



# Comparison of plant species diversity and its relationship with physical environmental factors in Gotjawal Forest, Jeju Island, Republic of Korea, using the modified Whittaker plot method

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**Background:** To effectively understand and evaluate plant diversity in a specific area and make meaningful comparisons between regions, standardized methods that measure diversity irrespective of survey plot size are crucial. This study proposes a model equation for comparing plant species diversity using the modified Whittaker plots. Plant species diversity was measured in two Gotjawal areas on Jeju Island, where the coexistence of northern and southern limit species significantly impacts diversity. By analyzing the relationship between plant species diversity and environmental factors, the study clarified the characteristics of plant and habitat diversity in the Gotjawal ecosystem.

**Results:** The species richness of vascular plants, herbaceous plants, and woody plants increased with area and was higher in Jeoji Gotjawal than in Seonheul Gotjawal. Similarly, the species turnover rate (slope value) was higher in Jeoji Gotjawal (4.37) than in Seonheul Gotjawal (3.85). This indicates that the species richness in Jeoji Gotjawal increases more with the expansion of the survey area (1-1,000 m<sup>2</sup>), reflecting a faster species turnover rate. Additionally, in Gotjawal areas, species richness increased with greater leaf litter depth, elevation, slope, and rock ratio. These results indicate that differences in plant species diversity were attributed to soil environmental factors.

**Conclusions:** The plant species diversity of Gotjawal, surveyed using standardized methods, was lower than that of forested areas in the central region of South Korea where the same method was applied. Most previous studies on species diversity likely compared diversity without considering a consistent survey area. Therefore, when comparing plant species diversity domestically and globally, it emphasizes the need for the use of standardized survey methods.

**Keywords:** biodiversity, soil environmental factors, species turnover rate, standardized survey methods, vascular plants

## Introduction

Biodiversity is commonly used to denote the diversity of species within a specific area, and sometimes it is used to denote the diversity of habitats, biotic communities, or ecosystems in that area (Barbour et al. 1980). The importance of biodiversity is highlighted due to the various benefits it provides to humans through 'ecosystem services' offered by the natural environment (IPCC 2014; Yook et al. 2010). Therefore, it is necessary to understand and evaluate the state of biodiversity for its sustainable conservation and management (Krebs 1998). Consequently, there is a grow-

ing interest in quantifying biodiversity patterns at national and regional scales (Stohlgren 1995).

Many ecologists strive to use equivalent sampling methods, considering the appropriate size and shape of plots, to elucidate the plant species diversity of specific vegetation types (Barbour et al. 1980). One of the vegetation sampling methods involves measuring species diversity using nested plots of increasing size (Barbour et al. 1980). This method shows a tendency for species diversity to increase as the area of the plot increases (Diamond 1988); however, species richness varies with scale, making it not a standardized method (Mosley et al. 1989). Therefore, establishing stan-



standardized methods such as the size and arrangement of sampling plots is crucial for comparing and evaluating biodiversity between regions.

The patterns of plant diversity can only be revealed through consistent surveys and sampling across various spatial scales (Whittaker 1977). Considering this, Whittaker developed the nested vegetation sampling method, a standard technique for measuring species richness and diversity, in 1977 (Barbour et al. 1980). This method involves setting up nested plots of 1 m<sup>2</sup>, 10 m<sup>2</sup>, and 100 m<sup>2</sup> within a 1,000 m<sup>2</sup> area, and recording the occurrence of species in each plot, identifying unrecorded species as the plot size increases (Stohlgren et al. 1995; Whittaker 1977). Later, to evaluate species richness more accurately, the modified Whittaker plots (MWP) were developed by modifying this method (Shmida 1984; Stohlgren et al. 1995).

The MWPs method helps understand the influence of plot size on species-area relationships and provides a standardized approach to quantify species richness in different plant communities (Stohlgren et al. 1995). By obtaining a linear relationship of cumulative species numbers with increasing survey area, it allows for information on spatial patterns of species and enables comparisons and trend detection of diversity over time (Campbell et al. 2002). Due to these attractive characteristics, some countries have adopted MWPs for studying plant species diversity (Ghorbani et al. 2011; Stohlgren et al. 1995; Xu et al. 2021).

In Republic of Korea, sampling generally covers 0.01% to 0.1% of the total study area, and surveys are conducted in an irregular grid pattern within the region (Kim et al.

2007). However, this method has issues such as varying plot sizes depending on the area surveyed and differences in species richness and diversity due to the shape, size, and location of the plots. Moreover, there is a lack of standardized methods for studies that allow for comparisons of plant species diversity.

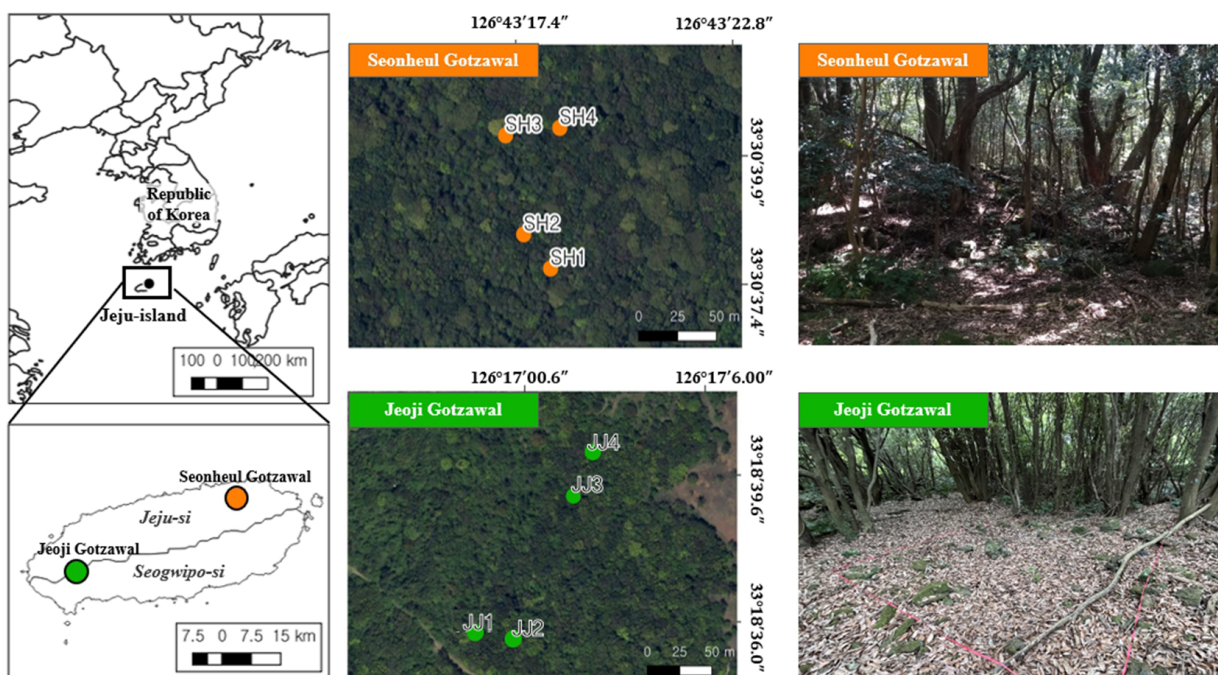
Therefore, this study aims to propose a model formula for comparing plant species diversity by applying the modified Whittaker plot, which is widely known as a standardized method for measuring plant species diversity. To achieve this, plant species diversity was measured in two Gotjawal areas on Jeju Island, where the coexistence of northern and southern boundary plant species plays an important role in plant diversity. Additionally, the study seeks to interpret the differences in plant species diversity between the two Gotjawal areas by analyzing their relationship with abiotic and biotic environmental factors.

## Materials and Methods

### Study site

Jeju Island in the Republic of Korea is a volcanic island formed by volcanic activity (Koh et al. 2013). It is home to the lava forest known as Gotjawal, which plays an important role in the flora of Jeju Island as it harbors approximately 46% of the plant species found on the island (Song 2007).

Jeoji Gotjawal is in Jeoji-ri, Hangyeong-myeon, Jeju-si, Jeju-do, South Korea (33° 18", 126° 17") (Fig. 1), and is characterized by a rugged terrain and lava caves formed by Aa



**Fig. 1** Seonheul Gotjawal (orange circle at the bottom left) and Jeoji Gotjawal (green circle at the bottom left) on Jeju Island, South Korea, indicate the locations where Modified Whittaker permanent plots were established, with four plots each for Seonheul Gotjawal (middle top) and Jeoji Gotjawal (middle bottom), and showing the overview photo of each Gotjawal (Jeoji Gotjawal; top right and Seonheul Gotjawal; bottom right).

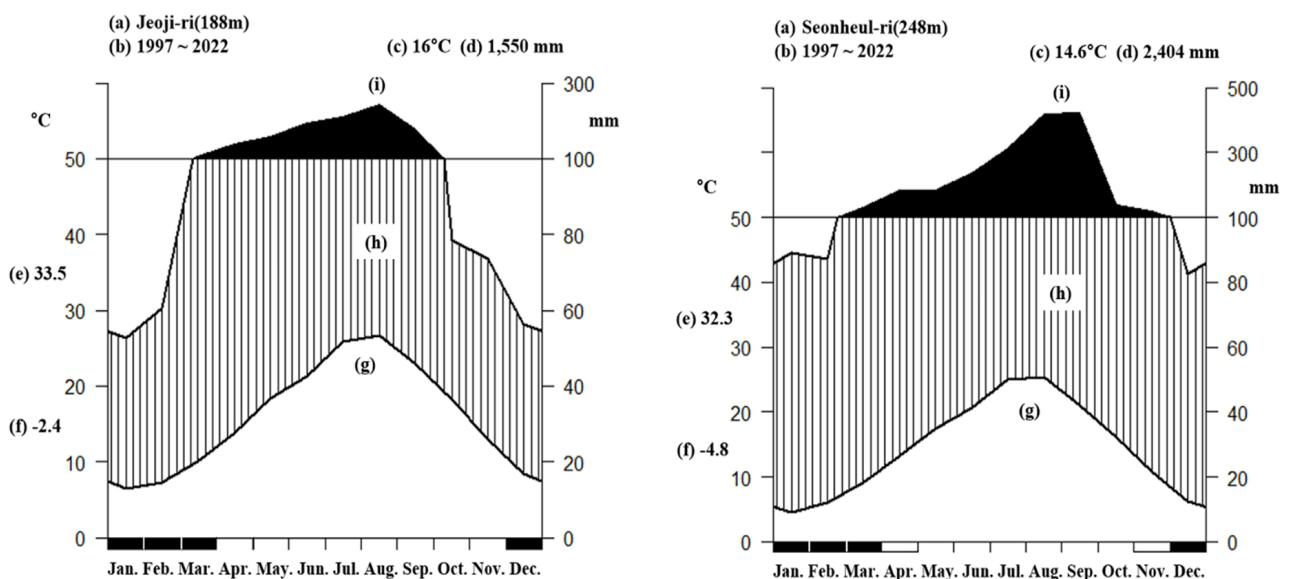
lava flows (Ahn et al. 2015). The most observed trunk diameter of the trees in this area ranges from 5 to 10 cm. The highest cover in the understory was observed in *Arachniodes exilis*, while the canopy layer is known to have a high importance value of evergreen broadleaf trees such as *Quercus glauca* (Kim et al. 2020). Additionally, the area is home to South Korea's native plant, *Daphne jejuensis*, as well as the endangered *Quercus gilva* (classified as Class II endangered wildlife), and the rare plant designated by the South Korea Forest Service, *Cremastra appendiculata* var. *variabilis*. A hiking trail is located about 10 to 20 m from the survey area, and there is also a road nearby that is accessible by vehicles. The climatic data for Jeoji-ri were compiled from the closest Seogwang Meteorological Station, using weather data from 1997 to 2022 (Korea Meteorological Administration 2023) to create a Climate diagram (Walter 1975). The average annual rainfall is 1,550 mm, the average annual temperature is 15.7°C, with the highest average annual temperature reaching 30.0°C, and the lowest average annual temperature at 2.2°C (Fig. 2).

Seonheul Gotjawal is in Seonheul-ri, Jocheon-eup, Jeju-si, Jeju-island, South Korea (33° 30', 126° 43') (Fig. 1), and features a tumulus terrain that forms when pahoehoe lava swells up like bread (Ahn et al. 2015). Trees with a trunk diameter of less than 5 cm were most commonly observed, with the highest coverage in the understory being *A. exilis*, while the canopy layer had a high proportion of evergreen broadleaf trees such as *Q. gilva* and *Camellia japonica*. The area also features dry ponds, which normally appear as regular land but turn into wetlands when it rains, collecting rainwater. In particular, the Dongbaekdongsan Forest located in this region was designated in 2011 as a Ramsar Wetland and a representative site of the Global Geoparks

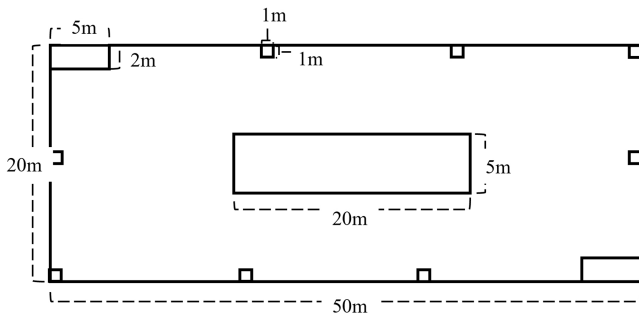
Network. The Dongbaekdongsan Forest is habitat to endangered species such as *Mankyua chejuensis*, *Daphne jejuensis* etc. and there is a hiking trail within 20 m of the survey area. The climatic data for Seonheul-ri were taken from the closest Wasan Meteorological Station, using data from 1997 to 2022 (Korea Meteorological Administration 2023) to create a Climate diagram (Walter 1975). The average annual rainfall is 2,404 mm, the average annual temperature is 14°C, with the highest average annual temperature reaching 28.5°C, and the lowest average annual temperature at 0.1°C (Fig. 2).

### Field survey

The survey was conducted from April to September 2023 at a total of eight survey sites, including four each in Jeoji Gotjawal and Seonheul Gotjawal. Based on the MWP (Stohlgren et al. 1995), a large plot measuring 20 m × 50 m (1,000 m<sup>2</sup>) was set up, and within it, 10 plots of 1 m × 1 m (1 m<sup>2</sup>), 2 plots of 2 m × 5 m (10 m<sup>2</sup>), and 1 plot of 5 m × 20 m (100 m<sup>2</sup>) were installed (Fig. 3). According to the original MWP's method, the 1 m<sup>2</sup> plot should be a 0.5 m × 2 m rectangle, but for convenience in the field, it was set up as a square. Plant surveys were conducted based on the phytosociological method (Braun-Blanquet 2013), and plants that could not be identified in the field were photographed or collected for indoor identification. The plant species were identified using the Illustrated Flora of South Korea (Lee 2003) and Easily Identifiable Subtropical Evergreen Broadleaf Trees (Choi et al. 2021). Species that could be misidentified or were difficult to classify in the field were identified indoors using photographic records of vegetative and reproductive organs. Additionally, the classification of plant life forms (woody and herbaceous) followed the stan-



**Fig. 2** Climate diagrams of Jeoji-ri, Jeju Island (left) and Seonheul-ri (right). a: location name and elevation; b: the period of observation; c: mean temperature; d: mean annual precipitation; e: maximum temperature of warmest month; f: minimum temperature of coldest month; g: mean daily monthly temperature; h: mean daily monthly precipitation; i: humid period.



**Fig. 3** A schematic of the modified Whittaker plot. After setting up the largest plot of 1,000 m<sup>2</sup>, one 100 m<sup>2</sup> plot is installed at the center, and along the lines of the plot, two 10 m<sup>2</sup> plots and ten 1 m<sup>2</sup> plots are installed (Stohlgren et al. 1995). In the original modified Whittaker plot, the 1 m<sup>2</sup> plots were supposed to be installed in a 0.5 m × 2 m rectangular shape, but for convenience during fieldwork, we modified into a 1 m × 1 m square.

dards of the National Institute of Biological Resources' Korean Peninsula Biodiversity database.

### Environmental factor investigation

From April to September 2023, environmental factors for each plot were analyzed by collecting data on elevation (m), slope (°), rock ratio (%), soil depth (cm), soil moisture content (%v), soil pH, leaf litter depth (cm), leaf litter weight (g), and soil organic matter content (%).

The elevation was measured at the center of a 1,000 m<sup>2</sup> plot using the Google Maps application installed on a smartphone. The accuracy of the GPS altitude measurement had a margin of error of approximately 10 m, which could vary due to various environmental factors. Therefore, to stabilize the precise position and altitude, coordinates were recorded after allowing about 3 minutes. Soil depth was measured by inserting a 3 mm-diameter rod with marked measurements into the soil and recording the depth to which it entered. Soil moisture content was measured using a soil moisture content meter (SM-150T; Delta-T Devices, Cambridge, UK), and soil pH was determined with a soil acidity and moisture meter (DM-5; Takemura, Tokyo, Japan). Leaf litter weight was measured by collecting leaf litter from an area of 20 cm × 20 cm (400 cm<sup>2</sup>) and weighing it.

These environmental factors were measured for all sizes of plots, and the measurements were taken during a period when more than two days had passed after rain, so that moisture wouldn't affect the results. Soil organic matter content was assessed by selecting three random points within the plot, removing the leaf litter layer, and collecting soil samples. The samples were sieved through a 2 mm soil sieve, The sieved soil was placed in a crucible, dried in an oven at 105°C for 48 hours, then ignited in an electric furnace at 550°C for 4 hours to determine the organic matter content based on the amount lost during ignition (You et al. 2015).

### Statistical analysis

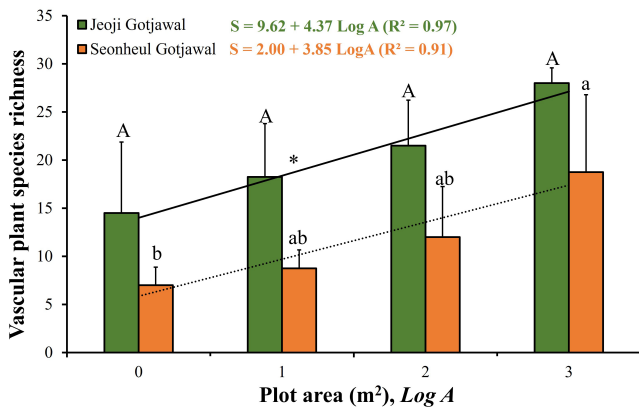
To compare the cumulative species richness recorded at 1 m<sup>2</sup>, 10 m<sup>2</sup>, 100 m<sup>2</sup>, and 1,000 m<sup>2</sup>, the normal distribution of the data was checked using the Kolmogorov–Smirnov test. If the data did not follow a normal distribution, non-parametric analysis was performed. Species richness between Jeoji-ri and Seonheul-ri was compared using the Mann–Whitney U-test, and differences in species richness according to plot size within each Gotjawal were tested using the Kruskal–Wallis H-test at a 5% significance level (No and Jung 2002).

Meanwhile, the degree of species turnover rate is determined by the slope of the regression equation, and a regression model ( $S = a + b \log P$ ; where  $S$  is the number of species, and  $P$  is the plot area) is calculated (Stohlgren et al. 1995). To compare the species turnover rates between the two Gotjawals, regression analysis was performed using Spearman's correlation analysis, and correlation analysis was conducted at a 5% significance level. The criterion for comparing species turnover rates was the slope, which is the coefficient of  $\chi$ . A larger slope indicates a higher species turnover rate, meaning that the number of additional species increases as a certain area increases. All statistical analyses were conducted using the STATISTICA 7 (Statsoft, Tulsa, OK, USA) software.

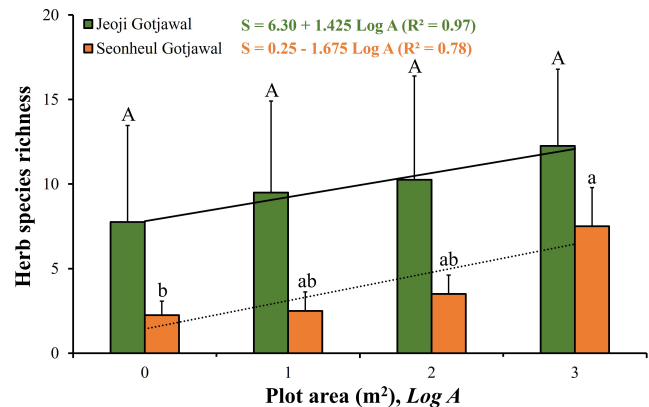
## Result

### Vascular plant species richness

The species richness of vascular plants in Jeoji Gotjawal was higher than in Seonheul Gotjawal. The overall species richness at 1 m<sup>2</sup> (mean ± standard deviation; no./ m<sup>2</sup>) was about 2.07 times higher in Jeoji Gotjawal ( $14.5 \pm 7.37$ ) than in Seonheul Gotjawal ( $7 \pm 1.87$ ), but the difference was not statistically significant ( $p > 0.05$ ). In the 10 m<sup>2</sup> plots, Jeoji Gotjawal ( $18.25 \pm 5.54$ ) had a significantly higher species richness, approximately 2.09 times higher than Seonheul Gotjawal ( $8.75 \pm 1.92$ ) ( $p < 0.05$ ). For 100 m<sup>2</sup> plots, Jeoji Gotjawal ( $21.5 \pm 4.72$ ) had about 1.79 times higher species richness than Seonheul Gotjawal ( $12 \pm 5.24$ ), with no significant difference ( $p > 0.05$ ). In the 1,000 m<sup>2</sup> plots, Jeoji Gotjawal ( $28 \pm 1.58$ ) had about 1.49 times higher species richness than Seonheul Gotjawal ( $18.75 \pm 8.04$ ), with no significant difference ( $p > 0.05$ ). There were no statistically significant differences between plot sizes in Jeoji Gotjawal ( $p > 0.05$ ), while in Seonheul Gotjawal, there was significantly higher species richness in the 1,000 m<sup>2</sup> plots ( $p < 0.05$ ). The species turnover rate with increasing area was slightly higher in Jeoji Gotjawal compared to Seonheul Gotjawal (Jejoi Gotjawal: 4.375, Seonheul Gotjawal: 3.85) (Fig. 4).



**Fig. 4** Species richness of vascular plants in relation to plot area (Log A) in Jeoji Gotjawal and Seonheul Gotjawal in Jeju Island. The bars represent the average species richness across various plot sizes, and the vertical lines on the bars indicate the standard deviation. Uppercase letters represent differences in species richness among plots within Jeoji Gotjawal, and lowercase letters represent differences among plots within Seonheul Gotjawal. An asterisk (\*) indicates significant differences in species richness between the two regions within the same plot size.



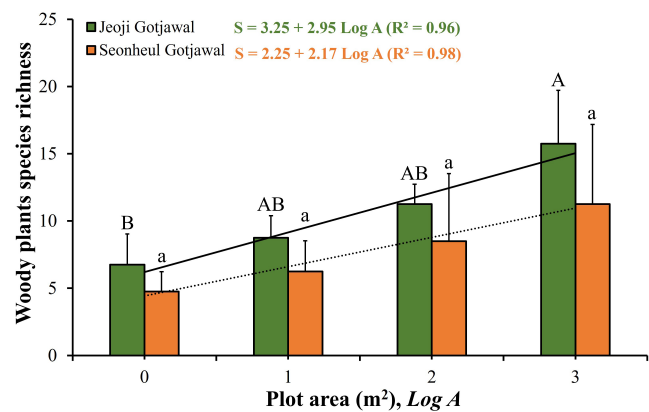
**Fig. 5** Species richness of herbaceous plants in relation to plot area (Log A) in Jeoji Gotjawal and Seonheul Gotjawal in Jeju Island. The bars represent the average species richness across various plot sizes, and the vertical lines on the bars indicate the standard deviation. Uppercase letters represent differences in species richness among plots within Jeoji Gotjawal, and lowercase letters represent differences among plots within Seonheul Gotjawal. An asterisk (\*) indicates significant differences in species richness between the two regions within the same plot size.

### Herbaceous plant species richness

The average species richness of herbaceous plants in Jeoji Gotjawal was higher than in Seonheul Gotjawal. The herbaceous species richness at 1 m<sup>2</sup> (mean ± standard deviation; no./ m<sup>2</sup>) was about 1.35 times higher in Jeoji Gotjawal (7.75 ± 5.72) compared to Seonheul Gotjawal (2.25 ± 0.83) ( $p > 0.05$ ). In the 10 m<sup>2</sup> plots, Jeoji Gotjawal (9.5 ± 5.41) had about 3.80 times higher richness than Seonheul Gotjawal (2.5 ± 1.12) ( $p > 0.05$ ). For 100 m<sup>2</sup>, Jeoji Gotjawal (10.25 ± 6.14) was significantly higher, about 2.93 times higher than Seonheul Gotjawal (3.5 ± 1.12) ( $p > 0.05$ ). In the 1,000 m<sup>2</sup> plots, Jeoji Gotjawal (12.25 ± 4.55) had about 1.63 times higher richness than Seonheul Gotjawal (7.5 ± 2.29) ( $p > 0.05$ ). There were no statistically significant differences among plot sizes in Jeoji Gotjawal ( $p > 0.05$ ), while in Seonheul Gotjawal, the highest species richness was observed in the 1,000 m<sup>2</sup> plot ( $p < 0.05$ ). The species turnover rate with increasing area was slightly higher in Seonheul Gotjawal compared to Jeoji Gotjawal (Jeoji Gotjawal: 1.425, Seonheul Gotjawal: 1.7) (Fig. 5).

### Woody plant species richness

The species richness of woody plants was higher in Jeoji Gotjawal than in Seonheul Gotjawal. The species richness of woody plants at 1 m<sup>2</sup> (mean ± standard deviation) was about 1.42 times higher in Jeoji Gotjawal (6.75 ± 2.28) compared to Seonheul Gotjawal (4.75 ± 1.48) ( $p > 0.05$ ). In the 10 m<sup>2</sup> plots, Jeoji Gotjawal (8.75 ± 1.64) had about 1.40 times higher richness compared to Seonheul Gotjawal (6.25 ± 2.28) ( $p > 0.05$ ). For 100 m<sup>2</sup> plots, Jeoji Gotjawal (11.25 ± 1.48) had about 1.32 times higher richness than Seonheul Gotjawal (8.5 ± 5.02) ( $p > 0.05$ ). In the 1,000 m<sup>2</sup> plots, Jeoji Gotjawal (15.75 ± 3.96) had about 1.4 times higher richness compared to Seonheul Gotjawal (11.25 ± 5.93) ( $p > 0.05$ ).



**Fig. 6** Species richness of woody plants in relation to plot area (Log A) in Jeoji Gotjawal and Seonheul Gotjawal in Jeju Island. The bars represent the average species richness across various plot sizes, and the vertical lines on the bars indicate the standard deviation. Uppercase letters represent differences in species richness among plots within Jeoji Gotjawal, and lowercase letters represent differences among plots within Seonheul Gotjawal. An asterisk (\*) indicates significant differences in species richness between the two regions within the same plot size.

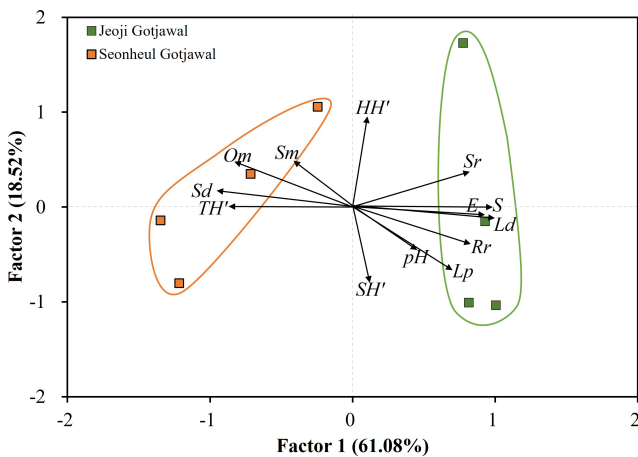
The species turnover rate with increasing area was also higher in Jeoji Gotjawal (Jeoji Gotjawal: 2.95, Seonheul Gotjawal: 2.175) (Fig. 6).

When comparing the coefficient of determination ( $R^2$ ) for each regression model, Jeoji Gotjawal showed an explanatory power of 97%, and Seonheul Gotjawal showed 92% for vascular plant species richness. For herbaceous plant species richness, Jeoji Gotjawal had a higher explanatory power of 97% compared to Seonheul Gotjawal's 86%. For woody plant species richness, Jeoji Gotjawal had an explanatory power of 96%, while Seonheul Gotjawal had 98%. Overall, all models showed a high correlation between species richness and plot area.

### Relationship of plant species biodiversity and environmental factor

The correlation between species richness of vascular plants, plant diversity indices by vegetation layer (herbaceous layer, shrub layer, and tree layer), and abiotic environmental factors (rock ratio, elevation, slope, soil moisture content, pH, soil depth, leaf litter depth, leaf litter production, and organic matter content) in the two Gotjawal areas was analyzed. Factors 1 (61.08%) and 2 (18.52%) explained 79.6% of the variance (Fig. 7, Table 1).

Factor 1 showed a strong correlation with leaf litter depth (0.99), slope (0.98), elevation (0.93), and soil depth (−0.95), while Factor 2 was strongly correlated with the herbaceous layer diversity index (0.94) (Fig. 7, Table 1). The two Gotjawal areas were clearly distinguished based on Factor 1, with Jeoji Gotjawal located in the first and fourth quadrants and Seonheul Gotjawal located in the second



**Fig. 7** The results of a factor analysis using 9 environmental factors and 3 biological factors from Jeoji Gotjawal and Seonheul Gotjawal, with 4 points from each region. Black circles represent Jeoji Gotjawal, white ones represent Seonheul Gotjawal, and diamonds represent the abbreviation letters of physical environmental factors (see Table 1). The dotted polygons indicate the two distinct groups of Jeoji Gotjawal and Seonheul Gotjawal.

and third quadrants (Fig. 7). These results indicate that the Jeoji Gotjawal area is primarily associated with higher elevation, slope, and leaf litter depth, suggesting that this area tends to have steeper slopes, higher elevations, and thicker leaf litter layers compared to Seonheul Gotjawal (Fig. 7).

Species richness (0.82) in the two Gotjawal areas showed a positive correlation with Factor 1, which was positively correlated with leaf litter depth, elevation, slope, and rock ratio, and negatively correlated with organic matter content, soil depth, and tree layer diversity index (Fig. 7). These results suggest that species richness in the Gotjawal areas increases with greater leaf litter depth, elevation, slope, and rock ratio, while it decreases with higher organic matter content, soil depth, and tree layer diversity index (Fig. 7).

### Discussion

To compare plant species diversity regardless of survey area size, the standardized MWP method was applied to two Gotjawal regions in Jeju Island (Jeoji Gotjawal and Seonheul Gotjawal). The results showed that the species richness of vascular plants, herbaceous plants, and woody plants was all higher in Jeoji Gotjawal than in Seonheul Gotjawal, and the turnover rate of species showed the same trend (Figs. 4–6). These results indicate that the species richness in Jeoji Gotjawal increases more with the increase in survey area (1–1,000 m<sup>2</sup>) compared to Seonheul Gotjawal, and the faster turnover rate of species (slope value: Jeoji [4.375], Seonheul [3.85]) suggests a greater diversity of habitats and organisms (Barbour et al. 1980).

Field research showed that plant species diversity in Jeoji Gotjawal included 55 genera, 66 species, 5 varieties, and a total of 71 taxa, whereas Seonheul Gotjawal had 36 genera, 41 species, 2 varieties, and a total of 43 taxa (Table S1). Jeoji Gotjawal had a higher number of taxa (Figs. 4–6). The differences in species richness between the two regions appear to be due to factors such as topography and soil envi-

**Table 1** The two factor loading values on the 12 environmental variables of two Gotjawal area

Environmental factors	Variables (abbreviation)	Factor 1	Factor 2
Abiotic factors	Soil moisture ( <i>Sm</i> )	−0.41	0.49
	pH	0.46	−0.44
	Organic matter content ( <i>Om</i> )	−0.83	0.48
	Soil depth ( <i>Sd</i> )	−0.95	0.17
	Litter depth ( <i>Ld</i> )	0.99	−0.12
	Litter production ( <i>Lp</i> )	0.70	−0.65
	Elevation ( <i>E</i> )	0.93	−0.08
	Slope degree ( <i>S</i> )	0.98	−0.01
	Rock ratio ( <i>Rr</i> )	0.83	−0.39
Biotic factors	species richness ( <i>Sr</i> )	0.82	0.38
	Herb layer species diversity index ( <i>HH'</i> )	0.10	0.94
	Shrub layer species diversity index ( <i>SH'</i> )	0.12	−0.79
	Tree layer species diversity index ( <i>TH'</i> )	−0.87	0.01

The given Factor 1 and Factor 2 show how they relate to each variable, with the abbreviations for each variable shown in parentheses.

ronment. Generally, areas with greater topographic variation can contain more diverse habitats, leading to higher species richness (Krebs 1998).

In fact, the two Gotjawal regions showed different topographical and soil environments (Fig. 7). Jeoji Gotjawal had higher elevation and steeper slopes compared to Seonheul Gotjawal and had a thicker leaf litter layer, whereas Seonheul Gotjawal had higher organic matter content, deeper soil, and higher moisture content (Fig. 7). Jeoji Gotjawal forest is characterized by a rough and rugged surface formed by Aa lava flow, creating an uneven terrain with caves between rocks (Ahn et al. 2015). Such irregular terrain creates diverse humidity conditions (Kim et al. 2021). On the other hand, Seonheul Gotjawal, formed by Pahoe-hoe lava, has a smooth surface with small gentle hills, a higher proportion of sediment layers, and fewer exposed rocks, resulting in less topographic variation compared to Jeoji Gotjawal (Ahn et al. 2015). These topographical or soil environmental factors led to lower habitat diversity in Seonheul Gotjawal, resulting in lower species richness and turnover rate compared to Jeoji Gotjawal. Additionally, Seonheul Gotjawal, with its flat lava flow, forms temporary wetlands during rainy or snowy periods, where water accumulates temporarily and drains after a few days (Kim 2017; Mattox et al. 1993). The lower species diversity of woody and herbaceous plants in Seonheul Gotjawal compared to Jeoji Gotjawal is likely due to the formation of wetlands by periodic flooding and the natural disturbances that only species adapted to such conditions can endure.

The major tree species dominating the canopy layer in both Gotjawal regions were evergreen broad-leaved species such as *Q. glauca* and *C. japonica*, with deciduous broad-leaved species such as *Ulmus parvifolia*, *Idesia polycarpa* being rare (Table S1). It is known that light availability greatly affects plant species diversity (Barbour et al. 1980). In fact, the decrease in species richness in the Gotjawal regions was partly due to the high species diversity index of the canopy layer (Fig. 7), with higher overall species turnover rates for vascular plants and herbaceous plants in Jeoji Gotjawal, whereas the turnover rate of woody plants was higher in Seonheul Gotjawal (Figs. 5, 6). Specifically, the species diversity index and species richness (based on 1,000 m<sup>2</sup> plots) of the canopy layer in Seonheul Gotjawal were approximately 3.7 times higher and more than 50% lower, respectively, compared to Jeoji Gotjawal (Fig. 6). Factors such as leaf morphology, life form of the canopy, and tree density create various light environments (Wagner et al. 2011), with the understorey vegetation in dense forests competing for limited light resources being greatly affected by changes in light (Barbour et al. 1980). The canopy layer in Seonheul Gotjawal, with its high species richness and coverage, absorbs most of the light in the canopy, allowing only species adapted to low light conditions to grow in the understorey, resulting in lower species richness compared to

Jejosi Gotjawal.

Shaded forests have lower species diversity compared to deciduous broad-leaved forests because species that can endure shade dominate, resulting in lower diversity (Kim et al. 2020; Park 2012). The light intensity at the lower layer of evergreen forests (composed of trees and shrubs) was  $37.56 \pm 44.60 \mu\text{mol/s/m}^2$ , while that of deciduous forests was  $616 \mu\text{mol/s/m}^2$ , showing a 16-fold difference (Suh et al. 2005). Additionally, the difference in species diversity due to light reaching the understorey between vegetation types was clearly shown when comparing the species richness of vascular plants in deciduous coniferous forests of China (1,000 m<sup>2</sup>,  $114.2 \pm 35.08$ ) with Gotjawal, where approximately 5.5 times more species were observed (Table 2).

Meanwhile, the species richness of vascular plants in Gotjawal (1,000 m<sup>2</sup>, Jeoji:  $28 \pm 1.58$ , Seonheul:  $18.7 \pm 8.04$ ) was approximately 2.5 times and 1.6 times lower, respectively, compared to the deciduous coniferous forests in central Korea (1,000 m<sup>2</sup>,  $45.8 \pm 9.80$ ), and the slope values were lower than those of the deciduous coniferous forests, indicating slower turnover rates in Gotjawal (You et al. 2023). When comparing species richness and turnover rates with the *Quercus mongolica* communities in central Korea, the species richness and turnover rates in the two Gotjawal regions were also lower than those in the *Quercus mongolica* communities (species richness: 45, turnover rate: 9.4) (You et al. 2023). Similarly, the species richness or turnover rates in Gotjawal were lower compared to other vegetation types in the same area (Table 2) (Ghorbani et al. 2011; Stohlgren et al. 1995; Xu et al. 2021). These results indicate that the species richness of plants in Gotjawal in Korea is lower compared to other regions and vegetation types, which is attributed to differences in habitat environmental factors according to vegetation types. Additionally, species diversity increases with the increase in area (Krebs 1998), and this pattern was consistent in this study (Figs. 4-6).

This study is the first systematic comparison of plant species diversity in two Gotjawal regions in Jeju Island, and it can provide an important reference for future biodiversity research in other regions of Korea. However, this study has limitations as it is confined to specific areas and generalization of the results is limited. Moreover, to compare plant community survey methods, it is necessary to compare the results of different survey methods in the same location. Nevertheless, this study demonstrates that by applying the standardized MWPs method, researchers can collect accurate species richness data unaffected by area, and clearly understand the impact of various environmental factors on plant species diversity. Furthermore, long-term monitoring can help track changes in biodiversity due to environmental changes, thereby contributing to understanding ecosystem responses to external factors such as climate change and devising appropriate countermeasures.

**Table 2** Comparison of turnover rates, genus and species richness (per 1,000 m<sup>2</sup>) using the modified Whittaker plots across vegetation types

Nation	Vegetation type or site	Regression model (R <sup>2</sup> )	Richness level		Reference
			Species	Genus	
Republic of Korea	Seonheul Gotzawal (n = 4)	S = 9.6 + 4.37 log A (97.3%)	18 (11–32) <sup>a</sup>	17 (11–27) <sup>a</sup>	This study
	Jeoje Gotzawal (n = 4)	S = 2 + 3.85 log A (91.9%)	28 (26–30) <sup>a</sup>	25 (23–26) <sup>a</sup>	This study
	<i>Larix leptolepis</i> plantation (n = 3)	S = 8.6 + 10.23 log A (99.7%)	46 (32–66)	34 (5–54)	You et al. (2023)
	<i>Quercus mongolica</i> community (n = 3)	S = 5.8 + 9.4 log A (96.2%)	45 (37–58)	28 (5–47)	You et al. (2023)
Iran	Grassland (n = 3)	S = 36.2 + 8.5 log A (91.1%)	68	-	Ghorbani et al. (2011)
	Shrubland (n = 3)	S = 20.8 + 4.5 log A (79.9%)	38	-	Ghorbani et al. (2011)
USA	Prairie (n = 18)	S = 4.5 + 25.5 log A (99.2%)	40 (37–43)	-	Stohlgren et al. (1995)
	Forest (n = 7)	-	40 (37–43)	-	Stohlgren et al. (1995)
	Ecotone (n = 7)	-	41 (38–44)	-	Stohlgren et al. (1995)
China	Deciduous forest (n = 3)	-	114 (26–167)	93 (71–127)	Xu et al. (2021)
	Conifers and broad-leaved trees mixed forest (n = 3)	-	123 (98–140)	93 (75–105)	Xu et al. (2021)

Values are presented as mean (range).

-: not provided.

<sup>a</sup>Data obtained directly from field surveys in this study.

## Conclusions

The plant species diversity of Jeoji Gotjawal was higher than that of Seonheul Gotjawal due to differences in topographic and environmental factors. Environmental factors such as high rock ratio and deep leaf litter depth in Jeoji Gotjawal increased the diversity of herbaceous and shrub species, while soil organic matter content and soil depth had a negative impact. These results indicate that different environmental factors in the two areas should be considered in the management of Gotjawal for biodiversity conservation. However, the plant species diversity of Gotjawal, surveyed using standardized methods, was lower than that of forested areas in the central region of Republic of Korea where the same method was applied. Most previous studies likely compared diversity without considering a consistent survey area. Therefore, the use of standardized survey methods is emphasized when comparing plant species diversity domestically and globally. Additionally, the standardized survey method used in this study could serve as foundational data for future biodiversity conservation and management.

## Supplementary Information

Supplementary information accompanies this paper at <https://doi.org/10.5141/jee.24.051>.

**Table S1.** List of vascular plant species surveyed using modified Whittaker plots in Jeoji Gotjawal and Seonheul Gotjawal of Jeju Island, Republic of Korea.

### Abbreviations

Not applicable.

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Not applicable.

### Authors' contributions

JSL conducted formal analysis, investigation, data curation and writing of original draft. YHY was responsible for conceptualization, funding acquisition, planning the methodology, supervision and writing of review & editing. JWP, YBP, YSK, JML, HIY, and BYJ conducted investigation and data curation. KMC created the visualization and reviewed the final manuscript. EJK conducted data curation and investigation, planning the methodology, created the visualization and writing of review and editing.

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#### Availability of data and materials

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#### Ethics approval and consent to participate

Not applicable.

#### Consent for publication

Not applicable.

#### Competing interests

The authors declare that they have no competing interests.

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