Variations in Species and Functional Plant Diversity among Forest Types on the Ridge of the Baekdudaegan Mountains, South Korea

Chang-Bae Lee1,2 · Hyun-Je Cho3 · Jung-Hwa Chun4 · Ho-Kyung Song5 · Hyungho Kim6,4*

1 Korea Green Promotion Agency, 121 Dunsanbukro, Seogu, Daejeon 302-831, Korea
2 Department of Forest Resources, Chungnam National University, 99 Daehakro, Yuseonggu, Daejeon 305-764, Korea
3 Institute of Agriculture and Life Sciences, Gyeongsang National University, Jinju 660-701, Korea
4 Department of Forest Environmental Resources, Gyeongsang National University, Jinju 660-701, Korea
5 Korea Forest Ecosystems Institute, 7-19 Hobakro 43gil, Bukgu, Daejeon 702-110, Korea
6 Division of Forest Ecology, Korea Forest Research Institute, 57 Hoegiro, Dongdaemun, Seoul 130-712, Korea

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ABSTRACT

This study was conducted to compare species and functional diversity of terrestrial plants among forest types by analyzing the variations in species and functional trait compositions in a large-scale natural forest ecosystem. Plant data were collected at 1,100 plots and a total of 802 plant species from 97 families and 342 genera were found along the ridge of the Baekdudaegan Mountains in South Korea. Forest types were divided into four categories including Quercus mongolica, Pinus densiflora, other deciduous and other coniferous forest types. To analyze the variations in plant diversity among forest types, we used two species diversity indices such as species richness and the Shannon-Weaver index as well as a newly introduced functional diversity such as Rao’s index. In functional trait composition, megaphanerophyte, geophyte and hemicyryptophyte were the dominant traits, whereas the relative proportion of helophyte and hydrophyte and epiphyte indicated less than 1%. In diversity patterns among forest types, species richness and diversity for total plants showed the lowest value in P. densiflora forest type, while other deciduous and Q. mongolica forest types had the highest values of species richness and diversity for woody and herbaceous plants, respectively. However, functional diversity did not depict a clear distinction among four forest types for plant groups. This study suggests that although taxonomical richness and diversity may be different among forest types, there may be no differences in functional diversity. Moreover, these indistinct patterns in functional diversity may be a result of disturbance and successional gradients compounded in a forest type in addition to the type of functional traits used for comparison and contrast among forest types. Therefore, a further study with various functional traits and different environmental gradients should be consistently evaluated to achieve a better understanding of the diversity patterns of plant communities in mountain ecosystems.

Key words - Baekdudaegan Mountains; Forest type; Functional diversity; Species diversity; Species richness

*Corresponding author: Hyungho Kim
Tel: +82-55-772-1857
Fax: +82-55-772-1859
E-mail: khh@gnu.kr
I. INTRODUCTION

Biodiversity is a key issue of nature conservation and consists of all the natural resources that provide useful goods and services for human beings (Hakim et al., 2012). The diversity in plants is especially fundamental to total forest biodiversity as plants provide resources and habitats for almost all other forest species (Pandeya et al., 2007; Ozcelik and Eler 2009). A number of complex and interacting variables affect the spatial variation in plant diversity. At relatively small spatial scales, environmental variables, such as chemical and physical soil properties (Fu et al., 2004; Poulsen et al., 2006), topography (Cielo-Filho et al., 2007), canopy gaps (Slik et al., 2002), and human disturbance variables, such as logging (Slik et al., 2002) and livestock grazing (McEvoy et al., 2006), are important drivers of community structure and diversity. On a larger scale, climatic variables, altitude, latitude, soil, and forest types are frequently used to explain differences in diversity (Archibold, 1995; Lee et al., 2012).

Plant diversity varies basically and naturally among forest types. A forest type can be generally defined as a category of forest it is distinguished by its composition and site factors, as categorized by each country in a system suitable to its situation. Using forest type categories is a flexible approach to collecting and organizing forest information, including biodiversity inventory in a given region, according to a typology which is useful for understanding differences that are relevant to a specific application (Barbati and Marchetti, 2004). Forest types optimize sustainable forest management and biodiversity assessment. Every plant community, belonging to a particular forest type, will not display the same level of diversity as other communities within the forest type. Geography, forest history, soils, water and other factors, create variability within a particular forest type. The differences in diversity among forest types along environmental gradients are regarded as the changes of plant diversity. The changes in species composition among forest types strongly imply concurrent changes in both diversity pattern and ecosystem functioning in natural forest ecosystems (Sun et al., 2009). It is one of the most important elements in biodiversity studies and is helpful for discovering the correlations between biodiversity and ecological factors.

In recent years, many investigators have demonstrated that biodiversity plays a pivotal role in ecosystem functioning, such as productivity, stability and resilience, and perhaps reduces invisibility with evidence explored from both theoretical and experimental approaches (Engelhardt and Ritchie, 2002). Although biodiversity has been defined as the variety of life forms at all levels of biological organization, including taxonomic, genetic, phoenetic and phylogenetic diversity (Tilman, 2001; Stevens et al., 2003), species diversity has long been recognized and used as the most important component and measurement of biodiversity in many studies (Naem et al., 1994). However, in recent decades, traditional biodiversity indices, such as species richness and diversity, have been supplemented or replaced by functional diversity, which is used to measure those components of biodiversity that influence how an ecosystem operates or functions (Lewis et al., 2010). Functional diversity
is defined as the extent of functional differences among the species in a community or ecosystem and is often used to describe several different aspects of community or ecosystem structure, such as the variation in the functional characters (Petchey and Gaston, 2002).

In this context, although many studies have examined variations in species diversity among forest types, and it has been generally recognized that broad-leaved or mixed forests have a higher diversity than those of pure coniferous forests, few studies have analyzed the variations of both plant species and functional diversity among forest types in large-scale natural forest ecosystems (Saha, 2003). Therefore, the aims of this study are to: (1) compare and contrast species and functional diversity of terrestrial plants among forest types by analyzing the variations in species and functional trait compositions, on a broad scale, along the ridge of the Baekdudaegan Mountains (hereinafter referred to as ‘the Baekdudaegan’) in South Korea and (2) discuss the potential causes for differences in species and functional diversity among forest types.

II. MATERIALS AND METHODS

2.1 Study area

The study transect covered the main ridge of the Baekdudaegan (35°15’-38°22’N, 127°28’-129°3’E) in South Korea (Figure 1). The Baekdudaegan consists of about 487 mountains, hills, and peaks, which run along the Korean peninsula and are a major resource for forest biodiversity (Korea Forest Research Institute, 2003). The protected area of the Baekdudaegan was designated in September 2005 by the Korea Forest Service; the total protected area, including the main ridge, covers 2,634 km² (1,712 km² core area and 922 km² buffer zone). The main ridge extends about 650 km from Hyangnobong Peak (1,287 m above sea level, a.s.l) to Mt. Jiri (1,917 m a.s.l) in South Korea. Therefore, one can travel along the ridgelines without crossing any rivers or streams. The altitudinal gradient of the main ridge extends from 200 to 1,909 m a.s.l., based on a digital elevation model (DEM) generated using a mosaic of 1:25000 topographical maps, produced by the National Geographic Information Institute that covers the study area.

The Baekdudaegan in South Korea belongs to a mountain ecoregion and temperate deciduous forest biome (Yim and Kim, 1975; Shin, 2002). The soil consists of granite, granite gneiss, and highly deformed and recrystallized sedimentary rocks (Shin, 2002). Even though the natural environment of the Baekdudaegan is not well known due to insufficient survey data, the Baekdudaegan has many biodiversity hotspots and offers a natural habitat for abundant and varied fauna and flora. The Korea Forest Research Institute (2003) reported that a total of 1,477 plant species were distributed along the Baekdudaegan accounting for 35.2% of the vascular plant diversity on the Korean peninsula.

The vegetation on the Baekdudaegan can be categorized into 49 communities, including 7 planted communities (e.g., the Larix kaempferi community) and 42 natural vegetation communities (e.g., the Quercus mongolica community). The Korea Forest Research
Fig 1. Location, topography, and climate diagrams of the study area on the ridge of the Baekdudaegan Mountains, South Korea. Graphs show relationships between (a) latitude and altitude and between altitude and (b) mean annual temperature and (c) precipitation. Mean annual temperature and precipitation were calculated for each altitudinal band along an imaginary 100-m-wide transect on the ridge of the Baekdudaegan Mountains.

Institute (2003) divided the Baekdudaegan in South Korea into three parts, based on characterized plant community groups: (1) The northern part, characterized by *Acer komarowii* and *Betula ermanii*, (2) The central part, characterized by *Acer pseudosieboldianum* and *Fraxinus rhynchophylla*, and (3) The southern part, characterized by *Abies koreana* and *Fraxinus mandshurica*. The vegetation on the Baekdudaegan can also be divided into four major zones along an altitudinal gradient. These altitudinal vegetation zones include: (1) Temperate (montane) deciduous broad-leaved and pine forest (< 550 m a.s.l) dominated by *P.
Table 1. Vegetation characteristics among four forest types along the ridge of the Baekdu-daegan, South Korea.

<table>
<thead>
<tr>
<th>Forest type</th>
<th>QM</th>
<th>PD</th>
<th>OD</th>
<th>OC</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. plots</td>
<td>378</td>
<td>176</td>
<td>362</td>
<td>184</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>1,101 ± 283²</td>
<td>700 ± 299</td>
<td>873 ± 384</td>
<td>1,401 ± 337</td>
</tr>
<tr>
<td>Direction (°)</td>
<td>88 ± 110</td>
<td>164 ± 80</td>
<td>161 ± 119</td>
<td>65 ± 91</td>
</tr>
<tr>
<td>Slope (°)</td>
<td>23.4 ± 11.1</td>
<td>21.8 ± 12.8</td>
<td>22.6 ± 11.1</td>
<td>24.5 ± 20.2</td>
</tr>
<tr>
<td>Coverage of upper tree (T1) layer</td>
<td>67.3 ± 18.4</td>
<td>61.4 ± 20.5</td>
<td>66.4 ± 18.0</td>
<td>58.8 ± 22.5</td>
</tr>
<tr>
<td>Coverage of lower tree (T2) layer</td>
<td>35.7 ± 23.4</td>
<td>36.6 ± 24.3</td>
<td>41.8 ± 22.0</td>
<td>43.4 ± 21.6</td>
</tr>
<tr>
<td>Coverage of shrub (S) layer</td>
<td>37.2 ± 20.7</td>
<td>43.9 ± 23.5</td>
<td>40.0 ± 22.6</td>
<td>40.5 ± 21.4</td>
</tr>
<tr>
<td>Coverage of herb (H) layer</td>
<td>34.9 ± 23.4</td>
<td>26.7 ± 18.5</td>
<td>26.2 ± 23.9</td>
<td>49.7 ± 28.1</td>
</tr>
<tr>
<td>Average number of species</td>
<td>23</td>
<td>20</td>
<td>24</td>
<td>23</td>
</tr>
</tbody>
</table>

Tree species
- Quercus mongolica
- Pinus densiflora
- Pinus koraiensis
- Tilia amurensis
- Fraxinus mandshurica
- Fraxinus chinesis
- Betula schmidtii
- Betula costata
- Betula ermanii
- Malus baccata
- Picea jezoensis
- Abies koreana
- Abies nephrolepis
- Sorbus commixta
- Maackia amurensis var. amurensis
- Acer barbinerve
- Acer ukurunduense
- Rhus tricocarpa

Shrub species
- Lonicera sachalinensis
- Deutzia glabrata
- Symlocos chinensis for. pilosa
- Lespedeza bicolor
- Alangium platanyfolium var. trilobum
- Rhododendron brachycarpum

Herbaceous species
- Carex humilis var. nana
- Spodiopogon cotulifer
- Atractylodes ovata
- Dendranthema zawadskii var. latilobum
- Solidago virgaurea subsp. asiaticavar.asiatica
- Viola japonica
- Clintonia udensis
- Lycopodium serratum
- Lycopodium chinense
- Melica onoi
- Primula jesoana
- Arachniodes borealis
- Vicia chosenensis

Q, M, PD, OD and OC indicate Q.mongolica, P.densiflora, other deciduous and other coniferous forest types, respectively.
²Mean ± standard deviation.
³Mean percentage frequency (mean coverage) is shown for a species in each forest type. ÷ and = mean less than 1% mean coverage and no individuals observed, respectively. The other species were omitted by the authors.
densiflora and Rhus tricocarpa, (2) Temperate deciduous broad-leaved and coniferous mixed forest (550-1,100 m a.s.l) dominated by Quercus mongolica, Quercus serrata, Pinus koraiensis, and Abies holophylla, (3) Sub-alpine coniferous forest (1,100-1,600 m a.s.l) dominated by Taxus cuspidata, Abies koreana, and Abies nephrolepis, and (4) Alpine forest (> 1,600 m a.s.l) dominated by Betula ermanii and Pinus pumila (Yim, 1977; Kong, 2008).

2.2 Vegetation sampling and data analysis

For field sampling, an imaginary 100m-wide transect was established in a north-south direction along the ridge of the Baekdudaegan. Plant data were collected from this 100m-wide transect between May 2005 and August 2009 and vegetation sampling was performed to cover the most common and specific physiognomic vegetation types. The data were obtained from a total of 1,100 plots of 400 m² in size. Plants in each plot were surveyed following the method proposed by Braun-Blanquet (1965).

In order to compare and contrast plant diversity patterns among forest types on the ridge of the Baekdudaegan, forest types were divided into four categories, including Quercus mongolica dominant (hereinafter referred to as QM), Pinus densiflora dominant (hereinafter referred to as PD), other deciduous (hereinafter referred to as OD) and other coniferous (hereinafter referred to as OC) forest types. Table 1 provides a summary of vegetation characteristics among the four different forest types along the ridge of the Baekdudaegan, South Korea. Detrended correspondence analysis (DCA; Hill and Gauch, 1980), with detrending by segments and non-linear rescaling, was used to describe the differences in species composition among the forest types. It was used abundance data for computation of DCA.

In each forest type, species and functional diversity indices were calculated with abundance data. Mean values and standard deviations for diversity indices were used to analyze variations in plant diversity among forest types. Three diversity indices were calculated: (1) Species richness was defined as the number of species per a plot, (2) Shannon-Weaver Index (H') as a measurement of species diversity was traditionally calculated as:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

where S is the number of species (i.e., species richness) and $p_i$ is the proportion of the $i_{th}$ species in the data set.

In addition to species diversity indices, functional diversity (FD), which is based on the adaptation of an index of species dissimilarity (Rao, 1982) was also calculated:

$$FD = \sum_{i=1}^{S} \sum_{j=1}^{S} d_{ij} p_i p_j$$

In this formula, FD is the sum of the dissimilarity in trait space among all possible pairs of species, weighted by the product of the species’ relative abundance. The species distance $d_{ij}$ have been traditionally applied for species taxonomical differences (Shimatani, 2001; Bhat and Magurran, 2006). The index is the expected dissimilarity of two randomly chosen species. The formula has a similar meaning for $p_i$ calculated on the basis of other quantitative characteristics but, instead of two randomly selected
individuals, it refers to the expected similarity of two species, when each species is selected with its probability $p$, and each selection is independent (de Bello et al., 2006). Rao’s FD can be used with various measurements of dissimilarity between species and the average of the FD, calculated by single traits results in a compound index of functional diversity (Lepš et al., 2006). To calculate Rao’s FD, plant species was classified into nine functional traits, according to Raunkiaer’s system (1934); megaphanerophyte, microphanerophyte, nanophanerophyte, therophyte, geophyte, hemicyryptophyte, chamaephyte, helophyte and hydrophyte and epiphyte. A one-way analysis of variance (ANOVA) and Tukey’s multiple comparison were performed to test for variations of species and functional diversity among forest types. All diversity indices and analyses were calculated for total, woody and herbaceous plants.

### III. RESULTS

#### 3.1 General descriptions

A total of 802 plant species belonging to 97 families and 342 genera were recorded from 1,100 plots along the ridge of the Baekdudaegan (Table 2). More than half of these species were herbaceous (69%; 62 families, 249 genera, and 554 species), while woody species accounted for 31% (47 families, 99 genera, and 248 species). In the QM forest type, a total of 569 plant species belonging to 89 families and 265 genera were recorded from 378 plots on the Baekdudaegan ridge. More than half of these species were herbaceous plants (69%; 55 families, 187 genera and 390 species), while woody plant species accounted for 31% (44 families, 83 genera and 179 species). In the PD forest type, from 176 plots, there were a total of 343 plant species belonging to 77 families and 200 genera with 130 and 213 species of woody and herbaceous plants, respectively. There were a total of 604 plant species belonging to 94 families and 286 genera with 208 and 396 species of woody and herbaceous plants, respectively, from 362 plots in the OD forest type. Moreover, in the OC forest type, a total of 475 plant species with 172 and 303 species of woody and herbaceous, respectively, belonging to 84 families and 243 genera were recorded from 184 plots.
Table 2. Summary of plant richness and diversity indices encountered in this study along the ridge of the Baekdudaegan, South Korea.

<table>
<thead>
<tr>
<th></th>
<th>QM¹</th>
<th>PD</th>
<th>OD</th>
<th>OC</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. plots</td>
<td>378</td>
<td>176</td>
<td>362</td>
<td>184</td>
<td>1100</td>
</tr>
<tr>
<td>Family richness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>89</td>
<td>77</td>
<td>94</td>
<td>84</td>
<td>97</td>
</tr>
<tr>
<td>Woody</td>
<td>44</td>
<td>38</td>
<td>47</td>
<td>42</td>
<td>47</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>55</td>
<td>46</td>
<td>59</td>
<td>51</td>
<td>62</td>
</tr>
<tr>
<td>Genus richness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>265</td>
<td>200</td>
<td>286</td>
<td>243</td>
<td>342</td>
</tr>
<tr>
<td>Woody</td>
<td>83</td>
<td>75</td>
<td>92</td>
<td>80</td>
<td>99</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>187</td>
<td>127</td>
<td>198</td>
<td>165</td>
<td>249</td>
</tr>
<tr>
<td>Species richness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>569</td>
<td>343</td>
<td>604</td>
<td>475</td>
<td>802</td>
</tr>
<tr>
<td>Woody</td>
<td>179</td>
<td>130</td>
<td>208</td>
<td>172</td>
<td>248</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>390</td>
<td>213</td>
<td>396</td>
<td>303</td>
<td>554</td>
</tr>
<tr>
<td>Species diversity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5.254</td>
<td>4.824</td>
<td>5.472</td>
<td>5.186</td>
<td>5.478</td>
</tr>
<tr>
<td>Woody</td>
<td>4.082</td>
<td>3.916</td>
<td>4.566</td>
<td>4.181</td>
<td>4.469</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>4.965</td>
<td>4.381</td>
<td>5.080</td>
<td>4.838</td>
<td>5.121</td>
</tr>
<tr>
<td>Functional diversity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.799</td>
<td>0.813</td>
<td>0.809</td>
<td>0.810</td>
<td>0.809</td>
</tr>
<tr>
<td>Woody</td>
<td>0.646</td>
<td>0.649</td>
<td>0.647</td>
<td>0.646</td>
<td>0.650</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>0.571</td>
<td>0.599</td>
<td>0.591</td>
<td>0.588</td>
<td>0.586</td>
</tr>
</tbody>
</table>

¹QM, PD, OD and OC indicate *Q. mongolica*, *P. densiflora*, other deciduous and other coniferous forest types, respectively.

In the DCA plots, the first DCA axis of the forest type ordination separated the PD and OC forest types from the OD forest type, and the second DCA axis separated the QM forest type from the OD forest type (Figure 2).

In relative proportions of functional traits, megaphanerophyte (22.6%), geophyte (22.3%) and hemicyryptophyte (21.6%) were the dominant life forms on the ridge of the Baekdudaegan (Figure 3a). This pattern is similar to those of the four forest types. Megaphanerophyte, geophyte and hemicyryptophyte were the dominant traits (more than 60% in all forest types), whereas the relative proportion of helophyte and hydrophyte and epiphyte indicated less than 1% (Figure 3b).

3.2 Plant diversity among forest types

The results of the analysis of variance (ANOVA)
and Tukey’s multiple comparisons for plant diversity among four different forest types are presented in Table 3 and Figure 4. Species and functional diversity of all plant groups, with the exception of herbaceous functional diversity, showed significant differences ($p<0.001$) in the ANOVA test. Species richness of total plants showed the lowest value in PD forest type and the other forest types did not show significant difference. In woody plants, the species richness of OD forest type were the highest and the species richness of the QM and PD forest types were significantly lower than those of OD and OC forest types. Herbaceous species richness of the QM forest type showed a higher value than those of the PD and OD forest types but was not significantly different from that of the OC forest type.

Functional diversity of total plants in the QM and PD forest types were higher than that of the OD forest type, but there were no significant differences with the functional diversity of the OC forest type. In woody plants, functional diversity of the PD forest type was higher than that of the OD forest but was not significantly different to those of QM and OC forest types. Functional diversity in herbaceous plants did not show significant differences among the forest types.

Overall, species richness showed similar patterns with species diversity, whereas the patterns of functional diversity were different from species richness and diversity among the forest types. Species richness and diversity for total plants showed the lowest value in the PD forest type, whereas OD and QM forest types had the highest values of species richness and diversity for woody and herbaceous plants, respectively. However, functional diversity did not show significant difference among the forest types.
Table 3. Results of analysis of variance (ANOVA) of mean value (± standard deviation) of species richness and diversity and functional diversity for total, woody and herbaceous plants among four forest types along the ridge of the Baekdudaegan, South Korea.

<table>
<thead>
<tr>
<th>Species richness</th>
<th>QM&lt;sup&gt;1&lt;/sup&gt;</th>
<th>PD</th>
<th>OD</th>
<th>OC</th>
<th>df</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>22.94 ± 9.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.68 ± 8.13&lt;sup&gt;b&lt;/sup&gt;</td>
<td>23.67 ± 10.35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>23.30 ± 8.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3</td>
<td>7.44</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Woody</td>
<td>10.39 ± 4.45&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.49 ± 4.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.43 ± 5.97&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.18 ± 3.82&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3</td>
<td>27.94</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>12.69 ± 7.23&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.35 ± 5.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.45 ± 6.95&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>11.30 ± 6.35&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>3</td>
<td>12.12</td>
<td>&lt;0.001</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Species diversity</th>
<th>QM&lt;sup&gt;1&lt;/sup&gt;</th>
<th>PD</th>
<th>OD</th>
<th>OC</th>
<th>df</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>2.95 ± 0.48&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.79 ± 0.42&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.96 ± 0.47&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.97 ± 0.41&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3</td>
<td>6.66</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Woody</td>
<td>2.18 ± 0.46&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.19 ± 0.41&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.40 ± 0.49&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.34 ± 0.38&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3</td>
<td>19.41</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>2.29 ± 0.69&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.03 ± 0.55&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.03 ± 0.76&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.18 ± 0.63&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>3</td>
<td>11.02</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Functional diversity</th>
<th>QM&lt;sup&gt;1&lt;/sup&gt;</th>
<th>PD</th>
<th>OD</th>
<th>OC</th>
<th>df</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.754 ± 0.054&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.754 ± 0.051&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.732 ± 0.079&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.747 ± 0.087&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3</td>
<td>7.79</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Woody</td>
<td>0.576 ± 0.090&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.596 ± 0.057&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.572 ± 0.091&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.575 ± 0.100&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>3</td>
<td>2.96</td>
<td>0.031</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>0.497 ± 0.129&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.492 ± 0.133&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.482 ± 0.158&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.503 ± 0.134&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3</td>
<td>1.16</td>
<td>0.326</td>
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</table>

<sup>1</sup>QM, PD, OD and OC indicate Q.mongolica, P.densiflora, other deciduous and other coniferous forest types, respectively. Same letters indicate no significant difference.

IV. DISCUSSION

Forest type is useful in understanding overall forest dynamics and diversity patterns in temperate forests. Oak forests, including Q. mongolica, occupy 75% of the total natural broad-leaved forests and comprise 27% of the total standing stock volume (Suh and Lee, 1998). Q. mongolica forests are a predominant type of oak species forests in Korea and the forests are distributed from 100m to 1,800m above sea level, but are most abundant at altitudes near 700m above sea level (Suh and Lee, 1998). P. densiflora, which is the most abundant tree species in Korea, covers about 24% of the total forest area in Korea and about 17% of the forest area is located in the Gangwon Province (Lee et al., 2009). Furthermore, P. densiflora is an important timber species and the most widely distributed conifer species in Korea (Kim et al., 2008). Its range extends from Hambuk Province in North Korea to the Jeju Province in South Korea. However, it currently suffers from various harmful insects, which were introduced from foreign countries. Besides this, the ecosystem in Korea is gradually losing its balance due to climate changes and rapid industrialization. However, it is observed at alpine region, that their main distribution range is low to moderate elevation. It
often stands along the mountain ridges and slopes but sometimes forms mixed stands with hardwood species in Korea. Moreover, *P. densiflora* is vulnerable to increasing disturbance and many authors recognize that *P. densiflora* forests will be replaced by *Q. mongolica* forests (Kim et al., 2009). Other temperate deciduous and coniferous forests are mainly composed of *Fraxinus* spp., *Acer* spp., *Betula* spp., *Pinus* spp., *Abies* spp., *Taxus* spp. etc. on the Baekdudaegan (Korea Forest Research Institute, 2003).

In this study, forests on the ridge of the Baekdudaegan were divided into four types. Overall, *P. densiflora* forest types had lower species richness and diversity than those of the other forest types. Species richness and diversity of total and herbaceous plants showed the lowest value in *P. densiflora* forest type. Furthermore, although species richness and diversity were somewhat different for woody and herbaceous plants, overall species richness and diversity exhibited similar patterns among *Q. mongolica*, other deciduous and other coniferous forest types. Indeed, previous studies have revealed that *P. densiflora* community, which is distributed in natural forests, has simple species composition and is mainly composed of drought-plants on the ridge of the Baekdudaegan (Cho, 2009; Cho and Lee, 2011). Moreover, these results of

**Fig 4.** Comparisons of species richness (a–c), species diversity (d–f), and functional diversity (g–i) for total (left column), woody (middle column), and herbaceous (right column) plants for the four forest types. Same letters indicate no significant difference. Abbreviations for the forest types are listed in footnote 1, Table 1.
species diversity among forest types are consistent with those of a recent study on vascular plants along the northern part of the BaekduDaeogna ridge, conducted by Hwang et al. (2012). It was observed that total plant species diversity in the *Q. mongolica*, other deciduous and other coniferous forest types have higher species diversity than *P. densiflora* forest type, although there were no significant differences among the former three forest types.

One possible explanation for these results is the allelopathic effect, which is the inhibition through the production and release of chemical attractants, stimulators or inhibitors on the germination or development of other plants (Putnam and Tang, 1986). In general, many pine trees are known to have allelopathic effects. Kil and Yim (1983) expanded research on the allelopathic potential of *P. densiflora*. They found that toxic substances inhibited seed germination and growth of other species in the forests. These substances were released in fresh and fallen leaves, roots, pine forest soil, and pine pollen rain. Allelopathic interactions have been shown to play a crucial role in natural forests. Such interactions are pivotal in determining the composition of the vegetation growing as understory vegetation and in understanding forest regeneration (Rizvi et al., 1992).

Another possibility is the characteristics of habitats dominated by *P. densiflora*. In general, it is recognized that *P. densiflora* forests distribute along the infertile mountain ridge, slope and rocky area due to illegal logging and forest regeneration. The soil conditions in such an area are not suitable to support various plant species.

However, the functional diversity among four forest types does not show the distinct pattern. Indistinct pattern in functional diversity among forest types may be common in natural forest ecosystems. In general, functional diversity shows a large difference along disturbance or successional gradients (Biswas and Mallik, 2010). This current study could not divide forest types into successional or disturbance stages due to a limitation of information in the data set. Therefore, all stages of disturbance or successional gradients may be compounded in each forest type of this study. Another possibility may be the type of functional traits used in this study. In general, two approaches have been used to estimate *a priori* functional diversity in biodiversity-ecosystem process studies. Most studies have used a broad designation of species groups, which are based on key traits, such as growth form, photosynthetic pathway or N-fixing capacity (Tilman, 2001; Hooper and Dukes, 2004). Broad designations are often easy to employ because they rely on ‘soft’ traits that are readily distinguished for most species and are easily scored as categorical variables (Hooper et al., 2005). Broad designations also permit the identification of types of species that have particular effects on ecosystem processes or that complement species from other groups (Hooper and Dukes, 2004). However, broad designations mask within-group trait variability, and such fine-scale differences may also be a consequence of ecosystem processes (Craine et al., 2002). A fine-scale approach relies on quantitative differences (so called ‘hard traits’) between species in the values of particular functional traits that are hypothesized to affect ecosystem processes (Mason et al., 2003). For example, Petchey and Gaston (2006) proposed a quantitative measure of functional diversity analogous to a similar measure of phylogenetic diversity that is based on the branch length of the functional dendrogram of species clustered in trait space. Their index appears to be a better predictor of aboveground productivity than species richness or other measures of functional distance (Petchey et al., 2004). Therefore, due to the
functional traits based on Raunkiaer’s growth forms in this study, it may be difficult to find significant differences among the forest types.

Finally, this study suggests that although taxonomical richness and diversity may be different among the forest types, there may be no differences in functional diversity. Moreover, this indistinct pattern may be due to disturbance and successional gradients compounded in a forest type and the type of functional traits used for comparisons and contrasts among forest types. Therefore, a further study with various functional traits (i.e. soft and hard traits) and different environmental gradients (i.e. forest successional stage and disturbance intensity) should be consistently evaluated to achieve a better understanding of the diversity patterns of plant communities in mountain ecosystems.

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