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Species Composition and Ecological Niche Overlap of Alien and Endemic Plants in South Korea: Insights from the National Ecosystem Survey

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Abstract

Biodiversity conservation in South Korea faces increasing challenges from alien plant invasions. These invasions threaten endemic species uniquely adapted to specialized habitats, making it crucial to understand their ecological interactions. This study quantitatively compared the species composition, ecological niches, and species turnover patterns of alien and endemic plants in South Korea using data from the National Ecosystem Survey. Non-metric multidimensional scaling (NMDS) and multi-response permutation procedure (MRPP) analyses revealed significant compositional heterogeneity between groups. Kernel density estimation (KDE) revealed niche overlap in water-related factors (precipitation, water yield), but clear separation in topographic and climatic variables (altitude, slope, temperature). Alien plants exhibited broader niche breadths, confirming their ecological generalist traits, whereas endemic species displayed narrower niches confined to specialized habitats. Zeta diversity analysis indicated slower species turnover in alien species, suggesting niche assimilation and habitat homogenization. Both groups fit a power-law model, emphasizing deterministic environmental filtering. These findings highlight the ecological risks posed by alien species to stability of endemic plant communities and underscore the importance of targeted, science-based management strategies.

Keywords: zeta diversity; niche breadth overlap; alien plant; plant invasion

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1. Introduction

The recently adopted Kunming-Montreal Global Biodiversity Framework identifies the management of invasive alien species and biodiversity conservation (Targets 6 and 23) as key challenges. It emphasizes the importance of establishing a management system for alien species, controlling their spread, and analyzing their impacts on ecosystems [1].

The vascular flora of South Korea comprises 3975 taxa (3307 species and 668 infraspecific taxa, including subspecies, varieties, forms, and hybrids) classified into 951 genera and 183 families. This includes 31 lycophytes, 333 ferns and allies, 30 gymnosperms, and 3581 angiosperms [2]. Of these, 3878 taxa are confirmed to occur in Korea, while 97 remain uncertain, and three are considered extinct or possibly extinct. The alien vascular flora comprises 619 taxa 6 (96 families, 353 genera, 595 species, 6 subspecies, 11 varieties, 1 forma, and 6 hybrids) [3]. A revised checklist identifies 373 endemic taxa (64 families, 179 genera, 304 species, 6 subspecies, 49 varieties, and 14 nothospecies) [4]. The flora of the Korean Peninsula shares many biogeographic similarities with those of neighboring

regions such as northeastern China, Japan, and the Russian Far East. For example, a recent study of Northeast Asia's vascular plants found that Korea ranks among the top in species richness and shares many dominant genera and families with other temperate East Asian regions [5].

The colonization and spread of alien plant species have consistently been regarded as primary threats to ecosystem function and biodiversity stability, and the international community recognizes them as critical drivers of biodiversity loss. The spread of alien plants threatens the structure and function of native plant communities by causing resource competition, ecological niche overlap, and ecosystem disruption, ultimately leading to biodiversity instability and reduced ecosystem services [6,7].

The invasion of alien plants adds species to specific habitats and alters the ecological niches and resource utilization patterns of native and endemic plants within existing ecosystems. This process intensifies competition within native plant communities, especially among endemic species adapted to specialized habitats. In this context, comparative studies of the ecological interactions between alien and endemic plants are essential for understanding their status, temporal dynamics, and implications for ecosystem structure and health [8].

Several domestic and international studies have examined the relationships between alien plants and species in specialized habitats, including resource competition, spatial arrangements between alien and endemic plants, and predictions of invasiveness and resource overlap based on niche analyses [9–11]. Furthermore, previous studies have examined the physiological characteristics of alien plants, focusing on their environmental adaptation, such as assessing their range within vegetation types based on soil moisture conditions [12–15].

Research on alien plants in South Korea has mainly focused on their relationships with environmental factors, invasion risks, and the spatial distribution of hotspot areas using GIS approaches [16–22]. However, studies comparing alien plants with other plant communities, such as endemic plants or native plants, and analyzing their ecological niches, are lacking. One study suggested the potential for examining success in becoming established depending upon various environmental factors between native and alien plants within ecological restoration sites [23]; however, this was limited to a specific habitat category (e.g., disturbed areas). In this context, it is necessary to secure basic data to establish and develop management strategies through supplementary analyses of the ecological niches of alien plants at the national level. In summary, clarifying the management and geographical distribution of alien plants in South Korea is crucial. Additionally, the interpretation that alien plants cause biodiversity loss presupposes their impact on the survival of native plants within their habitats. However, quantitative comparative studies on species interactions remain scarce. Therefore, while studies on environmental factors within single populations of alien plants are important for their management, quantitative analyses of their correlations with other species, ecological niche overlap, and environmental suitability are also necessary [24,25].

In particular, endemic plants, owing to their narrow distributions and environmental specificity, are more vulnerable to climate change and habitat disruption than alien plants. They also possess unique phytogeographical characteristics and value [26–28]. Thus, more precise habitat-based analyses of alien plants are required to establish and develop conservation and response strategies.

The coexistence patterns of alien and endemic plants can be comprehensively analyzed through quantitative comparisons of ecological niche structures and resource utilization patterns [29]. Recent studies have attempted to analyze their competitive structures and ecological isolation using various statistical techniques, including ecological niche overlap

analysis, estimation of niche breadth for environmental variables, spatial species composition, and zeta diversity analysis [9,30]. To address the lack of comprehensive data on these parameters, this study aimed to compare species composition, ecological niches, and spatial species turnover patterns of alien and endemic plants using regional ecological data collected from the National Ecosystem Survey of South Korea. The specific objective was to identify ecological differences between the two groups and their underlying factors. Specifically, this study incorporated ecosystem service indicators as environmental factors to assess the potential for alien plant dispersal and its ecological implications within the broader framework of human–nature interactions. In summary, research on ecological niche theory will provide a strong foundation for habitat-based species conservation and restoration, as well as for developing and implementing effective policies for ecosystem and biodiversity conservation [31].

This study was designed based on the following three hypotheses:

Hypotheses 1. *The species compositions of alien and endemic plants are heterogeneous.*

Hypotheses 2. *The ecological niches of alien and endemic plants overlap in specific environmental factors, resulting in differences in niche breadth.*

Hypotheses 3. *The differences in the ecological niches of the two groups originate from a deterministic process.*

Based on these hypotheses, we examine and interpret the ecological assimilation process of alien plants and the spatial separation structure of endemic plants, providing fundamental data for effective biodiversity conservation and alien plant management strategies.

2. Materials and Methods

2.1. Biotic Data and Selection of Target Sites

In this study, we tested the proposed hypotheses by analyzing extracted data with various statistical tools (Figure 1).

The 800 survey grids were established using the 1:25,000 digital topographic map system, the standard unit of the National Ecosystem Survey conducted by the Korean Ministry of Environment [32]. Each grid reflects the spatial extent of the corresponding map and was structured to facilitate the use of national vegetation survey data in ecological analysis. This national survey system facilitates integrated analyses of plant species composition and environmental factors based on quantified ecological data. In this study, we considered each grid a single plot and assessed the presence of specific plant species.

Spatial distribution data on flora were obtained from 800 plots using the Spatial Join tool in ArcGIS (ver. 10.8; Esri, Redlands, CA, USA). Plant species were extracted from each grid, and species richness was then calculated. Species richness was defined as the number of plant species recorded in each plot [33]. The survey period for plant species ranged from 2006 to 2023. Alien plants, the target group of this study, identified based on the Korean Invasive Alien Species Database [34], while endemic plants were identified using the species list of Chung et al. and the Ministry of Environment [4,35].

We selected 80 plots with the highest species richness (top 10%) for both alien and endemic plants, resulting in 160 plots in total, and compared their ecological characteristics and species composition. Plots with high species richness represent the core niche space within the ecological niche of the flora and serve as a sample group enabling a clear comparison of preferences for environmental resources [36]. Furthermore, plots with a high probability of species occurrence were selected to analyze specific habitat niches, a

sampling method that enhances the reliability of environmental and species distribution analyses [37,38].

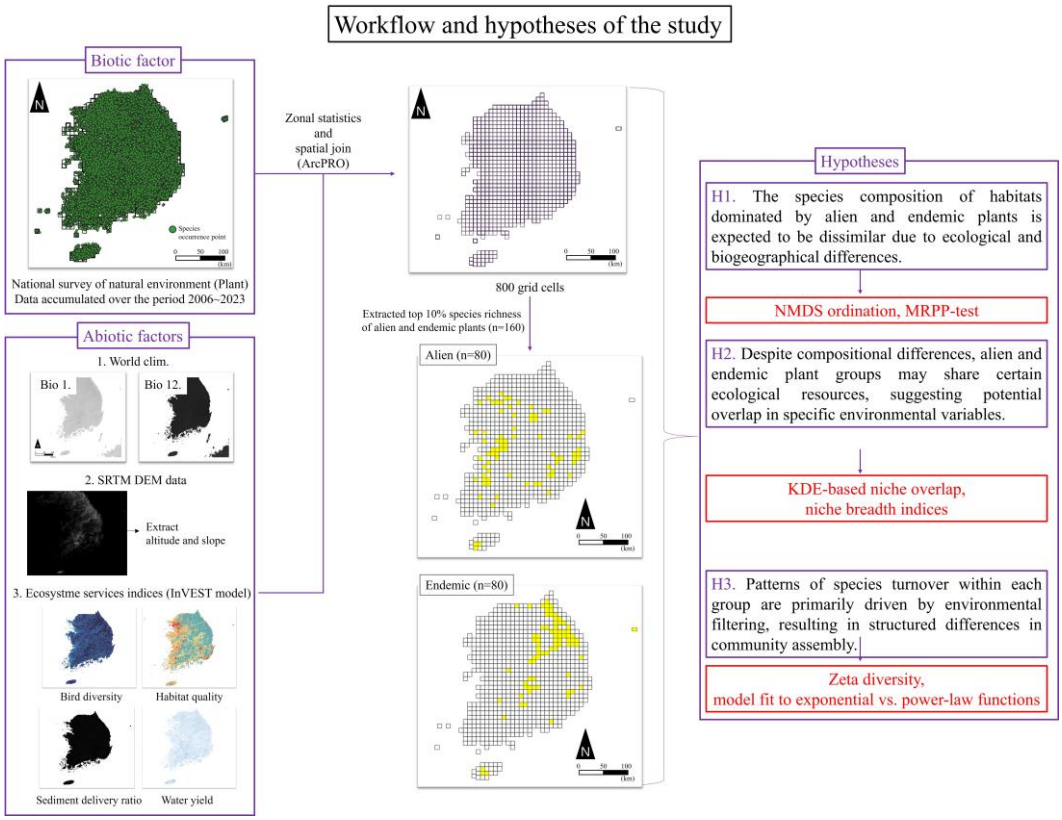

Figure 1. Workflow chart of research directions, hypothesis setting, and analysis (yellow highlight: the grids with the top 10% species richness of alien and endemic plants among the 800 survey units).

2.2. Abiotic and Ecosystem Service Variables

We identified a total of eight factors using ArcGIS to determine the environmental conditions of the 160 plots. The environmental factors assessed were temperature, precipitation, altitude, slope, habitat quality (HQ), bird diversity, water yield (WY), and sediment delivery ratio (SDR). These variables were chosen because they represent key climatic, topographic, and ecosystem service factors known to influence the distribution and ecological characteristics of plant species, particularly alien and endemic species, as supported by previous studies [39–53]. Temperature and precipitation layers were derived from WorldClim Bioclim data (v.2.1; 30 arc-second resolution, representing 1970–2000 climate averages), and altitude and slope were calculated using NASA's Shuttle Radar Topography Mission (SRTM) digital elevation model (30 m resolution).

Data on ecosystem service indicators, such as HQ, bird diversity, WY, and SDR, were computed using the InVEST program (v3.14.1; Natural Capital Project, Stanford University, CA, USA) based on land cover maps and spatial environmental data provided by the Korean National Institute of Ecology [54].

HQ was calculated based on habitat type, habitat sensitivity, and threat levels. Habitat types were derived from the Korean Land Use and Land Cover (LULC) dataset, and the calculation formula is as follows [54]:

$$HQ = H \times \left(1 - \left(\frac{D^2}{D^2 + K^2}\right)\right) \quad (1)$$

HQ: Habitat quality

H: The habitat suitability of land use type

D: Threat level by habitat type

K: Half-saturation constant

Bird diversity was defined as species richness per grid cell based on data from the National Ecosystem Survey [54]. For WY, values for each pixel were derived by subtracting the annual actual evapotranspiration (*AET*) from the annual precipitation (*PRE*). The formula is as follows [54]:

$$\mathrm{WY} = \left(1 - \frac{AET}{PRE}\right) \times P \quad (2)$$

WY: Water yield

AET: The annual actual evapotranspiration

PRE: The annual precipitation

SDR was calculated based on rainfall- and erosion-related factors as well as slope steepness. The calculation formula is as follows [54]:

$$\mathrm{SDR} = \mathrm{R} \times \mathrm{Ks} \times \mathrm{LS} \times \mathrm{C} \times \mathrm{P} \quad (3)$$

SDR: The sediment delivery ratio

R: Rainfall erosivity factor

Ks: Soil erodibility factor

LS: Slope length and steepness factor

C: Cover management factor

P: Support practice factor

All spatial data values were extracted for each plot using ArcGIS and normalized to a 0–1 scale for cross-variable comparisons. The distribution patterns of alien and endemic plants differ depending on these indicators [55–57]. Ecosystem service indicators were calculated using the InVEST program.

2.3. Analytical Methods

We analyzed species composition differences between alien and endemic plant habitats using non-metric multidimensional scaling (NMDS), selecting two axes with the highest R^2 values [58–60]. The multi-response permutation procedure (MRPP) was applied to test group differences in species composition, with T and A statistics used to interpret heterogeneity and within-group agreement [58,61].

To analyze ecological niche overlap and breadth, all environmental variables were normalized (min–max scaling) to a 0–1 range for comparability across units. Ecological niche overlap for each environmental factor was visualized using kernel density estimation (KDE) and quantified with Schoener's D index [62,63]. The KDE-based probability density function integrates to 1 over the entire domain, which is a fundamental property of probability density functions. Schoener's D index ranges from 0 to 1 and quantifies the area of overlap between the two groups, indicating the degree to which the groups actually share ecological niche space for each environmental factor [62,63].

The KDE formula is presented in Equation (4).

$$f_h(x) = \frac{1}{nh} \times \sum_{i=1}^{n} Kf \times \left(\frac{x - x_i}{h}\right) \quad (4)$$

$f_h(x)$: Estimated probability density value at point x

n: Number of samples

h: Bandwidth (smoothing parameter)

Kf: Kernel function (e.g., Gaussian normal distribution kernel)

x_i: Observed values

The smoothing parameter (h, bandwidth) determines the shape of the KDE curve, was calculated using Silverman's rule of thumb (Equation (5)) [64].

$$h = 1.06 \times \sigma \times n^{-1/5} \quad (5)$$

σ: Sample standard deviation

n: Number of data points

The Gaussian normal distribution kernel used in this study was:

$$K(u) = \frac{1}{\sqrt{2\pi}} \times e^{-\frac{1}{2}u^2} \quad (6)$$

K(u): Kernel function

u: The normalized value of the distance between the data point and the center of the kernel.

To compare the ecological niche breadth between groups for each environmental factor, we employed KDE bandwidth, interquartile range (IQR), and Shannon entropy [33,64–66]. Each indicator was applied using 1000 bootstrap resampling iterations for the two groups to derive the mean and standard error [33,67]. Based on these results, the statistical significance between the two groups was analyzed with an independent samples *t*-test. By presenting both ecological niche overlap area and niche breadth indicators, we aimed to accurately interpret the functions and interaction patterns of each habitat based on ecological niche structure.

We analyzed zeta diversity to quantify multi-site species turnover and shared species patterns across plots [30,68]. Zeta ratio analysis was also applied to assess species persistence and regional similarity [30,68,69]. The zeta ratio represents the probability of a species occurring in the *n*th plot given its occurrence in the $n-1$ plot. The equation used is presented below.

$$\zeta - ratio = \frac{\zeta_n}{\zeta_{n-1}} \quad (7)$$

ζ_n: The number of species shared between n areas

ζ_{n-1}: The number of species shared between (n−1) areas.

We compared power-law and exponential models to infer ecological assembly processes. The power-law model indicates deterministic, niche- and environment-based filtering, whereas the exponential model aligns with neutral theory and stochastic turnover [30,68,70]. Model fit was evaluated using Akaike's information criterion (AIC), with lower AIC values indicating better fit [71].

As for the analysis program, biotic and abiotic factors were extracted using ArcGIS and PC-ORD (ver. 7.0; MjM Software Design, Gleneden Beach, OR, USA) was employed for NMDS and MRPP tests. R Studio (ver.4.5.1; R Foundation for Statistical Computing, Vienna, Austria) with the packages 'ggplot2', 'vegan', 'boot,' and 'zetadiv' was employed for KDE modeling, niche overlap analysis, and zeta diversity analysis.

3. Results

3.1. Ordination and MRPP-Test

We performed NMDS ordination to analyze the species composition heterogeneity of alien and endemic plant habitats (Figure 2). The stress value in the two-dimensional ordination was 17.581, below the acceptable threshold of 20 in ecological analyses (p = 0.004), indicating reliable results [58]. The R^2 values for the first and second axes were 0.609 and 0.211, respectively, with an overall R^2 value of 0.820. When comparing

the species composition of alien and endemic plant habitats, the two groups partially overlapped, but their centroids were separated in two-dimensional space, indicating heterogeneous composition. The environmental variables influencing the arrangement of species composition were included gradient, HQ, SDR, precipitation, temperature, and bird diversity.

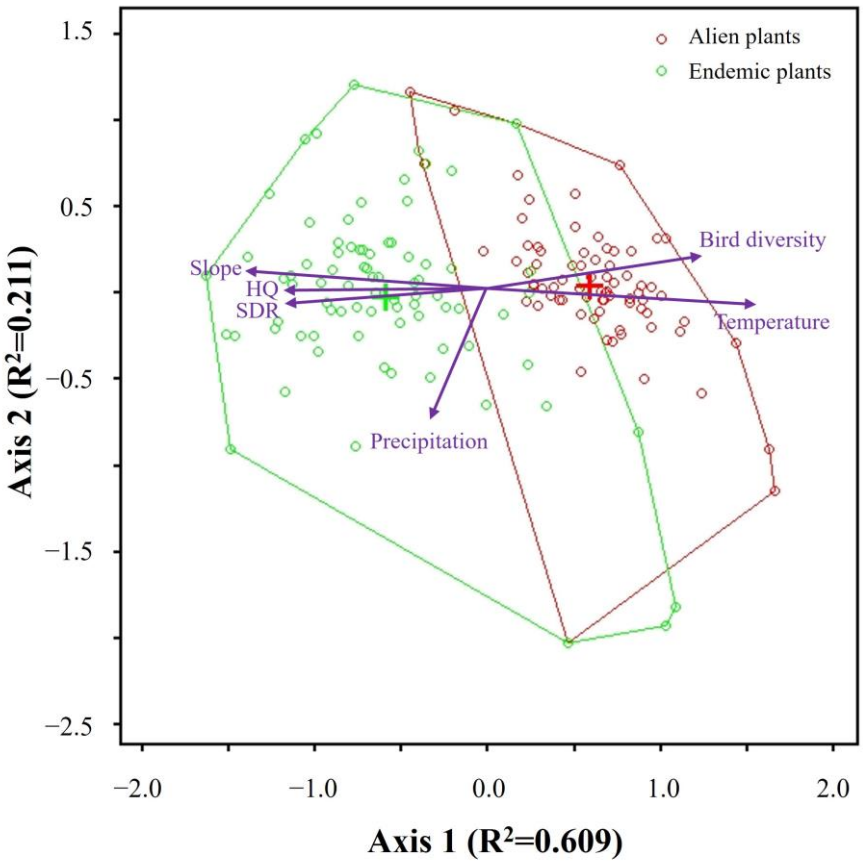

Figure 2. NMDS ordination (cut-off $R^2 = 0.3$) of species composition for each group. Purple arrows represent environmental vectors fitted using a joint plot in PC-ORD 7.0. The length and direction of the arrows indicate the strength ($R^2 > 0.3$) and direction of correlation with the ordination axes. The cross symbol indicates the centroid of species composition for each group.

The MRPP results (Table 1) showed T = −73.8937 and A = 0.2814, indicating significant differences between groups, while within-group similarity remained relatively high ($p < 0.001$).

Table 1. Summary of MRPP results comparing species composition across different groups. The T statistic indicates the separation between groups, while A represents the chance-corrected within-group agreement. Significant results ($p < 0.05$) suggest that community composition differs among groups.

Compared Plant Groups	T	A	*p*-Value
Alien vs. Endemic	−73.894	0.281	<0.001

3.2. Ecological Niche Comparisons of Habitats of Alien and Endemic Plants

We performed KDE analysis to determine the degree of sharing of available resources between each group based on the overlap area of the ecological niches of alien and endemic plant habitats. The degree of shared resource use reflects the level of competition between the two groups for growth and distribution [72,73]. To compare the degree of overlap

between the ecological niches of alien and endemic plants, KDE-based overlap (Schoener's D) was calculated for eight environmental variables (Figure 3, Table 2). Schoener's D values quantify the area of overlap between two distributions on a scale from 0 to 1; the higher the value, the greater the resource sharing (or competition) between the two groups.

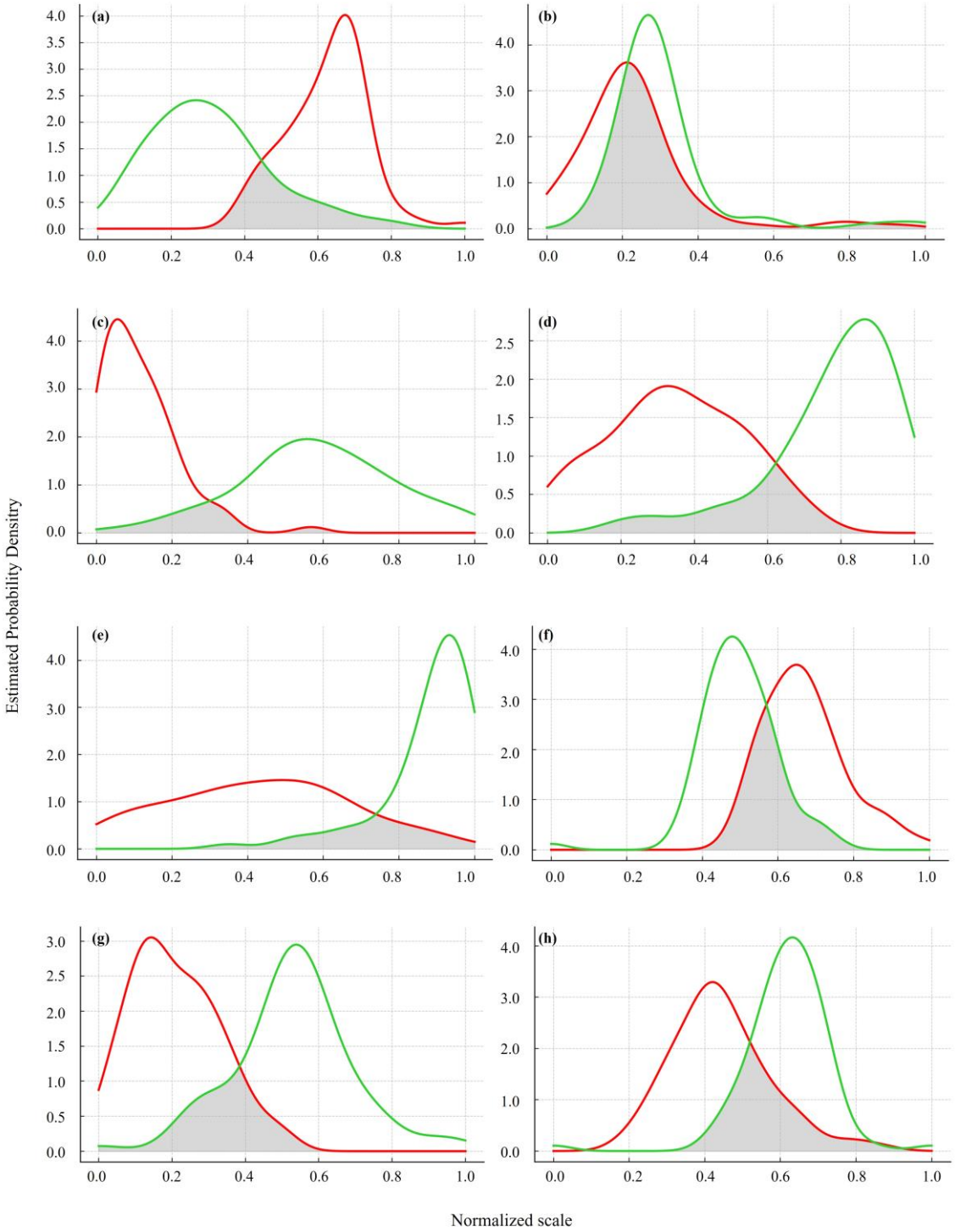

Figure 3. Kernel density estimation (KDE) curves showing ecological niche distributions of Alien (red) and Endemic (green) species groups across eight normalized environmental gradients. Gray shading indicates the overlapping region between the two distributions. The x-axis represents the normalized scale of each environmental variable, and the y-axis represents the estimated probability density. Environmental variables are as follows: (**a**) temperature, (**b**) precipitation, (**c**) altitude, (**d**) slope, (**e**) habitat quality, (**f**) bird diversity, (**g**) sediment delivery ratio, (**h**) water yield.

Table 2. Overlap metrics for 8 Environmental variables (Schoener's D).

Variable	Schoener's D
Temperature	0.276
Precipitation	0.719
Altitude	0.157
Slope	0.261
Habitat quality	0.255
Bird diversity	0.419
Water yield	0.397
Sediment delivery ratio	0.277

Precipitation showed the highest overlap (0.719), indicating similar water-resource niches for the two communities. Bird diversity (0.419) and water yield (0.397) followed, and these ecosystem service indicators are interpreted as factors related to habitat connectivity and moisture conditions within habitats, respectively.

In contrast, altitude showed the lowest overlap at 0.157, followed by gradient (0.261) and temperature (0.276). These results imply that the two groups occupy distinct ecological niches shaped by topographic and temperature conditions. These environmental variables suggest that their distributions are influenced by different ecological characteristics.

In summary, alien plants share ecological niches with endemic plants in relation to moisture-related variables but tend to be confined to specific habitats under topographic and temperature conditions.

The interpretation of the x-axis (normalized scale) and y-axis (estimated probability density) for each environmental factor in the KDE graph reveals that alien plants were generally concentrated in the mid-range or slightly lower normalized scale, whereas endemic plants, except for temperature and bird diversity, were concentrated in the relatively higher normalized scale. Concentration in the lower normalized scale indicates that these plants are abundant even under conditions with limited environmental resources. Higher normalized scales indicate that these plants can particularly grow and develop in environments with abundant resources or require specific conditions for growth. Accordingly, this analysis demonstrated that endemic plants were more specialized in their environmental requirements for growth compared to alien plants.

We analyzed three niche breadth indicators—KDE bandwidth, IQR, and Shannon entropy—for eight environmental variables (Figure 4) to compare the ecological niches of alien and endemic plants. KDE bandwidth represents the quantitative range of ecological niche breadth, while IQR indicates the core area where 50% of the data is distributed based on the KDE curve. Shannon entropy is used to confirm the evenness of the distribution.

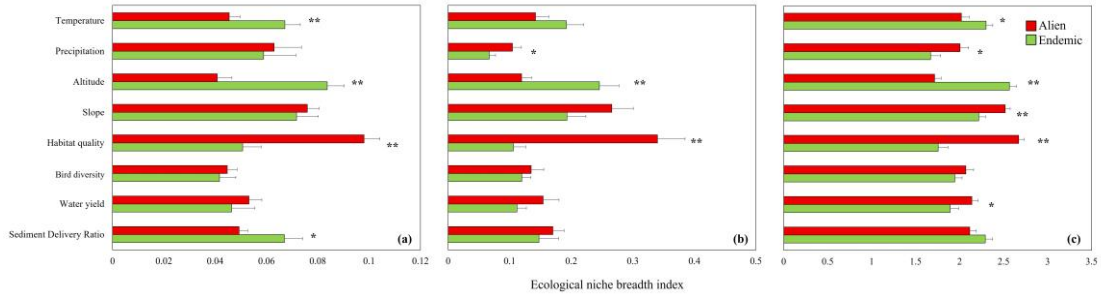

Figure 4. Ecological niche breadth of Alien (red) and Endemic (green) species groups across eight environmental variables, based on (**a**) KDE bandwidth, (**b**) interquartile range (IQR), and (**c**) Shannon entropy. Error bars represent standard errors derived from 1000 bootstrap replicates. Statistical significance between groups was assessed using two-sample *t*-tests ($p < 0.05$ is indicated by * and $p < 0.01$ by **).

3.3. Zeta Diversity Analysis

Based on the above ecological niche analysis results, we can raise the following question: Do the distribution characteristics of the two groups (alien and endemic plants) according to environmental variables affect changes in species composition or species turnover patterns? To answer this question, we derived a graph of the decrease in zeta diversity and analyzed the associated ecological processes (Figure 5).

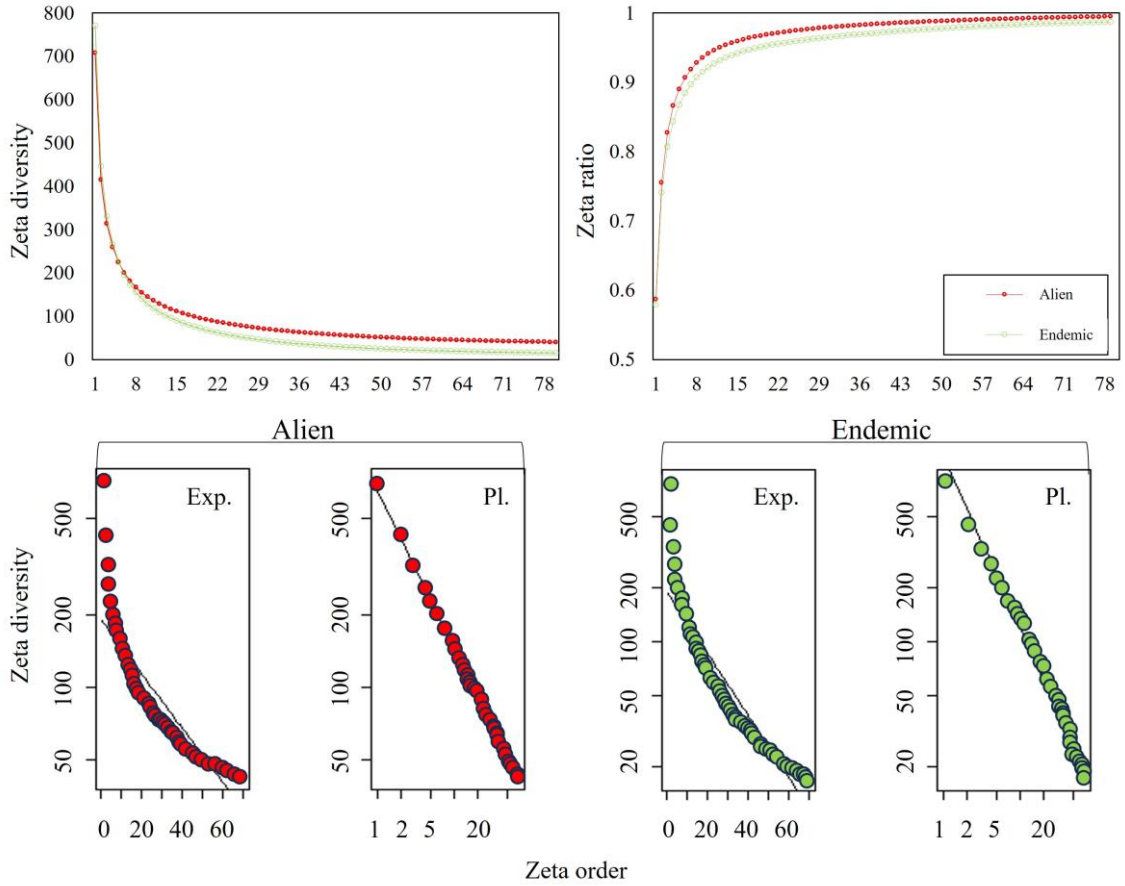

Figure 5. Comparisons of zeta diversity decline and the zeta ratio for each group. To determine the ecological processes for each habitat associated with alien and endemic species groups, AICs of exponential and power-law function regression were calculated.

Zeta diversity decreased with increasing spatial order in both alien and endemic plants, but the decline was slower in alien plants. The zeta ratio graph tended to converge to 1 as the zeta order increased in both groups. Table 3 presents the AIC values of the power-law and exponential function models based on the graph of the decrease in zeta diversity. The AIC values of the power-law function and exponential function models for alien plants were −530.3144, and −109.6002, respectively, and the values for endemic plants were −302.4994 and −85.1348, respectively. These results indicate that the power-law function model better explained the ecological processes in both groups.

Table 3. Comparison of AIC values for exponential and power-law models fitted to zeta diversity decay in alien and endemic plant groups.

Index	Power Law	Exponential
Alien	−530.3144	−109.6002
Endemic	−302.4994	−85.1348

4. Discussion

4.1. (Hypothesis 1) The Species Compositions of Alien and Endemic Plants Are Heterogeneous

The NMDS analysis showed clear distinctions in species composition between alien and endemic plant groups, and the MRPP test confirmed statistically significant differences. This implies that the two plant groups formed under different environmental requirements [58]. The primary distribution areas of alien plants in South Korea are ports, landfills, and areas near airports, and their distribution ranges extend to roads, construction sites, and development areas [22,74]. In South Korea, some endemic plants occur along roadsides and forest edges, but most are restricted to specialized habitats. Most species are limited to habitats with strong environmental specificity, such as high mountain areas, cliffs, and rocky areas, where human access is limited [75–79]. A similar trend is found worldwide, with native plants generally adapted to habitats limited by environmental filters such as altitude, precipitation, and soil, and showing high sensitivity to anthropogenic disturbance. Although the NMDS contour overlay revealed heterogeneous spatial patterns, some areas of overlap between alien and endemic plants were also observed. This can be interpreted as reflecting a transitional spatial structure where alien plants are gradually invading habitats where endemic plants have been established for a long time [80]. The habitats of the two groups are not completely separated, and alien plants are gradually invading the habitats of endemic plants. After disturbance, native and alien plants may coexist in specific habitats if resources are sufficient. However, as succession progresses, these habitats become more heterogeneous [23]. Alien plants exhibit distinct species composition and distribution patterns over time to avoid competition with native species and utilize newly available resources [9]. With respect to altitude and gradient, alien plants were distributed under lower environmental conditions than endemic plants. The distance between the density centroids was longer, indicating that differentiation occurred due to the adaptation of endemic species to the unique climate conditions resulting from vertical distribution and geographical isolation. Furthermore, the relationship between gradient and the ecological niche of alien plants in this study was consistent with a previous study that found alien plants frequently occurred in vegetation established at low gradients [18].

In consideration of the direction of the joint plot of environmental factor vectors, alien plants were correlated with bird diversity and temperature, while endemic plants were correlated with altitude, HQ, SDR, and precipitation [58]. This result is consistent with the highest density points on the normalized scale found in the KDE-based ecological niche analysis in this study. In other words, alien plants were concentrated in areas with high temperature and bird diversity on a normalized scale, while endemic plants exhibited a high distribution density pattern in environments with high altitude and gradients. These results align with the joint plot analysis results of NMDS ordination.

These findings indicate that the species composition of each group did not originate from a stochastic process, but rather from a deterministic process, i.e., the filtering effect of specific environmental factors. This study will discuss this environmental filtering mechanism in more detail in the following sections (Sections 4.2 and 4.3) to clarify its close connection with community structure, ecological niche breadth, and spatial species turnover (zeta diversity).

4.2. (Hypothesis 2) The Ecological Niches of Alien and Endemic Plants Overlap in Specific Environmental Factors, Resulting in Differences in Niche Breadth

We analyzed ecological niche overlap (Schoener's D) and niche breadth (KDE bandwidth, IQR, Shannon entropy) for eight environmental variables to quantitatively compare niche characteristics of alien and endemic plants [62–66,70].

For temperature, alien plant densities were concentrated in warmer ranges, reflecting their adaptation to high-temperature environments and suggesting that their distribution may expand under ongoing climate warming [7,42]. Endemic species showed higher densities in moist habitats (precipitation and WY), indicating reliance on stable water resources and vulnerability to habitat drying [55,56,79].

Regarding HQ, alien species were broadly distributed across the entire normalized scale, whereas endemic plants were concentrated in high-HQ areas, demonstrating their preference for undisturbed, biodiversity-rich habitats [26,54,75,78]. The broad distribution of alien plants suggests high adaptability to diverse disturbance regimes [6,24,80].

Alien species were more common in areas with higher bird diversity, implying that heterogeneous or recovering habitats facilitate their dispersal [52,53]. In contrast, endemic species were associated with areas of lower bird diversity, suggesting environmental uniqueness or microhabitat specialization [77,79]. For sediment SDR, alien species occurred mostly in low-SDR regions, such as managed areas and gentle slopes, whereas endemic plants were concentrated in eroded or rocky terrain, indicating strong topographic specificity [46,54–56].

KDE-based overlap analysis showed the largest overlap for water-related variables (precipitation, WY), suggesting high competition potential for water resources between groups [58,76]. Endemic KDE curves peaked in high precipitation and WY ranges, while alien KDE curves peaked in intermediate to low conditions. Previous studies similarly demonstrated that alien species, such as *Bromus tectorum* in Nevada grasslands, alter hydrological cycles by reducing deep soil moisture availability and increasing surface moisture use [8,12–15].

Conversely, topographic variables such as altitude, slope, and temperature showed lower overlap, indicating clearer niche separation between alien and endemic plants [81]. Endemic species' wider niche breadth for altitude and temperature highlights ecological adaptation to temperature gradients, consistent with NMDS ordination showing strong compositional diversity along elevation gradients [82,83].

Across all factors, alien plants exhibited a wider ecological niche breadth than endemic species in five or six environmental variables, supporting their classification as ecological generalists capable of thriving under diverse conditions. Endemic species had significantly broader niche breadth only in temperature and altitude, consistent with their adaptation to specialized environments and narrower ecological tolerance.

HQ-related metrics reinforced these findings: alien plants had significantly wider niche breadth ($p < 0.01$) with even KDE distributions across HQ values, whereas endemic species were concentrated at high HQ levels (0.8–1.0), highlighting their vulnerability to anthropogenic disturbance.

Together, these metrics—kernel bandwidth (habitat dispersion), IQR (variation around the median), and Shannon entropy (environmental resource diversity)—provide quantitative insight into ecological connectivity and resource utilization [9,29]. Our findings highlight alien plants as ecological generalists occupying broad environmental ranges, while endemic species are specialists restricted to narrow conditions [84]. This supports our hypothesis that alien and endemic species exhibit overlapping niches for moisture-related variables but contrasting niche breadth patterns overall.

Our findings are consistent with recent predictive modeling studies that emphasize the importance of mechanistic niche models in projecting invasive species potential under climate change scenarios [85]. Further, analyses of niche shifts and regional risk in recent literature parallel our observations of niche breadth differences between alien and endemic plants [86].

4.3. (Hypothesis 3) The Differences in the Ecological Niches of the Two Groups Originate from a Deterministic Process

Zeta diversity analysis revealed a slower decline in species turnover among alien plants compared to endemic plants. The zeta ratio graphs for both groups showed an upward trend, converging toward 1; however, the convergence occurred at a faster zeta order in alien plants. Furthermore, the decline in zeta diversity for both groups supported a power-law function model, suggesting that species turnover and changes in species composition are driven by a deterministic process [70].

Contrary to our prediction that alien plants would generally show large variations in species composition depending on local environmental conditions and regional heterogeneity, the findings of this study indicate that alien plants adapt swiftly to diverse habitats, and habitats became stabilized with the repeated appearance of specific species [87]. This is consistent with the slower decline observed for alien plants in the graph [30,68].

This pattern was also observed in the zeta ratio, with alien plants showing a tendency to converge to 1 more rapidly than endemic plants, particularly between the 4th and 25th orders. This indicates that alien plants undergo rapid niche assimilation, swiftly adapting to diverse habitats, occupying ecological niches, and homogenizing species composition [88]. This process may induce competition between the two groups as the overlap of available resources increases [89].

In contrast, endemic plants showed relatively large changes in species composition between habitats, and the convergence of the zeta ratio appeared slower even at higher orders, indicating a species composition structure in which regional specificity was relatively maintained compared to alien plants. These results suggest that endemic plants, like rare species, follow distribution strategies strongly linked to environmental gradients or isolated habitat characteristics [27,43,90,91].

Additionally, the decrease in zeta diversity based on the power-law function suggests changes in species composition in line with selective distribution and environmental suitability rather than random distribution. Combined with the previously previous reports on ecological niche breadth and overlap area, this strongly supports the distinct ecological separation and species turnover structures between the two groups. Consequently, endemic and alien plants are shaped by different environmental filters, forming distinct ecological structures in both spatial patterns and species composition. The zeta diversity decline curve for alien plants was gentler compared to endemic plants, which may indicate the spatial persistence of common species and a wide environmental tolerance range [30,70].

These results support the potential for alien plants to penetrate and spread across various habitats in South Korea. In this context, the gentle slope of zeta diversity in the alien plant group, as found in this study, underpins the ecological process of stable species turnover. Simultaneously, endemic plants may be more vulnerable to climate change or habitat fragmentation due to ecological niche conservatism and local specificity [92,93].

5. Conclusions

This study quantitatively compared species composition, ecological niches, and species turnover patterns of alien and endemic plants in South Korea, using national-scale data from the National Ecosystem Survey. Alien plants were identified as ecological generalists with broad niche breadth across multiple environmental factors, whereas endemic plants exhibited specialized niches confined to specific conditions.

Zeta diversity analysis showed that alien plants maintain relatively homogeneous species composition across regions, highlighting their rapid establishment and the potential risks of habitat homogenization. Their wide ecological niche, particularly for ecosystem

service indicators such as habitat quality (HQ), suggests their potential to spread into areas of high conservation value.

This study demonstrates the utility of national biodiversity datasets for multidimensional ecological assessments and provides a foundation for effective monitoring and management strategies. However, as our analysis was based on grid-level presence-absence data, future studies should incorporate species population dynamics, functional traits, and impact indices to better inform management priorities. Science-based and selective strategies, rather than indiscriminate control, are essential to balance alien plant management with the ecological roles of native and endemic communities.

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