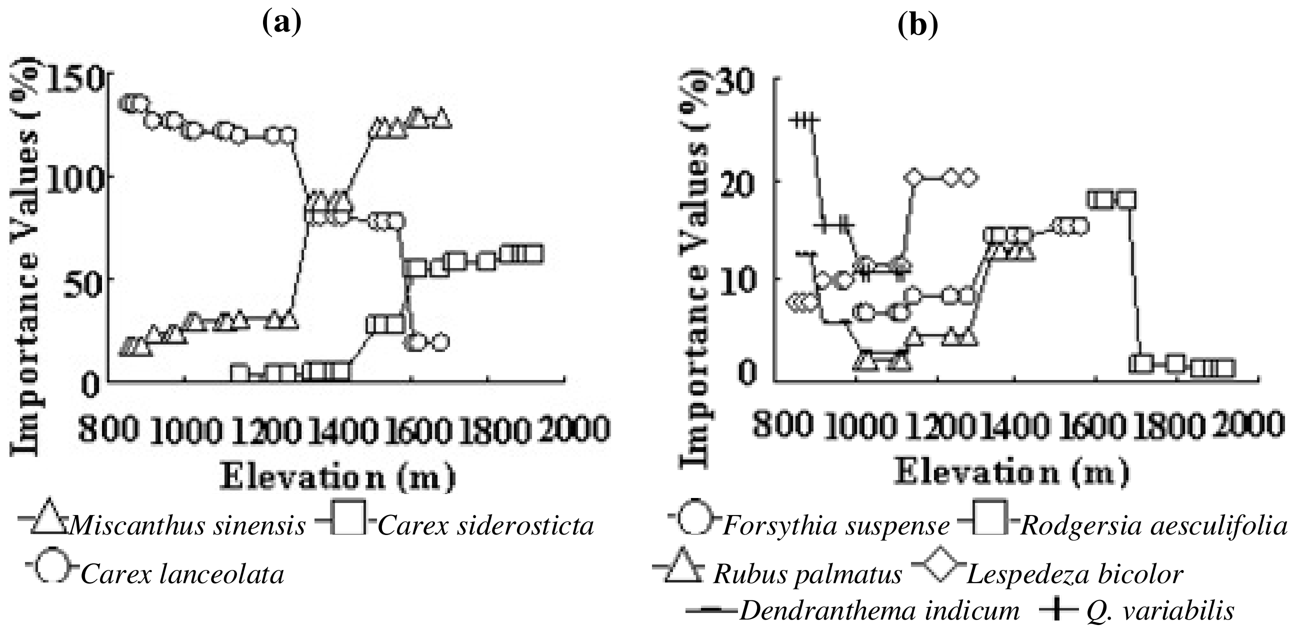

Figure 8. (a) Dynamics in importance values of dominant herbaceous species and (b) companion herbaceous species.

Table 3. The correlation between elevation and IV of dominant and companion species in plant functional groups composition.

Tree layer	Correlations	Shrub layer	Correlations	Herb layer	Correlations
Q. variabilis	-0.926**	*Q. variabilis*	-0.924**	*Carex lanceolata*	-0.910**
Q. glandulifera	-0.943**	*Q. glandulifera*	0.890**	*C. siderosticta*	0.934**
Q. aliena	0.874**	*Q. aliena*	0.897*	*Miscanthus sinensis*	0.947**
Pinus armandii	0.957**	*Q. acutidentata*	-0.923**	*Forsythia suspensa*	0.937**
Q. acutidentata	0.914**	*Crataegus cuneata*	0.882*	*Rubus palmatus*	0.915**
Pinus tabulaeformis	0.907**	*Tilia chinensis*	-0.760**	*Lespedeza bicolor*	0.909**
Platycarya strobilacea	0.847*	*Forsythia suspensa*	0.945**	*Q.variabilis*	-0.896**
Toxicodendron verniciﬂuum	-0.876**	*Pinus armandii*	0.921**	*Dendranthema indicum*	-0.888**
Lindera obtusiloba	0.872**	*Acer davidii*	0.904**	*Rodgersia aesculifolia*	-0.802**
Rhus chinensis	-0.833*	*Pinus tabulaeformis*	-0.942**		
Carpinus cordata	0.930**	*Acer mono*	0.823*		
C. turczaninowii	0.974**	*Carpinus turczaninowii*	0.945**		
Tilia chinensis	-0.921**	*Platycarya strobilacea*	0.847*		
		Rhododendron simsii	-0.971**		
		Euonymus alatus	0.823*		

*P<0.05; **P<0.01.

Conclusion

This study may help policy makers formulate/approach (example, evaluating /model/theory systems, plant traits/ biomass mechanistic approach, quantification of hemicelluloses, scale dependence) better biodiversity (landscape diversity, ecosystem diversity, community diversity, meta-population diversity, functional groups diversity, species diversity, seeds diversity, and genetic diversity) conservation and restoration plans (example the relationship between climate change and biodiversity, organic agriculture, the relationship between soil-plant-animal, the relationship between ecosystems and bio-diversity) (Chazal and Rounsevell, 2009; Clark and McLachlan, 2004; Dirzo and Loreau, 2005; Esther, 2008; Funes, 1999; Gilbert, 2010; Hanski, 2005; Hector and Bagchi, 2007; Heller and Zavaleta, 2009; James and Vorhies, 2010; Keeling et al., 2008; Liao et al., 2010, 2011; Vázquez et al., 2009; Thompson, 1994; Steinmann et al., 2009; Shipley et al., 2006; Schädel et al., 2010;

Crowder et al., 2010; Navarro et al., 2006; Kumaresan et al., 2010; McCann, 2000).

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