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Analysis of Changes in the Important Plant Communities (*Quercus mongolica*, *Quercus variabilis*, *Pinus densiflora*) of the Korean Peninsula in the Last 10 Years, Focusing on the Ecological and Nature Map

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ABSTRACT

Recent changes in the dominant plant communities in South Korea (Southern Korean Peninsula) remain unclear. By analyzing vegetation data from the Ecological and Natural Map, we examined spatial changes over the past decade in the three most dominant plant communities in South Korea: *Quercus mongolica*, *Quercus variabilis*, and *Pinus densiflora*. *Q. mongolica* and *P. densiflora* communities have gradually decreased in the area. In contrast, the *Q. variabilis* community steadily expanded in the past decade, leading to an increase in its vegetation conservation grade within the Ecological and Natural Map. The decline in the *Q. mongolica* community was mainly due to the outbreak of oak wilt disease and thinning operations conducted as part of forestry projects by the Korea Forest Service. Similarly, the decline in the *P. densiflora* community was primarily caused by pine wilt disease, pine gall midge infestations, and thinning under forest management. However, *Q. variabilis* naturally competes with *Q. mongolica* and *P. densiflora* in natural ecosystems. With the decline in these two species, *Q. variabilis* gained a competitive edge. Its strong resistance to oak wilt disease, along with its use as a major species in afforestation and reforestation, led to a gradual increase in its area.

Keywords: Ecological and Nature Map, *Quercus mongolica*, *Quercus variabilis*, *Pinus densiflora*, Vegetation

Introduction

The Ecological and Natural Map is a nationwide mapping system established under the Natural Environment Conservation Act. It classifies the natural environment across South Korea, including mountains, rivers, inland wetlands, lakes, agricultural lands, and urban areas, into graded categories based on ecological, natural, and scenic values. This classification is derived from various national-scale environmental surveys, such as the National Natural Environment Survey, National Inland Wetlands Survey, and Winter Bird Census, and categorizes regions into grades 1, 2, 3, and specially managed areas (NIE, 2023).

As comprehensive repositories of ecological data, the Ecological and Natural Map serves as fundamental resource for a wide range of ecological and environmental studies. In particular, it provides an extensive database of vegetation types and plant communities throughout South Korea, enabling monitoring of annual changes in

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vegetation and shifts in community distribution and extent.

In this study, we utilized the Ecological and Natural Map to analyze 10-year trends and spatial changes in three dominant plant communities: *Quercus mongolica*, *Quercus variabilis*, and *Pinus densiflora*. The primary objectives of this study were to elucidate the patterns of vegetation succession, assess community dynamics, and explore the extent to which these patterns were influenced by forest management practices.

In South Korea, members of the genus *Quercus* cover significantly larger areas than other tree species groups (Kim *et al.*, 2009). The major species include *Quercus acutissima*, *Q. variabilis*, *Q. mongolica*, *Quercus aliena*, *Quercus dentata*, and *Quercus serrata*, along with 12 naturally occurring hybrids spanning 6 taxonomic groups (Lee, 2003).

The three focal species in this study, *Q. mongolica*, *Q. variabilis*, and *P. densiflora*, are among the most dominant and widely distributed forest communities in the Korean Peninsula, and have been extensively studied. Research on *Quercus* species has examined topics such as the growth and water physiology of *Q. variabilis* under varying site conditions (Chung & Shin, 2003), phytosociological analyses of *Q. mongolica* forests (Song *et al.*, 2003), and soil respiration in *Q. acutissima* stands (Lee & Mun, 2001). Studies on *P. densiflora* have addressed the classification and geographic distribution of Korean pine forests (Chun & Lee, 2007), silvicultural strategies based on vegetation type (Lee *et al.*, 2009), and the phytosociological perspectives of pine forest conservation (Bae & Lee, 1999).

Despite the extensive body of species- and community-level research, no comprehensive study has yet examined the overall area changes, successional trajectories, and responses to developmental pressures in these three major forest communities.

Therefore, this study analyzed the 10-year data for spatial changes in the distribution of *Q. mongolica*, *Q. variabilis*, and *P. densiflora*, using the Ecological and Natural Map. Through this analysis, we aimed to reveal trends in vegetation succession, characterize community change patterns, and assess the extent to which artificial forest management, rather than natural factors such as climate, nutrient availability, or water supply, has shaped the dynamics of these communities.

Materials and Methods

Verification of vegetation conservation grades

The vegetation conservation grades were verified based on the Ecological and Natural Map integration dataset, which was compiled using vegetation survey data from the National Natural Environment Survey. Using the QGIS program (QGIS Geographic Information System Version 3.34; QGIS Association, Zürich, Switzerland), we extracted vegetation conservation grades over the past 10 years for three major communities—*Q. mongolica*, *Q. variabilis*, and *P. densiflora*—and calculated the areas corresponding to each grade.

The vegetation dataset of the Ecological and Natural Map consists of five conservation grades from Grade I to Grade V. Accordingly, the vegetation conservation grades for each community were extracted annually across these five categories. Grade V was excluded from this study because it represents areas such as residential zones, water bodies, and developed lands, where the ecological function of vegetation communities is minimal. Therefore, only data up to Grade IV were included in the analysis. Furthermore, mixed forests containing two or more communities were excluded from the analysis. Only areas identified as pure, single-species communities in the Ecological and Natural Map were selected for this study.

Analysis of community area within the Ecological and Natural Map

As mentioned above, the vegetation communities in the Ecological and Natural Map were categorized into five vegetation conservation grades, which were then reclassified into three ecological grades: Grades I and II correspond to Ecological Grade 1; Grades III and IV to Ecological Grade 2; and Grade V to Ecological Grade 3 (NIE, 2023).

Five annual vegetation conservation grades were categorized into this three-level ecological grading system, and the total area changes over time for the three communities were analyzed. All area measurements were standardized in square meters (m^2), and temporal trends were assessed to identify annual changes in the extent of distribution of each community.

Results and Discussion

The baseline data, calculated as the area of vegetation conservation grade changes over the past decade within the Ecological and Natural Map for *Q. mongolica*, *Q. variabilis*, and *P. densiflora* communities, are summarized in Table 1. Species-specific analyses were conducted based on baseline data.

A comprehensive graph based on the above chart is shown in Fig. 1.

Changes in vegetation conservation grades of the *Quercus mongolica* community

Q. mongolica forms the largest community among the species of the *Quercus* genus in the Korean Peninsula (South Korea), both in terms of distribution and extent, and is also the most widely distributed *Quercus* community in the Ecological and Natural Map.

Table 1. Changes in vegetation class of *Quercus mongolica*, *Quercus variabilis*, *Pinus densiflora* in the past 10 years (m^2)

	Year	Vegetation class s	Vegetation class II	Vegetation class III	Vegetation class IV	Total
Q. mongolica	2013	698,492,003	2,208,843,866	2,250,193,983	7,054,077	5,164,583,929
	2014	1,503,614,334	3,469,882,893	2,589,502,972	7,103,826	7,570,104,025
	2015	682,943,098	2,208,306,404	2,294,776,636	8,540,671	5,194,566,809
	2016	700,328,625	2,484,951,382	2,480,352,212	8,921,057	5,674,553,276
	2017	663,426,952	2,352,418,723	2,165,007,134	8,921,057	5,189,773,866
	2018	534,059,664	2,393,109,911	2,246,842,651	8,274,571	5,182,286,797
	2019	560,015,381	2,283,210,511	2,099,806,226	8,221,611	4,951,253,729
	2020	565,718,634	2,255,557,322	2,120,925,709	8,221,611	4,950,423,276
	2021	210,910,136	2,238,833,618	1,926,557,809	666,678	4,376,968,241
	2022	165,554,492	1,968,600,224	1,835,668,440	666,678	3,970,489,834
	2023	142,631,249	1,885,537,702	1,890,448,686	664,960	3,919,282,597
Q. variabilis	2013	13,334,291	301,713,653	1,297,693,285	6,259,957	1,619,001,186
	2014	13,334,291	301,035,048	1,297,719,680	6,259,957	1,618,348,976
	2015	13,310,186	299,922,137	1,395,540,252	6,779,897	1,715,552,472
	2016	13,300,253	361,033,387	1,515,309,972	8,837,324	1,898,480,936
	2017	13,215,644	362,633,336	1,582,576,750	8,837,324	1,967,263,054
	2018	16,823,871	333,851,182	1,558,304,362	8,300,142	1,917,279,557
	2019	11,991,885	298,757,256	1,648,606,136	8,330,858	1,967,686,135
	2020	11,957,665	299,477,883	1,653,117,629	8,330,858	1,972,884,035
	2021	17,474,026	489,887,956	1,676,612,294	924,793	2,184,899,069
	2022	9,571,561	409,661,868	1,626,603,957	840,357	2,046,677,743
	2023	13,705,372	500,864,547	1,674,212,003	817,307	2,189,599,229
P. densiflora	2013	133,467,329	1,297,969,490	5,785,679,082	35,164,512	7,252,280,413
	2014	133,311,466	1,297,667,481	8,078,638,418	35,164,512	9,544,781,877
	2015	119,121,798	1,258,113,426	8,300,217,417	40,541,386	9,717,994,027
	2016	120,777,831	1,511,745,834	8,293,928,380	66,037,735	9,992,489,780
	2017	114,052,448	1,438,556,917	7,137,932,340	67,082,869	8,757,624,574
	2018	80,760,958	1,424,113,191	7,325,219,285	40,838,237	8,870,931,671
	2019	78,545,423	1,395,588,765	7,367,522,557	38,781,863	8,880,438,608
	2020	78,447,797	1,390,468,151	7,161,210,131	38,002,136	8,668,128,215
	2021	32,242,267	1,262,148,596	6,934,399,399	41,432,361	8,270,222,623
	2022	29,804,581	1,053,130,507	6,663,849,229	52,015,890	7,798,800,207
	2023	36,445,806	1,125,794,241	5,944,980,927	51,670,901	7,158,891,875

Over the past 10 years, the *Q. mongolica* community has shown a gradual decline in the area within the Ecological and Natural Map (Fig. 2). In particular, there has been a notable decrease in the vegetation conservation Grades I and II, which correspond to Ecological Grade 1. Among these, the decline in Grade I has been especially pronounced.

In addition, the *Q. mongolica* community showed a decreasing trend, even in Grade IV areas. This suggests that the decline was not merely a shift in conservation grades within the community, but rather a continued reduction in the total area occupied by *Q. mongolica*. This trend could be interpreted as a decrease in the population of mature individuals capable of forming stable communities across South Korea.

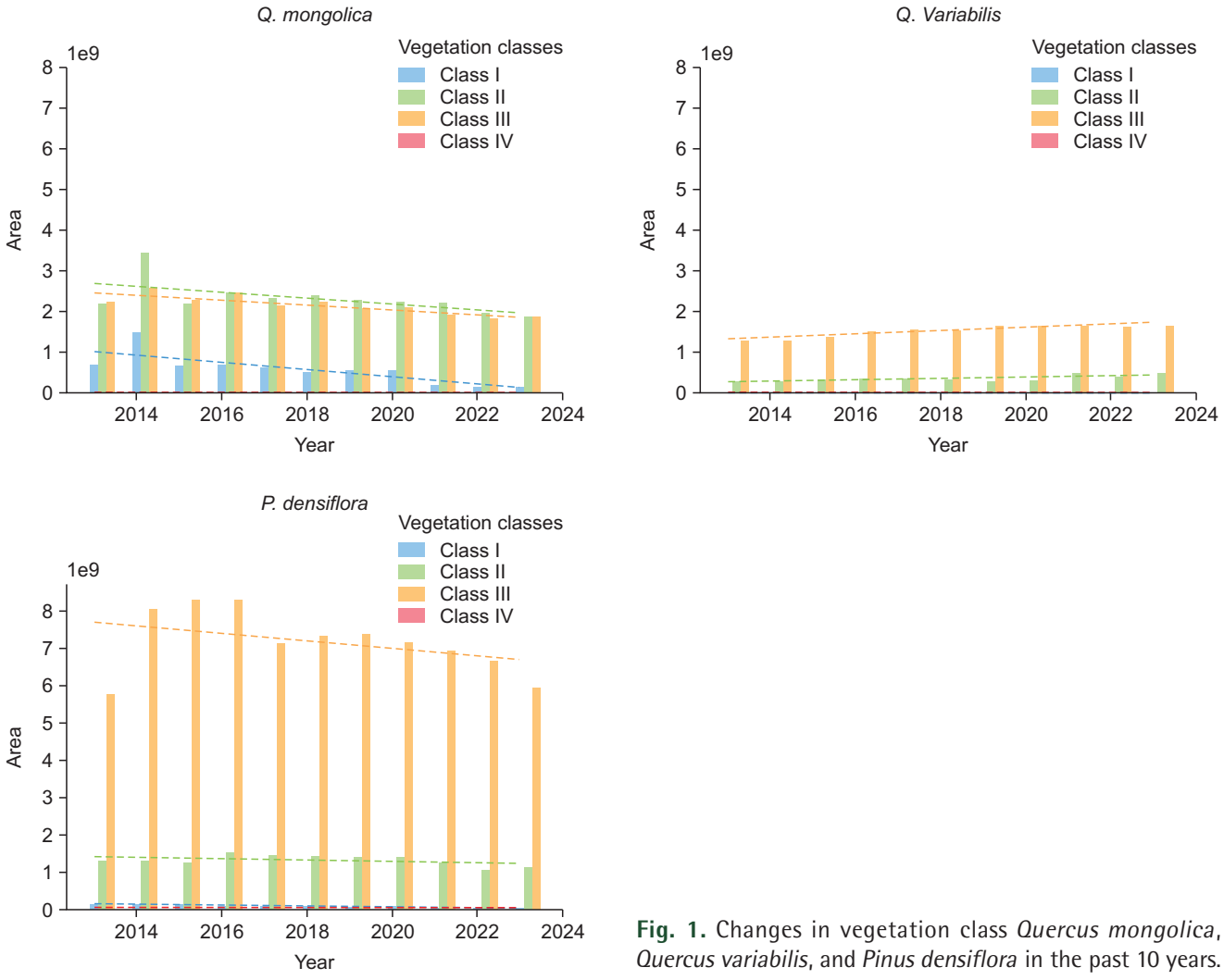

Fig. 1. Changes in vegetation class *Quercus mongolica*, *Quercus variabilis*, and *Pinus densiflora* in the past 10 years.

Changes in the vegetation conservation grades of the *Quercus variabilis* community

In contrast, the *Q. variabilis* community exhibited a consistent annual increase in distribution. Although its total habitat area remains smaller than that of *Q. mongolica* and the area classified as Vegetation Conservation Grade I is still minimal, the area corresponding to Grade II has been gradually increasing. This indicates a continuous expansion of areas designated as Ecological Grade 1 within the ecological and natural maps, specifically in pure *Q. variabilis* communities.

Moreover, most of the *Q. variabilis* communities are concentrated under Vegetation Conservation Grade III, which corresponds to Ecological Grade 2, and possibly, most of the *Q. variabilis* distribution across South Korea falls within this grade. Notably, the area occupied by *Q. variabilis* in Grade III has been steadily expanding over the years (Fig. 3).

Changes in the vegetation conservation grades of the *Pinus densiflora* community

P. densiflora forms the largest single-species community in the Korean Peninsula (South Korea) and is the most extensively distributed plant community in the Ecological and Natural Map. However, over the past decade, all vegetation conservation grades in the *P. densiflora* community have gradually declined. This indicates that regardless of the conservation grade, the overall extent of *P. densiflora* communities has been continuously decreasing across South Korea.

Notably, in 2013, the area of pure *P. densiflora* communities classified as Vegetation Conservation Grade I was recorded at a substantial 133,467,329 m^2. However, by 2023, this area had drastically reduced to 36,445,806 m^2, representing a loss of nearly 100,000,000 m^2 over the past decade (Fig. 4).

In addition, a continuous decline has been observed over the past decade in Vegetation Conservation Grade III,

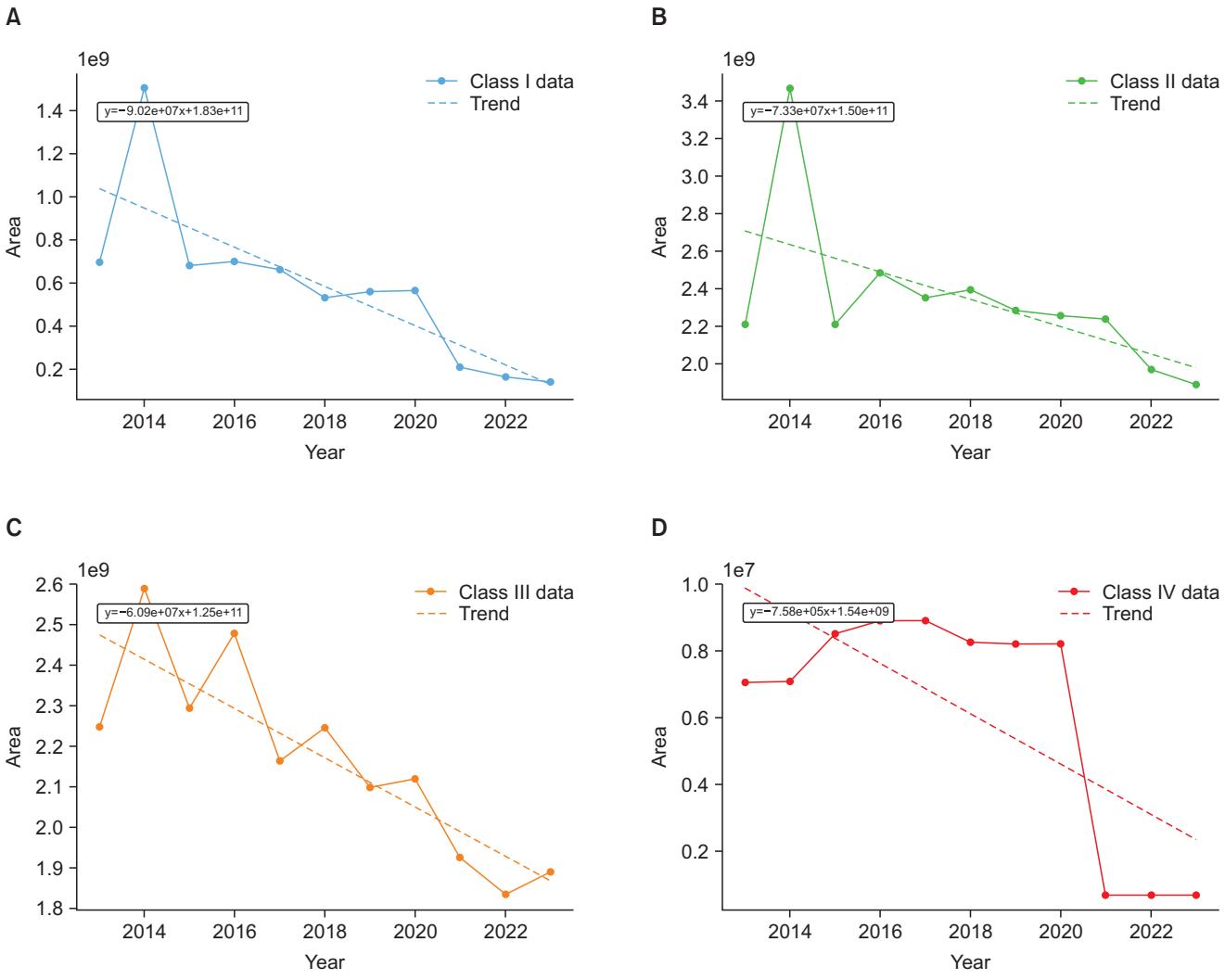

Fig. 2. Temporal trends of vegetation classes in *Quercus mongolica* from 2013 to 2023. (A) Vegetation Class I. (B) Vegetation Class II. (C) Vegetation Class III. (D) Vegetation Class IV.

which occupies the largest area among *P. densiflora* communities.

Primary causes of the decline in the *Quercus mongolica* community

The *Q. mongolica* community occupies the largest area among the four major genera of *Quercus* spp. (*Q. mongolica*, *Q. variabilis*, *Q. serrata*, and *Q. acutissima*) in the Korean Peninsula (South Korea). In other words, *Q. mongolica* is the most widely distributed genus *Quercus* spp. in this region. This broad distribution is attributable to its optimal habitat conditions, with a Warmth Index of 55-90°C·month, latitudinal range of 35-38° N, and altitudinal range of 200-1,400 m (Kim *et al.*, 1988; Oh *et al.*, 2013; Yim & Kim, 1992), all of which are well-represented across South Korea.

Additionally, *Q. mongolica* is predominantly found around higher-elevation ridges, where human disturbances and developmental pressures tend to be low (Choung, 1998). Compared to other *Quercus* spp., *Q. mongolica* exhibits a broader ecological niche, largely because of its high adaptability to varying light conditions (Lee & You, 2009), which has contributed to its dominance in the Korean Peninsula. As a result, the *Q. mongolica* community typically shows higher proportions of Vegetation Conservation Grade I than the other major *Quercus* spp.

However, the results of this study indicate that the *Q. mongolica* community has experienced a gradual decline in both area and extent over time. According to Lee and Kim (1995), during the post-slash-and-burn succession process, *Q. mongolica* competes with *P. densiflora* during the mid-successional stage (25-50 years) and is expected to persist as a pure stand during the late successional stage (50-80 years). Under normal successional trajecto-

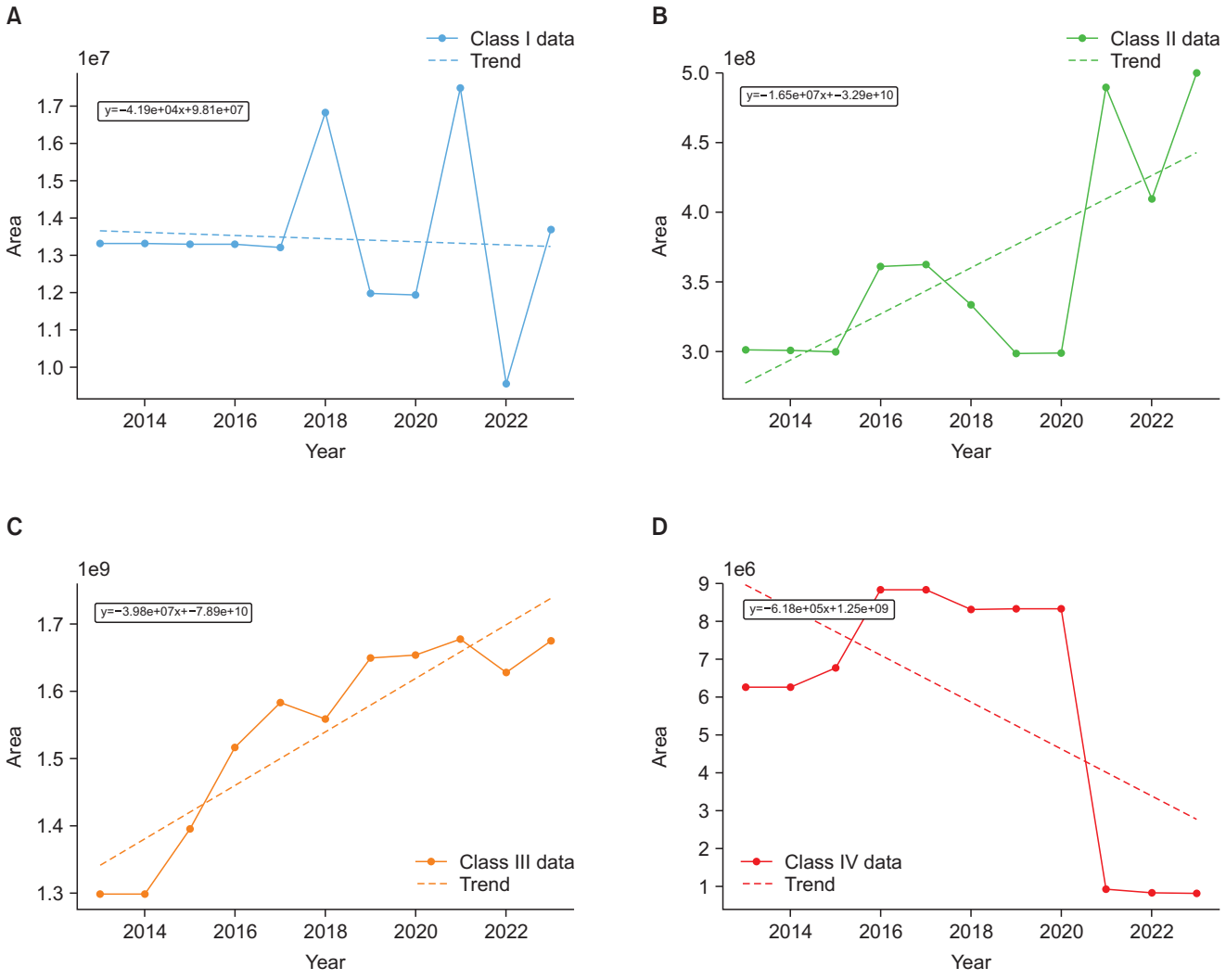

Fig. 3. Temporal trends of vegetation classes in *Quercus variabilis* from 2013 to 2023. (A) Vegetation Class I. (B) Vegetation Class II. (C) Vegetation Class III. (D) Vegetation Class IV.

ries, the area occupied by *Q. mongolica* should remain stable or even expand. Nevertheless, our findings revealed a continuous reduction in the community area.

The decline in the *Q. mongolica* community appeared to be driven by a combination of factors, with two major causes identified as below:

Oak wilt disease

Globally, the decline in oak species (*Quercus* spp.) has emerged as a significant ecological concern, with oak wilt disease identified as the primary cause of mass mortality events. A major outbreak occurred in South Korea when the ambrosia beetle (*Platypus koryoensis*), first reported in 1935, experienced an explosive population increase, leading to widespread infestations. The primary host species is *Q. mongolica*, particularly mature and large-diameter trees (Kim, 2007).

The scale of damage was substantial: in 2004, approximately 10,250 infected trees were recorded, and by 2006, this number surged to 194,419 trees. Continuous damage from oak wilt disease has been reported since 2020 (Kim *et al.*, 2020).

According to Lee and Um (2014), most cases of oak wilt occur in *Q. mongolica*, which has a disproportionately high impact on medium- and large-diameter trees. This study further highlighted a clear preference for *Q. mongolica* over other *Quercus* spp. Consequently, it can be inferred that the ongoing decline in *Q. mongolica* communities across South Korea is largely due to the mortality of medium- and large-diameter individuals, particularly those with Vegetation Conservation Grades I and II, due to oak wilt disease.

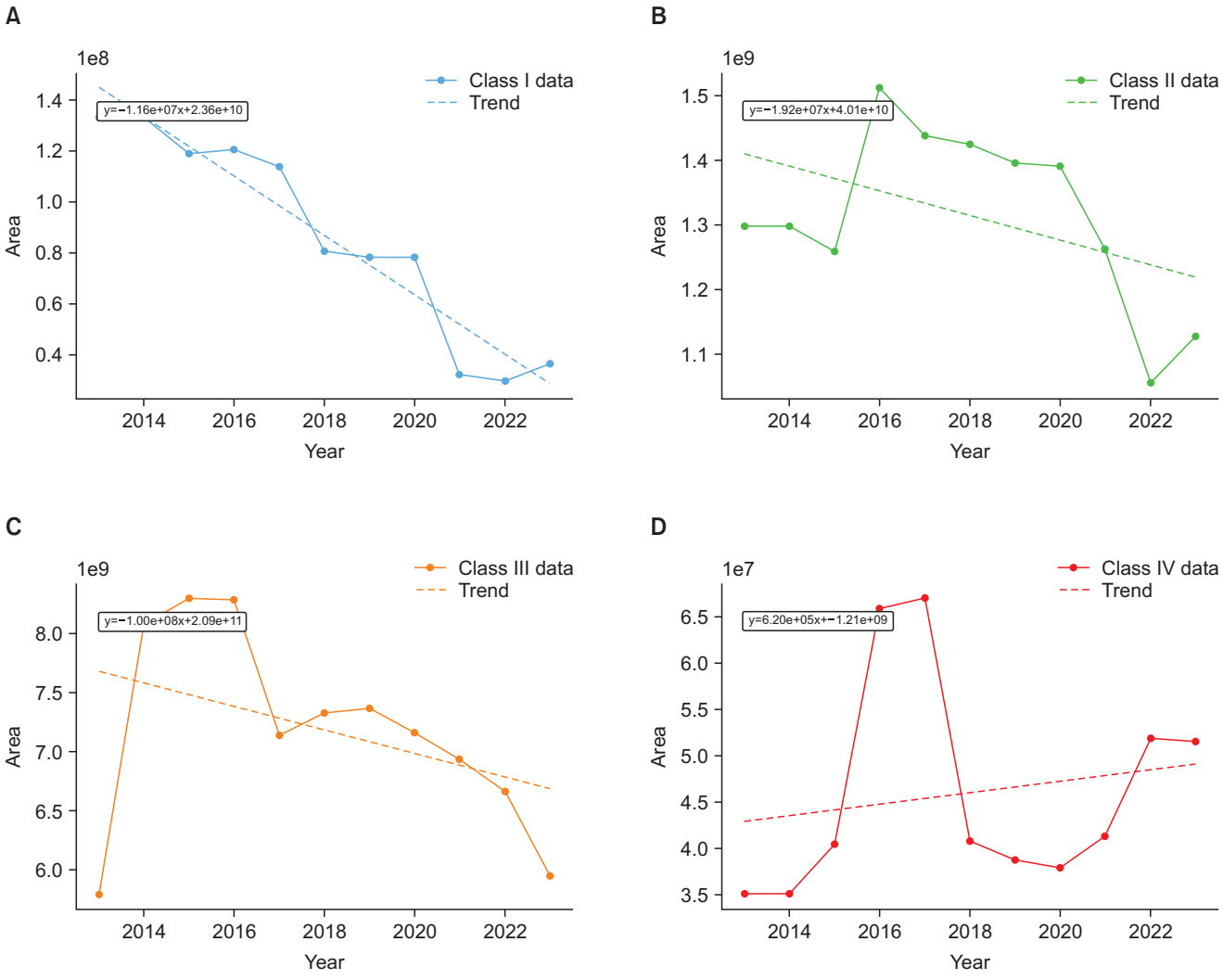

Fig. 4. Temporal trends of vegetation classes in *Pinus densiflora* from 2013 to 2023. (A) Vegetation Class I. (B) Vegetation Class II. (C) Vegetation Class III. (D) Vegetation Class IV.

Forest management practices

According to Article 2, Clause 3 of the Forest Resources Management Act (abbreviated as the Forest Resources Act) of South Korea, forest management practices refer to activities carried out within forests for the creation, cultivation, utilization, disaster prevention, restoration, and recovery of resources to maintain, enhance, or restore forest functions. Management activities such as thinning (forest tending) and logging are actively implemented to improve both the economic value and ecological functions of forests, resulting in the annual removal of large forest areas.

These forest management practices are shaped by the policy dynamics between the Ministry of the Environment, which oversees the Ecological and Natural Map, and the Korea Forest Service, which is responsible for forest policies and operations. Consequently, forest management activities under the jurisdiction of the Korea Forest Service have a significant impact on the vegetation conservation grades designated by the Ministry of Environment.

The area of forest management activities within Ecological Grade 1 regions was 23,964,000 m^2, accounting for 5.6% of the total forest management area (427,547,000 m^2) (Table 2). Among these, logging accounted for 10,525,000 m^2 (43.9 %), forest tending 7,024,000 m^2 (29.3 %), and afforestation 6,414,000 m^2 (26.8%). Additionally, the average elevation of forest management sites within Ecological Grade 1 regions was 356 m. Logging areas were found to have the highest mean and maximum elevations among the management types, as well as the largest elevation range (minimum 7 m to maximum 1,121 m).

Additionally, according to the felling permit data provided by the Korea Forest Service, the analysis of felling volume by tree species revealed the species that had

Table 2. Current status of forest management in Ecological and Natural Map first-grade zones

Class	Area		Altitude (m)		
	Area (m^2)	Ratio (%)	Average	Lowest	Highest
Logging	10,525,000	43.9	401	7	1,121
Forest tending	7,024,000	29.3	351	12	878
Reforestation	6,414,000	26.8	277	19	1,058
Total	23,964,000	100.0	356	7	1,121

Table 3. Damage area and frequency by tree species–pine gall-midge, black pine bast scale (m^2)

	2017	2018	2019	2020	2021
Pine gall-midge (*Thecodiplosis japonensis*)	357,070,000	389,760,000	325,310,000	275,300,000	276,380,000
Black pine bast scale (*Matsucoccus thunbergianae*)	40,430,000	77,180,000	63,800,000	50,240,000	35,660,000
Total	774,470,000	805,650,000	698,120,000	634,460,000	609,660,000

been harvested. The most representative oak species were included in the category *Quercus* spp. In 2021, approximately 148,460,000 m^2 of *Quercus* spp. forests were felled, and this figure increased to approximately 158,140,000 m^2 by 2022. These data indicate that on average, approximately 150,000,000 m^2 of oak forests are harvested annually. Such extensive harvesting directly affects the grading of the Ecological and Natural Map, contributing to the downgrading of conservation grades.

As discussed earlier, the combined impact of oak wilt disease in *Q. mongolica* and the widespread, indiscriminate felling of oak species each year were identified as the primary drivers of the continuous decline in *Q. mongolica* community area. Although *Q. mongolica* grows predominantly at higher elevations (Chung & Lee, 1998), where human disturbance is relatively low, oak wilt occurs regardless of elevation. Furthermore, in the context of forest management activities such as clear-cutting, thinning, and logging, *Quercus* spp. rank among the most frequently felled species nationwide, second only to *P. densiflora*. Thus, the decline in *Q. mongolica* communities can be interpreted as a result of the combined effects of both factors.

Decline of the *Pinus densiflora* community and expansion of the *Quercus variabilis* community

The *P. densiflora* community has also been confirmed to have gradually declined over the past 10 years. Distributed across most regions of South Korea, excluding high-altitude mountainous areas, *P. densiflora* represents the largest single-species forest in terms of area, and is considered one of the country's most important economic tree species (Yang, 2002). This species occupies the largest community area in the Ecological and Natural Map as well. However, based on the results of the present study, a decline in the *P. densiflora* community is undeniable. Two primary factors were identified as the main drivers of this decline.

Pests and diseases, including the pine gall midge (Thecodiplosis japonensis) and pinewood nematode (Bursaphelenchus xylophilus), have driven subsequent clear-cutting and thinning

As many as 147 pest species have been recorded in *Pinus* spp. (FRI, 1995), among which the pinewood nematode (*Bursaphelenchus xylophilus*), pine gall midge (*Thecodiplosis japonensis*), and pine bast scale (*Matsucoccus thunbergianae*) are considered the most problematic (Lee *et al.*, 2008). These pests and diseases hinder the normal growth of *Pinus* spp. and have a significant impact on the vegetation conservation grades of *P. densiflora* communities in the Ecological and Natural Map.

The area affected by the pine gall midge (*T. japonensis*) averaged 324,764,000 m^2 annually over the five-year period from 2017 to 2021, while the pine bast scale (*M. thunbergianae*) affected an average of 53,462,000 m^2 per year, indicating that numerous *P. densiflora* communities are infected by pine-related diseases each year (Table 3). In addition, pine wilt disease caused by the pinewood nematode (*B. xylophilus*), which has recently emerged as a major problem not only in East Asia, including the Korean Peninsula and China, but also in Europe, has been confirmed to affect an average of 450,000 *P. densiflora* communities annually in South Korea (Kim *et al.*, 2015), which has led to subsequent control measures, including clear-cutting and thinning operations (Table 4).

Such infections in *P. densiflora* communities lead to the mortality of numerous trees. Control measures, including

chemical treatments, partial clear-cutting, and thinning of the affected *P. densiflora* stands, exert both short- and long-term impacts on these communities. These interventions suppressed the normal growth of *P. densiflora*, and as a result, it was concluded that the area occupied by *P. densiflora* within the Ecological and Natural Map inevitably decreased annually.

The logging of numerous Pinus densiflora

P. densiflora is the most extensively logged single-species tree in the Korean Peninsula (South Korea). By 2021, approximately 474,690,000 m^2 of *P. densiflora* communities were logged, and in 2022, the logged area increased to approximately 627,190,000 m^2 (Table 5). Each year, many *P. densiflora* trees are harvested for economic value, species renewal, and forest management. This extensive logging has become a decisive factor contributing to the decline in the vegetation conservation grades of *P. densiflora* communities in the Ecological and Natural Map over the past decade.

Increase of the Quercus variabilis community

Competition is generally classified as intraspecific competition (within the same species) and interspecific competition (between different species) (Chung & Lee, 1998). In South Korea, *P. densiflora* and *Q. variabilis* engage in interspecific competition across many countries, often co-occurring in harsh mountainous environments at around 600 m of elevation, where they sometimes form a partial edaphic climax (Kim & Kil, 2000). In these areas, *Q. variabilis* is frequently found mixed with *Q. mongolica*. *Q. variabilis* spans the habitat ranges of both *Q. mongolica* and *P. densiflora*, making it one of the most prominent competitors of these species in South Korea.

Q. mongolica and *P. densiflora* have been steadily declining over the past decade owing to oak wilt disease, forest management activities, pine wilt disease, and extensive logging. In contrast, *Q. variabilis*, the competing species, continued to expand. A key reason for this is its greater resistance to oak wilt disease compared to *Q. mongolica* and the relatively lower levels of logging compared to *P. densiflora*. Furthermore, resprouting-based regeneration and reforestation efforts, which are often conducted as part of forest management practices, predominantly involve oak species, particularly *Q. variabilis*. Considering that most forests are now under the management of the Korea Forest Service, the expansion and maintenance of *Q. variabilis* communities appear to have resulted from anthropogenic management rather than natural succession. This is reflected in the fact that over the past decade, *Q. variabilis* communities have maintained their conservation grades in the Ecological and Natural Map.

Conclusion

This study analyzed changes in the dominant communities of *Q. mongolica*, *P. densiflora*, and *Q. variabilis* in the southern Korean Peninsula over the past decade using data from the Ecological and Natural Map. The results revealed that the communities of *Q. mongolica* and *P. densiflora* have gradually declined in the area owing to continuous forestry projects, pest outbreaks, and subsequent logging, whereas the *Q. variabilis* community has steadily expanded, gaining a competitive advantage. These findings indicate that forestry projects and immediate logging as pest control measures play a decisive role in driving short-term changes in the forest vegetation structure. However, the current pest control and forestry project-oriented policies of the Korean Forest Service conflict with the ecosystem conservation policies pursued through the Ecological and Natural Map of the Ministry of Environment. In particular, large-scale logging conducted for timber supply and pest control may provide short-term economic and protective benefits. However, in the long term, it risks undermining forest ecosystem stability and the conservation value emphasized in the Ecological and Natural Map. Therefore, future forest management policies should move beyond an approach centered solely on forestry projects, logging for timber production, and pest control. Instead, they should establish legislated management standards based on the coordination and cooperation between the Korea Forest Service and the Ministry of Environment. In addition, a sustained and systematic monitoring system for forest vegetation changes should

Table 5. Logging area by tree species (2013-2023)

Year	Species of trees	
	Quercus spp.(m^2)	*Pinus densiflora* (m^2)
2021	148,460,000	474,690,000
2022	158,140,000	627,190,000

Table 4. Pest damage distribution and occurrence trend–pine wilt (ea)

	2017	2018	2019	2020	2021
Pine wilt *(Bursaphelenchus xylophilus)*	686,422	490,693	406,362	307,919	378,079

be implemented to ensure that forestry projects and ecosystem conservation goals function in a complementary manner. Such measures are essential for strengthening the resilience and long-term sustainability of forest ecosystems.

Author Contributions

Conceptualization: KHP. Data curation: KHP, DHS. Formal analysis: KHP, DHS. Funding acquisition: KHP. Methodology: KHP. Validation: KHP. Visualization: KHP. Writing – original draft: KHP. Writing – review & editing: KHP.

Conflict of Interest

The authors declare that they have no competing interests.

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