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 surrounding areas in Mt. Cheonggye, Republic of Korea to explore conservation implications for preservation areas and surrounding transition areas. We calculated diversity indices to identify properties of the preservation areas and the surrounding areas that are relevant to conservation efforts. We then compared the plant community composition between areas using field and quadrat surveys in the preservation area and surrounding areas. The covers of dominant species in all tree and herb layers were markedly higher in the preservation area than in the peripheral zones. Additionally, species richness indices were significantly higher in the preservation area than in the peripheral zones. Ordination by detrended canonical correspondence analyses showed that the covers of dominant tree species and rock could explain the distributions of plant species in the Cartesian space of the ordination. Our results demonstrate that physiognomically designated protected areas match well with ecological data based upon diversity indices and ordination analyses and disturbances in the areas surrounding ecological landscape of the 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 the preservation areas.

Introduction

Individual species and species assemblages are indices of forest health that act as indicators of the ecosystem conditions (Sanders and Grochowski 2014). The worldwide National Park Systems serve as important spaces for conservation of natural ecosystems, though human activities can have destructive impacts on national parks.

The areas surrounding conservation areas, such as landscape preservation areas (PAs) in urban forests or national parks, have an important role in buffering the interior conservation area from excessive anthropogenic activity. These transition areas can function as external support zones where limited urban development is permitted, with little disturbance in 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 themselves (Xie 2019). Hence, the ecological conditions in the gradient from the conserved core into the surrounding transition area should be studied to better monitor the current ecosystem health status and analyze the relationships between the transition and core zones. An understanding of 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 climactic variables, land use influences plant community structures; thus, 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 the Singalila National

Park in the eastern Himalaya of India, for example (Sinha et al. 2018; Nacoulma et al. 2011). In Asian regions, designated protected areas have received little attention, resulting in limited or poor ecological data and necessitating more robust ecological investigation.

In this study, we compared the vegetation structures of ecological landscape the PA and surrounding areas (SAs) to inform the best management planning strategies for the two systems. We also aimed to assess the ecological status of the physiognomically designated protected areas and evaluate whether the designated protected areas warrant their protection.

Materials And Methods

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 the ecosystem conservation areas experience greater disturbance than the ecological landscape PA (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 the south to the north and the connected summits of Mt. Cheonggye include Oknyeobong (374.7m), 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 within the middle part of the cool temperate zone (Yim and Kira 1976).

Mt. Cheonggye is covered by thick forests and is visited by climbers seeking the enjoyment of forest therapy. Its 2-km-long valleys always have clean water flowing with lush forests alongside them, which attracts significant human activity. Wonter Valley in Mt. Cheonggye was designated an ecological landscape of the PA in 2004 by the Seoul city government (http://parks.seoul.go.kr/ecoinfo/ecology/index.do). Wonter Valley has an area of 146,281 m^2. 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: average temperature, 12.5°C; average annual highest temperature, 17.0°C; average annual lowest temperature, 8.6°C; and average annual precipitation, 1450.5 mm (http://data.kma.go.kr). Mt. Cheonggye is composed of mainly metamorphic rocks and partly of acidic rocks. The predominant soil order of Mt. Cheonggye is inceptisols (http://soil.rda.go.kr/geoweb/soilmain.do), and the soil texture of the PA is largely sandy loam and that of the SA is sandy loam and fine sandy loam.

Vegetation sampling

We sampled vegetation from both the PA and SA. We selected study locations based on maps delineating different vegetation types taken 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, quadrats in the PA and SA 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) in each site and collected data on twelve environmental variables (altitude, direction, exotic, grade, H, hierarchy, rock, S, slope degree, species, T1, T2) in the PA and SA. “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, potentiality of vegetation restoration, integrity of species composition, integrity of vegetation structure, presence of important species, and diameter of planted trees at breast height); “hierarchy” refers to the layering of vegetation structure (four layers of tree, subtree, shrub and herbaceous species: 4; three layers of tree, shrub and herbaceous species: 3; two layers of tree and herbaceous species: 2; one layers of tree species: 1); “rock” refers to surface area of rocks relative to the sites (rock cover within quadrats: %); and “species” is 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 selected randomly within the PA and SA. 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 the vascular plants followed was as described by Lee (1985) and Park (1995, 2001). Exotic species in this study were defined as introduced and established species deliberately or accidently across the Korean border from foreign habitats.

Species diversity indices

We calculated species diversity indices to compare community diversities across quadrats in the PA and SA, including richness, dominance, diversity, and evenness indices.

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

Species dominance (D`) was calculated as: $\mathrm{D}‘=\overset{s}{\underset{i=1}{?}}\left(\frac{n_i}{n}\right)^2$ and the Simpson index was defined as 1-D $.\,Sha\cap on\in dex(H)$ was calculated as: $\mathrm{H}‘=-\overset{s}{\underset{i=1}{?}}\frac{n_i}{n}ln\frac{n_i}{n}$. Where s equals the number of species and $\frac{n_i}{n}$ is the relative cover of ith species (Whittaker 1972; Pielou 1975; Rad et al. 2009). The species evenness index (E) was calculated as:$e^{H‘}/s$

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

Ordination

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

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 SA areas of Mt. Cheonggye for comparisons over the entire study site ($p < 0.05$). We found a significant difference in plant community indices between PA and SA (Kruskal–Wallis test; $p < 0.05$); therefore, we compared the means of the indices for each study area using the Mann–Whitney test ($p < 0.05$). The cover of dominant species in each vegetation layer and species diversity indices of the tree and herb layers were also examined statistically using the Mann–Whitney test ($p < 0.05$). All statistical analyses were performed using the PAST 3.22 version software (Hammer 2018).

Results

Characteristics of vegetation

We found a total of 154 plant species in the PA (36 quadrats) and 171 plant species in the SA (58 quadrats). We detected a total of 46 distinct plant communities in the PA (14) and SA (38), six of which were common to both areas. Among plant associations, the *Quercus mongolica* community had the highest rank among 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 in the vegetation of the PA; however, *Q. mongolica, Q. mongolica – P. densiflora*, and *P. densiflora – Q. mongolica* were dominant in the canopy layers in the vegetation of the SA. The plant association shows greater diversity in the vegetation of the PA compared to that of the SA. Additionally, the cover of dominant herbaceous species in the PA was significantly higher than that in the SA, and the cover of dominant shrub species in the PA was also significantly higher than that in the SA (Table 1).

Diversity indices comparison of PA and SA

The total number of species identified in the PA was higher than that in the SA (Table 1). Accordingly, α diversity, which represents the species number within a specific area, was significantly higher in the PA than in the SA (Fig. 2a). Similarly, the Shannon index of the PA was significantly higher than that of the SA (Fig. 2b). Finally, the Simpson index of the PA was significantly higher than that of the SA (Fig. 2c) but contrarily the evenness index of the PA was significantly less than that of the SA (Fig. 2d).

Relationship between vegetation structure and environmental factors

We performed DCCA that included the 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%). The ordination was based on 224 species in 94 quadrats and twelve 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 SA were significantly different ($p < 0.05$), but 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 coefficients 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 study sites with only four physical factors showed that slope, altitude and rock exposure were also significantly related with the first axis (Fig. 4). Finally, the DCCA of study sites with only seven biological factors, except for grade, demonstrated that the cover of dominant species in the S layer, cover of dominant species in the H layer, and number of species were significantly related with the first axis (Fig. 5).

Discussion

Vegetation of the PA and SA

The covers of dominant tree species as well as of the shrub and herbaceous layers in the PA were significantly higher than those in the SAs. The cover of dominant subtrees was similar under the canopies of the tree layers. Shrub development, however, was limited in both the SAs. The cover of dominant herbaceous species was significantly higher in the PA than in the SA, likely because the mountain managers routinely remove the 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 plants species (Table 1). Similar to what we observed, invasive species are commonly found in harvested and disturbed sites in the managed portions of the boreal forest of eastern North America (Jean *et al*. 2019). Intensive human activities, such as agriculture, tree thinning, and medicinal plant overharvesting, can have negative impacts on 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 (Squeo *et al*. 2016; Nacoulma et al. 2011).

Diversity indices in the PA and SA

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

The numbers of plant species were higher in the PA than in the SAs, whereas the plant evenness index was higher in the SAs, which is indicative of dominance by some of the plant species in the PA. Our calculations showed that the PA had greater diversities of plant species than the SAs, likely because the specific dominant species in the SA suppressed the diversity in the underlying vegetation. The distribution of the number of plant species was more even in the SAs than in the PA.

Impacts by exotic plants

The primary exotic plants that appeared in the PA and the SAs included *M. obovata*, *Robinia pseudoacacia*, and *Festuca arundinacea*. *M. obovata* has been planted historically as a horticultural tree, but it has invaded forest interiors due to dispersal by seed eating birds. Therefore, the *M. obovata* was rarely distributed only in artificially planted areas at the beginning of its introduction, but recently, the frequency and area of its range in urban forests has increased and the need for research is growing. The frequency of *M. obovata* produced from the ratio of the number of quadrats present to the total number of quadrats was about 0.17% and the total mean cover of *M. obovata* within the quadrats present was about 13%. The presence frequency of *M. obovate* within the quadrats was more 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 been introduced deliberately for landscaping and honey production and 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 from the ratio of the number of quadrats present to the number of quadrats total, was about 0.13%, which included only one quadrat containing *R. pseudoacacia* in the PA. In the SAs, *R.*

pseudoacacia dominated the tree cover in the canopy areas in 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 above species (NIER 2012).

Ordination analyses

Within the coordinates of the ordination plot, the quadrats from the PA and SAs clustered separately. Among physical variables, slope, altitude, and rock exposure had the greatest correlation with vegetation parameters. These nonbiological variables significantly contributed to explaining the distribution of quadrats in the ordination plot. Altitude and slope influence temperature and soil conditions, such as water and nutrient contents. 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 the forests in the PA and SAs may have influenced the distribution of the 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, respectively. The variation in the distributions of quadrats in the ordination space was reliably related to the distributions of plant community types in the PA and SAs. Thus, the distribution of quadrats in ordination space can help explain differences in plant community types in the PA and SAs.

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 of protected areas vary. The size and 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 of conservationists recommend for representation elements (Sher and Primack 2019). Therefore, the scientific and ecological data from potential protected areas are the core criteria used to decide the location and size of future protected areas. Traditionally, developing countries, including Korea, formerly depended on unilateral views of the minority professionals for choosing protected areas despite a lack in reliable ecological data. The previous physiognomical designation of protected areas represents appointment into protected areas from simply external abundance of ecosystem.

In this study, we found that the plant associations are more diverse in the vegetation of the PA than 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 SA. From ordination analyses using DCCA, the variations of vegetation with species composition and covers were significantly segregated along the environmental variables in the ordination space. Finally, these ecological data may provide evidence that can be fitted with the results of the physiognomical designation of the PAs.

Conclusions

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

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 the grade on the first DCCA axis. This highlights the importance of ecological data, including diversity indices and ordination analyses, for designating protected areas despite consistency with rough and physiognomical determination of protected area from historic landscape perspectives.

Declarations

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript. The authors have no relevant financial or non-financial interests to disclose. Kee Dae Kim wrote the main manuscript text and Sung Chan Jeong analyzed all the data. DaeMin Pi, Il Won Lee and Jeong Yeon Lee helped the field works.

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Figures

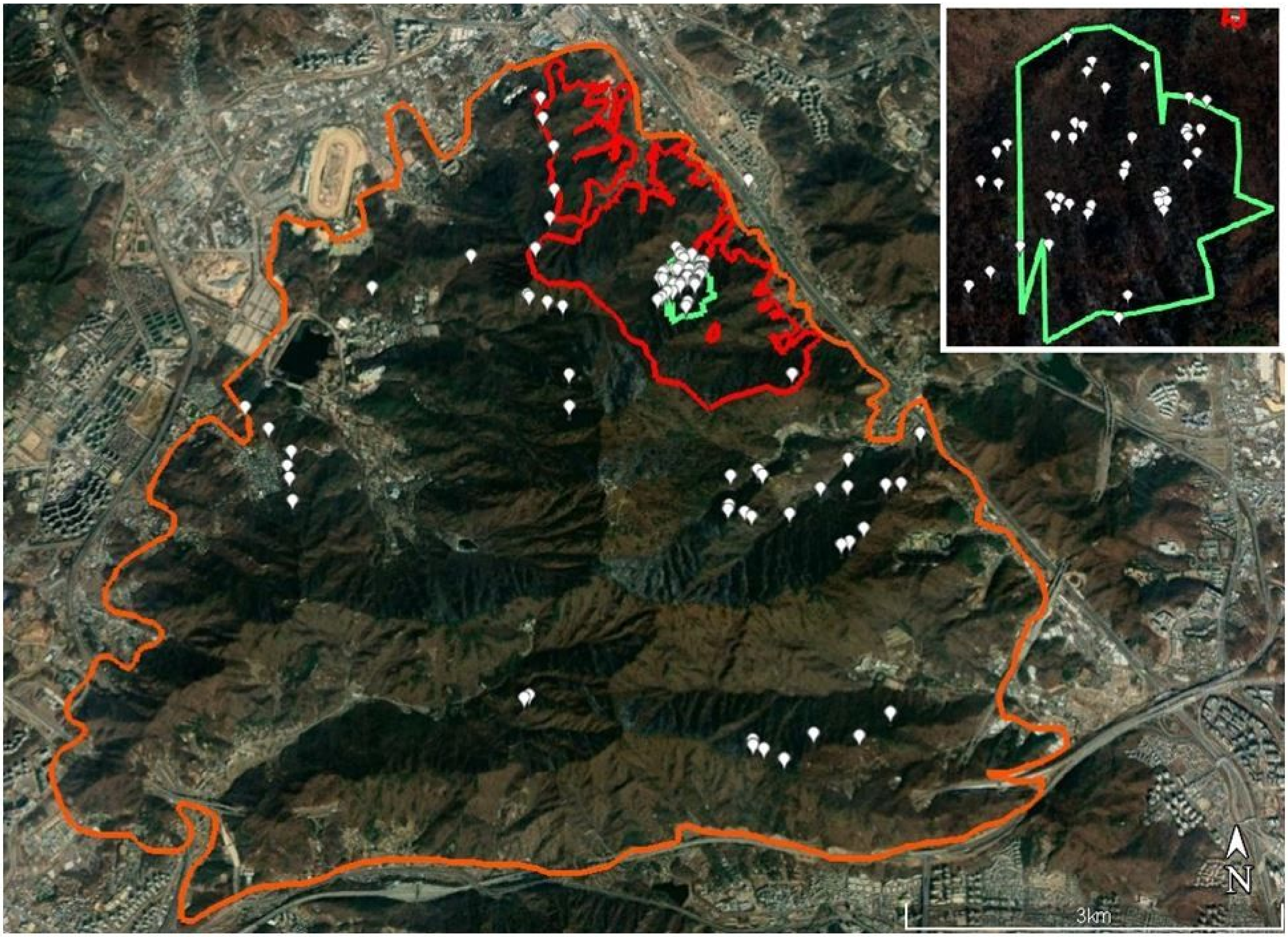

Figure 1

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.

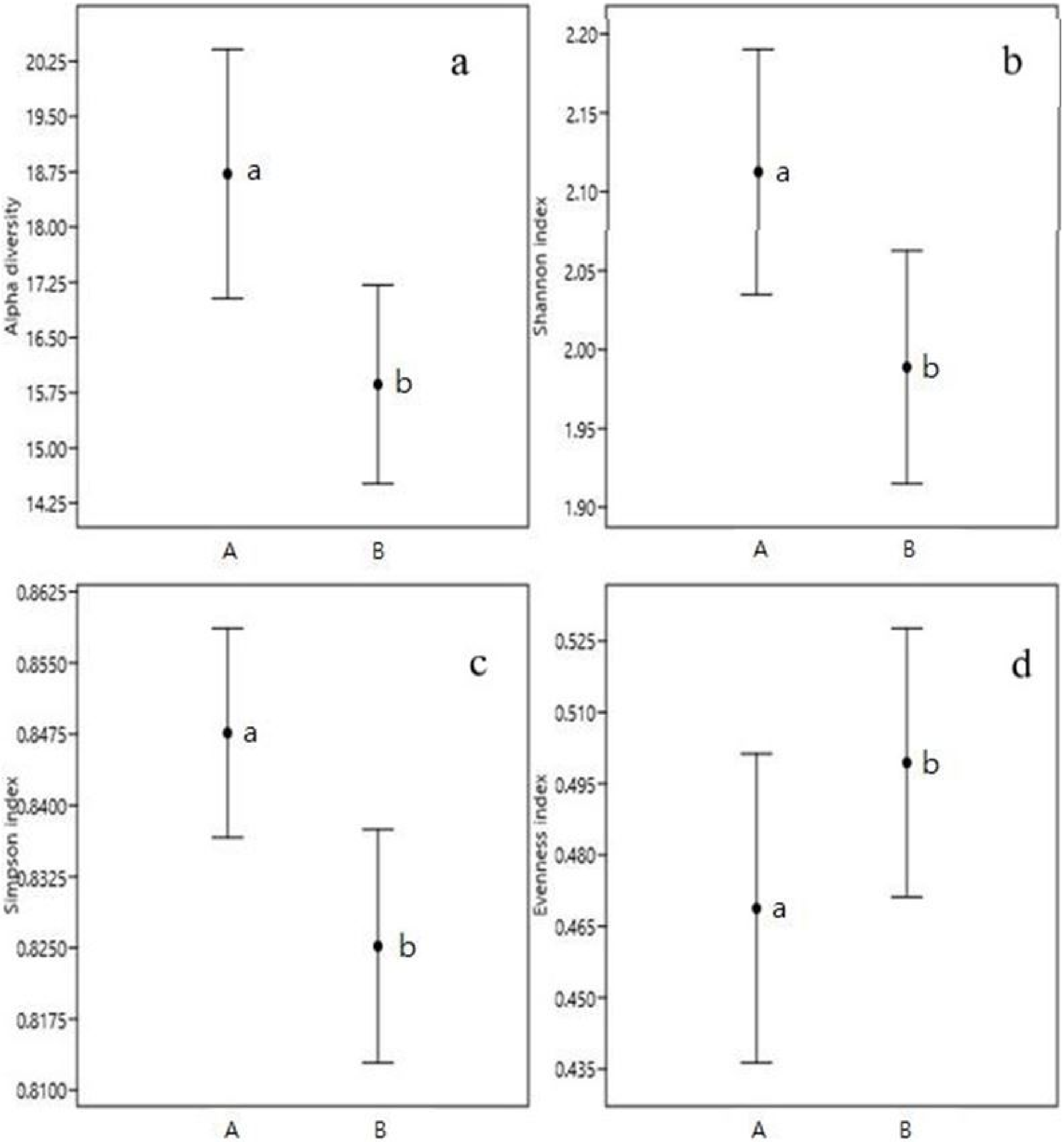

Figure 2

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 italic letters identify significantly different values (Mann–Whitney test, $p < 0.05$)

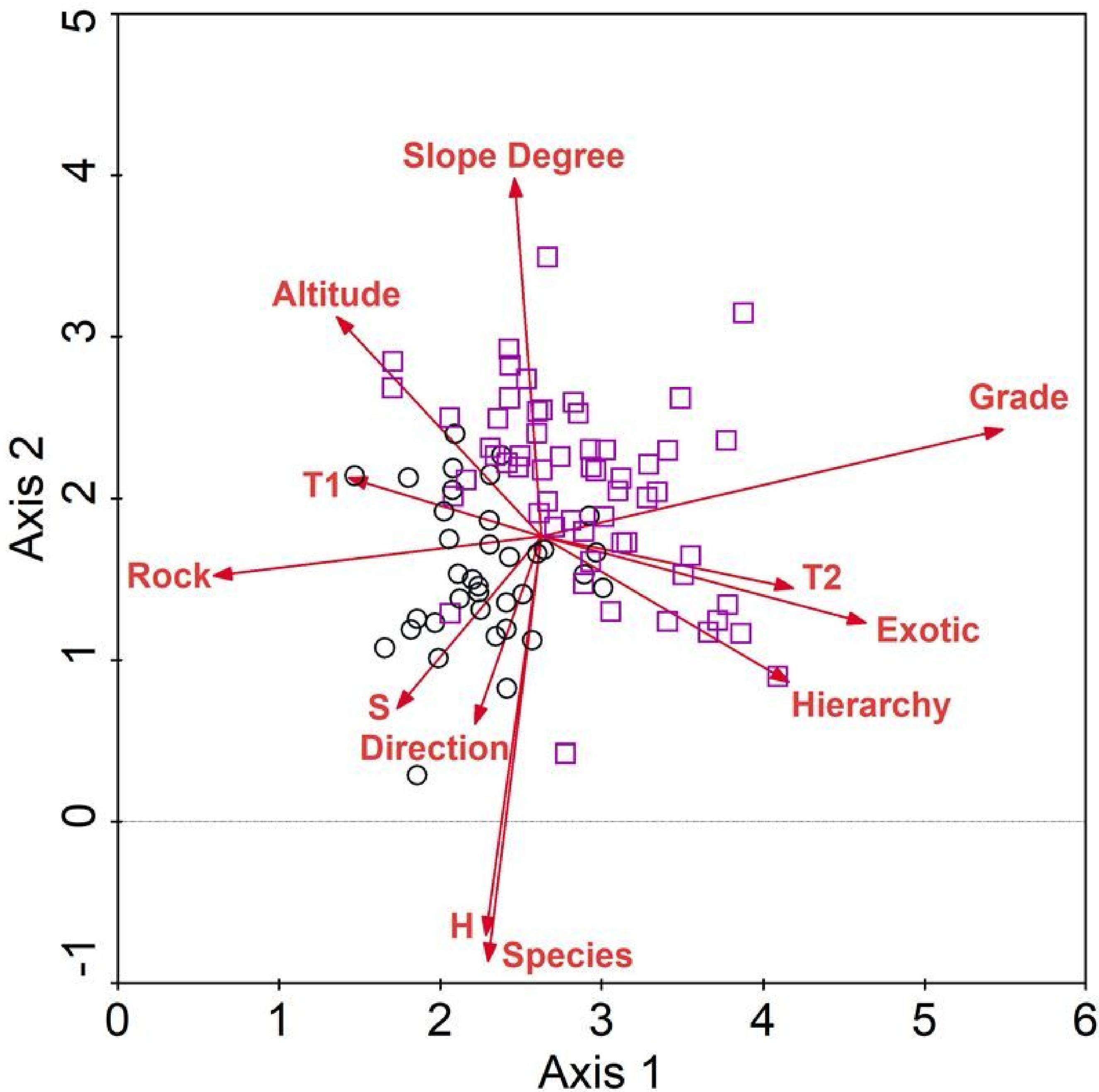

Figure 3

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).

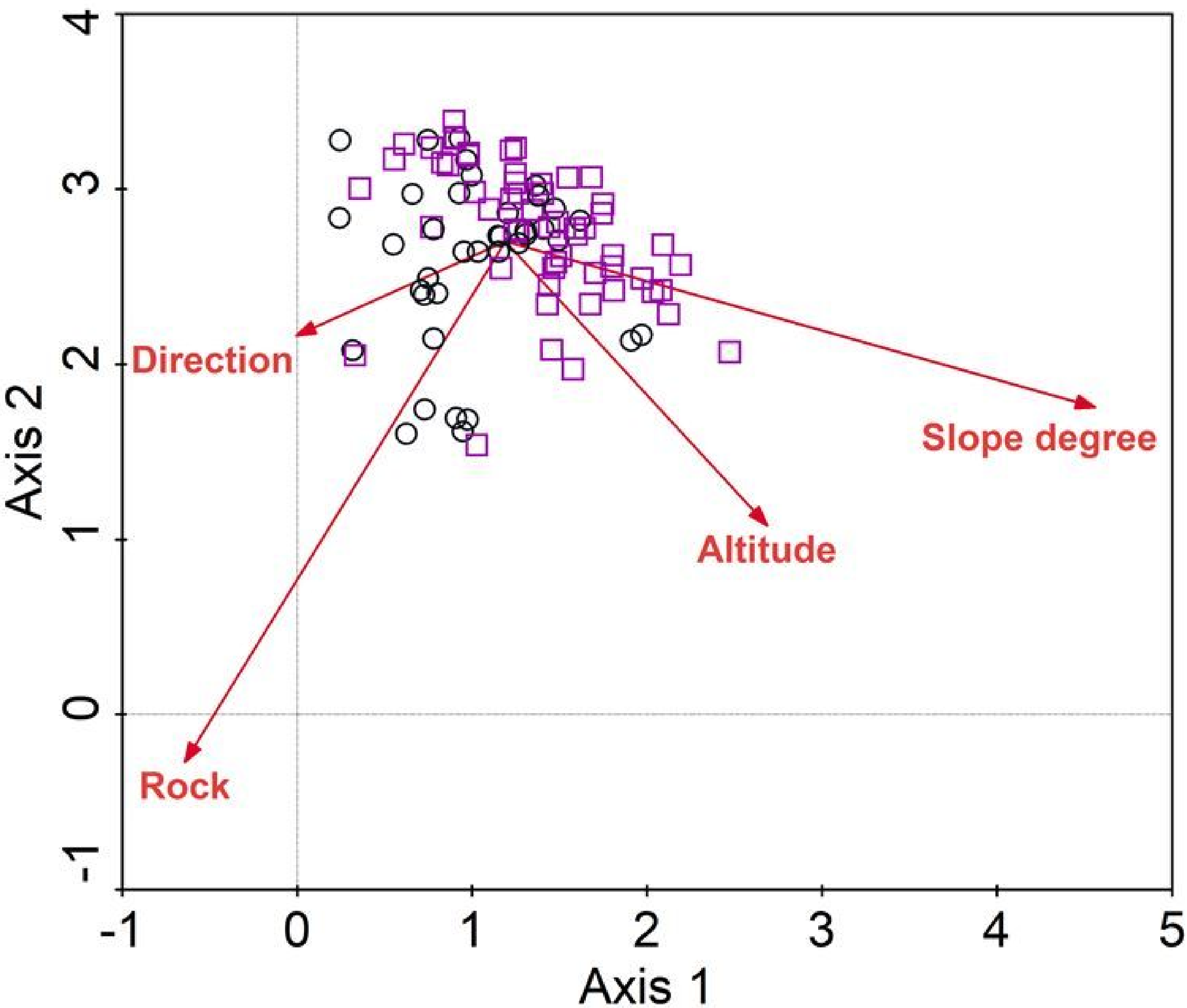

Figure 4

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).

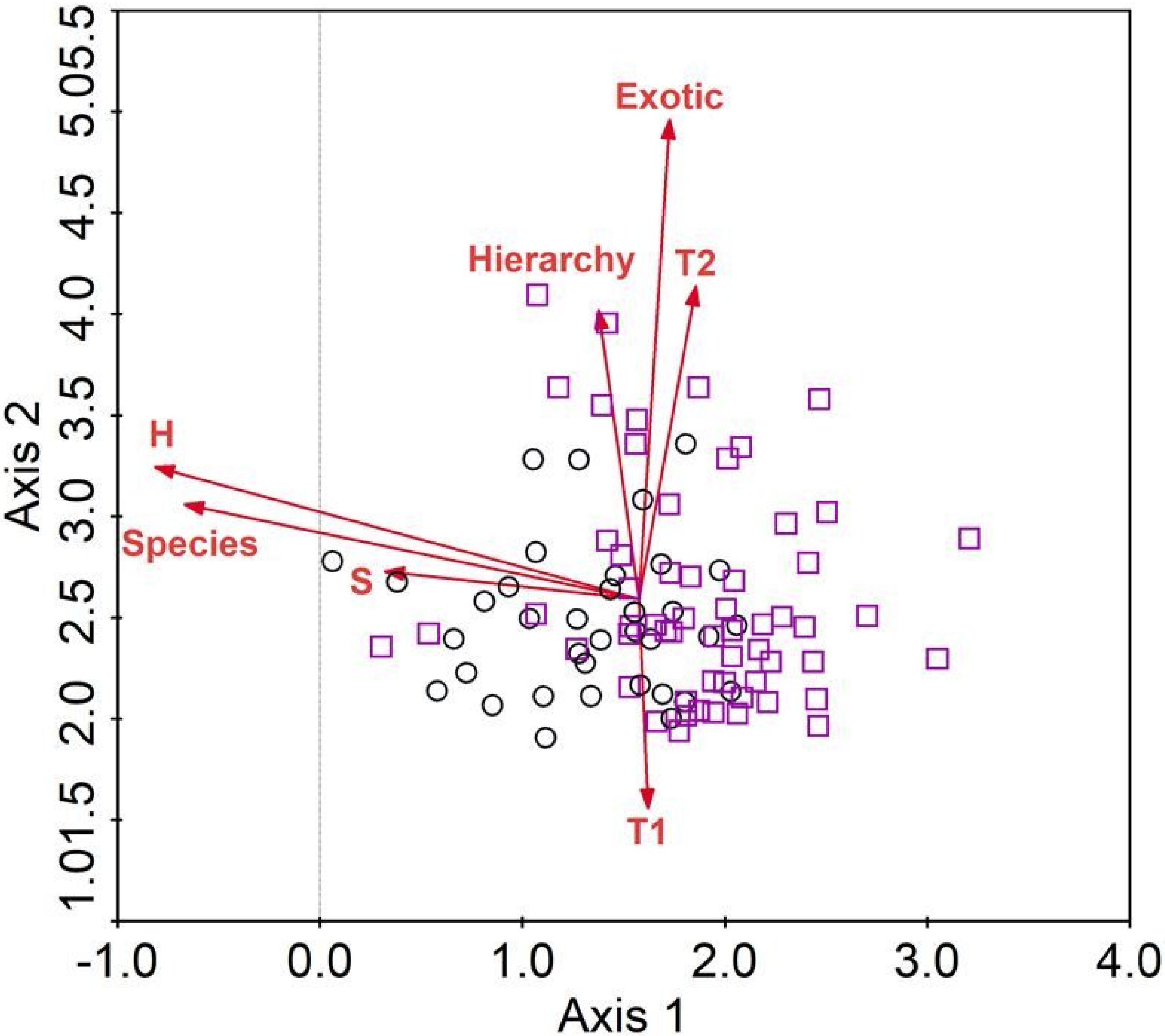

Figure 5

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).

Supplementary Files

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- Table1.jpg
- Table2.jpg