**Regular Article**
pISSN: 2288-9744, eISSN: 2288-9752
Journal of Forest and Environmental Science
Vol. 37, No. 4, pp. 269-279, December, 2021
https://doi.org/10.7747/JFES.2021.37.4.269

JFES
Journal of Forest and Environmental Science

# Classification of Forest Cover Types in the Baekdudaegan, South Korea

**Sang Hoon Chung and Sang Tae Lee***
*Forest Technology and Management Research Center, National Institute of Forest Science, Pocheon 11186, Republic of Korea*

## Abstract

This study was carried out to introduce the forest cover types of the Baekdudaegan inhabiting the number of native tree species. In order to understand the vegetation distribution characteristics of the Baekdudaegan, a vegetation survey was conducted on the major 20 mountains of the Baekdudaegan. The vegetation data were collected from 3,959 sample points by the point-centered quarter method. Each mountain was classified into 4-7 forests by using various multivariate statistical methods such as cluster analysis, indicator species analysis, multiple discriminant analysis, and species composition analysis. The forests were classified mainly according to the relative abundance of *Quercus mongolica*. There was a total of 111 classified forests and these forests were integrated into the following nine forest cover types using the percentage similarity index and by clustering according to vegetation type: 1) Mongolian oak, 2) Mongolian oak and other deciduous, 3) Oaks (Mixed *Quercus* spp.), 4) Korean red pine, 5) Korean red pine and oaks, 6) ash, 7) mixed mesophytic, 8) subalpine zone coniferous, and 9) miscellaneous forest. Forests grouped within the subalpine zone coniferous and miscellaneous classifications were characterized by similar environmental conditions and those forests that did not fit in any other category, respectively.

**Key Words:** classifying forests, ecological information, forest cover type, multivariate statistical analysis, Mongolian oak

## Introduction

The classification of vegetation is useful and natural because humans comfortably think and communicate in terms of classes. Vegetation classification can be approached in many different ways: Physiognomic, dominance, floristic composition, or plant productivity. Each of these approaches can involve different methods of investigation and different criteria for the definition of classes (Kimmins 2004). Forest cover type had been most commonly used to describe existing or present forest vegetation. This is a descriptive classification of forestland based on present occupancy of an area by tree species (Eyre 1980). The type is a unit of vegetation which possesses broad characteristics in physiognomy and structure sufficiently pronounced to permit its differentiation from other such units (Champion and Seth 1968). Canada, the United States, and Europe have nationally used forest vegetation classifications based on the species composition of the overstory (Society of American Foresters 1954; Vankat 1979, 1990; Eyre 1980; European Environment Agency 2006). Similar systems have been widely used by both the professional and scientific communities to obtain a standardized description of forests (Kimmins 2004) and effectively manage forests on a large spatial scale (Dai et al. 2011).

The Baekdudaegan is a mountain range that forms the backbone of the Korean Peninsula and stretches about 1,400 km from Baekdudaegan in North Korea to Jirisan in

Received: August 30, 2021. Revised: October 25, 2021. Accepted: October 27, 2021.

Corresponding author: Sang Tae Lee

Forest Technology and Management Research Center, National Institute of Forest Science, Pocheon 11186, Republic of Korea
Tel: +82-31-540-1154, Fax: +82-31-540-1188, E-mail: lst9953@korea.kr

the South (Korea Forest Service 2019). The South Korean portion of the range is 701 km long, from Hyangnobong to Jirisan. This mountain range contains essential habitats for plants, animals, and microbes, and is the source of the major river systems that drain the watersheds of the Korean Peninsula (Kim et al. 2015). The most abundant tree species in the mountains such as oaks, maples, ashes, birches, and alders account for 80% of Korea's current hardwood growing stock. Large areas of protected forests, which are ecologically complex and also contain economically valuable resources, are distributed in the Baekdudaegan. Since the forest resources are potentially of great anthropogenic value, these forests and the natural resources they contain must be effectively managed (Kim and Chung 2005).

Vegetation classification studies have been carried out in some mountains of the Baekdudaegan (Lee et al. 2009; Kwon et al. 2010; Yun et al. 2010; Chung and Kim 2012, 2013; Cho and Lee 2013; Cheon et al. 2014). The Korea Forest Research Institute (2003) divided the vegetation in the Baekdudaegan into three parts (northern, central, and southern) based on plant community characteristics. Yim (1977) and Kong (2007) also classified the vegetation into four zones along an altitudinal gradient: (1) temperate deciduous broad-leaved and pine forest (<550 m above sea level [masl]), (2) temperate deciduous broad-leaved and coniferous mixed forest (550-1,100 masl), (3) sub-alpine coniferous forest (1,100-1,600 masl), and (4) alpine forest (>1,600 masl). In addition, several studies have together classified forest cover in a portion of the northern Baekdudaegan (Hwang et al. 2012) and a portion of the southern Baekdudaegan (Lee et al. 2014). However, not all forests in the Baekdudaegan have yet been systematically classified according to forest cover.

Classifying forests in the Baekdudaegan would yield important ecological information on the current forest condition and will likely help to establish an ecological forest policy to protect and regulate utilization of each cover type. Further detailed forest classification would also provide data fundamental for the effective future management of forests, as they develop. Thus, the objective of this study was to clearly and comprehensively integrate and describe forest cover types in the South Korean Baekdudaegan, which is characterized by diverse and complex forests.

## Materials and Methods

### Study area

A vegetation survey was conducted on the major 20 mountains of the Baekdudaegan in South Korea (Fig. 1). The study sites were situated from 35° 20' to 38° 20' N and 127° 40' to 129° 05' E and were distributed from 615 to 1,915 m above sea level. The northern (Hyangnobong–Sobaeksan) and southern (Hwangaksan–Jirisan) portions of the mountain range consist of mountains 1,000 m high or more, while the central (Joryeongsan–Baekhaksan) part of the range encompasses shorter peaks 600-1,000 m high. The Baekdudaegan in South Korea has a temperate deciduous forest biome (Yim and Kira 1975; Shin 2002). The soil consists of granite, granite gneiss, and highly deformed and recrystallized sedimentary rocks (Shin 2002) with some limestone areas (Kim et al. 2005).

### Data collection

Vegetation data were collected for a total of the 20 mountains from 2015 to 2018 using the point-centered quarter sampling method (Brower and Zar 1977). Sample points were set randomly along a line transect with an average distance between points of around 50 m (min: 40 m; max: 60 m) as possible equally. At each point, four quadrants were delineated using one line in each of the four cardinal compass directions (N, S, E, and W). From the center of each quadrant, the following data were collected in each vertical

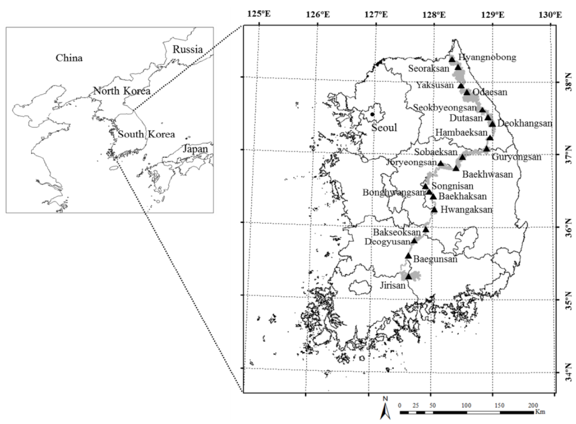


**Fig. 1.** Location of the major mountains in the Baekdudaegan. Black lines are administrative district boundaries in South Korea and the heavy grey line follows the Baekdudaegan mountain range.

layer (upper-, mid-, and understory): (1) distance from the center point to the nearest individual, (2) vegetation data (species name, DBH, height) of the individual, and (3) environmental variables. Three trees per quadrant were measured for a total of 12 trees measured for each quadrant center point (sample point). A total of 3,959 points and 47,508 trees were sampled. The number of sample points and the transect survey interval varied depending on the scale of the mountains.

### *Data analysis*

Forest cover types of the Baekdudaegan was categorized using several multivariate statistical methods (Fig. 2). Using Euclidean distances and Ward's linkage method, cluster analysis (CA) was performed based on the vegetation data in the upper story of each mountain. Hierarchical clustering has the advantage of being able to accurately grasp the process of cluster formation, but if the size of the data is large, it may be difficult to analyze and the interpretation may be complicated.

A fundamental problem of the CA is to determine the appropriate number of clusters, which has a deterministic effect on the clustering results. The indicator species analysis (ISA) can be used to decide on an optimal cluster level. Dufrêne and Legendre (1997) found that indicator values peak at suitable level of clustering, and that the position of this peak will vary by species.

Either the lowest average p value or the highest number of significant indicators ($p < 0.05$), or both, could be the basis for choosing the optimum number of groups (McCune et al. 2002). The multiple discriminant analysis (MDA) using the stepwise method was conducted for the testing of the classification using the CA and ISA (as in Lüth et al. 2011; Matthews et al. 2011; Chung and Kim 2013). The species composition analysis (SCA) was carried out to comprehend the ecological properties and to be named of classified forests. The SCA considered the importance value (IV, Curtis and McIntosh 1951) together with the sum of the three relative density, frequency, and coverage (basal area). Classified forests were named according to the common name of the tree(s) with the highest IV in each category. Finally, the classified forests in each mountain were intergrated into several forest cover types having similar ecological and environmental characteristics by percent similarity index (PSI, Whittaker 1952; Brower and Zar 1977).

CA and ISA were done with PC-ORD version 5.17 (McCune and Mefford 2006), SCA and PSI with Microsoft Excel version 2010 (Microsoft 2010), and MDA with SPSS version 20.0 (IBM 1989-2011).

## Results and Discussion

### *The process of classifying forests*

Since the same analysis method is applied to classify the forests of each mountain, the forest classification process is described for representative places (the Hyangnobong, northernmost in the baekdudaegan) among the 20 mountains.

#### Cluster analysis

The dendrogram was scaled by the Wishart's objective function (1969) and percentage of information remaining process of classifying the Hyangnobong forest information from the 12 species×204 sample point matrix (Fig. 3). Since the grouping process results in a continuous scale from ungrouped to completely grouped, the derived dendrogram can be a basis for a rough judgment that can determine an appropriate grouping level. The differences between the groups were better than several small clusters up to 14 clusters when the loss of information was 25% (75% of remained information). There are no standard rules for determining suitable number of groups. Although the convention for many years was to cut the dendrogram vertically,

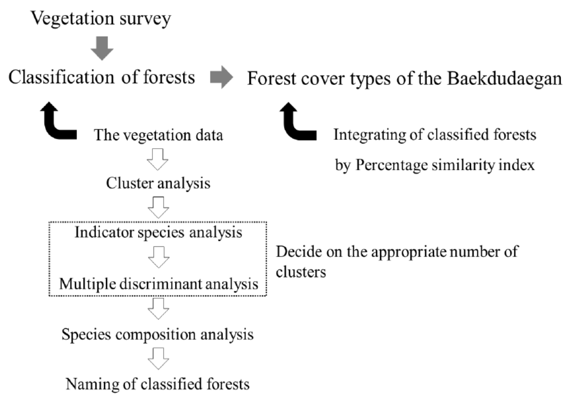


**Fig. 2.** Data collected, analyses performed, and decisions made when categorizing forest cover.

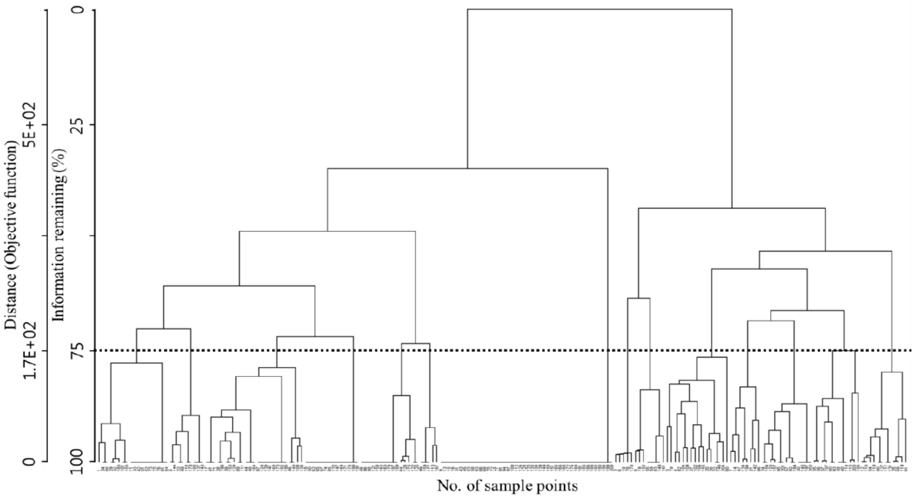


**Fig. 3.** Dendrogram from the cluster analysis of species abundance at each sample point in the Hyangnobong forests (using Euclidean distances and Ward's method).

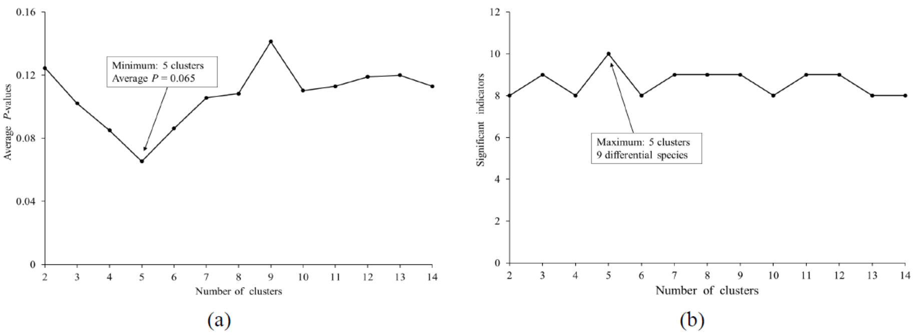


**Fig. 4.** Results of indicator species analysis with 2 to 14 clusters. (a) p value after 4,999 permutations of the Monte Carlo test averaged across 12 species. (b) The number of species with $p < 0.05$ for each number of clusters.

**Table 1.** The confusion matrix summarizes the reclassification of the predicted group membership

| Classified cluster* | Predicted group membership (%) | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| 1 | **92.4**** | 0 | 1.5 | 4.5 | 1.5 |
| 2 | 0 | **100** | 0 | 0 | 0 |
| 3 | 0 | 1.6 | **96.7** | 0 | 1.6 |
| 4 | 0 | 0 | 0 | **100** | 0 |
| 5 | 0 | 0 | 0 | 0 | **100** |

*Five clusters classified by ISA.
**Percentages in rows represent MDA classifications of the data used to create the ISA clusters given in the first column (correct classification in bold).

it is sometimes more desirable to interpret some portions of the dendrogram at deeper levels than others.

### Indicator species analysis

In each cluster step, the indicator values were calculated for 12 species occupying the upper story and the values were assessed for statistical significance using Monte Carlo randomizations with 4,999 permutations. Then the number of significant indicators species was tallied until 14th clustering levels (Fig. 4). The lowest average p value (0.065) of the Monte Carlo tests was seen with five clusters (Fig. 4a). The number of species with significant indicators at five clusters was high at nine species (about 75% of the total number of species) (Fig. 4b). The optimum number of clusters was five to being decided by the lowest average p-value and the highest number of significant indicators.

#### Multiple discriminant analysis

Predicted group A was correctly classified 92.4% of sample points from cluster 1 and group B, D, E were entirely accurately classified (Table 1). The overall classification success was 96.6%, and then the Hyangnobong were eventually classified into five forests.

#### Species composition analysis and forest naming

The five Hyangnobong forests were named as follows: *Quercus mongolica*, *Q. mongolica-Kalopanax septemlobus-Betula costata*, *Q. mongolica-Tilia amurensis*, *Q. mongolica* only, and *Q. mongolica-Pinus koraiensis* (Table 2). The term 'only' was applied when only one tree species dominated the classified forest. We separated *Q. mongolica* only from *Q. mongolica* forest composing more than 75% of the individual.

### *Classified forests at each mountain*

Each mountain was classified into four to seven forests and a total of 20 mountains were divided into 111 forests (Table 3) by the steps illustrated above (Fig. 2). *Q. mongolica* (QM) and *Q. mongolica* only (QMo) forest accounted for 29% of the total classified forests. *Q. mongolica* had a high dominance ratio in all mountain, even at sites with other abundant species. This species had an important influence on when all the classified forests were named by the ratio.

Mixed mesophytic (MM) forest was found in all mountain excluding Hyangnobong, Baekhaksan, and Deogyusan. The term "mixed mesophytic" has been used since 1916 (Braun 1916; Sampson 1930) and is known as the representative forest cover type of the Appalachian Mountains in the United States (Braun 1950). This type of forest was composed of various mesophytic plants such as *Fagus*, *Liriodendron*, *Tilia*, *Acer*, *Castanea*, *Aesculus*, *Quercus*, *Tsuga*, *Betula*, *Prunus*, *Fraxinus*, and *Ulmus* species. It is also characterized by a lower composition ratio of the various plants without one or several clearly dominant species (Braun 1950; Vankat 1979; Barbour and Billings 1988). The mixed mesophytic forests in this study consisted of *Quercus* species, *Tilia amurensis, Betula ermanii, B. costata, Fraxinus rhynchophylla, Fraxinus mandshurica, Ulmus davidiana* var. *japonica*, *Prunus sargentii*, and *Acer pictum* subsp. *mono*. This forest had no species that accounted for more than 25% of the individuals observed.

QM-other deciduous forest of Odaesan composed of QM (37%), *F. rhynchophylla* (9.7%), *B. ermanii* (9.3%), *T. amurensis* (7.9%), *F. mandshurica* (6.6%), and others. QS (*Q. serrata*)-other deciduous forest of Baegunsan consisted of QS (36%), *Carpinus laxiflora* (8.8%), *Cornus controversa* (8.8%), *Q. variabilis* (6.5%), *A. pictum* subsp.

**Table 2.** Importance value (%) of the most abundant tree species (underlined) in the upper story of each classified forest

| Species name | Forest classification name | | | | |
|---|---|---|---|---|---|
| | QM[1]* | QM-KS[2]-BC[3] | QM-TA[4] | QM pure | QM-PK[5] |
| [1]*Quercus mongolica* | 65.4 | 38.8 | 27.8 | 100 | 55.0 |
| [2]*Kalopanax septemlobus* | 4.2 | 27.6 | - | - | 1.6 |
| [3]*Betula costata* | 0.8 | 23.8 | 3.7 | - | - |
| [4]*Tilia amurensis* | 5.8 | | 24.4 | - | 2.9 |
| *Fraxinus rhynchophylla* | 7.6 | - | 6.1 | - | - |
| *Acer pictum* subsp. *mono* | 4 | 3.8 | 8.6 | - | - |
| *A. mandshuricum* | 0.4 | 2.4 | 3 | - | - |
| *Carpinus cordata* | - | - | 5.6 | - | - |
| [5]*Pinus koraiensis* | - | - | - | - | 36.3 |
| *Abies holophylla* | - | - | 0.3 | - | 1.8 |

*The abbreviations of classified forest name are shown in species name respectively.

**Table 3.** The number of optimal forest groups and the name of those groups for each mountain

| Site no. | Mountain name | No. of forests | Forest name |
|---|---|---|---|
| 1 | Hyangnobong | 5 | QM*, QM-PK, QMo, QM-KS-BC, QM-TA |
| 2 | Seoraksan | 6 | MM, PK-AN-QM, QS-QM-CL, SM, QM, PD |
| 3 | Yaksusan | 5 | QMo, QM, PK-QM-FR, MM, AH |
| 4 | Odaesan | 5 | QM-other deciduous, PD-QM, MM, BE, QM |
| 5 | Seokbyeongsan | 4 | PD-QM, PDo, MM, QM |
| 6 | Dutasan | 5 | QM, QM-BE, QMo, MM, PDo |
| 7 | Deokhangsan | 5 | PD, MM, QM, QM-PD, QMo |
| 8 | Hambaeksan | 6 | QMo, QM, FR-QM-BE, MM, QM-TA, BE |
| 9 | Guryongsan | 5 | QM-TA, MM, QM, PD-QV, QMo |
| 10 | Sobaeksan | 7 | MM, TC, FR-QM, BE-QM, PDo, QM, QMo |
| 11 | Joryeongsan | 4 | MM, QV-PD, QM, PD |
| 12 | Baekhwasan | 5 | MM, QS, CC, QV, QM |
| 13 | Songnisan | 5 | QM, QS, MM, QV-PD, PDo |
| 14 | Bonghwangsan | 4 | QV-QM-PD, MM, PD-QM, QM |
| 15 | Baekhaksan | 5 | QD-QV, QV-QM-QS, QVo, QM, PD |
| 16 | Hwangaksan | 4 | PD, QM-QV-QS, MM, QMo |
| 17 | Bakseoksan | 6 | QV-QS-QM, MM, CC, PDo, QM, QMo |
| 18 | Deogyusan | 6 | QS-PD-QM, PDo, FM-FR-CC, FMo, QM, QMo |
| 19 | Baegunsan | 6 | MM, QS-other deciduous, CL, QVo, QM, QMo |
| 20 | Western Jirisan | 7 | QMo, QM, MM, AK, FM, CL, QS |
| | Eastern Jirisan | 6 | FM-BC-AK, MM, QM, QV-QS, QS-PD-QV, AK |
| | Total | 111 | |

*The abbreviations of forest names are as follows: AH, *Abies holophylla*; AK, *Abies koreana*; AN, *Abies nephrolepis*; BC, *B. costata*; BE, *B. ermanii*; CL, *Carpinus laxiflora*; CC, *Cornus controversa*; FR, *Fraxinus rhynchophylla*; FM, *F. mandshurica*; FMo, *F. mandshurica* only; KS, *Kalopanax septemlobus*; MM, *Mixed mesophytic*; PD, *Pinus densiflora* ;PDo, *P. densiflora* only; PK, *P. koraiensis*; QD, *Quercus dentate*; QM, *Q. mongolica*; QMo, *Q. mongolica* only; QS, *Q. serrata*; QV, *Quercus variabilis*; QVo, *Q. variabilis* only; SM, *Salix maximowiczii*; TA, *T. amurensis* ; TC, *Taxus cuspidate*.

*mono* (4.7%), *Zelkova serrata* (4.6%), and others. These forests were dominated by only one species (QM or QS) and the other deciduous species present all accounted for less than 10% of observed individuals.

### *Integrating 111 classified forests*

Forest communities are heterogeneous when the percent similarity index comparing them is less than 20%, similar when the PSI is more than 40%, and homogeneous when the PSI is more than 80% (Whittaker 1956; Whittaker and Fairbanks 1958; Grassle and Smith 1976; Haedrich and Krefft 1978). All forests within each classification were compared using PSI to verify that they had a minimum PSI of 40% and were quantitatively considered to be similar (Table 4).

The classifications encompassing the highest number of forests were QM only and QM, which included forests that were 70.8% similar. Other *Quercus* forests (QVo, QV, QV-QS, QS-PD-QV, QD-QV, and QS) were 57.9% similar. Although the MM designation included 18 forests, its mean PSI was low, likely because MM forests were composed of a variety of species with relatively uniform abundance. Forests in the TC (*Taxus cuspidate*), AH (*Abies holophylla*), and SM (*Salix maximowiczii*) categories were the least similar and had different species compositions from other classified forests.

## Conclusion

### *Forest cover types of the Baekdudaegan*

The 111 classified forests were integrated into the following nine forest cover types based on the PSI and envi-

**Table 4.** Mean percent similarity index (PSI) of the forests within each classification

| Mean PSI (%) | Forest name* | No. of this type of forest |
|---|---|---|
| 95.0 | AK | 2 |
| 79.3 | PDo and PD | 11 |
| 70.8 | QMo and QM | 32 |
| 70.4 | CC | 2 |
| 67.4 | BE-QM and BE | 3 |
| 66.9 | PD-QM, QM-PD, QV-PD, and PD-QV | 7 |
| 66.2 | QM-KS-BC, QM-TA, QM-BE, and QM-other deciduous | 6 |
| 65.7 | CL | 2 |
| 61.6 | FMo, FM, FM-BC-AK, FM-FR-CC, FR-QM, and FR-QM-BE | 6 |
| 60.7 | PK-AN-QM, QM-PK and PK-QM-FR | 3 |
| 57.9 | QVo, QV, QV-QS, QS-PD-QV, QS-PD-QM, QV-QM-PD, QV-QM-QS, QS-QM-CL, QM-QV-QS, QV-QS-QM, QD-QV, QS, and QS-other deciduous | 16 |
| 41.6 | MM | 18 |
| 5.3 | TC | 1 |
| 3.1 | AH | 1 |
| 2.7 | SM | 1 |
| | Total classified forests | 111 |

*Abbreviations explained in Table 3.

ronmental characteristics: (1) Mongolian oak, (2) Mongolian oak and other deciduous, (3) oak, (4) Korean red pine, (5) Korean red pine and oak, (6) ash, (7) mixed mesophytic, (8) subalpine zone coniferous, and (9) miscellaneous (Fig. 5). Six forests were grouped into subalpine zone coniferous by which they have similar vertical distributions (above 1,000 masl). Miscellaneous was composed of rare forests in the Baekdudaegan. These cover types were composed by growth environment and uncommon distributions rather than SPI.

### Mongolian oak

Mongolian oak (*Q. mongolica*) is a deciduous oak species that grows throughout the Korean Peninsula and in Japan, northeast China, and Siberia (Forestry Research Institute 1992). This species is widely distributed throughout Korea from 100 m to 1,800 masl (Chung and Lee 1965) and dominates Korean deciduous forests in terms of abundance. This cover type was distributed from 300 m to 1,550 m in this study and was most abundant on ridges and slopes at altitudes near 700 m. This species is widely distributed at least in part because it reproduces using both seeds and sprouts. In fact, more than 70% of their seedlings have been known to originate from sprouts (Suh and Lee 1998). Sprouting allows the species to reoccupy an area faster than other species due to its rapid early growth. The Mongolian oak has also adapted well to the environmental conditions in Korean forests, contributing to its widespread abundance in the Baekdudaegan.

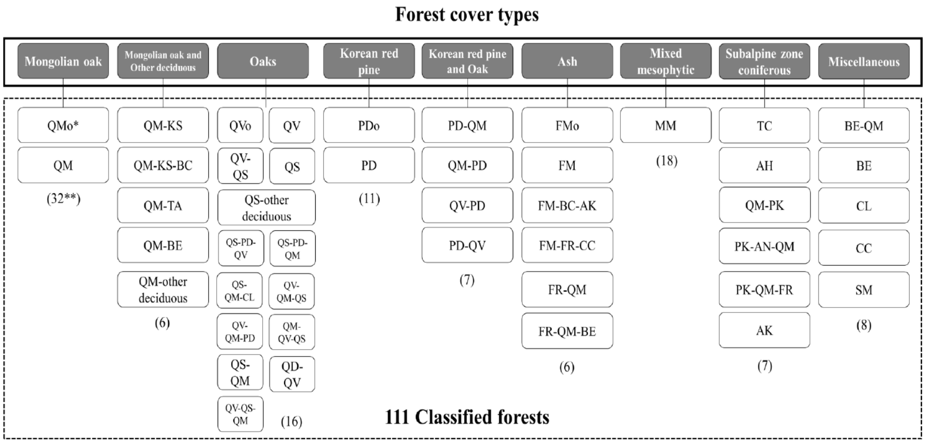


**Fig. 5.** Structure of nine forest cover types for the Baekdudaegan. *Abbreviations of forest names are explained in Table 3. **The number of forests classified within each forest cover type.

### Mongolian oak and other deciduous

The dominance of *Q. mongolica* was a key reason that the tree was given its own category separate from this forest cover type. Although *Q. mongolica* was the most abundant species in this category, other deciduous species were present in forests within this classification (Fig. 5), though they only comprised an average of 4.2% of the individuals in these forests.

### Oaks

This cover type was dominated by oak species such as *Q. mongolica*, *Q. variabilis*, *Q. serrata*, and *Quercus dentata*. These other, non-*Q. mongolica*, oak species were typically more abundant than *Q. mongolica* in this forest type. This cover type was mainly located below the latitude of 36 degrees north and distributed in the average elevation 350-840 m. Although intensive distribution area of oak species is below the central Korea (Kim et al. 1981), the distribution range of this cover type is wide because the location environment is different for each species of oak tree. The distribution pattern of this cover type was closely related to the annual average temperature of the Baekdudaegan. The annual mean temperature in the northern Baekdudaegan is 7 to 10°C while in the central and southern it is 10-12°C (Korea Meteorological Administration 2021). *Q. mongolica* grows optimally at 8°C while other oak species grow best at 10-11°C (Ministry of Agriculture and Forestry 2003).

### Korean red pine

Korean red pine forests were seen on ridges and slopes at altitudes near 800 masl. The Korean red pine, *P. densiflora* has a wide geographical range and is one of the most economic and cultural tree species in South Korea. While the upperstory was dominated by the pine, the mid- and understories were dominated by oaks. This pine is commonly considered to a pioneer species. Many pioneer species have the advantage of rapid early growth, but light intensity has a strong influence on early seedling growth (Zobel and Antos 1991). Since the seedling growth of the pine is inferior to that of shade tolerant species under a closed canopy, the secondary growth of this cover type will not be dominated by the pine and thus forests with this classification are likely undergoing succession.

### Korean red pine and oak

Pine and oak mixed forests are widely known as secondary growth forests (Oosting 1942; Byun et al. 1998; Sekikawa et al. 2000; Hayashi 2003; Choo and Kim 2005; Oh et al. 2005; An and Choo 2010; Lee et al. 2010). The upperstory of this cover type was composed of similar numbers of pines and oaks. However, pine abundance decreased noticeably, to below 3% of surveyed individuals, in the mid-story and was not observed in the understory at all. The pine is one of the tree species with the highest conservation value because of its historical and cultural importance. Forest management practices should consider pine growth characteristics in order to encourage growth of pine-(co-)dominated secondary growth forests.

### Ash

*Fraxinus* species such as *F. mandshurica* and *F. rhynchophylla* were most abundant in these forests. This forest type was observed on hillsides and in valleys with rich, moist soils (the preferred habitat of *Fraxinus* species) over a wide range, which extends from western China to Korea and the Russian Far East (Mustila Arboretum 2019).

### Mixed mesophytic

No species was consistently most abundant in these forests. This classification included the most diverse of the deciduous forests with around 30 overstory tree species and characterized by the highest species diversity indices of all forest cover types. This description is typical of the Korean mixed mesophytic forests described elsewhere (Hwang et al. 2012; Chung and Kim 2013; Lee et al. 2014).

Because of the large number of species in this forest type, the composition and relative abundance of the most abundant species varied spatially. Thus, forests in this category will likely develop into apparently distinct climax forests. For instance, oak- and birch-dominated forests would develop in drier sites such as the upper and/or south facing slopes, while maple- and basswood-dominated forests would prevail in wetter sites such as lower and/or north facing slopes (Kim et al. 2015).

### Subalpine zone coniferous

Subalpine coniferous forests are developed in the northern part of North Korea (42°N) and spread southwards along the main Taebaek mountain range up to 38°N. This type was observed above 1,000 masl and dominated by coniferous tree such as *Taxus cuspidate*, *Abies holophylla*, *Pinus koraiensis*, and *A. nephrolepis*, which was expected as the subalpine zone is usually composed of evergreen coniferous species and distributed from 1,000 to 1,800 masl in temperate regions (Song 1991).

### Miscellaneous forests

There were no characteristic species compositions or environmental conditions among these forests because the forests were scattered throughout the Baekdudaegan. The Baekdudaegan includes rugged terrain with diverse environmental conditions, allowing it to host a variety of forest communities adapted to local environments. Although this cover type was composed of only a few small-scale forests and was named "miscellaneous," this category reflects the diversity and complexity of the Baekdudaegan.

Since forest cover types are classified based on the species composition of the upper layers, forests included in the same forest cover type have a precondition for having a similar site environmental factor. Although site environmental information for each cover type was described, there is a limit to being representative. Through multiple analysis using vegetation data, forest type map, and forest site map, it is judged that it can be classified as a forest cover type that reflects the site conditions.

## References


An HC, Choo GC. 2010. Vegetation Structure of the Woongseokbong in the Jirisan (Mt.). Korean J Environ Ecol 24: 547-555. (in Korean with English abstract)

Barbour MG, Billings WD. 1988. North American Terrestrial Vegetation. Cambridge University Press, Cambridge.

Braun EL. 1916. The Physiographic Ecology of the Cincinnati Region. Ohio State University, Columbus, OH.

Braun EL. 1950. Deciduous Forests of Eastern North America. Blackburn Press, Caldwell, NJ.

Brower JE, Zar JH. 1977. Field and Laboratory Methods for General Ecology. 2nd ed. Wm. C. Brow, Dubuque, IA.

Byun DW, Lee HJ, Kim CH. 1998. Vegetation Pattern and Successional Sere in the Forest of Mt. Odae. Korean J Ecol 21: 283-290. (in Korean with English abstract)

Champion HG, Seth SK. 1968. A Revised Survey of the Forest Types of India. Manager of Publications, Delhi.

Cheon KI, Byun JG, Jung SC, Sung JH. 2014. Community Structure of Quercus mongolica Stand in Hyangrobong Area, Baekdudaegan. J Agric Life Sci 48: 1-13. (in Korean with English abstract)

Cho HS, Lee SD. 2013. Plant Community Structure of Haneoryoung~Daetjae Ridge, the Baekdudaegan Mountains. Korean J Environ Ecol 27: 733-744. (in Korean with English abstract)

Choo GC, Kim GT. 2005. Vegetation Structure of Mountain Ridge from Bubong to Poamsan in Baekdudaegan, Korea. Korean J Environ Ecol 19: 83-89. (in Korean with English abstract)

Chung SH, Kim JH. 2012. The Classification of Forest Types by Factor Analysis in Natural Forests of Dutasan. J Agric Life Sci 46: 21-30. (in Korean with English abstract)

Chung SH, Kim JH. 2013. The Classification of Forest Cover Types by Consecutive Application of Multivariate Statistical Analysis in the Natural Forest of Western Mt. Jiri. J Korean Soc For Sci 102: 407-414. (in Korean with English abstract)

Chung TH, Lee WC. 1965. A study of the Korean woody plant zone and favorable region for the growth and proper species. Thesis Collect Sungkyunkwan Univ 10: 329-366. (in Korean with English abstract)

Curtis JT, McIntosh RP. 1951. An Upland Forest Continuum in the Prairie-Forest Border Region of Wisconsin. Ecology 32: 476-496.

Dai L, Wang Y, Su D, Zhou L, Yu D, Lewis BJ, Qi L. 2011. Major forest types and the evolution of sustainable forestry in China. Environ Manage 48: 1066-1078.

Dufrêne M, Legendre P. 1997. Species Assemblages and Indicator Species: The Need for a Flexible Asymmetrical Approach. Ecol Monogr 67: 345-366.

European Environment Agency. 2006. European Forest Types: Categories and Types for Sustainable Forest Management Reporting and Policy. Publications Office of the European Union, Luxembourg.

Eyre FH. 1980. Forest Cover Types of the United States and Canada. Society of American Foresters, Washington, DC.

Forestry Research Institute. 1992. Illustrated Woody Plants of Korea. Forestry Research Institute, Seoul. (in Korean)

Grassle JF, Smith W. 1976. A similarity measure sensitive to the contribution of rare species and its use in investigation of variation in marine benthic communities. Oecologia 25: 13-22.

Haedrich RL, Krefft G. 1978. Distribution of bottom fishes in the Denmark Strait and Irminger Sea. Deep Sea Res 25: 705-720.

Hayashi I. 2003. [Plant Ecology: Basics and Applications]. 22nd Century Art, Tokyo. (in Japanese)

Hwang KM, Lee JM, Kim JH. 2012. Community Classification and Successional Trends in the Natural Forest of Baekdudaegan in Gangwon Province; Focused on Hyangrobong, Odaesan, Seokbyeongsan, Dutasan, Deokhangsan and Hambaeksan. J Agric Life Sci 46: 41-55. (in Korean with English abstract)

IBM. 2011. IBM SPSS Statistics for Windows, Version 20.0.

IBM Corp, Armonk, NY.
Kim JH, Chung SH. 2005. The current situation and management perspective for the hardwood resources in Korea. J Res For Kangwon Natl Univ 25: 1-10. (in Korean with English abstract)
Kim JH, Jin G, Chung SH. 2015. Stand development patterns of forest cover types in the natural forests of northern Baekdudaegan in South Korea. J For Res 26: 381-390.
Kim JS, Lee BC, Chung JM, Pak JH. 2005. Flora and Phytogeography on Mt. Deokhang (Gangwon-do), Limestone area in Korea. Korean J Plant Taxon 35: 337-364. (in Korean with English abstract)
Kim YS, Ko SC, Oh BU. 1981. Distribution atlas of plants of Korea (V). Atlas of in Fagaceae Korea. J Sci Eng Korea Univ 22: 93-133. (in Korean with English abstract)
Kimmins JP. 2004. Forest Ecology: A Foundation for Sustainable Forest Management and Environmental Ethics in Forestry. 3rd ed. Prentice Hall, Upper Saddle River, NJ.
Kong WS. 2007. Biogeography of Korean Plants. GeoBook, Seoul. (in Korean)
Korea Forest Research Institute. 2003. Ecological Aspects of Baekdu Mountains in Korea and Delineation of Their Management and Conservation Area. Korea Forest Research Institute, Seoul. (in Korean)
Korea Forest Service. 2019. Forest Policy. Baekdudaegan Mountains. https://english.forest.go.kr. Accessed 11 Aug 2021.
Korea Meteorological Administration. 2021. Automated Synoptic Observing System Data (2000∼2019). National Climate Data Center, Seoul.
Kwon HJ, Gwon JH, Han KS, Kim MY, Song HK. 2010. Subalpine Forest Vegetation of Daecheongbong Area, Mt. Seoraksan. Korean J Environ Ecol 24: 194-201. (in Korean with English abstract)
Lee JM, Hwang KM, Kim JH. 2014. The Classification of Forest by Cluster Analysis in the Natural Forest of the Southern Region of Baekdudaegan Mountains. J Korean Soc For Sci 103: 12-22. (in Korean with English abstract)
Lee KJ, Ki KS, Choi JW. 2009. Vegetation Succession and Vegetation Management of the *Pinus densiflora* S. et Z. Forest in the Beopjusa Area, Songnisan National Park. Korean J Environ Ecol 23: 208-219. (in Korean with English abstract)
Lee KS, Kim SK, Bae SW, Lee JH, Jung MH. 2010. Vegetation Type and Stand Structure of *Pinus densiflora* Forests in Samcheok and Taebaek of Kangwon Southern Region. J Korean Soc For Sci 99: 855-862.
Lüth C, Tasser E, Niedrist G, Dalla Via J, Tappeiner U. 2011. Classification of the Sieversio montanae-Nardetum strictae in a cross-section of the Eastern Alps. Plant Ecol 212: 105-126.
Matthews ER, Peet RK, Weakley AS. 2011. Classification and description of alluvial plantcommunities of the Piedmont region, North Carolina, USA. Appl Veg Sci 14: 485-505.
McCune B, Grace JB, Urban DL. 2002. Analysis of Ecological Communities. MjM Software Design, Gleneden Beach, OR.
McCune B, Mefford MJ. 2006. PC-ORD. Multivariate Analysis of Ecological Data, Version 5.17. MJM Software Design, Gleneden Beach, OR.
Microsoft. 2010. Microsoft Office Excel, Version 2010. Microsoft Corporation, Redmond, WA.
Ministry of Agriculture and Forestry. 2003. The Study of Eco-physiological Properties and Biomass of Oaks for their Highly Value-Added Utilization and Emploitation of their Application Technology. Ministry of Agriculture and Forestry, Seoul. (in Korean with English abstract)
Mustila Arboretum. 2019. Fraxinus rhynchophylla. http://www.mustila.fi/en/plants/fraxinus/rhynchophylla. Accessed 11 Aug 2021.
Oh KK, Choi SH, Kim SH, Choi WK. 2005. Analysis of the Forest Community Structure in the Woraksan National Park; Case Study of Yeongbong and Doraksan Region. Korean J Environ Ecol 19: 90-98.
Oosting HJ. 1942. An Ecological Analysis of the Plant Communities of Piedmont, North Carolina. Am Midl Nat 28: 1-126.
Sampson HC. 1930. The Mixed Mesophytic Forest Community of Northeastern Ohio. Ohio J Sci 30: 358-367.
Sekikawa S, Sugimoto K, Kimura K, Nakano T, Mariko S. 2000. Floristic composition, stand structure and tree ring growth of a *Pinus densiflora* forest on Lava at the northern foot of Mt. Fuji. Bull Fac Agric Tamagawa Univ 40: 15-29.
Shin JH. 2002. Ecosystem geography of Korea. In: Ecology of Korea (Lee DW, Jin V, Choe JC, Son YW, Yoo SJ, Lee HY, Hong SK, Ihm BS, eds). Bumwoo Publishing, Seoul, pp 19-46. (in Korean)
Society of American Foresters. 1954. Forest Cover Types of North America (Exclusive of Mexico). Society of American Foresters, Washington, DC.
Song JS. 1991. Phytosociology of subalpine coniferous forests in Korea I. Syntaxonomical interpretation. Ecol Res 6: 1-19.
Suh MH, Lee DK. 1998. Stand structure and regeneration of *Quercus mongolica* forests in Korea. For Ecol Manag 106: 27-34.
Vankat JL. 1979. The Natural Vegetation of North America: An Introduction. Wiley, New York, NY.
Vankat JL. 1990. A classification of the forest types of North America. Vegetatio 88: 53-66.
Whittaker RH, Fairbanks CW. 1958. A Study of Plankton Copepod Communities in the Columbia Basin, Southeastern Washington. Ecology 39: 46-65.
Whittaker RH. 1952. A Study of Summer Foliage Insect Communities in the Great Smoky Mountains. Ecol Monogr 22: 1-44.
Whittaker RH. 1956. Vegetation of the Great Smoky Mountains. Ecol Monogr 26: 1-80.
Wishart D. 1969. 256. Note: An Algorithm for Hierarchical Classifications. Biometrics 25: 165-170.

Yim YJ, Kira T. 1975. Distribution of forest vegetation and climate in the Korean Peninsula.: I. distribution of some indices of thermal climate. Jpn J Ecol 25: 77-88.
Yim YJ. 1977. Distribution of forest vegetation and climate in the Korean Peninsula: IV. Zonal distribution of forest vegetation in relation to thermal climate. Jpn J Ecol 27: 269-278.
Yun JW, Jung SC, Koo GS, Lee JH, Yun CW, Joo SH. 2010. Forest Vegetation Classification on Sobaeksan National Park in the Baekdudaegan. Korean J Environ Ecol 24: 630-637. (in Korean with English abstract)
Zobel DB, Antos JA. 1991. Growth and Development of Natural Seedlings of *Abies* and *Tsuga* in Old-Growth Forest. J Ecol 79: 985-998.