Growing environment characteristics and vegetation structure of Vaccinium Oldhamii Miq. native habitats in Korea

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ABSTRACT
In the present study was surveyed the flora, vegetation structure, growing environment, and soil characteristics in the wild habitats of Vaccinium oldhamii and offered basic information for habitat conservation and restoration. Most of the wild habitats of V. oldhamii were located at altitudes between 5 and 1095 m with inclinations of 2–33°. Dense populations were found around the climbing routes of the north-facing mountain slopes and dry rocky areas along mountain ridges. Vascular plants identified in the surveyed V. oldhamii habitats (28 quadrats in 12 habitat areas) included 129 taxa (50 families, 94 genera, 115 species, 9 varieties, 2 subspecies and 3 forms), of which woody plants accounted for 31.1%. The flora identified in the habitat areas were classified into four community types: Community I (Pinus densiflora – Quercus mongolica), Community II (Pinus thunbergii), Community III (Pinus rigida), and Community IV (Castanea crenata). The differences among communities within V. oldhamii habitats were more dependent on the occurrence of species with high importance percentages than on the population sizes of the species observed. The soil characteristics of V. oldhamii habitats were as follows: mostly silty loams; well-drained; shallow available-soil depth; high acidity (pH 3.93–5.07, mean = 4.63, lower than the mean Korean forest soil pH of 5.5); and mean available phosphate (≈9.485 mg/kg, lower than the mean Korean forest soil available phosphate of 26 mg/kg). Mean species diversity, evenness and dominance were calculated as 1.216, 0.954 and 0.046, respectively.

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Introduction
There is growing awareness and recognition of the value of biological resources worldwide, as demonstrated by the activities of the Convention on Biological Diversity (CBD), International Union for Conservation of Nature (IUCN) Red List and Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Some studies have projected that 20% of the currently existing 250,000 vascular plant species will become extinct in the future (Falk and Olwell 1992; Lee et al. 2011). Many scholars have stated that biodiversity provides a wide range of benefits to human life (Nelson et al. 2009; Le et al. 2016).

Since the fundamental cause of reduction in biological diversity is habitat loss owing to artificial development and damage to ecosystems by human activities, an approach to address the biodiversity decline is to restore disturbed ecosystems back to their original, healthy states (Ryu 2002). Based on the social responsibility for conserving and maintaining biodiversity, growing interest is being devoted to conservation strategies, such as the proliferation of living biota and growth environment characteristics, with particular focus on in situ conservation as stipulated in Article 8 of the CBD (Lee et al. 2011).

Vaccinium oldhamii Miq., the species investigated in this study, is a deciduous shrub (form the family Ericaceae) that grows to a height of 1–4 m and is native to eastern China, Japan and Korea. In South Korea, its habitats are distributed in the mountainous areas of Gyeongbuk, South of Chungbuk and along the West coast (Anmyeondo Island) (Jeong and Hyeon 1989). It grows well in half-shade, even in infertile areas, owing to its drought hardiness. Other characteristics are its high pollution resistance, easy replanting ability and tendency to form small communities (Kim et al. 2010).

Vaccinium is a genus of about 300 species worldwide that includes blueberries, which are one of the top 10 ‘superfoods’ listed by the US weekly news magazine TIME. Blueberries have a high antioxidant content and anti-aging properties at the cellular level, and are known to prevent dementia and obesity owing to the cholesterol-lowering effects of the dietary fibers they contain. Studies are also underway to test their potential anti-diabetic and cancer effects. Furthermore, anthocyanins, the dark-purple pigments found in blueberries, have been reported to prevent and treat...
eye-related symptoms, such as eye fatigue and blurred vision (Kim et al. 2013).

*V. oldhamii*, commonly called Korean blueberry, is a promising species worthy of blueberry-like ‘superfood’ status. Its fruits have been used in Korea and China for their preservative, astringent, stomachic and diuretic effects as remedies for cystitis, vomiting, gonorrhea, diarrhea and rashes. According to a recent study on bioactive materials with anti-obesity and anti-diabetic effects, substances inhibiting α-amylase activity were isolated from the leaves of *V. oldhamii*, acetylcholinesterase inhibitors, namely taraxerol, lyonioside (a compound of scopoletin and lignan) and ssioride, were isolated from the twigs, and the content of anthocyanins in the fruits was found to be 1.9-fold higher than that of blueberries (Song et al. 2015).

There have only been a small number of studies on *V. oldhamii*, which were mostly focused on its pharmaceutical uses, such as the antioxidant effect of its fruits (Chae et al. 2010), physiological activity, antimicrobial effects (Chae et al. 2012) and anti-inflammatory effects (Lee et al. 2017). One study investigated the morphology of its leaves and fruits (Kim et al. 2012). In terms of habitat-related research, one study investigated the genus *Vaccinium*’s growth environment and vegetation characteristics (Park et al. 2009), but it was limited to the southern coastal areas of the Korean Peninsula. There is also a general lack of studies focusing specifically on the species *V. oldhamii*. For instance, no research has been carried out to examine the sexual or asexual reproduction of *V. oldhamii*. However, there is a pressing need to examine its habitat characteristics as baseline research for its application as a food and drug resource.

Given the above paucity of important research on *V. oldhamii*, this study aimed to identify the flora, vegetation structure, growth environment characteristics and soil characteristics of this species’ natural habitats to provide a baseline database for projects aiming to conserve its habitats and develop propagation and cultivation techniques.

**Materials and methods**

**Study sites and habitat survey**

We selected 28 plots in 12 habitat areas on the Korean peninsula, covering the latitudinal range of 33° 21’ N to 36° 26’ N, where populations of *V. oldhamii* are found in relatively stable vegetation structures without man-made disturbance. There 3 plots in Gumi, 3 in Gimcheon, 3 in Taean, 3 in Nonsan, 2 in Buan, 2 in Muju, 2 in Gurye, 2 in Haenam, 2 in Gwangyang, 2 in Gwangju, 2 in Jeju and 2 in seogwipo (Figure 1).

We measured latitude, longitude, altitude and slope using a GPS (Garmin, GPSMAP64S) and Suunto Clino Compass to examine the growth environment characteristics of this species.
of each plot. The mean importance percentage (MIP) was derived by assigning weight to each layer. Diversity and evenness of species of each layer were determined using the Shannon-Weaver Diversity Index (H'). The maximum H', evenness (J') and dominance (D) were obtained using the equations $H' = \log S$ (S denotes the total number of species), $J' = H' / H'_{\text{max}}$ and $D = 1 - J'$ (Pielou 1975). Additionally, similarity indices at the community level were calculated using the similarity index formula of Sorensen (1948). We used two-way cluster analysis and detrended correspondence analysis (DCA) to determine the similarities and differences between the vegetation structures of different habitats, thereby applying the weights of all clusters identified in the study sites. Additionally, we analyzed the relationships between the community characteristics and species and environmental factors, such as habitat and soil characteristics, by using Principal Component Analysis (PCA) ordination. This was performed using the program PC-ORD v. 5.17 (McCune and Mefford 2006) for community and ordination analysis.

### Soil analysis

Soil characteristics play an important role as habitat components of forest vegetation, greatly influencing the uptake of water and nutrients necessary for plant growth. We extracted three soil samples per plot at 10–20 cm depth after removing the organic matter layer. We then analyzed the chemical composition of the soil using the pipet method according to the U.S. Department of Agriculture classification system, and quantified the content of organic matter (OM) with the Walkley-Black method, available phosphate (P₂O₅) with the Lancaster method, total nitrogen (TN) with the Kjeldahl method, and exchangeable cations by ICP analysis with a 1N-NH₄OAc (pH 7.0) leaching method. The cation exchange capacity (CEC) was calculated with the NH₄-N Kjeldahl distillation technique by leaching soil samples with 1N-NH₄OAc solution buffered at pH 7.0. Electrical conductivity and pH of the soil samples diluted 1:5 were measured with an EC meter (HANNA, HI 98331) and a pH meter (HANNA, HI 99121).

### Results and discussion

#### Growth environment

*V. oldhamii* habitats were distributed over widely varying altitudes, ranging between 5–11 m (Taean) and 1090–1095 m (Seogwipo) and slopes ranging between 2–33 and slopes (Table 1). Habitat slopes showed southeasterly, westerly, northeasterly, northerly and northwesterly aspects, thus exhibiting preference of the species for northerly aspects but no preferences related to altitude and slope gradient. The mean number of *V. oldhamii* individuals found in the 28 plots per 100 m² (10×10 m) quadrat was 15.3, ranging between 7 (mean of two plots in Seogwipo) and 28 (mean of three plots in Gumi). The mean height of the tree layer ranged between 6.26 m (Seogwipo) and 11.70 m (Nonsan), and the mean diameter at breast height (DBH) of trees was between 15.5 cm (Seogwipo) and 24 cm (Muju). The high altitude of Seogwipo is assumed to be the cause of the lowest observed mean height and DBH of the tree layers there. The shrub layer showed high evenness in height and DBH, which were around 1.5 m and 1.5 cm, respectively, in most

| Location | Plot No. | Aspect | Slope (°) | Altitude (m) | Population | Tree layer (mean) | Shrub (mean) |
|----------|----------|--------|-----------|-------------|------------|------------------|--------------|
| Gurye    | 1        | SE     | 27        | 650         | 10         | 8.2 | 9 | 1.5 | 1.5 |
|          | 2        | SE     | 30        | 670         | 15         | 8.5 | 19 | 1 | 1.3 |
| Haenam   | 3        | SW     | 7         | 200         | 7          | 8   | 15.5 | 1.3 | 1.5 |
|          | 4        | S      | 12        | 230         | 10         | 8   | 15 | 1.3 | 1 |
| Buan     | 5        | NE     | 25        | 136         | 19         | 6.5 | 16 | 1.5 | 1.5 |
|          | 6        | NE     | 20        | 101         | 28         | 10  | 25 | 1.7 | 1.7 |
| Taean    | 7        | SW     | 3         | 5           | 12         | 9   | 15 | 1.5 | 1.5 |
|          | 8        | SW     | 5         | 8           | 17         | 9   | 16 | 1 | 1 |
|          | 9        | W      | 10        | 11          | 18         | 8   | 18 | 1 | 1.5 |
| Nonsan   | 10       | NE     | 27        | 246         | 12         | 11.8 | 20 | 1.5 | 1.7 |
|          | 11       | NE     | 24        | 226         | 16         | 11.5 | 20 | 1.3 | 1.5 |
| Gimcheon | 12       | SW     | 15        | 210         | 10         | 11.7 | 16 | 1 | 1.3 |
|          | 13       | SE     | 30        | 654         | 15         | 10.3 | 16.5 | 1 | 1 |
|          | 14       | NE     | 33        | 637         | 24         | 10  | 15 | 1.5 | 1.5 |
| Gumi     | 15       | SE     | 32        | 619         | 22         | 9.5  | 16 | 1.5 | 1.5 |
|          | 16       | NW     | 27        | 513         | 32         | 9   | 16 | 1.7 | 1.7 |
|          | 17       | NW     | 30        | 482         | 24         | 9   | 16 | 1.7 | 1.7 |
|          | 18       | NW     | 28        | 507         | 28         | 7.5  | 20 | 1.5 | 1.7 |
| Muju     | 19       | N      | 22        | 720         | 11         | 8.4  | 23 | 1.5 | 1.5 |
|          | 20       | NE     | 25        | 730         | 12         | 9   | 25 | 1.5 | 1.5 |
| Gwangyang| 21       | N      | 17        | 490         | 8          | 8.7  | 19 | 1 | 1.5 |
|          | 22       | NE     | 20        | 470         | 12         | 8.5  | 18 | 1 | 1.5 |
| Gwangju  | 23       | SW     | 26        | 830         | 14         | 8   | 19 | 1.7 | 2 |
|          | 24       | SW     | 28        | 850         | 17         | 8.4 | 18.5 | 1.7 | 2 |
| Seogwipo | 25       | W      | 2         | 1,095       | 7          | 6   | 15 | 1.3 | 1 |
|          | 26       | NW     | 5         | 1,090       | 7          | 6.5 | 16 | 1.5 | 1.5 |
| Jeju     | 27       | SE     | 17        | 746         | 12         | 8   | 18 | 1.5 | 1 |
|          | 28       | SE     | 22        | 748         | 9          | 9   | 18.5 | 1.5 | 1 |
locations (Table 1). Most V. oldhamii habitats were located around the hilly climbing routes and dry rocky areas along mountain ridges.

**Vegetation structure**

Of all the plant species identified in V. oldhamii habitats, the 25 most common ones were subjected to detrended correspondence analysis (DCA) using PC-ORD v. 5.10 (McCune and Mefford 2006). Based on the results of this analysis, the V. oldhamii populations in their natural habitats were classified into four community types (Figure 2). In 15 plots, *Pinus densiflora-Quercus mongolica* were co-dominant (Community I), *P. thunbergii* was dominant in 5 plots (Community II), *P. rigida* dominated 4 plots (Community III), and *Castanea crenata* dominated 4 plots (Community IV). The cluster analysis dendrogram (Figure 3) representing this result was consistent with the DCA result. The first community type identified was the *P. thunbergii* community that was dominant in plots 4, 25, 26, 27 and 28, followed by the *C. crenata* community in plots 19, 20, 21 and 22, and then the *P. rigida* community in plots 7, 8, 9 and 10. Finally, 15 plots within the clusters dominated by *P. densiflora – Q. mongolica* were identified. The following characteristic species were identified in each community type: *P. densiflora*, *Q. variabilis* and *Q. serrata* in Community I, *P. thunbergii* and *Sasa borealis* in Community II, *P. rigida*, *Rhus tricocarpa*, *Polygonatum odoratum* var. *pluriflorum*, *Pteridium aquilinum* var. *latiusculum* and *Sorbus alnifolia* in Community III, and *Rhododendron yedoense* for. *poukhanense*, *Acer pseudosieboldianum*, *C. crenata*, *Carpinus laxiflora* and *R. mucronulatum* in Community IV (Figure 3).

**Flora of each community type**

Vascular plants identified in V. oldhamii habitats belonged to 129 different taxa (50 families, 94 genera, 115 species, 9 varieties, 2 subspecies and 3 forms), of which woody plants accounted for 31.1%, whereas the remaining were 6 pteridophyta, 9 gymnosperm taxa, and 114 angiosperm taxa (Table 2). Five native species were identified: *Stewartia pseudocamellia* Maxim., *Forsythia koreana* (Rehder) Nakai, *Vicia chosenensis* Ohwi, *Saussurea seoulensis* Nakai and *Carex okamotoi* Ohwi. Only two naturalized plants were identified: *Robinia pseudoacacia* L. and *Amorpha fruticosa* L. (Table 2).

Community I, consisting of 15 plots, showed the highest number of taxa (39 families, 76 genera, 9 varieties, 3 forms, 1 subspecies and 79 species), followed by Community II with 45 taxa (26 families, 33 genera, 4 varieties, 1 form, 1 subspecies and 39 species), Community III with 39 taxa (21 families, 32 genera, 4 varieties, 2 forms and 33 species, and Community IV with 27 taxa (19 families, 24 genera, 3 varieties, 1 form and 23 species) (Table 2).
Importance percentage

Table 3 presents the importance percentage (IP) of the plants of each vegetation layer identified in each community within the \textit{V. oldhamii} habitat areas surveyed in this study. In Community I, the dominant species of the tree layer was \textit{P. densiflora} (IP: 38.07%), and \textit{Q. mongolica} (IP: 16.49%) was the dominant species in the subtree layer, followed by three competing species: \textit{Fraxinus sieboldiana} (IP: 10.16%), \textit{Acer pseudosieboldianum} (IP: 7.96%), and \textit{Q. serrata} (IP: 7.28%). The dominant species in the shrub layer was \textit{V. oldhamii} (IP: 26.24%), followed by \textit{Rhododendron mucronulatum} (IP: 13.88%), \textit{Lindera obtusi-loba} (IP: 7.49%) and \textit{Rhododendron schlippenbachii} (IP: 6.95%). The dominant species of the herb layer was \textit{Sasa borealis} (IP: 14.90%), followed by \textit{Carex humilis} (IP: 9.94%) and \textit{Disporum smilacinum} (IP: 7.85%), and seedlings of \textit{Lindera obtusi-loba}, \textit{Rhus tricocarpa} and \textit{Quercus variabilis} were also observed.

In Community II, the dominant species of the tree layer was \textit{P. thunbergii} (IP: 32.11%), followed by \textit{Q. serrata} (IP: 19.88%), \textit{Prunus sargentii} (IP: 18.06%) and \textit{Q. acutissima} (IP: 9.67%). The dominant species of the subtree layer was \textit{Q. serrata} (IP: 14.70%), with \textit{Cornus kousa} (IP: 12.73%), \textit{Sorbus alnifolia} (IP: 12.12%) and \textit{Acer pseudosieboldianum} (IP: 11.59%) closely competing with it. In the shrub layer, \textit{V. oldhamii} (IP: 36.83%) was dominant, and \textit{R. yedoense} for. poukhanense (IP: 8.94%), \textit{Lindera obtusi-loba} (IP: 8.43%), \textit{Ilex crenata} (IP: 8.00%) and \textit{Maackia fauriei} (IP: 6.65%) were observed. In the herb layer, \textit{Sasa borealis} (IP: 51.32%) was dominant.

In Community III, the dominant species of the tree layer was \textit{P. rigida} (IP: 49.86%), \textit{P. densiflora} (IP: 19.37%), \textit{Q. serrata} (IP: 12.64%) and \textit{Q. variabilis} (IP: 11.02%) were also observed. \textit{P. rigida} (IP: 23.19%) was dominant in the subtree layer as well, followed by \textit{Prunus sargentii} (IP: 15.08%), \textit{Rhus tricocarpa} (IP: 14.69%), \textit{Sorbus alnifolia} (IP: 13.88%) and \textit{Q. serrata} (IP: 11.03%). In the shrub layer, \textit{V. oldhamii} (IP: 29.25%) was dominant, \textit{R. mucronulatum} (IP: 8.94%), \textit{Lindera obtusi-loba} (IP: 8.43%), \textit{Ilex crenata} (IP: 8.26%) and \textit{Q. serrata} (IP: 6.06%) were also observed. In the herb layer, \textit{Polygonatum odoratum} var. pluriflorum (IP: 23.89%) was dominant, followed by \textit{Spodiopogon cotulifer} (IP: 12.15%) and \textit{Smilax sieboldii} (IP: 6.52).

In Community IV, the dominant species of the tree layer was \textit{C. crenata} (IP: 37.65%), followed by \textit{P. densiflora} (IP: 26.26%), \textit{Carpinus laxiflora} (IP: 17.28%), and \textit{Q. aliena} (IP: 7.49%). In the subtree layer, \textit{Carpinus laxiflora} (IP: 32.60%) was dominant, followed by \textit{Styrax obassia} (IP: 11.77%). In the shrub layer, \textit{V. oldhamii} (IP: 29.25%) was dominant, followed by \textit{R. yedoense} for. poukhanense (IP: 22.93%), \textit{Rhus mucronulatum} (IP: 12.19%) and \textit{Acer pseudosieboldianum} (IP: 8.36%). In the herb layer, \textit{Sasa borealis} (IP: 48.53%) was dominant, \textit{Oplopanus undulatifolius} (IP: 8.86%), \textit{Disporum smilacinum} (IP: 8.68%) and \textit{Lindera
| Species                        | Community I | Community II | Community III | Community IV |
|-------------------------------|-------------|-------------|--------------|-------------|
| Carex humilis                 | OUSMOUSHM   | OUSMOUSHM   | OUSMOUSHM    | OUSMOUSHM   |
| Quercus myrsinaefolia         | 2.95 1.64   | 14.69 8.83  | 11.02 2.95   | 32.11 8.83  |
| Rhizus tricocarpa             | 14.69 8.83  | 12.73 3.29  | 6.17         | 21.67 8.83  |
| Quercus variabilis            | 5.59 1.64   | 5.59 1.64   | 4.35 1.64    | 5.59 1.64   |
| Spodopteran catalifer         | 15.08 5.59  | 12.73 3.29  | 6.17         | 21.67 8.83  |
| Ilex crenata var. crenata     | 8.31 3.3    | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Ulmus davidiana               | 5.59 1.64   | 12.73 3.29  | 6.17         | 21.67 8.83  |
| Acer pseudosieboldianum       | 11.02 2.95  | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Ilex macropoda                | 5.59 1.64   | 12.73 3.29  | 6.17         | 21.67 8.83  |
| Camellia japonica             | 5.59 1.64   | 12.73 3.29  | 6.17         | 21.67 8.83  |
| Polygonatum odoratum          | 23.89 2.39  | 23.89 2.39  | 23.89 2.39   | 23.89 2.39  |
| Styrax japonicus              | 23.89 2.39  | 23.89 2.39  | 23.89 2.39   | 23.89 2.39  |
| Pinus rigida                  | 49.86 2.39  | 23.89 2.39  | 23.89 2.39   | 23.89 2.39  |
| Quercus mongolica             | 12.73 3.29  | 23.89 2.39  | 23.89 2.39   | 23.89 2.39  |
| Castanea crenata              | 11.02 2.95  | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Viburnum cedrast              | 9.04 1.64   | 12.73 3.29  | 6.17         | 21.67 8.83  |
| Cornus kousa                  | 2.57 15.08  | 6.07 18.06  | 6.07 18.06   | 6.07 18.06  |
| Fraxinus sieboldi             | 11.02 2.95  | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Robinia pseudocerasa          | 5.59 1.64   | 12.73 3.29  | 6.17         | 21.67 8.83  |
| Disporum smilacium            | 8.31 3.3    | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Vaccinium ovalbum             | 2.57 15.08  | 6.07 18.06  | 6.07 18.06   | 6.07 18.06  |
| Sassafras albidum             | 11.02 2.95  | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Quercus variabilis            | 8.31 3.3    | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Quercus mongolica             | 2.57 15.08  | 6.07 18.06  | 6.07 18.06   | 6.07 18.06  |
| Robinia pseudocerasa          | 5.59 1.64   | 12.73 3.29  | 6.17         | 21.67 8.83  |
| Disporum smilacium            | 8.31 3.3    | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Vaccinium ovalbum             | 2.57 15.08  | 6.07 18.06  | 6.07 18.06   | 6.07 18.06  |
| Sassafras albidum             | 11.02 2.95  | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Quercus variabilis            | 2.57 15.08  | 6.07 18.06  | 6.07 18.06   | 6.07 18.06  |
| Robinia pseudocerasa          | 5.59 1.64   | 12.73 3.29  | 6.17         | 21.67 8.83  |
| Disporum smilacium            | 8.31 3.3    | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Vaccinium ovalbum             | 2.57 15.08  | 6.07 18.06  | 6.07 18.06   | 6.07 18.06  |
| Sassafras albidum             | 11.02 2.95  | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Quercus variabilis            | 2.57 15.08  | 6.07 18.06  | 6.07 18.06   | 6.07 18.06  |
| Robinia pseudocerasa          | 5.59 1.64   | 12.73 3.29  | 6.17         | 21.67 8.83  |
| Disporum smilacium            | 8.31 3.3    | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Vaccinium ovalbum             | 2.57 15.08  | 6.07 18.06  | 6.07 18.06   | 6.07 18.06  |
| Sassafras albidum             | 11.02 2.95  | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Quercus variabilis            | 2.57 15.08  | 6.07 18.06  | 6.07 18.06   | 6.07 18.06  |
| Robinia pseudocerasa          | 5.59 1.64   | 12.73 3.29  | 6.17         | 21.67 8.83  |
| Disporum smilacium            | 8.31 3.3    | 5.59 1.64   | 3.29         | 5.59 1.64   |
| Vaccinium ovalbum             | 2.57 15.08  | 6.07 18.06  | 6.07 18.06   | 6.07 18.06  |
| Sassafras albidum             | 11.02 2.95  | 5.59 1.64   | 3.29         | 5.59 1.64   |
obtusiloba (IP: 8.36%) were also observed as competing species. The dominant species of Community IV is currently C. crenata, with the importance percentage of Carpinus laxiflora rapidly growing in the subtree layer; however, Community IV is projected to shift to a Carpinus laxiflora community.

**Species diversity**

Table 4 presents the Shannon-Weaver species diversity index (H'), maximum H' (H' max), evenness (J'), and dominance (D') of the plant communities observed in each plot (per 100 m² quadrat) of V. oldhamii habitat, Community I and Community III showed the highest species diversity index (1.285 for both), and Community II the lowest (1.144). The highest and lowest values of maximum species diversity (H' max), which is calculated on the basis of the total number of species identified, were found for Community I and IV, which were 1.322 and 1.201, respectively. Evenness represents the degree to which the distribution of individuals of each species is even, with values closer to 1 meaning higher evenness (Brower and Zar 1977). The evenness of the communities in V. oldhamii habitats ranged between 0.901 and 0.982, which is indicative of relatively stable and even species composition attributable to the inter-species competition within the given vegetation structure. In the case of Community III, however, it should be noted that P. rigida is dominant through landscaping, thus resulting in this community type showing higher evenness than the others. Regarding dominance, one species is said to be dominant when the dominance index exceeds 0.9, two or three species are competing for dominance if their indices range from 0.3 to 0.7, and four or more species are competing for dominance when the dominance index is lower than 0.3 (Whittaker 1956). It can thus be inferred that V. oldhamii habitats, for which the mean dominance index was found to be 0.046, typically have a vegetation structure dominated by four or more species.

**Similarity index**

A similarity index value between communities below 20% indicates that they are dissimilar, whereas an index over 80% indicates similar communities (Whittaker 1956), i.e. the similarity index becomes higher as the species distributions in two ecosystems become more similar (Cox 1972; Noh et al. 2013). The inter-community similarity indices calculated among the V. oldhamii habitat areas studied exceeded 20% (Table 5), with Community II and III showing the highest similarity index to each other (42.9%) and Community III and IV similarly showed a high index of similarity (38.9%). In contrast, Community I and II were the most dissimilar communities (20.1%). These results are consistent with those of the cluster analysis, in which ordination of samples is determined according to Euclidean distance. Such inter-community dissimilarities may be ascribed to the widely varying growth environment of V. oldhamii habitats in terms of their altitude and slope, and how they range from coastal areas to high mountains.

**Soil characteristics**

Table 6 outlines the results of soil analysis. The soil samples from the plots of Community I and II were silt loam soils with higher silt percentages, whereas those of Community III and IV were loam and sandy loam, respectively. The soils of the habitat areas in Gurye, Gimcheon and Gwangyang were sandy loam, whereas those of Taean and seogwipo were sand and silt, respectively, and all other habitat areas were found to have silt loam soils. Soil pH ranged from 3.93 to 5.07 (mean pH: 4.63), showing a mean soil pH lower than the mean Korean forest soil pH (5.48) (Jeong et al. 2002), presumably owing to the dominance of coniferous trees, such as P. densiflora, P. thunbergii and P. rigida, in the V. oldhamii habitats. Organic matter (OM) contents ranged from 5.37 to 19.13% (mean: 10.87%), showing large inter-community differences. Plants in the genus Vaccinium are reported to have reduced growth at low soil pH and OM content lower than 3% (Westwood 1993). In our analyses, the soils in the V. oldhamii habitats had low pH, but relatively high OM content. Since soil OM is the primary source of soil nitrogen (Miller and Donahue 1965), the total nitrogen (TN) content is closely correlated with soil OM (Kim et al. 1991). The mean TN content of our soil samples (0.37%) was higher than the mean Korean forest soil TN content (0.19%) (Jeong et al. 2002). The TN content varied widely among communities, with Community II exhibiting the highest value (0.64%). The content of available phosphate (Av. P₂O₅) showed a relatively low range (5.11–14.75 mg kg⁻¹), which is presumably associated with the soil acidity, which induces phosphate to precipitate thereby lowering its availability to plants (Vitousek et al. 2010). The cation exchange capacity (CEC) ranged from 12.71 to 22.37 cmolₑ⁻¹ kg⁻¹ (mean: 16.27 cmolₑ⁻¹ kg⁻¹), which falls

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**Table 4.** Species diversity indices of woody and herbaceous species in the investigated plots.

| Sites          | Species diversity (H') | Maximum (H' max) | Evenness (J') | Dominance (D') |
|---------------|------------------------|-----------------|---------------|---------------|
| Community I   | 1.285                  | 1.322           | 0.973         | 0.027         |
| Community II  | 1.144                  | 1.274           | 0.901         | 0.099         |
| Community III | 1.285                  | 1.309           | 0.982         | 0.018         |
| Community IV  | 1.152                  | 1.201           | 0.958         | 0.042         |
| Average       | 1.216                  | 1.277           | 0.954         | 0.046         |

Note. Community I(P. densiflora-Q. mongolica Com.), Community II(P. thunbergii Com.), Community III(P. rigida Com.), Community IV(C. crenata Com.).

**Table 5.** Similarity index(%) between communities.

| Community I | Community II | Community III | Community IV |
|-------------|-------------|---------------|-------------|
| 20.11       | 42.90       | –             | 38.88       |
| 27.48       | 30.43       | 38.88         | 30.43       |

Note. Community I(P. densiflora-Q. mongolica Com.), Community II(P. thunbergii Com.), Community III(P. rigida Com.), Community IV(C. crenata Com.).
within the range of the mean Korean forest soil CEC (16–20 cmolₖg⁻¹) (Jeong et al. 2002). The mean content of exchangeable cations was determined to be Ca²⁺ 0.60 cmolₖg⁻¹, Mg²⁺ 0.41 cmolₖg⁻¹, Na⁺ 0.10 cmolₖg⁻¹ and K⁺ 0.07 cmolₖg⁻¹. Electric conductivity (EC) ranged from 0.14 to 0.26 ds/m⁻¹, without much deviation.

**Ordination analysis**

Principle component analysis (PCA) was performed to determine the associations between the environmental and soil characteristics of the individual plots to *V. oldhamii* habitat characteristics (Figure 4). Of the soil characteristics tested, sand and soil pH were factors determining variation among plots for more than half of the plots (n = 15) in the habitat areas, such as Taean, Nonsan, Gimcheon, Muju and Gwangyang. The influence of sand was particularly strong, with most of the plots influenced by sand showing sandy loam soil characteristics. In contrast, silt and clay were found to have negligible effects on *V. oldhamii* habitats. Plots 27 and 28 (Jeju) and plot 16 (Gumi) were influenced by EC, exchangeable cation Na⁺, and Av. P₂O₅.

**Table 6. Soil Characteristic in each vegetation colony of *V. oldhamii*.**

| Com. | Sand (%) | Silt (%) | Clay (%) | pH | OM (%) | TN (%) | P₂O₅ (mg/kg⁻¹) | CEC | K⁺ | Na⁺ | Ca²⁺ | Mg²⁺ | EC (ds/m⁻¹) |
|------|----------|----------|----------|-----|--------|--------|----------------|------|----|-----|------|-------|--------|---------|
| Mean | 28.86    | 56.24    | 14.91    | 4.61| 10.45  | 0.35   | 8.98           | 16.81| 0.07| 0.10| 0.77 | 0.41  | 0.18   |
| S.D. | 25.24    | 22.59    | 5.88     | 0.21| 7.85   | 0.25   | 5.22           | 6.13 | 0.03| 0.06| 0.50 | 0.30  | 0.08   |
| Mean | 12.08    | 77.04    | 10.87    | 4.63| 19.13  | 0.64   | 14.75          | 22.37| 0.08| 0.17| 0.58 | 0.55  | 0.26   |
| S.D. | 4.10     | 7.25     | 9.39     | 0.34| 8.70   | 0.29   | 7.94           | 4.66 | 0.04| 0.08| 0.40 | 0.53  | 0.12   |
| Mean | 45.75    | 43.09    | 11.15    | 4.58| 6.16   | 0.17   | 5.11           | 13.57| 0.05| 0.07| 0.35 | 0.36  | 0.14   |
| S.D. | 26.30    | 20.70    | 5.86     | 0.05| 3.16   | 0.12   | 2.07           | 5.36 | 0.02| 0.01| 0.08 | 0.09  | 0.04   |
| Mean | 52.60    | 36.75    | 10.68    | 4.68| 5.37   | 0.21   | 8.05           | 12.71| 0.05| 0.07| 0.22 | 0.20  | 0.14   |
| S.D. | 11.88    | 9.26     | 2.58     | 0.04| 2.47   | 0.05   | 4.60           | 4.59 | 0.01| 0.01| 0.06 | 0.03  | 0.01   |
| Average| 34.82 | 53.28 | 11.90     | 4.63| 10.28 | 0.34   | 9.22           | 16.37| 0.06| 0.10| 0.48 | 0.38  | 0.18   |

*Note.* Community I (*P. densiflora-Q. mongolica* Com.), Community II (*P. thunbergii* Com.), Community III (*P. rigida* Com), Community IV (*C. crenata* Com.).

**Figure 4.** Soil and environment feature and of the based on PCA.
presumably owing to the low influence thresholds of these factors compared with other growth environment characteristics such as TN and OM content. The remaining plots except for 5 and 6 (Buan) were influenced by the number of the *V. oldhamii* individuals (population size) within the quadrats, while those in Buan, especially plot 6, were influenced by the population size and slope. These habitats seem to be influenced more strongly by environment characteristics than soil characteristics.

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Appendix 1. The list of vascular plants in *V. oldhamii* native habitats.

| Flora                        | Community | Community |
|-----------------------------|-----------|-----------|
| Lycopodiaceae               |           |           |
| Lycopodium serratum Thunb.  |           |           |
| Aspleniaceae                |           |           |
| Athyrium niponicum (Mett.) Hance |       |           |
| Peridium aquilinum var. luctuosum |   |           |
| Athyrium yokosanense H.Christ |       |           |
| Pinaceae                    |           |           |
| Pinus thunbergii Parl.      |           |           |
| Pinus nigra Mill.           |           |           |
| Pinus densiflora Siebold & Zucc. |    |           |
| Larix kaempferi (Lamb.) Carriere |   |           |
| Abies holophylla Maxim.     |           |           |
| Fagaceae                    |           |           |
| Quercus myrsinaefolia Blume |           |           |
| Quercus aliena Blume        |           |           |
| Quercus variabilis Blume    |           |           |
| Quercus mongolica var. crispa H.Ohashi | | |
| Castanea crenata Siebold & Zucc. |   |           |
| Quercus acutissima Carruth. |           |           |
| Quercus mongolica Fisch. ex Ledeb. | | |
| Quercus serrata Thunb. ex Murray |   |           |
| Magnoliaceae                |           |           |
| Magnolia sieboldii K.Koch   |           |           |
| Menispermaceae              |           |           |
| Menispernum diurianum DC.   |           |           |
| Saxifragaceae               |           |           |
| Deutzia glabrata Kom.       |           |           |
| Leguminosae                 |           |           |
| Vicu amenoisch Fisch. ex DC. |           |           |
| Lathyrus japonicus Willd.   |           |           |
| Vicia chassiorientis Ohwi   |           |           |
| Maackia amurensis Rupr. & Maxim. |       |           |
| Indigofera kirilowii Maxim. ex Palib. | | |
| Anglicarpaea brahearta subsp. nongguwathiri | | |
| Maackia fauriei (H.H.L.) Takeda | | |
| Ledegera bicolar Turcz.     |           |           |
| Robinia pseudacacia L.      |           |           |
| Aescynome indica L.         |           |           |
| Ledegera masamiirociai C.K.Schneid. | | |
| Amopha fruticosa L.         |           |           |
| Euphorbiaceae               |           |           |
| Acalypha australis L.       |           |           |
| Triandra sebifera (L.) Small |       |           |
| Anacardiaceae               |           |           |
| Rhus tecomacarpa Miq.       |           |           |
| Aquifoliaceae               |           |           |
| Ilex crenata Thunb.         |           |           |
| Ilex macropoda Miq.         |           |           |
| Ilex crenata var. microphylla |           |           |
| Staphyleaceae               |           |           |
| Staphylea burludala DC.     |           |           |
| Vitaceae                    |           |           |
| Vitis coignetiae Pulliat ex Planch. | | |
| Cornaceae                   |           |           |
| Cornus kousa F.Bueger ex Miqel | | |
| Cornus controversa Hemsl. ex Prain | | |
| Pyrolaceae                  |           |           |
| Pyrola japonica Klenze ex Alef. |         |           |
| Primulaceae                 |           |           |
| Lysmachia clothoides Doby   |           |           |
| Ebenaceae                   |           |           |
| Diacrysia lotus L.          |           |           |
| Styracaceae                 |           |           |
| Styrax japonicus Siebold & Zucc. |       |           |
| Styrax obsias Siebold & Zucc. |       |           |
| Oleaceae                    |           |           |
| Forythia koreana (Rehdler) Nakai |       |           |
| Fraxinus rhynchophylla Hance |           |           |
| Fraxinus sieboldiana Blume  |           |           |
| Labiatae                    |           |           |
| Isodon inflatus (Thunb.) Kudo |           |           |
| Meconopsis urichiifolia (M.) Makino | | |
| Plantaginaceae              |           |           |
| Plantago asiatica L.        |           |           |
| Compositae                  |           |           |
| Artemisia stolonifera (Maxim.) Kom. | | |
| Anisulae acerifolia Sch.Bip. |           |           |
| Saussurea souensis Nakai    |           |           |
| Dendranthema bungei Ling ex Kitam. | | |
| Athynctylodes ovata (Thunb.) DC. | | |
| Peridieraceae               |           |           |
| Conogramme intermedia Hieron. |         |           |
| Dryopterideraceae           |           |           |
| Dryopterus crassifolius Nakai |         |           |
| Cupressaceae                |           |           |
| Juniperus rigida Siebold & Zucc. |       |           |
| Thuja orientalis L.         |           |           |
| Taxaceae                    |           |           |
| Taxus cuspidata Siebold & Zucc. |       |           |
| Betulaceae                  |           |           |
| Corylus heterophylica Fisch. ex Trautv. | | |
| Betula schmidtii Regel      |           |           |
| Carpinus laxiflora Blume    |           |           |
| Alnus japonica (Thunb.) Steud. |         |           |
| Ulmaceae                    |           |           |
| Ulmus davidiana var. japonica Nakai | | |
| Cannabaceae                 |           |           |
| Humulus japonicus Siebold & Zucc. |       |           |
| Urlicaceae                  |           |           |
| Boehmeria tricuspis (Hance) Makino | | |
| Urtica thunbergiana Siebold & Zucc. | | |
| Lauraceae                   |           |           |
| Lindera obtusiloba Blume    |           |           |
| Theaceae                    |           |           |
| Stewardia pseudocamellia Maxim. |       |           |
| Camellia japonica L.        |           |           |
| Rosaceae                    |           |           |
| Rubus phoenicolasius Maxim. |           |           |
| Stephanandra incisa (Thunb.) Zabel | | |
| Pyrus pyrifolia (Burm.f.) Nakai |         |           |
| Sorbus commutata Hedl.      |           |           |
| Ducheniina incisa (Andr.) Focke |       |           |
| Prunus serrulata var. spontanea |         |           |
| Prunus sargentii Rehder      |           |           |
| Crataegus pinnatifida Bunge  |           |           |
| Spirana blumei G.Don        |           |           |
| Rosa multiflora Thunb.       |           |           |
| Sorbus alnifolia K.Koch     |           |           |
| Daphniphyllaceae            |           |           |
| Daphniphyllum macropodum Miq. |         |           |
| Rutaceae                    |           |           |
| Zanthoxylum schinifolium     |           |           |
| Meliaceae                   |           |           |
| Cedrela sinensis Juss.      |           |           |
| Aceraceae                   |           |           |
| Acer pictum subsp. mon Ohashi |         |           |
| Acer palmatum Thunb. ex Murray |       |           |
| Acer pseudobulbifolium (Pax) Kom. | | |
| Celtaceaceae                |           |           |
| Euryonymus japonicus Thunb. |           |           |
| Euryonymus hamiltonianus Wall. |         |           |
| Euryonymus olatus for. colladontatus | | |
| Violaceae                   |           |           |
| Viola rossi Hemsl.          |           |           |
| Viola orientalis (Maxim.) W.Becker | | |
| Araliaceae                  |           |           |
| Aralia elata (Miq.) Seem.   |           |           |
| Ericaceae                   |           |           |
| Vaccinium hirtum var. koreanum Kitam. | | |
| Rhododendron yedoense for. paukhanense | | |
| Vaccinium oldhamii Miq.     |           |           |
| Rhododendron mucronulatum Turcz. | | |
| Rhododendron weychnchi Maxim. |         |           |
| Rhododendron schippchenbachi Maxim. | | |
| Symplolaceae                |           |           |
| Symplocoa chinensis for. plosa Ohwi | | |
| Apocynamaceae               |           |           |
| Trachelospermum asiaticum Nakai |       |           |
| Verbenaceae                 |           |           |
| Callicarpa japonica Thunb.  |           |           |
| Scrophulariaceae            |           |           |
| Veronica larnifolia Pall. ex Link | | |
| Caprifoliaceae              |           |           |
| Lonicera maackii (Rup.) Maxim. |         |           |
| Viburnum carlesii Nakai    |           |           |
| Viburnaceae                 |           |           |
| Polygonatum odoratum var. pluriflorum | | |
| Hosta longipes Matt.        |           |           |
| Smilax japonica Miq.        |           |           |
| Disporum simulacrum A.Gray  |           |           |

(continued)
| Flora                                      | Community | Community |
|--------------------------------------------|-----------|-----------|
| Syneilesis palmata (Thunb.) Maxim.         | I II III IV | I II III IV |
| Iridaceae                                  |           |           |
| Iris sanguinea Donn ex Horn                |           |           |
| Caryophyllaceae                            |           |           |
| Pseudostellaria heterophylla               |           |           |
| Cyperaceae                                 |           |           |
| Carex humilis var. nana Ohwi               |           |           |
| Carex lanceolata Boott                     |           |           |
| Carex siderosticta Hance                   |           |           |
| Carex okamotoi Ohwi                        |           |           |

Note. Community I(P. densiflora-Q. mongolica Com.), Community II(P. thunbergii Com.), Community III(P. rigida Com), Community IV(C. crenata Com.).