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ORIGINAL ARTICLE

Do Physiognomically Designated Protected Areas Match Well with Ecological Data based upon Diversity Indices and Ordination? Implications for Urban Forest Conservation

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Abstract

We surveyed the vegetation of an ecological landscape preservation area (legally protected conservation areas or national parks) and the surrounding areas of Mt. Cheonggye, Republic of Korea, to explore the conservation implications for preservation areas and surrounding transition areas. We calculated diversity indices to identify the properties of the preservation and surrounding areas that are relevant to conservation efforts. We then compared the plant community composition between the areas using field and quadrat surveys in the preservation and surrounding areas. The cover of the dominant species in all tree and herb layers was markedly higher in the preservation area than in the peripheral zones. The species richness indices were significantly higher in the preservation area than in the peripheral zones. Ordination using detrended canonical correspondence analyses showed that the cover of the dominant tree species and rocks could explain the distribution of plant species in the Cartesian space of the ordination. Our results demonstrate that physiognomically designated protected areas match well with ecological data based on diversity indices and ordination analyses and that disturbances in the areas surrounding the ecological landscape of preservation areas can have considerable impacts on plant diversity indices. Hence, the preservation and management of surrounding areas are essential conservation elements for protecting the entire ecological landscape of preservation areas.

Key words : Plant diversity index, Vegetation, Mt. Cheonggye, Conservation, Ordination

1. Introduction

Individual species and species assemblages are indices of forest health and act as indicators of ecosystem conditions (Sanders and Grochowski, 2014). Globally, national park systems serve as important spaces for the conservation of natural ecosystems, although human activities can have destructive impacts on national parks.

Areas surrounding conservation areas, such as landscape preservation areas (PAs) in urban forests and national parks play an important role in buffering interior conservation areas from excessive anthropogenic activity. These transition areas can function as external support zones where limited urban development is permitted with little disturbance to the core areas, as outlined by the biosphere reserve strategies of the United Nations (Withgott and Laposata, 2012). While these transition areas fall outside the protected area, they are still subject to environmental scrutiny to mitigate the impacts of surrounding human activities on the interior national parks (Xie, 2019). Hence, the ecological conditions along the gradient from the conserved core to the surrounding transition area should be studied to better monitor

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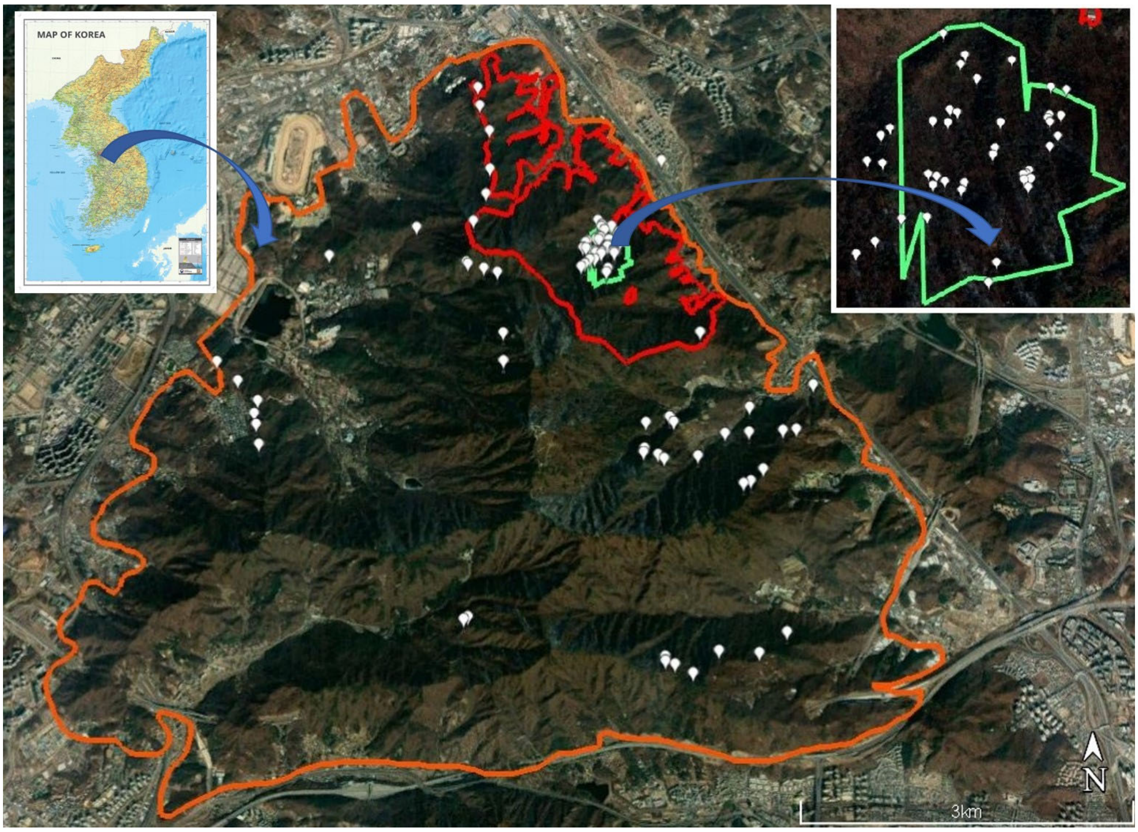

Fig. 1. Study area. The map shows the entire area (red line) of the Mt. Cheonggye, Republic of Korea. The right inlet map (green line) shows the ecological landscape of the preservation area and each balloon indicates each study area. The surrounding red-lined, closed curves outside the ecological landscape of the PA indicate the ecosystem conservation areas.

the current ecosystem health status and analyze the relationships between the transition and core zones. Understanding ecological zonation in human-impacted and natural systems can facilitate appropriate park or forest-protection strategies (Young, 1993).

The term “vegetation” encompasses all plant life in a given area and is synonymous with the term “plant community” (Barbour et al., 1999). In addition to elevation and climatic variables, land use influences plant community structures, and having a mixture of protected areas and zones open to human use can help balance human activity with biodiversity conservation in savannas, such as in Singalila National Park in the eastern Himalayas of India (Nacoulma et al., 2011; Sinha et al., 2018). In Asian regions, designated protected areas have received little attention, resulting in limited or poor ecological data, necessitating more robust ecological investigation.

In this study, we compared the vegetation structures of the ecological landscape of PAs and surrounding areas (SAs) to determine the best management planning strategies for the two systems. We also assessed the ecological status of physiognomically designated PAs and evaluated whether the designated protected areas warrant protection.

2. Materials and Methods

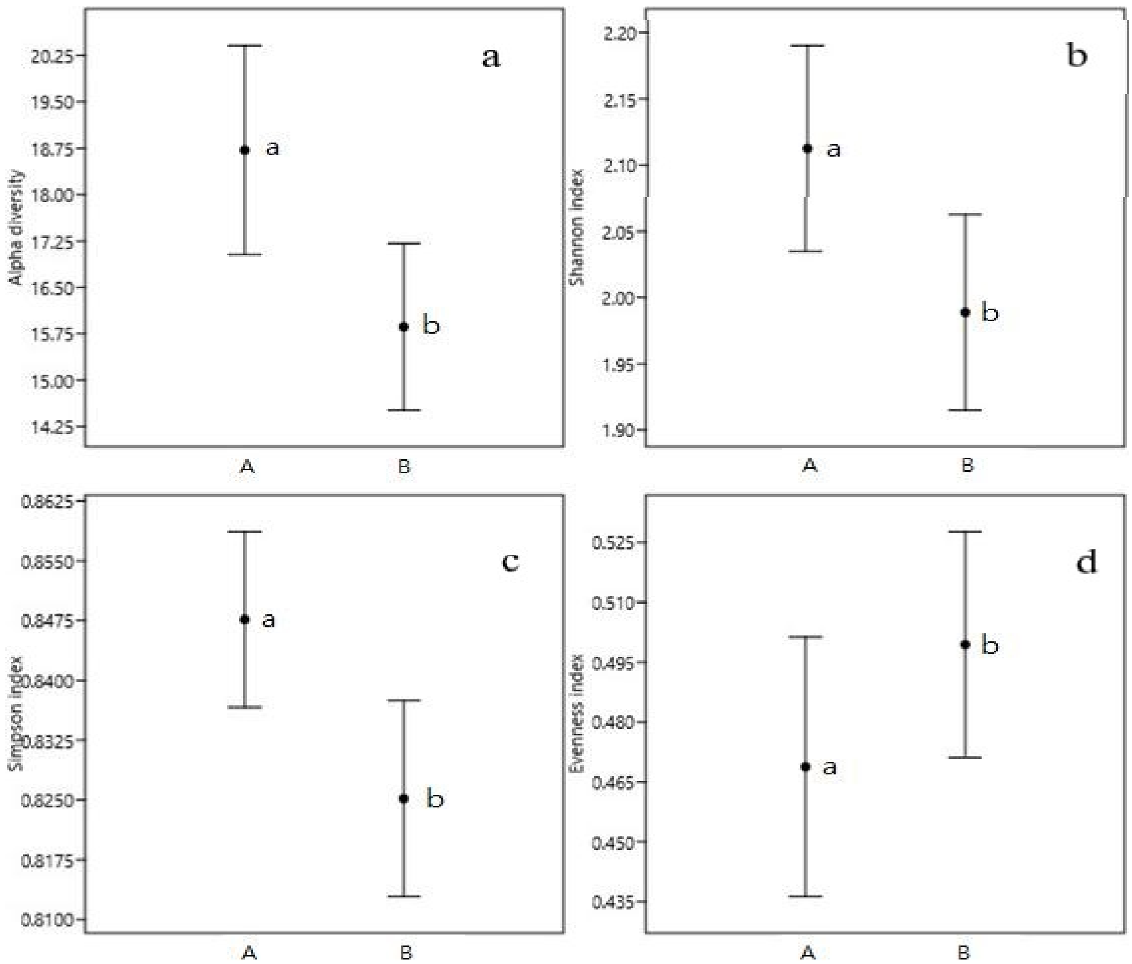

Fig. 2. Mean confidence intervals of diversity indices for different sites based on plant species and numbers(preservation area: A; surrounding areas: B; α diversity: a, Shannon diversity: b; Simpson diversity: c; evenness diversity: d). Different letters identify significantly different values (Mann-Whitney test, $p < 0.05$).

2.1. Study site

We compared a landscape PA and the SA of Mt. Cheonggye, located in the southern part of Seoul (37°23′27.18″–36°27′33.79″N, 127°00′ 12.81″–127°20′29.63″E) (Fig. 1). The ecosystem conservation areas outside the ecological landscape of the PA were designated as the SAs in this study because they experienced greater disturbance than the PA ecological landscape (Fig. 1). The summit height of Mt. Cheonggye is 618 m, and its range links Uiwang, Gwacheon, and Seongnam City in the Gyeonggi Province with Yangjae-dong in Seoul. These areas are commonly known as “Jwacheong” (dragon ascending into heaven on the left) and “Ubaekh” (white tiger on the right) by Korean citizens, due to their role in safeguarding Seoul and the Gwanak Mountain. The summit of this mountain, called Cheonyong Mountain, includes an area called Manggyeongdae (altitude 618 m), with peaks named “Maebong” (hawk peak) and “Oknyeobong” (https://www.uiwang.go.kr/english/UWENGTOUR0101).

The ridges of Mt. Cheonggye run from south to north and the connected summits include Oknyeobong (374.7 m), Maebong (492.7 m), Manggyeongdae (618 m), Jeolgogae (350 m), Uungbong (348.8 m), and Guksabong (540 m) (Lee and Ahn, 1995). The primary plant biome of the mountain falls in the middle of the cool temperate zone (Yim and Kira, 1976).

Mt. Cheonggye is covered by thick forests and is visited by climbers seeking forest therapy. Its 2-km-long valleys always have clean water flowing with lush forests alongside them, which attracts significant human activity. The Wonter Valley on Mt. Cheonggye, with an area of 146,281 m^2, was designated an ecological landscape of the PA in 2004 by the Seoul City government (http://parks.seoul.go.kr/ecoinfo/ecology/index.do). The climate parameters were obtained from data from the Mt. Gwanak climatological station, which is close to the study site; the average parameters for the years 1981–2010 were as follows: the average temperature was 12.5°C, average annual highest temperature was 17.0°C, average annual lowest temperature was 8.6°C, and average annual precipitation was 1450.5 mm (http://data.kma.go.kr). Mt. Cheonggye is mainly composed of metamorphic rocks and partly of acidic rocks. The predominant soil order of Mt. Cheonggye is inceptisols, and the soil texture of the PA is largely sandy loam, whereas that of the SAs is sandy loam and fine sandy loam (http://soil.rda.go.kr/geoweb/soilmain.do).

2.2. Vegetation sampling

We sampled vegetation from both the PA and SAs in 2022. We selected study locations based on maps delineating different vegetation types obtained by aerial photographs as well as digital maps (scale, 1:25,000) provided by the National Institute of Ecology, Republic of Korea (http://www.nie.re.kr/contents/siteMain.do?mu_lang=ENG). The total numbers of study sites and quadrats in the PA and SAs were 36 and 58, respectively (total: 94) (Fig. 1). We conducted quadrat sampling to determine the plant species composition, plant species cover, and dominance (covers of dominant plant species in the tree [T1], sub-tree [T2], shrub [S], and herb [H] layers) at each site and collected data on 12 environmental variables, including biological variables (altitude, direction, exotic, grade, H, hierarchy, rock, S, slope degree, species, T1 and T2) in the PA and SAs. "Exotic" indicates the presence of exotic species (presence: 1; absence: 0), "grade" means vegetation conservation grade (I, II, III, IV, and V; assessed using distribution rarity, the potentiality of vegetation restoration, integrity of species composition, the integrity of vegetation structure, presence of important species, and diameter of planted trees at breast height), "hierarchy" refers to the layering of vegetation structure based on vertical stratification (four layers of tree, subtree, shrub and herbaceous species: 4; three layers of the tree, shrub and herbaceous species: 3; two layers of tree and herbaceous species: 2; one layer of tree species: 1), "rock" refers to surface area of rocks relative to the sites (rock cover within quadrats: %), and "species" indicates the total number of species identified in each quadrat. Quadrats measuring 10 × 10 m were sufficiently large to include tree species in the canopy layers of the forests and were selected randomly within the PA and SAs. Plant species cover was quantified using the Braun-Blanquet scale (Braun-Blanquet, 1932). The class numbers of the scale were transformed into mean values following the procedures outlined by Mueller-Dombois(1974).

The nomenclature and classification system used for vascular plants were as described by Lee (1985) and Park(1995, 2001). Exotic species were defined as species introduced and established deliberately or accidently across the Korean border from foreign habitats.

2.3. Species diversity indices

We calculated species diversity indices to compare community diversities across quadrats, including richness, dominance, diversity, and

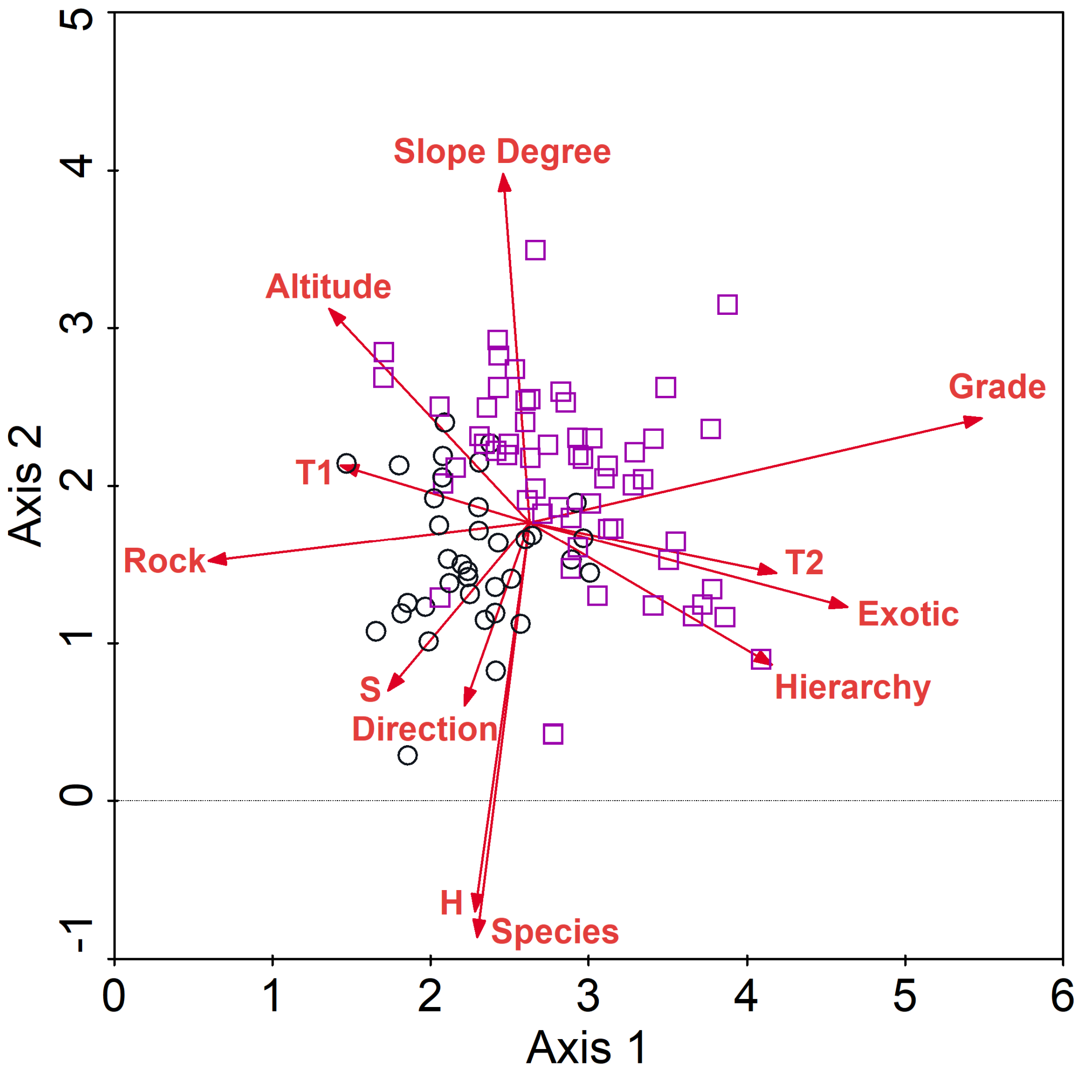

Fig. 3. Detrended canonical correspondence analysis (DCCA) of study sites containing all twelve environmental factors. Correlations with environmental factors are shown for cases where r 〉 0.254 (Axis 1: altitude, r = -0.2902; cover of dominant species in the T1 layer, r = -0.2811; cover of dominant species in the T2 layer, r = 0.3675; presence of exotic species, r = 0.4723; rock exposure, r = -0.4846; hierarchy, r = 0.3563; grade, r = 0.6841, Axis 2: direction, r = -0.2925; slope degree, r = 0.5525; altitude, r = 0.3302; cover of dominant species in the S layer, r = -0.2728; cover of dominant species in the H layer, r = -0.6196; number of species, r = -0.6600). In the plot, (○) represents the PA while (□) represents the SAs.

evenness indices, in the PA and SAs.

The existing index was estimated based on randomly sampled plot data from the study area. The species richness index represents the number of species in each plot.

Species dominance (D`) was calculated as: $D` = \sum_{i=1}^{s}\left(\frac{n_i}{n}\right)^2$ and the Simpson index was defined as 1-D`. Shannon index (H`) was calculated as: $H` = -\sum_{i=1}^{s}\frac{n_i}{n}\ln\frac{n_i}{n}$. where s is the number of species and $\frac{n_i}{n}$ is the relative cover of ith species (Whittaker, 1972; Pielou, 1975; Rad et al., 2009). Species evenness index (E) was calculated as: $e^{H'} / s$

Species richness and Simpson, Shannon, and evenness indices were calculated from data on the identified plant species and their individual numbers within each quadrat in the PA and SAs.

2.4. Ordination

To analyze the differences in vegetation structure between the PA and SAs and to identify significant correlations with environmental variables, we ordinated the samples using detrended canonical correspondence analysis (DCCA). The relative cover of herbs (H) and woody species (T1, T2, and S) was ordinated in relation to 12 environmental variables (altitude, direction, exotic, grade, H, hierarchy, rock, S, slope degree, species, T1, and T2). The DCCA was performed separately using either physical or biological factors. Our premise was that plots in the PA would cluster together and separately from the clustered plots in the SA, assuming the homogeneity of vegetation types within the areas. All ordination analyses were performed using CANOCO 4.55 software (Ter Braak and Smilauer, 2002).

2.5. Statistical analyses

To verify and compare the significance of the mean values of the indices, we used the Kruskal-Wallis test to examine data from the PA and SAs of Mt. Cheonggye for comparisons over the entire study site ($p < 0.05$). We found a significant difference in plant community indices between the PA and SAs (Kruskal-Wallis test; $p < 0.05$); therefore, we compared the means of the indices for each study area using the Mann-Whitney U test ($p < 0.05$). The cover of dominant species in each vegetation layer and the species diversity indices of the tree and herb layers were also examined statistically using the Mann-Whitney U test ($p < 0.05$). All statistical analyses were performed using the PAST 3.22 version software (Hammer, 2018).

3. Results

3.1. Characteristics of vegetation

We identified 154 plant species in the PA (36 quadrats) and 171 plant species in the SAs (58 quadrats). We identified 46 distinct plant communities in the PA (14) and SAs (38), six of which were common to both areas. Among the plant associations, the *Quercus mongolica* community ranked highest among the vegetation conservation indices (I: climax community, II: community restored by secondary succession, III: disturbed community, IV: afforestation, and V: orchard or arable lands; https://egis.me.go.kr/main.do). *Quercus aliena, Q. mongolica, Q. mongolica* - *Pinus densiflora* and *Q. aliena* - *P. densiflora* were dominant in the canopy layers of the PA vegetation ; however, *Q. mongolica, Q. mongolica* - *P. densiflora,* and *P. densiflora* - *Q. mongolica* were dominant in the canopy layers of the SA vegetation. Plant associations showed greater diversity in the vegetation of the PA than in the SAs. Additionally, the cover of the dominant herbaceous species in the PA was significantly higher than that in the SA, and the cover of the dominant shrub species in the PA was also significantly higher than that in the SAs (Table 1). The exotic plants that appeared in the PA and SAs were *M. obovata*, *Robinia pseudoacacia*, and *Festuca arundinacea*.

3.2. Diversity indices comparison of the PA and SA

The total number of species identified in the PA was higher than that in the SAs (Table 1). Accordingly, α diversity, which represents the species number within a specific area, was significantly higher in the PA than in the SAs (Fig. 2a). Similarly, the Shannon index of the PA was significantly higher than that of the SAs (Fig. 2b).

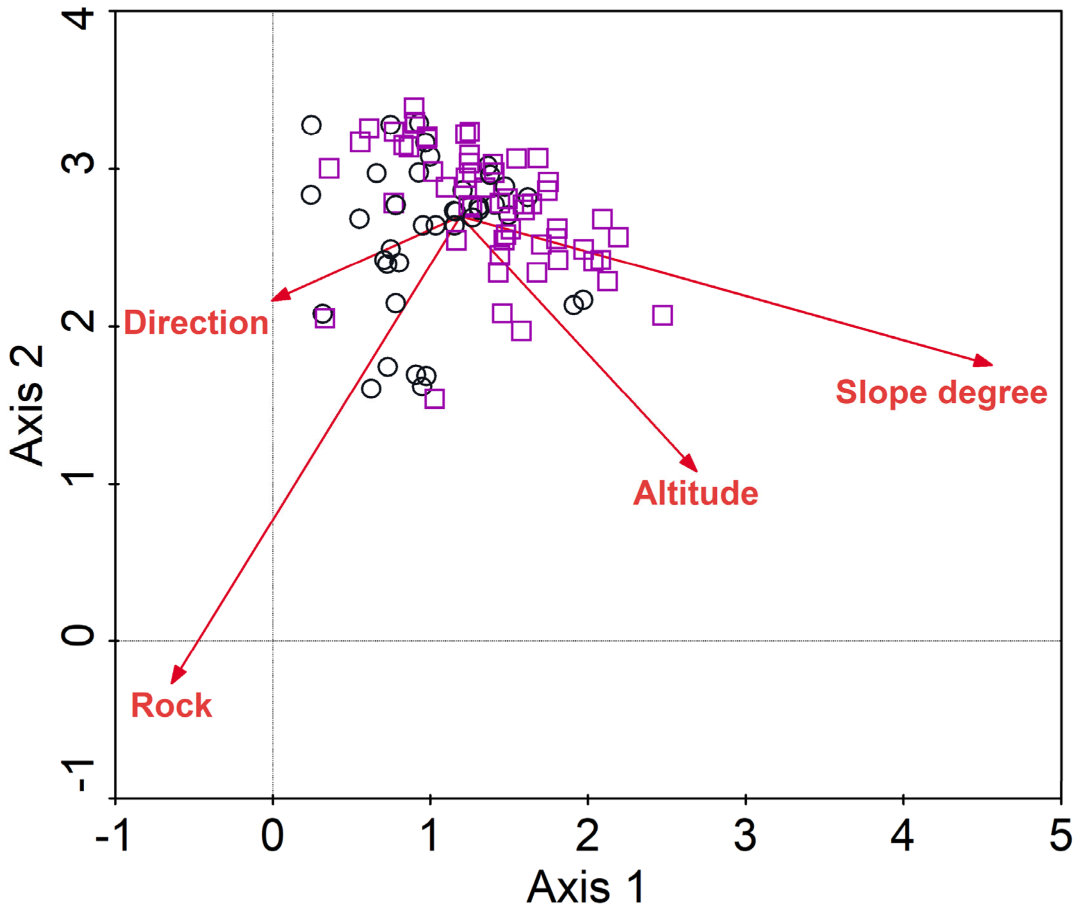

Fig. 4. Detrended canonical correspondence analysis (DCCA) of study sites with physical factors. Correlations with environmental factors are shown for cases where r 〉 0.254 (Axis 1: slope, r = 0.7423; altitude, r = 0.3591; rock exposure, r = -0.3181; Axis 2: slope, r = -0.2813; altitude, r = 0.3591; rock exposure, r = -0.5751). ((○) preservation area, (□) surrounding areas).

Finally, Simpson index of the PA was significantly higher than that of the SAs (Fig. 2c); however, the evenness index of the PA was significantly lower than that of the SAs (Fig. 2d).

3.3. Relationship between vegetation structure and environmental factors

We performed DCCA that included biological and environmental variables in the two areas based on relative species cover (Fig. 3, Table 2; first axis length: 2.62; cumulative percentage variance in the species–environment relationship: 14.4%; second axis length: 3.21; and variance explained by the relationships: 28.9%). Ordination was based on 224 species in 94 quadrats and 12 environmental factors (slope degree, grade, rock exposure, direction, altitude, exotic species, vegetation hierarchy, covers of dominant species in the tree [T1], sub-tree [T2], shrub [S], and herb [H] layers and number of species).

The means of seven environmental factors in the PA and SAs were significantly different ($p < 0.05$), while those for altitude, cover of T1, T2, hierarchy and DBH were not (Table 1). The significance level (r > 0.254) was set based on critical values from the correlation coefficient table (Rohlf and Sokal, 1995). The first axis of the ordination was highly correlated with altitude (PA = 237.53 m, SA = 250.43 m), the mean cover of dominant species in the T1 layer (PA = 68%, SA = 64.7%), the mean cover of dominant species in the T2 layer (PA = 33.04%, SA = 34.07%), the presence of exotic species (PA = 0.08, SA = 0.21), rock exposure (PA = 29.63, SA = 11.65), hierarchy (PA = 3.69, SA = 3.69), and ecological conservation grade (PA = 3.09, SA = 3.90) (Fig. 3; Table 1). The second axis was highly correlated with direction (PA = 253.25°, SA = 215.69°), the slope angle (PA = 18.14°, SA = 22.54°), altitude (PA = 237.53 m, SA = 250.43 m), the cover of the dominant species in the S layer (PA = 44.33%, SA = 35.01%), the mean cover of dominant species in the H layer (PA = 33.36%, SA = 18.62%), and the number of species (PA = 19, SA = 15.79).

The DCCA of the study sites with only four physical factors showed that slope, altitude, and rock exposure were significantly related to the first axis (Fig. 4). Finally, the DCCA of the study sites with only seven biological factors, excluding grade, demonstrated that the cover of dominant species in the S layer, cover of dominant species in the H layer, and the number of species were significantly related to the first axis (Fig. 5).

4. Discussion

4.1. Vegetation of the PA and SA

The covers of the dominant tree species as well as of the shrub and herbaceous layers in the PA were higher than those in the SAs. The cover of the dominant subtrees under the canopy of the tree layers was similar. However, shrub development was limited in the SAs. The cover of dominant herbaceous species was significantly higher in the PA than in the SA, likely because mountain managers routinely remove forest floor debris outside the PA, which allows exotic species, such as the exotic tree *Magnolia obovata,* to invade the forest interiors and compete with the native plant species (Table 1). Similar to our observations, invasive species are commonly found in harvested and disturbed sites in managed portions of the boreal forests of eastern North America (Jean et al., 2019). Intensive human activities, such as agriculture, tree thinning, and medicinal plant overharvesting can negatively affect the growth of plants in the herb layers, thereby limiting the health of the native plant community and leaving room for invasion.

Furthermore, the greater area under plantation forests in the SAs may have disturbed the PA. Land-use patterns and intense anthropogenic activity can change the surrounding vegetation beyond national park boundaries (Nacoulma et al., 2011; Squeo et al., 2016).

4.2. Diversity indices in the PA and SA

We compared the overall regional trends using conventional community diversity indices and found that the trends were similar for all three indices (Fig. 2a, 2b, and 2c). The values of conventional species diversity indices for the study sites were higher than those for other sites in Korea that have been previously studied (Shannon diversity index national range: 1.2202–1.3428; Kim and Lee, 2012). The Shannon diversity indices calculated for the PA and SAs were similar to those calculated for temperate vegetation zones in other nations (Rad et al., 2009).

The number of plant species was higher in the PA than in SAs, whereas the plant evenness index was higher in the SAs, which is indicative of dominance by some plant species in the PA. The PA had a greater diversity of plant species than the SAs, likely because the specific dominant species in the SA suppressed the diversity in the underlying vegetation.

4.3. Impacts by exotic plants

The primary exotic plants that appeared in the

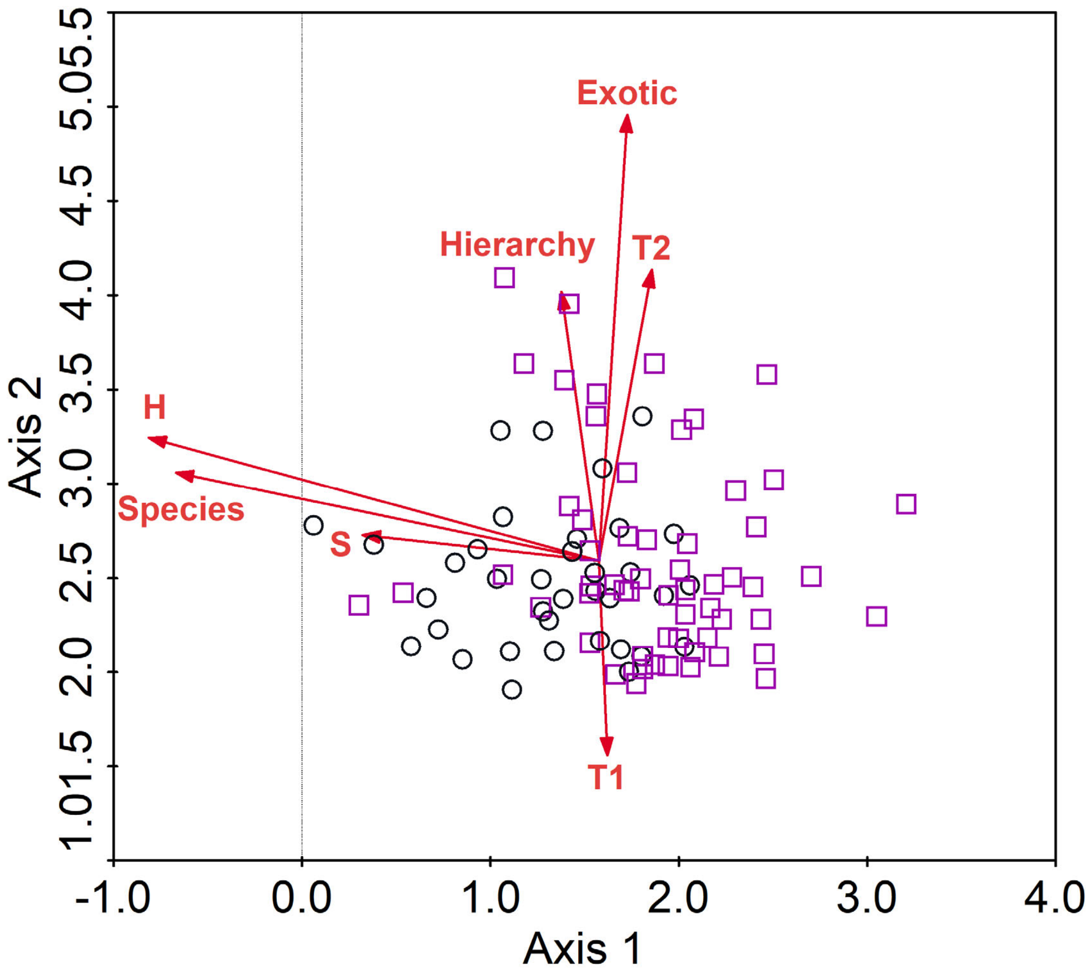

Fig. 5. Detrended canonical correspondence analysis (DCCA) of study sites with biological factors. Correlations with environmental factors are shown for cases where r 〉 0.254 (Axis 1: cover of dominant species in the S layer, r = -0.3550; cover of dominant species in the H layer, r = -0.6785; number of species, r = -0.6366, Axis 2: presence of exotic species, r = 0.6469; hierarchy, r = 0.3915). ((○) preservation area, (□) surrounding areas).

PA and the SAs were *M. obovata*, *Robinia pseudoacacia*, and *Festuca arundinacea*. *M. obovata* has historically been planted as a horticultural tree, but it has invaded forest interiors through dispersal by seed-eating birds. Therefore, *M. obovata* was rarely distributed in artificially planted areas at the beginning of its introduction; however, recently, the frequency and area of its range in urban forests have increased and the research need for *M. obovata* is growing. The frequency of *M. obovata* produced from the ratio of the number of quadrats present to the total number of quadrats was approximately 0.17% and the total mean cover of *M. obovata* within the quadrats was approximately 13%. The frequency of *M. obovate* within the quadrats was higher in the SAs than in the PA. The similarity index between communities studied was high among the communities invaded by *M. obovata*, which could homogenize the local species composition (Lee, 2022).

R. pseudoacacia, a leguminous exotic tree, has

Table 1. Difference in environmental factors between preservation and surrounding area (mean ± standard error). Exotic meaning the presence of exotic species is a nominal classification that need not to be assessed by statistical analyses

	Preservation area	Surrounding area	t-value	d.f.	P-value
Direction (O)	253.25 ± 6.64	215.69 ± 7.55	3.44	93	〈 0.001
Slope (O)	18.14 ± 1.05	22.5 ± 0.98	2.93	93	0.004
Altitude (m)	237.53 ± 6.59	250.43 ± 9.55	0.98	93	0.331
T1 (%)	68 ± 1.37	64.7 ± 1.09	1.86	93	0.066
T2 (%)	33.04 ± 2.40	34.07 ± 2.16	0.31	93	0.760
S (%)	44.33 ± 2.09	35.01 ± 1.53	3.68	93	〈 0.001
H (%)	33.36 ± 2.63	18.62 ± 2.12	4.34	93	〈 0.001
Species	19 ± 0.86	15.79 ± 0.70	2.86	93	0.005
Exotic*	0.08 ± 0.05	0.21 ± 0.05			
Rock (%)	29.63 ± 5.54	11.65 ± 2.61	3.29	93	0.001
Hierarchy	3.69 ± 0.06	3.69 ± 1.07	0.05	93	0.961
Grade	3.09 ± 0.01	3.90 ± 0.09	5.92	93	〈 0.001
DBH (cm)	31.52 ± 1.28	29.13 ± 1.02	1.46	93	0.148

been introduced deliberately for landscaping and honey production and is spread out in disturbed areas near forests; however, it is thought to be competitively excluded by native tree species within similar ecological niches. The frequency of *R. pseudoacacia*, calculated as the ratio of the number of quadrats present to the total number of quadrats, was approximately 0.13%, and included only one quadrat containing *R. pseudoacacia* in the PA. In the SAs, *R. pseudoacacia* dominated tree cover in the canopy areas of the quadrats where it was present. Although the frequency of *F. arundinacea,* was fairly low throughout the PA and SAs in this study, it is ubiquitous across South Korea, unlike the aforementioned species (NIER, 2012).

4.4. Differences in species distribution in the PA and SAs from ordination analyses

Within the coordinates of the ordination plot, the quadrats from the PA and SAs clustered separately. Among the physical variables, slope, altitude, and rock exposure had the strongest correlation with vegetation parameters. These non-biological variables contributed significantly to the distribution of the quadrats in the ordination plot. Altitude and slope influence temperature and soil conditions such as water and nutrient content. The covers of dominant species in the tree, sub-tree, shrub, and grass layers, and species number also contributed substantially to explaining the distribution of quadrats in the ordination. Hence, the dominance of tree species in the vertical community structure of forests in the PA and SAs may have influenced the distribution of species composition in the ordination space. The dominance of some plant species can influence the establishment and distribution of other plant species in the PA and SAs. The variation in the distribution of quadrats in the ordination space was reliably related to the distribution of plant community types in the PA and SAs. Thus, the distribution of quadrats in the ordination space can help explain the differences in plant community types between the PA and SAs.

4.5. Implications of ecological data for legal designation of the PA in urban forests

All countries have created legally protected areas (UNEP-WCMC, 2018), but the designation procedures for protected areas vary. The size and

Table 2. Summary of detrended canonical correspondence analysis (DCCA) ordination results with correlations of environmental factors with axes. Those with r 〉 0.254 are in bold type

Axes	Axis 1	Axis 2	Total inertia
Eigenvalues	0.322	0.291	11.313
Lengths of gradient	2.621	3.206	
Species-environment correlations	0.846	0.849	
Cumulative percentage variance			
of species data	2.9	5.4	
of species-environment relation	14.4	28.9	
Direction	-0.1070	-0.2925	
Slope degree	-0.0222	0.5525	
Altitude	-0.2902	0.3302	
Mean cover of dominant species in T1	-0.2811	0.0822	
Mean cover of dominant species in T2	0.3675	-0.0676	
Mean cover of dominant species in S	-0.2214	-0.2728	
Mean cover of dominant species in H	-0.1022	-0.6196	
Number of species	-0.1004	-0.6600	
Presence of exotic species	0.4723	-0.1185	
Rock exposure	-0.4846	-0.0763	
Hierarchy	0.3563	-0.2136	
Grade	0.6841	0.1878	
Sum of unconstrained eigenvalues			11.313
Sum of canonical eigenvalues			2.038

location of the protected areas all over the world are determined by the distribution of people, potential land values, and the political endeavors of people with conservation ethics and historical factors (Mills et al., 2014). However, protected areas should harbor a large amount of biodiversity and be characterized by ecosystem and genetic variations, as most conservationists recommend representation elements (Sher and Primack, 2019). Therefore, scientific and ecological data from potential protected areas are the core criteria for determining the location and size of future protected areas. Traditionally, developing countries, including Korea, have depended on the unilateral views of minority professionals in choosing protected areas despite a lack of reliable ecological data. The previous physiognomical designation of protected areas represents an appointment into protected areas simply from the external abundance of the ecosystem.

In this study, we found that plant associations were more diverse in the vegetation of the PA than in the SAs because the environment in the PA may be more diverse than that in the SAs. Furthermore, most of the diversity indices, such as α diversity, Shannon index, and Simpson index, were also significantly higher in the PA than in the SAs. Ordination analyses using DCCA showed that variations in vegetation with respect to species composition and covers were significantly segregated along the environmental variables in the ordination space. Finally, these ecological data provide evidence that can be fitted to the results of the physiognomical designation of PAs.

5. Conclusions

The cover of dominant species in the tree, shrub, and herbaceous layers was markedly higher in the PA than in the SAs, indicating the dominance of a few species in the vertical structure of the PA. However, most other plant diversity indices were significantly higher in the PA than in the SAs.

The DCCA ordination showed that the distribution of quadrats in Cartesian space was strongly influenced by elevation, cover of dominant species in the tree (T1) layer, cover of dominant species in the sub-tree (T2) layers, the presence of exotic species, rock exposure, hierarchy, and grade on the first DCCA axis. This highlights the importance of ecological data, including diversity indices and ordination analyses, in designating protected areas despite consistency with the rough and physiognomical determination of protected areas from historic landscape perspectives.

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