Analysis of the Distribution and Characteristics of Invasive Plants using Plant Social Networks

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Research Article

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ABSTRACT

Globally, Invasive Alien Plants (IAPs) are recognized as a major factor in biodiversity loss. Recently, the influx of exotic plants has been accelerated due to climate change, leading to an increase in concerns and worries about the decline of biodiversity. Mudeungsan National Park and Geumdangsan, which is located about 11 km away in a straight line, have much smaller areas and fewer visitors. Although IAPs are recognized as a major factor in the decline of biodiversity, recent research has shown that they can interact positively or negatively with native species in their habitats. The results of this study showed that the number of IAP species in both Mudeungsan national park and geumdangsan was similar, with 25 out of 533 taxa in Mudeungsan and 26 out of 304 taxa in Geumdangsan. The plant society network was analyzed using Gephi 0.9.7. The results of the interspecies association showed that *Erigeron annuus* (L.) Pers., *Robinia pseudoacacia* L., and *Ambrosia artemisiifolia* L. had many correlations with native plant species, and native plant species such as *Artemisia indica* willd., *Persicaria filiformis* (Thunb.) Nakai ex T.Mori, *Pueraria lobata* (Willd.) Ohwi, and *Rosa multiflora* Thunb. showed high compatibility with IAP. Additionally, *Robinia pseudoacacia* was confirmed to be a species suitable for artificial cultivation, and *Erigeron annuus* was suggested as an IAP Indicator because it plays an important role as a bridge in the boundary between the forest edge and the central area.

Keywords: Invasive alien plants; IAP indicator; Plant social network; Interspecies association; Sociogram

INTRODUCTION

Biodiversity is declining due to global trade, increased travel around the world, climate change, and the impact of Invasive Alien Plants (IAP). As transportation has developed, humans have spread across the world and brought various species, both intentionally and accidentally. When IAPs are introduced into some regions, they can have a severe impact on native biodiversity. IAPs are known to be established in places such as farmland, landfills, pastureland, urban waterways, and harbors. Understanding the behavior of alien species in cities is really important because cities can act as immigration sources that can further spread into the landscape [1].

The invasion and spread of IAPs in native ecosystems is known to be influenced by factors such as the characteristics of the invader species, geographical location (latitude), temperature, size of the point of introduction, land use surrounding the point of introduction, and biodiversity of native plants. IAPs are known to commonly appear as pioneer species in disturbed environments, but in some cases they can also threaten the ecological niches of native species even in stable habitats. The introduction of exotic plants continues and the reality is that the transformation into invasive species is rapidly increasing. While some plants cause harm to ecosystems, others can coexist with native plants and survive without being a significant threat.

IAP rapidly colonizes the habitats of native species using chemical secretion, a fast life cycle, and a large number of seeds. It can quickly disappear from a large area after having bred in high numbers, but its seeds can remain in the soil and be capable of germinating when conditions become favorable, making continued monitoring necessary [2].

As negative perceptions about IAPs have increased, studies have been reported on the degree of invasion according to land use, the impact of invasive species on ecosystems, etc. By considering various spatial and temporal factors that can affect the appearance of invasive species in highly human disturbed urban forests, the distribution characteristics of four representative invasive species in South Korea (*Ageratina altissima* (L.) R.M.King and H.Rob., *Ambrosia artemisiifolia* L., *Bidens frondosa* L., *Pueraria montana* (Lour.) *Merr. var. lobata* (Willd.) Maesen and S.M.Almeida ex Sanjappa and Predeep) were quantitatively evaluated and compared based on GIS and satellite imagery, and potential habitats were able to be predicted. According to a study, the appearance of invasive species in urban forests was analyzed and found to significantly decrease in areas more than 60 m compared to 0 m and 20 m areas. Another study was conducted on the appearance and distribution of *Ageratina altissima* based on soil and habitat characteristics, which found that it appeared in abundance in introduced forests such as Robinia pseudoacacia, but not or rarely in natural forests such as Oak tree forests [3].

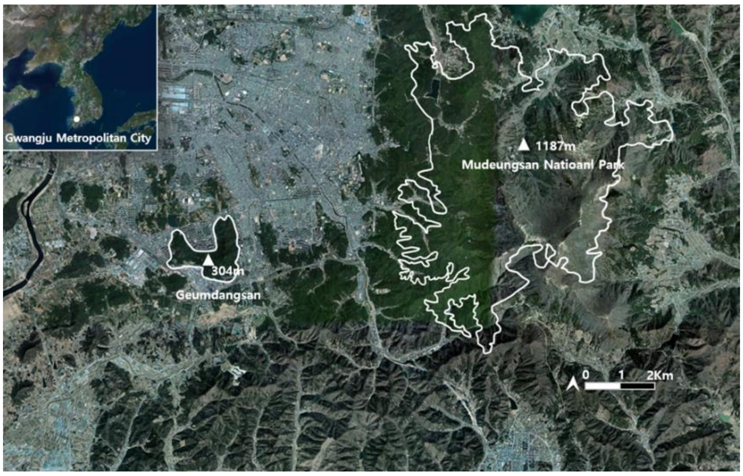
However, there hasn't been any research conducted on the relationship between the habitat species and IAPs yet. Forests and grasslands consist of different plant communities, each with a unique species composition and maintaining relationships with neighboring plant communities. The objective of this study is to gather fundamental data on IAP introduction and control by examining the relationship between IAPs and habitat species, as well as the network of plant communities among IAPs. Additionally, through interspecies association and combined analysis of plants, the aim is to reassess the negative perception of highly invasive plant species [4].

MATERIALS AND METHODS

Survey area

Mudeungsan national park and geumdangsan: Mudeungsan is located approximately 10 km east of the center of Gwangju metropolitan city and its elevation is 1,187 m, with a longitude range of 126°56'-127°03' and a latitude range of 35°04'-35°11' (Figure 1). Its total area is 75.425 km^2 and as of 2021, the number of visitors was 2,399,255, with many people visiting. Geumdangsan is located in the southern and western parts of Gwangju metropolitan city, with an elevation of 304 m, at a longitude of 126°53' and a latitude of 35°07'. Mudeungsan national park is approximately 11 km away from Geumdangsan, as a straight line distance, and is frequently visited by nearby residents (Figure 1) [5].

Figure 1. Location of Mudeungsan national park and Geumdangsan in Gwangju metropolitan city, South Korea.



Data collection

The Mudeungsan national park conducted surveys of various vegetation 31 times from June 2020 to July 2021 by setting up 10 m x 10 m quadrats, resulting in a total of 1,255 plots. The relive method of the Minnesota Resource Management Agency was modified to fit the purpose of the study (considering human disturbance, GPS coordinates, plot size, distance from previous plot, altitude, distance from stream, surrounding environment, presence of wind, height of plant species, aggregation, foliage, sociality, flowers, fruits, and presence of spines) [6].

Data was recorded in the field using the Braun Blanquet method. Plant species requiring detailed identification were photographed in detail using reproductive organs, nutrient organs, and overall condition, and then identified in the laboratory. Data was then transferred to excel for each plot.

The Geumdangsan was surveyed in the field 6 times from August to October 2020. The same 10 m x 10 m quadrats were set up as in Mudeungsan national park, and all plant species occurring in 161 plots were recorded in the field. The plant taxonomy was based on the National standard list of plants. The criteria for determining IAP (Invasive Alien plant) were based on the comprehensive review about alien plants in Korea [7].

Data preprocessing

The researchers analyzed the plant social network, which included all the species found in the survey plots, by dividing the surveyed plant groups into attribute data and relational data. The attribute data was characterized by visualizing the IAP and the native plant species, and the degree of connection [8]. In the case of connections, a non-directional approach was applied to reflect the characteristics of the plants fixed in one place. The relational data was analyzed by creating 2 x 2 contingency tables for all collected categories and conducting a *chi-square* test of association. If the *chi-square* test value was positive and less than 3.841, it was defined as positive (+), if greater than 3.841, it was defined as strong positive (++), and if greater than 6.635, it was defined as very strong positive (+++). If the *chi-square* test value was negative and less than 3.841, it was defined as negative (-), if greater than 3.841, it was defined as strong negative (--), and if greater than 6.635, it was defined as very strong negative (---) [9].

Naturalized index, urbanized index output

The Naturalized Index (NI) and the Urbanized Index (UI), used to determine the extent and distribution pattern of foreign plant invasion, were calculated using the following formula [10].

$$NI\ (\%) = E_i / S_i \times 100 \qquad (1)$$

E_i: Number of invasive alien plant taxa on survey site (i)
S_i: Total number of plant taxa on survey site (i)

$$UI\ (\%) = Et_i / St_i \times 100 \qquad (2)$$

E_{ti}: Number of invasive alien plant taxa in survey sites ($_{ti}$)
S_{ti}: Total number of invasive alien plant taxa in South Korea ($_{ti}$)

Network structure, centrality analysis, and visualization of plant society

To intuitively understand the results of the joint analysis of classification groups, the correlation values were visualized using Gephi 0.9.7 based on the definition, and the structure was analyzed (Table 1) [11]. In addition, the flow of information within the network was analyzed through centrality (Table 2). When visualized using Gephi 0.9.7, the centrality of the high node may appear in the center of the network or be pushed to the outer edge depending on the type of layout applied [12].

Table 1. Statistics of plant social networks.

Network overview	Definition
Nodes	Taxa
Edges	A connected line between taxa and taxa
Eccentricity	The shortest route from one node to another
Average diameter	Number of connectors required to cross the graph between the two farthest nodes
Graph density	The proportion of the number of possible relationships connected
Average path length	Shortest possible path between all nodes
Average clustering coefficient	Check the density of the graph with clustering values measured at the network level

Table 2. Centrality of plant social networks.

Centrality	Definition
Degree centrality	Visualization of how many nodes are connected to one node in one step

Closeness centrality	It is a representative indicator of overall centrality and is measured by its proximity to other nodes
Betweenness centrality	Acting as a bridge to connect information flowing into the network
Eigenvector centrality	Not just connecting to many other nodes, but connecting to the most influential nodes

RESULTS

Naturalized index, urbanized index

A total of 533 species of indigenous plants were confirmed in 1,255 survey areas in the Mudeungsan National Park during the survey period. There were 207 species of trees and 326 species of herbs, and 25 of them were IAPs (Table 3). The NI was 4.69%, and the domestic IAPs were 375 species, resulting in a UI of 6.67%. A total of 304 species of indigenous plants were confirmed in 161 survey areas of Geumdangsan. The number of vascular plants found in the survey area was 135 species of trees and 169 species of herbs, and 27 of these were IAPs (Table 3) [13]. The NI was 8.88% and the UI was 7.2%. It was observed that the NI was approximately 1.89 times higher in Geumdangsan compared to Mudeungsan national park, indicating that the proportion of exotic species was higher in Geumdangsan compared to the total number of plant species. The 15 IAPs that appeared in both regions included *Ambrosia artemisiifolia* L., *Amorpha fruticosa* L., and *Conyza canadensis* (L.) *Cronquist*. In particular, Diodia teres Walter was the only IAP found in both regions and was found in exposed rock areas on the summit ridge of Geumdangsan [14].

The common IAP species found in both regions were *Ambrosia artemisiifolia* L., *Lactuca serriola* L. was only found in Mudeungsan, and Solanum rostratum Dunal was only found in Geumdangsan. All three species are not yet threatening in terms of their number of individuals, but if environmental conditions are favorable, they can increase explosively at any time, so continuous attention and management are necessary [15].

Table 3. IAP taxa of Mudeungsan national park (M) and Geumdangsan (G).

Taxa	Area	Remark
Ambrosia artemisiifolia L.	M, G	h, t
Amorpha fruticosa L.	M, G	w
Bidens frondosa L.	G	h
Bromus catharticus Vahl	M	h
Conyza canadensis (L.) Cronquist	M, G	h
Coreopsis lanceolata L.	M, G	h
Cosmos sulphureus Cav.	G	h
Crassocephalum crepidioides (Benth.) S. Moore	G	h
Dactylis glomerata L.	M	h
Diodia teres Walter	G	h
Erigeron annuus (L.) Pers.	M, G	h
Euphorbia supina Raf.	G	h
Galinsoga ciliata (Raf.) S. F. Blake	M, G	h
Helianthus tuberosus L.	G	h
Ipomoea purpurea (L.) Roth	G	h

Lactuca serriola L.	M	h, t
Oenothera glazioviana Micheli	M, G	h
Oxalis articulata Savigny	G	h
Phytolacca americana L.	M, G	h
Quamoclit angulata (Lam.) Bojer	G	h
Robinia pseudoacacia L.	M, G	w
Rudbeckia laciniata L.	M, G	h
Rumex crispus L.	M, G	h
Senecio vulgaris L.	M	h
Solanum rostratum Dunal	G	h, t
Solidago gigantea Aiton	M	h
Sonchus oleraceus L.	M	h
Stellaria media (L.) Vill.	M, G	h
Symphyotrichum pilosum (Willd.) G. L. Nesom	G	h
Taraxacum erythrospermum Andrz. ex Besser	M	h
Taraxacum officinale F. H. Wigg.	G	h
Trifolium repens L.	M, G	h
Verbesina alternifolia (L.) Britton ex Kearney	M, G	h
Veronica arvensis L.	M	h
Viola papilionacea Pursh	M	h
Xanthium orientale L.	M	h
Zingiber mioga (Thunb.) Roscoe	M, G	h

Interspecies association (focusing on IAP)

The association among 533 taxonomic groups of vascular plants surveyed in 1,255 plots on the Mudeungsan was analyzed. On the Mudeungsan, *Erigeron annuus* (L.) Pers. had 125 friendly species, while *Robinia pseudoacacia* L. had 101 friendly species. In the Geumdangsan, *Phytolacca americana* L. had 104 friendly species, and *Robinia pseudoacacia* L. had 100 friendly species. The number of plant taxonomic groups with positive relationships with common IAPs in both regions and P-value <3.841 are listed in Table 4. *Erigeron annuus* (L.) Pers. had the most with 30 taxa, followed by *Robinia pseudoacacia* L. with 25 taxa, and *Ambrosia artemisiifolia* L. with 14 taxa (Table 5) [16].

Table 4. Results of interspecies association analysis focusing on IAP. The number in parentheses is the number of friendly species in the Geumdangsan area.

Taxa	Number of friendly species	Number of plant taxa positively related to P-value <3.841
Ambrosia artemisiifolia L.	73 (40)	14
Amorpha fruticosa L.	18 (36)	3
Bidens frondosa L.	(21)	
Bromus catharticus Vahl	11	
Conyza canadensis (L.) Cronquist	25 (75)	5
Coreopsis lanceolata L.	13 (32)	3
Cosmos sulphureus Cav.	(31)	
Crassocephalum crepidioides (Benth.)	(36)	

S. Moore		
Dactylis glomerata L.	62	
Diodia teres Walter	(22)	
Erigeron annuus (L.) Pers.	126 (99)	30
Euphorbia supina Raf.	(20)	
Galinsoga ciliata (Raf.) S. F. Blake	26 (3)	0
Helianthus tuberosus L.	(42)	
Ipomoea purpurea (L.) Roth	(26)	
Lactuca serriola L.	5	
Oenothera glazioviana Micheli	53 (35)	6
Oxalis articulata Savigny	(23)	
Phytolacca americana L.	26 (104)	4
Quamoclit angulata (Lam.) Bojer	(23)	
Robinia pseudoacacia L.	100 (100)	25
Rudbeckia laciniata L.	31 (22)	4
Rumex crispus L.	99 (15)	4
Senecio vulgaris L.	5	
Solanum rostratum Dunal	(16)	
Solidago gigantea Aiton	7	
Sonchus oleraceus L.	8	
Stellaria media (L.) Vill.	11 (14)	3
Symphyotrichum pilosum (Willd.) G. L. Nesom	(30)	
Taraxacum erythrospermum Andrz. ex Besser	5	
Taraxacum officinale F. H. Wigg.	(41)	
Trifolium repens L.	48 (20)	5
Verbesina alternifolia (L.) Britton ex Kearney	42 (38)	4
Veronica arvensis L.	26	
Viola papilionacea Pursh	5	
Xanthium orientale L.	18	
Zingiber mioga (Thunb.) Roscoe	25 (45)	6

Table 5. Native plant taxa friendly to IAP.

Taxa	Number of friendly species
Artemisia indica Willd.	11
Persicaria filiformis (Thunb.) Nakai ex T. Mori	7
Pueraria lobata (Willd.) Ohwi	5
Rosa multiflora Thunb.	4
Acer palmatum Thumb.	3
Callicarpa japonica Thunb.	3
Duchesnea indica (Andrews) Focke	3
Humulus scandens (Lour.)	3
Miscanthus sinensis Andersson var. *purpurascens* (Andersson) Matsum.	3
Plantago asiatica L.	3

Artemisia indica Willd. had the most IAP with positive relationships with 11 taxa, followed by *Persicaria filiformis* (Thunb.) Nakai ex T.Mori with 7 taxa and *Pueraria lobata* (Willd.) Ohwi with 5 taxa. *Artemisia indica*, *Persicaria filiformis*, *Pueraria lobata*, *Duchesnea indica*, *Plantago asiatica*, etc. primarily appear along paths traveled by humans [17]. The results of these plants having high intimacy with IAP show that invasion of IAP is mainly happening in areas where habitats are damaged by humans, and this agrees with the results of the sociogram analysis.

Visualization of plant social networks

The structure of plant communities in the two regions, Mudeungsan national park (1,255 plots) and Geumdangsan (161 plots), was analyzed and visualized based on the χ^2 test value of the correlation between the taxonomic groups that appeared in each area (Figures 2 and 3). The classic force based algorithm, the force atlas layout, was used, which pushes unrelated nodes away and draws connected nodes closer by pushing related nodes closer together. In the Mudeungsan sociogram, IAP, excluding stellaria media, was mainly distributed in the peripheral area far from the center, while in the Geumdangsan sociogram, relatively many IAP were located close to the center. This allows for an intuitive observation that IAP invasion is more advanced in Geumdangsan [18].

Figure 2. The plant social network in Mudeungsan national park was visualized using the betweenness centrality measure and represented as a sociogram. The size of the labels corresponds to the betweenness centrality, with pink nodes representing IAPs (Invasive Alien Plants) and green nodes representing native plants.

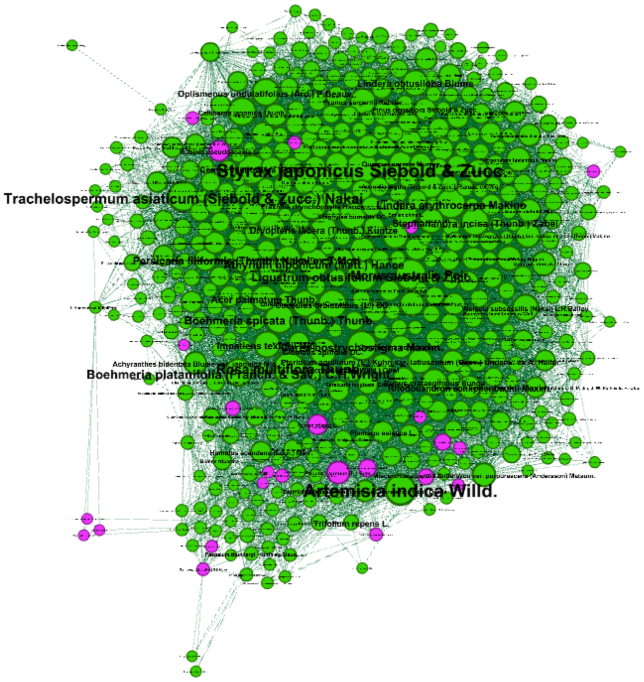
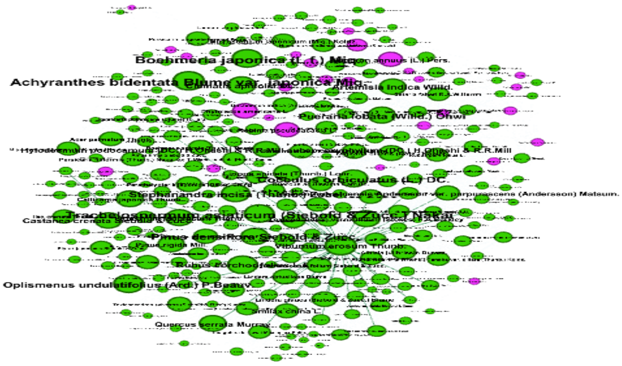


Figure 3. Sociogram of plant social network in Geumdangsan visualized as betweenness centrality. The larger the betweenness centrality, the larger the label size. Pink node: IAPs, Green node: Native plants.



Analysis of the structure of the plant social network (focusing on IAP)

The results of the statistical analysis of two survey areas using Gephi 0.9.7 are shown in Table 6. In Mudeungsan, one species has an average of about 60 species and interspecies associations, and the two species furthest apart require 4 steps to reach each other. On average, one species can reach another species in just 4 steps. The density is 0.113, showing a high level of homogeneity. Due to the smaller survey area and relatively smaller number of species in Geumdangsan, the density is slightly higher, and the network diameter and eccentricity are smaller [19].

Table 6. Statistics of plant social networks in Mudeungsan national park and Geumdangsan.

Network overview	Statistic value	
	Mudeungsan	Geumdangsan
Nodes	533	304
Edges	15,973	7,429
Eccentricity	3-4	2-3
Average degree	59.936	49.036
Network diameter	4	3
Graph density	0.113	0.162
Average path length	2.013	1.883
Average clustering coefficient	0.557	0.598

Centrality analysis

The results of the centrality analysis using Gephi 0.9.7 are as follows.

The Degree centrality, which simply shows how many nodes are connected to a node, was highest in *Erigeron annuus* and *Robinia pseudoacacia* in Mudeungsan, and *Phytolacca americana* and *Robinia pseudoacacia* in Geumdangsan, in that order.

The closeness centrality, which represents the overall centrality, was highest in *Erigeron annuus* and *Rumex crispus* in Mudeungsan, and *Phytolacca americana* and *Robinia pseudoacacia* in Geumdangsan, in that order.

The betweenness centrality, which plays a bridge role in the network, was highest in the following order: *Robinia pseudoacacia*, *Erigeron annuus* in the Mudeungsan and *Erigeron annuus*, *Robinia pseudoacacia* in the Geumdangsan. The eigenvector centrality, which indicates the extent to which a node is connected to the most influential node, was highest in the following order: *Robinia pseudoacacia*, *Erigeron annuus* in the Mudeungsan and *Phytolacca americana*, *Robinia pseudoacacia* in the Geumdangsan.

In terms of centrality, it can be seen that *Erigeron annuus*, *Phytolacca americana*, and *Robinia pseudoacacia* have a significant impact on the networks of the two regions. In the 533 taxa of the Mudeungsan, *Erigeron annuus* had a high centrality ranking with 60th in degree centrality, 57th in closeness centrality, 46th in betweenness centrality, and 118th in eigenvector centrality. *Robinia pseudoacacia* had a very high ranking of 36th in betweenness centrality. In the 304 categories of the *Geumdangsan*, *Phytolacca americana* and *Robinia pseudoacacia* had a high ranking of 25th and 26th in degree centrality and closeness centrality, respectively. Erigeron annuus had a high ranking of 18th in betweenness centrality, and *Phytolacca americana* had a high ranking of 35th in eigenvector centrality (Table 7) [20].

Table 7. Centrality analysis of IAP taxa in Mudeungsan national park (M) and Geumdangsan (G).

	Centrality							
	Degree		Closeness		Betweenness		Eigenvector	
Taxa	M	G	M	G	M	G	M	G
Ambrosia artemisiifolia	72	40	0.52	0.53	416.97	37.38	0.33	0.29
Amorpha fruticosa	17	36	0.49	0.53	1.88	43.03	0.1	0.3
Bidens frondosa		21		0.51		6.22		0.16
Bromus catharticus	11		0.44		1.98		0.05	
Conyza canadensis	26	75	0.49	0.56	69.03	189.81	0.09	0.45
Coreopsis lanceolata	12	32	0.45	0.52	0.27	61.26	0.06	0.18
Cosmos sulphureus		31		0.52		31.04		0.21
Crassocephalum crepidioides		36		0.53		21.32		0.28
Dactylis glomerata	62		0.52		74.65		0.31	
Diodia teres		22		0.51		6.62		0.16
Erigeron annuus	125	99	0.56	0.59	916.4	634.08	0.49	0.55
Euphorbia supina		20		0.48		0.06		0.1
Galinsoga ciliata	25	3	0.43	0.36	314.7	0	0.05	0.01
Helianthus tuberosus		42		0.53		35.14		0.31
Ipomoea purpurea		16		0.48		0.26		0.13
Lactuca serriola	5		0.35		0.37		0	
Oenothera glazioviana	54	35	0.52	0.52	189.72	54.61	0.25	0.21
Oxalis articulata		23		0.51		1.48		0.18
Phytolacca americana	26	104	0.5	0.6	33.37	448.49	0.12	0.69
Quamoclit angulata		23		0.5		0.63		0.18
Robinia pseudoacacia	101	100	0.54	0.6	1262.93	533.87	0.51	0.64
Rudbeckia laciniata	31	23	0.5	0.51	89.94	1.48	0.14	0.18
Rumex crispus	98	16	0.55	0.48	746.66	0.26	0.48	0.13
Senecio vulgaris	5		0.35		0.37		0	
Solanum rostratum		16		0.5		0.34		0.15
Solidago gigantea	7		0.44		0		0.04	
Sonchus oleraceus	8		0.45		0.63		0.04	
Stellaria media	12	14	0.46	0.5	2.79	1	0.05	0.13

Symphyotrichum pilosum		30		0.52		14.3		0.22
Taraxacum erythrospermum	5		0.35		0.37		0	
Taraxacum officinale		41		0.54		44.43		0.32
Trifolium repens		20		0.48		0.06		0.1
Verbesina alternifolia	41	38	0.51	0.52	162.81	57.2	0.18	0.27
Veronica arvensis	26		0.49		3.46		0.16	
Viola papilionacea	5		0.35		0.37		0	
Xanthium orientale	18		0.42		0.77		0.04	
Zingiber mioga	25	45	0.48	0.53	3.35	26.23	0.16	0.4

DISCUSSION

Distribution patterns and characteristics of IAP

The plant social network can be visualized as a sociogram, allowing for intuitive observation of the distribution pattern of the Invasive Alien Plant (IAP). As we go from the edge of the forest to the center, the frequency of IAP occurrence decreases, and it is evident that the IAPs are forming a network by being close to each other. This is because the forest was damaged for the purpose of farming and residential construction, creating a favorable environment for the IAPs to invade. Mudeungsan was designated as a national park in 2013, and the commercial operations in valleys were relocated, and the damaged ecosystem began to be restored by prohibiting crop cultivation. However, Geumdangsan is continuously invaded by IAPs due to the continuous damage to the habitat caused by local residents' crop farming. This can also be observed intuitively through the sociograms of the two regions, showing that IAPs are distributed to the center of the forest in Geumdangsan compared to Mudeungsan.

The interspecies association analysis allowed us to analyze the positive correlation between IAP and invasive species, and between invasive species and IAP. This analysis can be used as a basic data for the future control and prevention of the spread of IAP.

Centrality analysis reveals that some IAP species such as *Erigeron annuus* and *Robinia pseudoacacia* are already playing a significant role in the network. This means that IAP has become a part of the network configuration rather than just an invasive species.

IAP invasion prevention measures

Geumdangsan, with a total of 304 taxa appearing, is much smaller in area compared to Mudeungsan, which has a total of 533 taxa appearing (75.425 km^2). Despite its smaller area, it is relatively rich in plant species, which indicates that diverse plants are growing on a narrow area. However, the number of appearing species is relatively large, but the number of individuals in each species is small. In other words, Mudeungsan national park's ecosystem is well preserved and stable, while Geumdangsan's ecosystem is being damaged and causing gaps. To prevent the spread of IAPs, it is important to remove the individuals themselves before they scatter seeds, but it is considered more advisable in the long run to preserve habitats and not create conditions for IAPs to invade, through preservation of their habitats. This is because IAPs, which have a high demand for sunlight, are difficult to invade well-formed forests.

Suitability of *Robinia pseudoacacia* for reforestation construction

The restoration of damaged habitats of Mudeungsan and Geumdangsan was primarily achieved by planting *Robinia pseudoacacia* (Figure 4). *Robinia pseudoacacia* is a species that thrives well in harsh environments due to its symbiotic relationship with rhizobium bacteria and its fast growing roots that firmly grip the soil to prevent erosion. In both Mudeungsan and Geumdangsan, the values of degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality were all high. This indicates that *Robinia pseudoacacia* is helping to facilitate the influx of settled plants and rapidly recover the vegetation. In other words, *Robinia pseudoacacia* is playing a critical role as a bridge that connects the damaged vegetation and the surrounding vegetation. The fixed nitrogen by *Robinia pseudoacacia* improves the soil nutrient of the habitat, and the influx of settled plants into the habitat is promoted. This shows that while some Invasive Alien Species (IAPs) have a negative impact on native species, there are also species like *Robinia pseudoacacia* that have a positive impact.

Figure 4. *Robinia pseudoacacia.*

IAP Indicator

The betweenness centrality of *Erigeron annuus* is quite high in both regions, indicating that *Erigeron annuus* (Figure 5) plays an important role as a bridge connecting the plant clusters at the edge and center of the forest. From this perspective, it can be hypothesized that the presence of *Erigeron annuus* can act as an indicator of the general invasion distribution of IAP in the forest, providing a criterion for checking the invasion of primary IAP in the habitat. *Erigeron annuus*, a biennial herbaceous with a height of 30-100 cm, can easily be observed almost all year round, making it easy to use as an indicator.

Figure 5. *Erigeron annuus*.

CONCLUSION

Geumdangsan, which is about 11 km away from Mudeungsan National Park, has a smaller area and fewer visitors, but the presence of IAP (Invasive Alien Plant) was found to be similar, with 25 taxa out of a total of 533 taxa in Mudeungsan and 26 taxa out of 304 taxa in Geumdangsan. This result is believed to be related to the degree of ecological preservation, as the presence of IAP decreases as it approaches the center of the forest. Ultimately, preventing habitat damage and preserving the ecosystem by preventing IAP from invading the niche that occurs due to climate change is the most effective solution.

The species that are sympatric with the invasion of IAP have been identified as *Artemisia indica*, *Persicaria filiformis*, *Pueraria lobata*, *Rosa multiflora*, etc. These species do not necessarily push out IAP, but rather coexist and form networks with it. In particular, *Erigeron annuus*, *Robinia pseudoacacia*, and *Ambrosia artemisiifolia* have formed positive relationships with a considerable number of other species. In the case of *Ambrosia artemisiifolia*, it is an ecological disruptor and the pollen scattered by the wind causes allergies and health issues, so extra care is needed in managing the species.

The results of this study go beyond the previous focus on the reduction of invasions and establishment of exotic species by IAPs, and suggest a new perspective in recognizing IAP by focusing on the formation of plant-to-plant relationships. Through the analysis of mutual relationships between exotic and native plant species, the spread of IAPs can be predicted and potentially prevented in the long run. IAPs also play a role as a component of the producer in forming forests, and can also act as nurse plants to aid in the establishment of native species in disturbed habitats for restoration purposes. This could serve as a catalyst for improving the negative perception of IAPs and encourage the utilization of IAPs for the conservation of ecosystems. As climate change continues to be a pressing issue and may become even more serious in the future, it is time to consider how IAPs can be best utilized for ecological preservation.

DECLARATIONS

All authors have read, understood, and have complied as applicable with the statement on "ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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