pISSN 2765-2203
eISSN 2765-2211

PNIE

PROCEEDINGS OF THE

NATIONAL INSTITUTE OF ECOLOGY OF THE REPUBLIC OF KOREA

Volume 7 Issue 3 August 2026



PROCEEDINGS OF THE NATIONAL INSTITUTE OF ECOLOGY OF THE REPUBLIC OF KOREA
Volume 7 Issue 3, August 2026
National Institute of Ecology

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Proceedings of the National Institute of Ecology of the Republic of Korea (PNIE) is an open access and online journal aimed at promoting outcomes of basic ecological researches carried out in Korea and abroad. The journal focuses on not only basic ecological research on terrestrial and aquatic populations, communities, ecosystems and landscapes but also applied issues such as data science and climate change based on ecological research.

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Proceedings of the National Institute of Ecology of the Republic of Korea

Printed on July 25, 2026
Published on August 1, 2026

Publisher: National Institute of Ecology
Editor-in-Chief: Ohseok Kwon

Published by National Institute of Ecology (NIE)
1210 Geumgang-ro, Maseo-myeon, Seocheon-gun, Chungcheongnam-do, 33657, Korea
Tel: +82-41-950-5421, E-mail: pnie@nie.re.kr
Homepage: http://www.nie.re.kr

Printed by MEDrang Inc.
2nd Floor, Hyoryeong Building, 32 Mugyo-ro, Jung-gu, Seoul 04521, Korea
Tel: +82-2-325-2093, Fax: +82-2-325-2095, E-mail: info@medrang.co.kr
Homepage: http://www.medrang.co.kr

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pISSN 2765-2203
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pISSN 2765-2203
eISSN 2765-2211

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PNIE PROCEEDINGS OF THE NATIONAL INSTITUTE OF ECOLOGY OF THE REPUBLIC OF KOREA

Review Article

PNIE 2026;7(3):77-87
https://doi.org/10.22920/PNIE.2026.7.3.77
pISSN 2765-2203, eISSN 2765-2211

Review of the Role and Limitations of *Apis mellifera* in Ecosystem Service Assessment and Future Perspectives

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ABSTRACT

Pollination is a key ecosystem service supporting agricultural productivity and ecosystem stability. The managed honey bee, *Apis mellifera*, is the most widely reared pollinator worldwide and has been extensively used as a representative species in ecosystem service quantification and economic valuation. However, recent ecological research emphasizes that pollination functions are maintained through functional interactions within multispecies communities rather than by a single species and suggests that honey bee-centered assessment frameworks may fail to capture the complexity and resilience of ecological systems. This study systematically analyzes the biological and management-related factors that have led to the central role of *A. mellifera* in ecosystem service assessment and examines its application within major international assessment frameworks. It also critically reviews the conceptual and methodological limitations of honey bee-centered assessment frameworks and proposes the need for a transition toward assessment frameworks that integrate multispecies and trait-based approaches while incorporating landscape structure and temporal dynamics.

Keywords: Honey bee-centered approach, Multispecies interactions, Pollination services, Wild pollinators

Introduction

The concept of ecosystem services was developed as an analytical framework to describe the interdependence between human well-being and ecosystem functioning (Boyd & Banzhaf, 2007; Costanza *et al*., 1997; Daily, 1997). This concept originates from the recognition that the structure and processes of ecosystems underpin the material and cultural foundations of human society (de Groot *et al*., 2002). The Millennium Ecosystem Assessment (MEA) systematized ecosystem services into provisioning, regulating, cultural, and supporting services, making the linkages between ecosystem functions and human well-being explicit at the policy level (MEA, 2005). Subsequently, the Economics of Ecosystems and Biodiversity (TEEB; https://www.unep.org/topics/teeb) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) developed frameworks that integrate ecosystem services into economic valuation and policy decision-making processes (de Groot *et al*., 2002; Díaz *et al*., 2018; Potts *et al*., 2016b; TEEB, 2010). Along with these conceptual developments, ecosystem services research has become a field of rapidly growing academic interest over the past few decades. Indeed, the annual number of publications related to “ecosystem service(s)” indexed in Web

Received April 2, 2026; **Revised** May 21, 2026;
Accepted May 21, 2026

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of Science began to increase markedly in the mid-2000s, with several thousand studies now published each year (Fig. 1). A similar trend was observed in domestic journals, where the number of related publications indexed in the Korean Citation Index has continuously increased since the 2010s. This expansion of research reflects the strengthening of interdisciplinary approaches that link ecosystem functions to the sustainability of human societies and suggests a growing body of work focused on quantitatively understanding the structure and functioning of ecosystem services.

Pollination is a representative example of the regulation of ecosystem services, and constitutes a key ecological function directly linked to global food production systems (Klein *et al*., 2007; MEA, 2005; Potts *et al*., 2016a). Approximately 75% of the world's major crop species depend, to some extent, on animal-mediated pollination, and approximately 35% of global food production is estimated to be affected by pollination (Klein *et al*., 2007). Beyond increasing crop yield, pollination enhances fruit size, shape, storage quality, and seed set and contributes to the maintenance of genetic diversity (Aizen *et al*., 2009; Garibaldi *et al*., 2013). Cross-pollination plays an important role in supporting the resilience of agricultural systems and ensuring long-term production stability (Potts *et al*., 2016b).

However, quantification of ecosystem services tends to simplify complex ecological interactions (Boyd & Banzhaf, 2007; Fisher *et al*., 2009). Although pollination is a collective function performed by a wide range of wild insects and other taxa, its economic value and policy-oriented analyses are often reduced to the contributions of specific managed species (Aizen & Harder, 2009; Breeze *et al*., 2011; Winfree *et al*., 2008). In this context, *Apis mellifera* (Hymenoptera: Apidae) is widely used as a model species in research on pollination ecosystem services (Aizen & Harder, 2009; Delaplane & Mayer, 2000; Klein *et al*., 2007).

This tendency for pollination ecosystem service research to focus on *A. mellifera* was also reflected in the structure of the research keywords. An analysis of keyword co-occurrence networks based on publications indexed in Web of Science containing "ecosystem service*" and either "pollination" or "pollinator*" shows that core ecological concepts such as biodiversity, conservation, and diversity occupy central positions in the network, while bee- and honey bee-related keywords form major connecting axes (Fig. 2) (van Eck & Waltman, 2010). In particular, "honey bees (*A. mellifera*)" ranked fourth in frequency among the keywords analyzed, indicating that honey bees are a major focus of pollination ecosystem service research. However, given that pollination functions are carried out by diverse wild pollinators, this pattern implies that *A. mellifera* has been used as a centrally managed or representative species in research and management contexts, suggesting a potential bias in research trends.

A. mellifera is a representative domesticated insect that has been managed by humans for a long time (Crane, 1999) and has consequently become a standardized pollination service provider in industrialized agricultural systems (Aizen & Harder, 2009; Dicks *et al*., 2021). Its ability to form large colonies and be transported for commercial pollination has enabled the development of commercial pollination service markets (Calderone, 2012; Delaplane & Mayer, 2000). Consequently, honey bee pollination is increasingly regarded as a commercial input for agricultural production systems (Allsopp *et al*., 2008). This perspective has led to a distinction between managed and wild pollination and has contributed to framing pollination not solely as a natural ecological interaction, but as a service that can be managed (Gómez-Baggethun *et al*., 2010).

However, recent global reports of declines in both the abundance and diversity of wild pollinators have raised concerns regarding the ecological vulnerability associated with reliance on a single managed species (Dainese *et al*., 2019; Garibaldi *et al*., 2013; Potts *et al*., 2016a; Potts *et al*., 2016b; Winfree *et al*., 2007). A growing body of empirical studies has demonstrated that wild pollinators can play complementary or independent roles in crop pollination and that higher pollinator diversity is associated

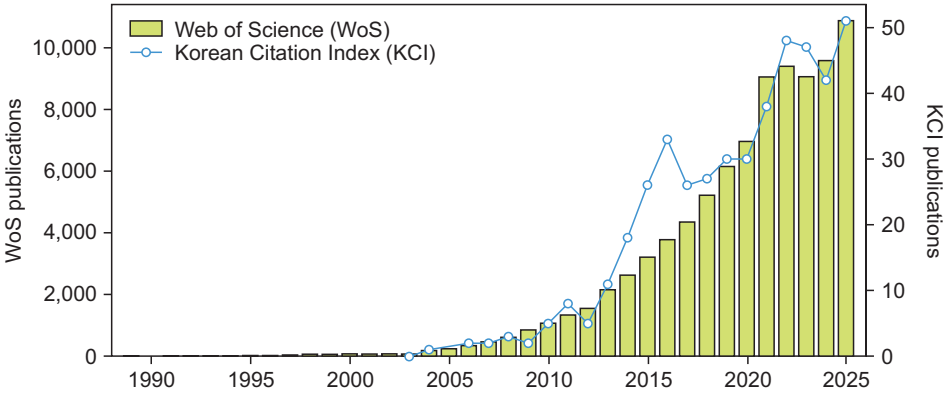

Fig. 1. Annual number of publications on ecosystem services indexed in WoS (bars) and KCI (line) from 1988 to 2025.

with improved pollination efficiency and greater stability of crop production (Albrecht *et al*., 2012; Hoehn *et al*., 2008; Hung *et al*., 2018; Kremen *et al*., 2002; Winfree *et al*., 2008). These findings suggest that an excessive reliance on a single managed species may undermine the long-term stability of pollination services. This shift in ecological understanding is also reflected in recent publication trends, with studies on wild pollinators and multispecies pollination networks consistently outnumbering those centered on *A. mellifera* in recent years (Fig. 3).

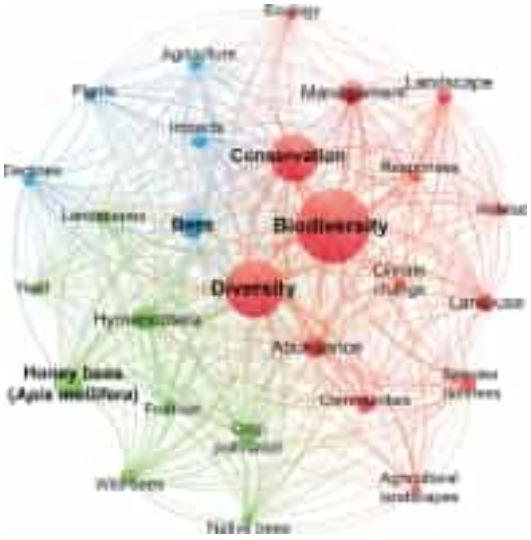

Fig. 2. Keyword co-occurrence network of the top 30 keywords from publications indexed in Web of Science using the query "ecosystem service* AND (pollination OR pollinator*)", visualized using VOSviewer (van Eck & Waltman, 2010). Node size indicates keyword frequency, and links represent co-occurrence relationships among keywords. Search terms ("ecosystem service", "pollination", "pollinator") were excluded from the keyword analysis.

This study examined the factors underlying the prominence of *A. mellifera* as a key pollinator in ecosystem service assessment research and evaluated its academic and policy implications. It further provides a comprehensive review of the influence of a honey bee-centered approach on pollination ecosystem service research, along with its associated limitations. Based on this analysis, this study highlights the need to move beyond a single managed-species perspective and to reinterpret pollination functions within the framework of ecological networks composed of diverse pollinating organisms, and draws implications for future perspectives in ecosystem service assessment research.

Main Subjects

Biological and ecological characteristics of *A. mellifera*

A. mellifera is a eusocial insect that forms a hierarchical colony structure comprising a queen, workers, and drones. A single colony typically consists of tens of thousands of individuals, and high colony density provides substantial pollination potential per unit area (Delaplane & Mayer, 2000; Seeley, 2009; Winston, 1991). In particular, worker bees exhibit age polyethism, in which their roles change with age: younger individuals are primarily engaged in brood care and hive maintenance, whereas older individu-

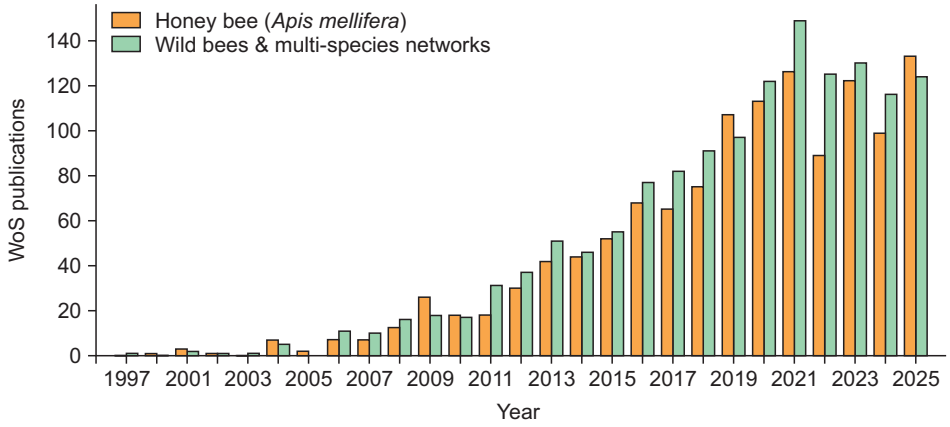

Fig. 3. Annual number of publications indexed in Web of Science (WoS) related to honey bee-centered and wild pollinator-centered ecosystem service research. The honey bee (*Apis mellifera*) category was searched using the terms: "ecosystem service" AND ("pollination" OR "pollinator*") AND ("*Apis mellifera*" OR "honey bee*" OR "honeybee*"). The wild bees and multispecies networks category was searched using: "ecosystem service" AND ("pollination" OR "pollinator*") AND ("wild bee*" OR "bumble bee*" OR "solitary bee*" OR "bee diversity" OR "pollinator diversity" OR "pollinator network*" OR "pollination network*"), covering publications up to and including 2025.

als forage outside the hive, resulting in a well-organized division of labor within the colony (Johnson, 2010; Robinson, 1992). These biological characteristics provide a basis for the use of *A. mellifera* as an effective pollinator in a wide range of agricultural and ecological systems, as detailed below.

First, *A. mellifera* maintained large colonies. A single hive contains tens of thousands of worker bees, and this collective foraging activity enables high pollination volume within a short period. This characteristic is particularly advantageous for providing large amounts of pollination services during limited time windows, such as the flowering period of agricultural crops (Delaplane & Mayer, 2000; Klein *et al*., 2007; Seeley, 2011).

In addition, honey bees possess efficient systems for resource detection and communication. Worker bees perform a distinctive behavior known as the waggle dance to convey the location of food sources to other members of a colony. This behavior encodes both the direction and distance of a resource, enabling efficient collective foraging by transmitting spatial information within a colony (Seeley, 2009; von Frisch, 1993). The direction of the waggle dance indicates the direction of the resource relative to the sun, whereas the duration of the waggle phase reflects the distance to the resource (Couvillon, 2012; von Frisch, 1993).

Another important characteristic of this species is its generalist foraging strategy. Rather than relying on specific plant species, honey bees utilize a wide range of floral resources, allowing them to pollinate both agricultural crops and wild plants. This flexibility enables honey bees to function as important pollinators in both agricultural and natural ecosystems (Aslan *et al*., 2016; Seeley, 2009; Winston, 1991).

Furthermore, honey bees are domesticated insects that have been managed by humans for thousands of years. Colonies can be maintained at the hive level and transported to different locations as required through migratory beekeeping. This system has enabled the development of commercial pollination service markets in which hives are moved in accordance with crop flowering periods (Calderone, 2012; Crane, 1999; Potts *et al*., 2016a).

Finally, both population size and colony density were managed with relatively high precision. By adjusting the number of hives, pollinator density per unit area can be directly controlled, and hive placement can serve as a key management variable, adjusted based on the crop type and cultivation conditions (Delaplane & Mayer, 2000). Moreover, the hive density required to achieve a given level of pollination depends not only on the number of hives but also on colony quality, including colony size and health status, allowing density adjustments that account for these factors. For example, a study on blueberry production systems reported that approximately 20 hives per hectare were required when low-quality colonies were used, whereas optimal pollination and yield could be achieved with approximately 4-7 hives per hectare when high-quality colonies were used (Ramírez-Mejía *et al*., 2024). This degree of controllability enables experimental manipulation and supports quantitative analysis in studies on agricultural productivity, economic valuation of pollination services, and ecosystem service assessment (Breeze *et al*., 2011; 2014; Delaplane & Mayer, 2000). This has contributed to the recognition of honey bees as measurable and manageable pollinators by researchers and policymakers. Accordingly, *A. mellifera* has been widely used as a model pollinator in ecosystem service research, and frequently serves as a reference species in the economic valuation and policy analysis of pollination services (Aizen & Harder, 2009; Breeze *et al*., 2011; Dicks *et al*., 2021; Potts *et al*., 2016a).

The role of honey bees in ecosystem service assessment frameworks

Major international ecosystem service assessment frameworks, including the MEA, TEEB, and IPBES, classify pollination as a key regulatory ecosystem service that underpins food production and ecosystem stability (MEA, 2005; Potts *et al*., 2016b; TEEB, 2010). As the reliance of agricultural production on animal-mediated pollination has become increasingly recognized, extensive research has been conducted on the ecological importance and economic value of pollination services (Klein *et al*., 2007; Porto *et al*., 2020; Potts *et al*., 2016a).

In economic valuation studies, managed honey bees have often been treated as primary providers of pollination services, and approaches that quantify service supply using indicators such as colony numbers have been widely adopted. Honey bees are recognized as key contributors to global agricultural economies, underpinning both smallholder and large-scale farming systems, with their pollination services contributing hundreds of billions of U.S. dollars in economic value (Khalifa *et al*., 2021; Nearman *et al*., 2025). Honey bees pollinate over 100 fruits, nuts, and vegetable crops, and more than 40 seed crops in the United States, contributing to the maintenance of billion-dollar crop production (Jordan *et al*., 2021). Breeze *et al*. (2014) quantified the supply and demand of pollination services across 41 European countries using national honey bee colony data and demonstrated the utility of bee-based indicators for assessing spatial imbalances in pollination services. In addition, a study applying a migratory beekeeping model to sunflower and oilseed rape production systems in Hungary estimated the economic value of honey bee pollination services to be approximately €377-503 per hectare using a production function approach (Feketéné Ferenczi *et al*., 2023). Honey bees also function as direct providers of ecosystem

services, such as honey production. In many countries, the number of beehives is regularly recorded as part of the official agricultural statistics (Food and Agriculture Organization, 2025), enabling the estimation of regional honey production potential based on floral resource distribution and foraging behavior (Feketéné Ferenczi *et al*., 2023).

This pattern has also been observed in spatial ecosystem service modeling. The InVEST Pollination Model estimates pollination services at the landscape scale by integrating parameters related to pollinator habitats and activity with land-use and land-cover information (Lonsdorf *et al*., 2009; Sharp *et al*., 2020). Although the model is theoretically capable of incorporating multiple pollinator species or functional units simultaneously, it requires the prior definition of ecological and behavioral parameters for each unit; thus, its practical application largely depends on the availability of empirical data (Groff *et al*., 2016; Lonsdorf *et al*., 2009). Parameters such as nesting resources, floral resources, and foraging distance vary substantially in availability with the level of data accumulation, which constitutes a major constraint for model implementation. Under these conditions, *A. mellifera* can be interpreted as a reference species because of the relatively abundant ecological and behavioral data available (Lonsdorf *et al*., 2009; Seeley, 2009; Winston, 1991).

Limitations of honey bee–centered assessment

In recent pollination ecosystem services research, debates have increasingly emerged regarding the validity of assessments centered on *A. mellifera* (Garibaldi *et al*., 2013; Iwasaki & Hogendoorn, 2021; Papa *et al*., 2022; Potts *et al*., 2016b). This trend stems largely from an imbalance in data availability across pollinator groups. Long-term and large-scale monitoring data for wild pollinators remain extremely limited worldwide (Potts *et al*., 2010; Potts *et al*., 2016b), and Potts *et al*. (2016b) explicitly identified this issue as a knowledge gap. Osterman *et al*. (2021) reported that although *A. mellifera* is among the most extensively monitored insect species, comparable levels of data accumulation and monitoring systems for wild pollinators are lacking.

This imbalance in data availability not only reinforces the tendency to use honey bees as the primary reference species in ecosystem service assessments but also raises more fundamental questions regarding whether current assessment frameworks can adequately represent multispecies pollination interactions (Dainese *et al*., 2019; Winfree *et al*., 2018). Pollination is a multispecies ecological process shaped by interactions among diverse pollinator taxa that differ in morphology, behavior, phenology, and environmental responses. Consequently, approaches that reduce pollination ecosystem services to a single representative species risk oversimplifying the ecological mechanisms underlying pollination functions and stability. Such simplification may underestimate the complementary and compensatory roles of wild pollinators and limit the ability of ecosystem service assessments to capture the complexity and resilience of real pollination systems (Blüthgen & Klein, 2011; Brittain *et al*., 2013; Garibaldi *et al*., 2016; Winfree *et al*., 2018).

Empirical studies have increasingly demonstrated that pollination services are maintained by interactions among multiple pollinator taxa, rather than by a single dominant species. Different pollinators contribute differently, depending on floral morphology, environmental conditions, and foraging behavior. For example, bumblebees (*Bombus* spp.) and several other wild bee taxa are capable of buzz pollination, in which vibrations are used to release pollen from flowers; however, *A. mellifera* lacks this ability (De Luca & Vallejo-Marín, 2013). Because many crops, including tomatoes and blueberries, depend heavily on this mechanism, wild bees often exhibit higher pollination efficiencies in these systems (Cooley & Vallejo-Marín, 2021; Javorek *et al*., 2002; Stubbs & Drummond, 2001). Numerous studies have shown that crop yield and fruit set are often enhanced when wild pollinators coexist with managed honey bees, indicating that different pollinator groups provide complementary ecological functions (Garibaldi *et al*., 2013; Hoehn *et al*., 2008; Winfree *et al*., 2018).

In addition to species-specific roles, pollination systems are structured by the functional diversity within pollinator communities. Pollinator species differ in traits such as body size, mouthpart morphology, foraging range, and activity period; these traits mediate how species respond to environmental conditions (Hoehn *et al*., 2008; Williams *et al*., 2010; Woodcock *et al*., 2019). As species respond differently to climatic variability and habitat conditions, diverse pollinator communities can maintain pollination functions even when certain species decline. This phenomenon is often described as an ecological insurance effect, in which functional redundancy and response diversity buffer the ecosystem against environmental disturbances (Winfree *et al*., 2007; Yachi & Loreau, 1999). Consistent with this interpretation, previous studies have shown that higher pollinator diversity is associated with greater stability of crop yield and pollination success across spatial and temporal scales (Brittain *et al*., 2013; Lemanski *et al*., 2022; Senapathi *et al*., 2021).

Simultaneously, the high-density introduction of managed honey bee colonies may alter the structure of wild pollinator communities through resource competition. Because honey bees can occur at extremely high local densities, competition for nectar and pollen resources may intensify in areas where managed colonies are heavily introduced (Goulson, 2003; Mallinger *et al*., 2017). Several empirical studies have reported reduced visitation rates

and behavioral shifts among wild pollinators in the presence of high honey bee densities (Lindström *et al.*, 2016). In some cases, such competition has been associated with colony-level effects in wild bees, including reduced worker body size in bumblebees resulting from decreased larval food availability (Goulson & Sparrow, 2009). Excessive reliance on managed honey bees may affect not only pollination service delivery but also the diversity and structural stability of wild pollinator communities.

This structural simplification has important implications for ecosystem resilience. Ecosystem service systems that are strongly dependent on a single managed species are inherently more vulnerable to external disturbances, such as disease outbreaks, pesticide exposure, and climate variability (Potts *et al*., 2016b). Large-scale colony losses in *A. mellifera* associated with *Varroa destructor* (a parasitic mite) infestation, colony collapse disorder, and pesticide exposure have repeatedly been reported worldwide (Osterman *et al.*, 2021; Potts *et al.*, 2010). Because pollination services in intensive agricultural systems are often closely tied to managed honey bee populations, such instability may directly increase the risk of pollination service shortages. In contrast, ecosystems supported by diverse pollinator assemblages are generally considered more resilient because functional redundancy and species turnover can partially compensate for the decline in individual pollinator species (Brittain *et al.*, 2013; Senapathi *et al.*, 2021). These findings collectively suggest that pollination ecosystem services cannot be fully understood through frameworks centered on a single managed species, but instead require approaches that explicitly incorporate multispecies interactions, functional diversity, and ecological complexity.

Future perspectives for ecosystem service assessment

Recent research on pollination ecosystem services has increasingly shifted beyond assessment frameworks centered on a single managed species to approaches that incorporate multispecies interactions, functional diversity, and ecological complexity. Although ecosystem service models such as the InVEST Pollination Model conceptually support the inclusion of multiple pollinator taxa, practical applications often remain constrained by limited species-specific ecological data (Kennedy *et al.*, 2013; Lonsdorf *et al.*, 2009). To overcome these limitations, pollination ecosystem service assessment frameworks should evolve in the following directions.

Pollination services are not functions provided by a single species but rather complex ecosystem processes involving multiple species operating simultaneously. Numerous studies have shown that crop yield and fruit set tend to increase when wild pollinators and managed honey bees coexist, which is often attributed to the complementary roles of these species (Garibaldi *et al.*, 2013; Hoehn *et al.*, 2008; Winfree *et al.*, 2018). In natural ecosystems, different pollinator species utilize floral resources through distinct strategies, including variations in floral morphological preferences, activity periods, and foraging behaviors. Such functional redundancy and complementarity are considered key ecological mechanisms that help maintain pollination services, even when certain pollinator species decline under changing environmental conditions (Blüthgen & Klein, 2011; Fontaine *et al.*, 2006). Accordingly, future assessments should move beyond single-species approaches to functional guild- or multispecies-based frameworks. Although spatially explicit models such as the InVEST Pollination Model already conceptually support this direction (Lonsdorf *et al.*, 2009), expanding the empirical parameter database remains essential for practical implementation.

In addition, there is a need to classify and model pollinators based on their functional traits. Recent ecosystem services research has increasingly emphasized trait-based approaches over taxonomy-based classifications. This approach allows for a more direct representation of ecological roles and enables the modeling of species with limited ecological information through functional similarity (Bartomeus *et al.*, 2018; Gagic *et al.*, 2015; Kremen *et al.*, 2007). Key functional traits in pollinator studies include body size, foraging range, phenology, floral specialization, and nesting strategy, all of which influence spatial movement and resource use patterns (Bommarco *et al.*, 2010; Greenleaf *et al.*, 2007; Williams *et al.*, 2010). For example, larger-bodied bees generally have broader foraging ranges, which can affect pollen dispersal and gene flow at the landscape scale (Greenleaf *et al.*, 2007). Consequently, future pollination ecosystem service models should move beyond species-specific parametrization and adopt trait-based parametrization to more realistically represent pollinator communities (Gagic *et al.*, 2015).

Another critical direction involves the incorporation of landscape-scale spatial structures and habitat heterogeneity in pollination service assessments. Pollination services are not determined solely at the level of individual fields or habitats but are strongly influenced by landscape configuration and connectivity (Kennedy *et al.*, 2013; Kremen *et al.*, 2007). The spatial arrangement of natural and agricultural habitats plays a key role in maintaining pollinator populations and facilitating their movement across landscapes. Empirical studies have shown that high proportions of natural or semi-natural habitats adjacent to agricultural fields are associated with increased pollinator diversity and visitation rates (Kremen *et al.*, 2002; Ricketts *et al.*, 2008). These findings highlight the importance of landscape heterogeneity and habitat connectivity for sustaining pollination services. Accordingly, future ecosystem service assessments should extend beyond site-level analyses and incorporate landscape-based spatial modeling that integrates land cover, habitat connectivity, and polli-

nator mobility. Given that these landscape effects emerge from the spatial configuration of multiple habitat types, assessments should not be restricted to a single land-use category but instead adopt integrative approaches that encompass diverse habitats.

To further operationalize these approaches, it is necessary to account for the functional role of natural habitats such as forests. Previous research has primarily focused on crop pollination, which is directly linked to agricultural productivity; however, pollination in natural ecosystems plays a crucial role in plant regeneration, gene flow, and the maintenance of community structure (Ashman *et al.*, 2004; Ollerton *et al.*, 2011). A substantial proportion of wild plant species depend on animal-mediated pollination, which directly influences long-term vegetation dynamics and biodiversity (Ollerton *et al.*, 2011). Moreover, plant-pollinator networks in natural ecosystems contribute to ecosystem resilience and functional stability under disturbance (Burkle *et al.*, 2013; Memmott *et al.*, 2004). Similar patterns have been observed in forest ecosystems, where pollinator community composition and abundance vary significantly depending on the habitat type (Woo & Jung, 2025). Forests serve as key habitats for maintaining pollinator diversity and for supporting pollination services in adjacent agricultural systems (Alison *et al.*, 2022; Ulyshen *et al.*, 2023). Therefore, future ecosystem service assessments should move beyond agriculture-focused productivity metrics to incorporate pollination functions across diverse natural ecosystems, including forests.

Temporal and climatic variabilities must also be considered. Pollination ecosystem services are strongly influenced not only by spatial factors but also by temporal dynamics. Many pollinating insects exhibit distinct phenological patterns, and plant flowering times are determined by climatic conditions, such as temperature and precipitation. Consequently, the actual provision of pollination services depends heavily on the phenological synchrony between pollinator activity and plant flowering (Hegland *et al.*, 2009). Climate change has been identified as a major factor disrupting these interactions. Several studies have reported advances in flowering phenology in response to rising temperatures; however, shifts in pollinator activity are often less pronounced, potentially leading to a phenological mismatch between plants and pollinators (Forrest, 2015; Kudo & Ida, 2013; Memmott *et al.*, 2007). These mismatches may reduce the provision of pollination services during critical periods. In addition, pollinator activity and population dynamics are highly sensitive to short-term weather conditions such as temperature, precipitation, and wind speed. For example, low temperatures or high rainfall can reduce the foraging activity of bees, thereby affecting pollination success (Corbet *et al.*, 1993; Vicens & Bosch, 2000). These findings indicate that pollination services are not determined solely by species presence but are closely linked to behavior mediated by climatic conditions. Accordingly, future models should evolve from static spatial representations to dynamic modeling approaches that incorporate seasonal activity patterns, interannual variability, and climate sensitivity. Integrating long-term monitoring data with climatic datasets is essential for understanding the temporal variability and predicting future changes in pollination services under climate change (Burkle *et al.*, 2013; Hegland *et al.*, 2009).

Finally, integrating wild pollinators into ecosystem service models requires the development of a long-term systematic data infrastructure. In many regions, information on pollinator distribution and ecological traits remains limited, and this data deficiency has been identified as a major constraint in ecosystem service modeling (Dicks *et al.*, 2013; 2021; Zattara & Aizen, 2021). Recent efforts have sought to integrate long-term monitoring data, species distribution models, citizen science observations, and remote sensing-based land-cover data to improve the resolution of pollinator distribution and ecological function analyses (Dicks *et al.*, 2021; Powney *et al.*, 2019; Zattara & Aizen, 2021). Furthermore, the development of integrated platforms that link these datasets with spatial models and economic valuation frameworks will play a key role in accurately capturing real-world supply structures of pollinated ecosystem services.

Conclusion

A. mellifera is the most important reference species in the development of pollination ecosystem service research and assessment. This is not because the species is ecologically exceptional but rather because it can be managed in large colonies, is relatively easy to handle, and has accumulated substantially more behavioral and ecological data than other pollinators. With the development of commercial migratory pollination systems, *A. mellifera* has become a manageable input to agricultural production systems, providing a critical foundation for the quantification and evaluation of pollination ecosystem services. Pollination is an inherently complex process carried out by diverse wild pollinators that contribute complementary functional traits and ecological roles. When reduced to a single managed species, key properties, such as functional diversity, resource competition, differential responses to environmental variability, and ecosystem resilience, are unlikely to be adequately represented. Therefore, a more accurate understanding of pollination ecosystem services requires recognizing both the explanatory power and the limitations of the existing honey bee-centered approach.

Although *A. mellifera* will continue to play an important role as a managed pollinator, a comprehensive understanding of the structure and stability of pollination

ecosystem services requires moving beyond a single-species-centered framework toward an integrative approach that incorporates diverse wild pollinators and considers multispecies and functional guild-based networks. Furthermore, such assessment frameworks should extend beyond agricultural systems to encompass natural ecosystems, including forests, where pollination contributes to plant regeneration, gene flow, and the maintenance of ecosystem functions. This transition will provide an essential foundation not only for advancing pollination ecosystem service research but also for informing biodiversity conservation and the development of sustainable ecosystem management strategies.

Author Contributions

Conceptualization: CYL. Data curation: CYL, SW. Formal analysis: CYL. Funding acquisition: JKJ. Investigation: CYL, SW. Methodology: SW. Project administration: JKJ. Resources: CYL. Software: CYL, SW. Supervision: JKJ. Validation: CYL. Visualization: CYL. Writing – original draft: CYL. Writing – review & editing: SW, JKJ.

Conflict of Interest

The authors declare that they have no competing interests.

Funding

This work was supported by a grant from the National Institute of Biological Resources (NIBR), funded by the Ministry of Climate, Energy and Environment (MCEE) of the Republic of Korea (NIBR202607201).

References

Aizen, M.A., Garibaldi, L.A., Cunningham, S.A., and Klein, A.M. (2009). How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Annals of Botany,* 103, 1579-1588. https://doi.org/10.1093/aob/mcp076

Aizen, M.A., and Harder, L.D. (2009). The global stock of domesticated honey bees is growing slower than agricultural demand for pollination. *Current Biology: CB,* 19, 915-918. https://doi.org/10.1016/j.cub.2009.03.071

Albrecht, M., Schmid, B., Hautier, Y., and Müller, C.B. (2012). Diverse pollinator communities enhance plant reproductive success. *Proceedings of the Royal Society B: Biological Sciences,* 279, 4845-4852. https://doi.org/10.1098/rspb.2012.1621

Alison, J., Botham, M., Maskell, L.C., Garbutt, A., Seaton, F.M., Skates, J., *et al.* (2022). Woodland, cropland and hedgerows promote pollinator abundance in intensive grassland landscapes, with saturating benefits of flower cover. *Journal of Applied Ecology,* 59, 342-354. https://doi.org/10.1111/1365-2664.14058

Allsopp, M.H., de Lange, W.J., and Veldtman, R. (2008). Valuing insect pollination services with cost of replacement. *PLoS One,* 3, e3128. https://doi.org/10.1371/journal.pone.0003128

Ashman, T.L., Knight, T.M., Steets, J.A., Amarasekare, P., Burd, M., Campbell, D.R., *et al.* (2004). Pollen limitation of plant reproduction: ecological and evolutionary causes and consequences. *Ecology,* 85, 2408-2421. https://doi.org/10.1890/03-8024

Aslan, C.E., Liang, C.T., Galindo, B., Kimberly, H., and Topete, W. (2016). The role of honey bees as pollinators in natural areas. *Natural Areas Journal,* 36, 478-488. https://doi.org/10.3375/043.036.0413

Bartomeus, I., Cariveau, D.P., Harrison, T., and Winfree, R. (2018). On the inconsistency of pollinator species traits for predicting either response to land-use change or functional contribution. *Oikos,* 127, 306-315. https://doi.org/10.1111/oik.04507

Blüthgen, N., and Klein, A.M. (2011). Functional complementarity and specialisation: the role of biodiversity in plant-pollinator interactions. *Basic and Applied Ecology,* 12, 282-291. https://doi.org/10.1016/j.baae.2010.11.001

Bommarco, R., Biesmeijer, J.C., Meyer, B., Potts, S.G., Pöyry, J., Roberts, S.P., *et al.* (2010). Dispersal capacity and diet breadth modify the response of wild bees to habitat loss. *Proceedings of the Royal Society B: Biological Sciences,* 277, 2075-2082. https://doi.org/10.1098/rspb.2009.2221

Boyd, J., and Banzhaf, S. (2007). What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics,* 63, 616-626. https://doi.org/10.1016/j.ecolecon.2007.01.002

Breeze, T.D., Bailey, A.P., Balcombe, K.G., and Potts, S.G. (2011). Pollination services in the UK: how important are honeybees? *Agriculture, Ecosystems & Environment,* 142, 137-143. https://doi.org/10.1016/j.agee.2011.03.020

Breeze, T.D., Vaissière, B.E., Bommarco, R., Petanidou, T., Seraphides, N., Kozák, L., *et al.* (2014). Agricultural policies exacerbate honeybee pollination service supply-demand mismatches across Europe. *PLoS One,* 9, e82996. https://doi.org/10.1371/journal.pone.0082996

Brittain, C., Kremen, C., and Klein, A.M. (2013). Biodiversity buffers pollination from changes in environmental conditions. *Global Change Biology,* 19, 540-547. https://doi.org/10.1111/gcb.12043

Burkle, L.A., Marlin, J.C., and Knight, T.M. (2013). Plant-pollinator interactions over 120 years: loss of species, co-occurrence, and function. *Science (New York, N.Y.),* 339, 1611-1615. https://doi.org/10.1126/science.1232728

Calderone, N.W. (2012). Insect pollinated crops, insect pollinators and US agriculture: trend analysis of aggregate data for the period 1992-2009. *PLoS One,* 7, e37235. https://doi.org/10.1371/journal.pone.0037235

Cooley, H., and Vallejo-Marín, M. (2021). Buzz-pollinated crops: a global review and meta-analysis of the effects of supplemental bee pollination in tomato. *Journal of Economic Entomology,* 114, 505-519. https://doi.org/10.1093/jee/toab009

Corbet, S.A., Fussell, M., Ake, R., Fraser, A., Gunson, C., Savage, A., *et al.* (1993). Temperature and the pollinating activity of social bees. *Ecological Entomology,* 18, 17-30. https://doi.org/10.1111/j.1365-2311.1993.tb01075.x

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., *et al.* (1997). The value of the world's ecosystem services and natural capital. *Nature,* 387, 253-260. https://

doi.org/10.1038/387253a0

Couvillon, M.J. (2012). The dance legacy of Karl von Frisch. *Insectes Sociaux,* 59, 297-306. https://doi.org/10.1007/s00040-012-0224-z

Crane, E. (1999). *The World History of Beekeeping and Honey Hunting*. Routledge.

Daily, G.C. (1997). *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press.

Dainese, M., Martin, E.A., Aizen, M.A., Albrecht, M., Bartomeus, I., Bommarco, R., *et al.* (2019). A global synthesis reveals biodiversity-mediated benefits for crop production. *Science Advances,* 5, eaax0121. https://doi.org/10.1126/sciadv.aax0121

de Groot, R.S., Wilson, M.A., and Boumans, R.M.J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics,* 41, 393-408. https://doi.org/10.1016/S0921-8009(02)00089-7

De Luca, P.A., and Vallejo-Marín, M. (2013). What's the 'buzz' about? The ecology and evolutionary significance of buzz-pollination. *Current Opinion in Plant Biology,* 16, 429-435. https://doi.org/10.1016/j.pbi.2013.05.002

Delaplane, K.S., and Mayer, D.F. (2000). *Crop Pollination by Bees*. CABI Publishing.

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., *et al.* (2018). Assessing nature's contributions to people. *Science (New York, N.Y.),* 359, 270-272. https://doi.org/10.1126/science.aap8826

Dicks, L.V., Abrahams, A., Atkinson, J., Biesmeijer, J., Bourn, N., Brown, C., *et al.* (2013). Identifying key knowledge needs for evidence-based conservation of wild insect pollinators: a collaborative cross-sectoral exercise. *Insect Conservation and Diversity,* 6, 435-446. https://doi.org/10.1111/j.1752-4598.2012.00221.x

Dicks, L.V., Breeze, T.D., Ngo, H.T., Senapathi, D., An, J., Aizen, M.A., *et al.* (2021). A global-scale expert assessment of drivers and risks associated with pollinator decline. *Nature Ecology & Evolution,* 5, 1453-1461. https://doi.org/10.1038/s41559-021-01534-9

Feketéné Ferenczi, A., Szűcs, I., and Bauerné Gáthy, A. (2023). Evaluation of the pollination ecosystem service of the honey bee (*Apis mellifera*) based on a beekeeping model in Hungary. *Sustainability,* 15, 9906. https://doi.org/10.3390/su15139906

Fisher, B., Turner, R.K., and Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics,* 68, 643-653. https://doi.org/10.1016/j.ecolecon.2008.09.014

Fontaine, C., Dajoz, I., Meriguet, J., and Loreau, M. (2006). Functional diversity of plant-pollinator interaction webs enhances the persistence of plant communities. *PLoS Biology,* 4, e1. https://doi.org/10.1371/journal.pbio.0040001

Food and Agriculture Organization (FAO) (2025). FAOSTAT: crops and livestock products database (Bees, Stocks). *FAO*. Retrieved Mar 25, 2026 from https://www.fao.org/faostat/en/#data/QCL.

Forrest, J.R.K. (2015). Plant-pollinator interactions and phenological change: what can we learn about climate impacts from experiments and observations? *Oikos,* 124, 4-13. https://doi.org/10.1111/oik.01386

Gagic, V., Bartomeus, I., Jonsson, T., Taylor, A., Winqvist, C., Fischer, C., *et al.* (2015). Functional identity and diversity of animals predict ecosystem functioning better than species-based indices. *Proceedings of the Royal Society B: Biological Sciences,* 282, 20142620. https://doi.org/10.1098/rspb.2014.2620

Garibaldi, L.A., Carvalheiro, L.G., Vaissière, B.E., Gemmill-Herren, B., Hipólito, J., Freitas, B.M., *et al.* (2016). Mutually beneficial pollinator diversity and crop yield outcomes in small and large farms. *Science (New York, N.Y.),* 351, 388-391. https://doi.org/10.1126/science.aac7287

Garibaldi, L.A., Steffan-Dewenter, I., Winfree, R., Aizen, M.A., Bommarco, R., Cunningham, S.A., *et al.* (2013). Wild pollinators enhance fruit set of crops regardless of honey bee abundance. *Science (New York, N.Y.),* 339, 1608-1611. https://doi.org/10.1126/science.1230200

Gómez-Baggethun, E., de Groot, R., Lomas, P.L., and Montes, C. (2010). The history of ecosystem services in economic theory and practice: from early notions to markets and payment schemes. *Ecological Economics,* 69, 1209-1218. https://doi.org/10.1016/j.ecolecon.2009.11.007

Goulson, D. (2003). Effects of introduced bees on native ecosystems. *Annual Review of Ecology, Evolution, and Systematics,* 34, 1-26. https://doi.org/10.1146/annurev.ecolsys.34.011802.132355

Goulson, D., and Sparrow, K.R. (2009). Evidence for competition between honeybees and bumblebees; effects on bumblebee worker size. *Journal of Insect Conservation,* 13, 177-181. https://doi.org/10.1007/s10841-008-9140-y

Greenleaf, S.S., Williams, N.M., Winfree, R., and Kremen, C. (2007). Bee foraging ranges and their relationship to body size. *Oecologia,* 153, 589-596. https://doi.org/10.1007/s00442-007-0752-9

Groff, S.C., Loftin, C.S., Drummond, F., Bushmann, S., and McGill, B. (2016). Parameterization of the InVEST Crop Pollination Model to spatially predict abundance of wild blueberry (*Vaccinium angustifolium* Aiton) native bee pollinators in Maine, USA. *Environmental Modelling & Software,* 79, 1-9. https://doi.org/10.1016/j.envsoft.2016.01.003

Hegland, S.J., Nielsen, A., Lázaro, A., Bjerknes, A.L., and Totland, Ø. (2009). How does climate warming affect plant-pollinator interactions? *Ecology Letters,* 12, 184-195. https://doi.org/10.1111/j.1461-0248.2008.01269.x

Hoehn, P., Tscharntke, T., Tylianakis, J.M., and Steffan-Dewenter, I. (2008). Functional group diversity of bee pollinators increases crop yield. *Proceedings of the Royal Society B: Biological Sciences,* 275, 2283-2291. https://doi.org/10.1098/rspb.2008.0405

Hung, K.J., Kingston, J.M., Albrecht, M., Holway, D.A., and Kohn, J.R. (2018). The worldwide importance of honey bees as pollinators in natural habitats. *Proceedings of the Royal Society B: Biological Sciences,* 285, 20172140. https://doi.org/10.1098/rspb.2017.2140

Iwasaki, J.M., and Hogendoorn, K. (2021). How protection of honey bees can help and hinder bee conservation. *Current Opinion in Insect Science,* 46, 112-118. https://doi.org/10.1016/j.cois.2021.05.005

Javorek, S.K., Mackenzie, K.E., and Kloet, S.P.V. (2002). Comparative pollination effectiveness among bees (Hymenoptera: Apoidea) on lowbush blueberry (Ericaceae: *Vaccinium angustifolium*). *Annals of the Entomological Society of*

America, 95, 345-351. https://doi.org/10.1603/0013-8746(2002)095[0345:CPEABH]2.0.CO;2

Johnson, B.R. (2010). Division of labor in honeybees: form, function, and proximate mechanisms. *Behavioral Ecology and Sociobiology,* 64, 305-316. https://doi.org/10.1007/s00265-009-0874-7

Jordan, A., Patch, H.M., Grozinger, C.M., and Khanna, V. (2021). Economic dependence and vulnerability of United States agricultural sector on insect-mediated pollination service. *Environmental Science & Technology,* 55, 2243-2253. https://doi.org/10.1021/acs.est.0c04786

Kennedy, C.M., Lonsdorf, E., Neel, M.C., Williams, N.M., Ricketts, T.H., Winfree, R., *et al.* (2013). A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. *Ecology Letters,* 16, 584-599. https://doi.org/10.1111/ele.12082

Khalifa, S.A.M., Elshafiey, E.H., Shetaia, A.A., El-Wahed, A.A.A., Algethami, A.F., Musharraf, S.G., *et al.* (2021). Overview of bee pollination and its economic value for crop production. *Insects,* 12, 688. https://doi.org/10.3390/insects12080688

Klein, A.M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., *et al.* (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences,* 274, 303-313. https://doi.org/10.1098/rspb.2006.3721

Kremen, C., Williams, N.M., Aizen, M.A., Gemmill-Herren, B., LeBuhn, G., Minckley, R., *et al.* (2007). Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. *Ecology Letters,* 10, 299-314. https://doi.org/10.1111/j.1461-0248.2007.01018.x

Kremen, C., Williams, N.M., and Thorp, R.W. (2002). Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences of the United States of America,* 99, 16812-16816. https://doi.org/10.1073/pnas.262413599

Kudo, G., and Ida, T.Y. (2013). Early onset of spring increases the phenological mismatch between plants and pollinators. *Ecology,* 94, 2311-2320. https://doi.org/10.1890/12-2003.1

Lemanski, N.J., Williams, N.M., and Winfree, R. (2022). Greater bee diversity is needed to maintain crop pollination over time. *Nature Ecology & Evolution,* 6, 1516-1523. https://doi.org/10.1038/s41559-022-01847-3

Lindström, S.A., Herbertsson, L., Rundlöf, M., Bommarco, R., and Smith, H.G. (2016). Experimental evidence that honeybees depress wild insect densities in a flowering crop. *Proceedings of the Royal Society B: Biological Sciences,* 283, 20161641. https://doi.org/10.1098/rspb.2016.1641

Lonsdorf, E., Kremen, C., Ricketts, T., Winfree, R., Williams, N., and Greenleaf, S. (2009). Modelling pollination services across agricultural landscapes. *Annals of Botany,* 103, 1589-1600. https://doi.org/10.1093/aob/mcp069

Mallinger, R.E., Gaines-Day, H.R., and Gratton, C. (2017). Do managed bees have negative effects on wild bees?: a systematic review of the literature. *PLoS One,* 12, e0189268. https://doi.org/10.1371/journal.pone.0189268

Memmott, J., Craze, P.G., Waser, N.M., and Price, M.V. (2007). Global warming and the disruption of plant-pollinator interactions. *Ecology Letters,* 10, 710-717. https://doi.org/10.1111/j.1461-0248.2007.01061.x

Memmott, J., Waser, N.M., and Price, M.V. (2004). Tolerance of pollination networks to species extinctions. *Proceedings of the Royal Society B: Biological Sciences,* 271, 2605-2611. https://doi.org/10.1098/rspb.2004.2909

Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-Being: Opportunities and Challenges for Business and Industry*. World Resources Institute.

Nearman, A., Crawford, C.L., Guarna, M.M., Chakrabarti, P., Lee, K., Cook, S., *et al.* (2025). Insights from U.S. beekeeper triage surveys following unusually high honey bee colony losses 2024-2025. *The Science of the Total Environment,* 1003, 180650. https://doi.org/10.1016/j.scitotenv.2025.180650

Ollerton, J., Winfree, R., and Tarrant, S. (2011). How many flowering plants are pollinated by animals? *Oikos,* 120, 321-326. https://doi.org/10.1111/j.1600-0706.2010.18644.x

Osterman, J., Aizen, M.A., Biesmeijer, J.C., Bosch, J., Howlett, B.G., Inouye, D.W., *et al.* (2021). Global trends in the number and diversity of managed pollinator species. *Agriculture, Ecosystems & Environment,* 322, 107653. https://doi.org/10.1016/j.agee.2021.107653

Papa, G., Maier, R., Durazzo, A., Lucarini, M., Karabagias, I.K., Plutino, M., *et al.* (2022). The honey bee *Apis mellifera*: an insect at the interface between human and ecosystem health. *Biology,* 11, 233. https://doi.org/10.3390/biology11020233

Porto, R.G., de Almeida, R.F., Cruz-Neto, O., Tabarelli, M., Viana, B.F., Peres, C.A., *et al.* (2020). Pollination ecosystem services: a comprehensive review of economic values, research funding and policy actions. *Food Security,* 12, 1425-1442. https://doi.org/10.1007/s12571-020-01043-w

Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O., and Kunin, W.E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution,* 25, 345-353. https://doi.org/10.1016/j.tree.2010.01.007

Potts, S.G., Imperatriz-Fonseca, V., Ngo, H.T., Aizen, M.A., Biesmeijer, J.C., Breeze, T.D., *et al.* (2016a). Safeguarding pollinators and their values to human well-being. *Nature,* 540, 220-229. https://doi.org/10.1038/nature20588

Potts, S.G., Ngo, H.T., Biesmeijer, J.C., Breeze, T.D., Dicks, L.V., Garibaldi, L.A., *et al.* (2016b). *The Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production*. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Powney, G.D., Carvell, C., Edwards, M., Morris, R.K.A., Roy, H.E., Woodcock, B.A., *et al.* (2019). Widespread losses of pollinating insects in Britain. *Nature Communications,* 10, 1018. https://doi.org/10.1038/s41467-019-08974-9

Ramírez-Mejía, A.F., Chacoff, N.P., Cavigliasso, P., and Blendinger, P.G. (2024). How much is enough? Optimizing beehive stocking densities to maximize the production of a pollinator-dependent crop. *Ecological Modelling,* 498, 110891. https://doi.org/10.1016/j.ecolmodel.2024.110891

Ricketts, T.H., Regetz, J., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Bogdanski, A., *et al.* (2008). Landscape effects on crop pollination services: are there general patterns? *Ecology Letters,* 11, 499-515. https://doi.org/10.1111/j.1461-0248.2008.01157.x

Robinson, G.E. (1992). Regulation of division of labor in in-

sect societies. *Annual Review of Entomology,* 37, 637-665. https://doi.org/10.1146/annurev.en.37.010192.003225

Seeley, T.D. (2009). *Wisdom of the Hive: The Social Physiology of Honey Bee Colonies*. Harvard University Press.

Seeley, T.D. (2011). *Honeybee Democracy*. Princeton University Press.

Senapathi, D., Fründ, J., Albrecht, M., Garratt, M.P.D., Kleijn, D., Pickles, B.J., *et al.* (2021). Wild insect diversity increases inter-annual stability in global crop pollinator communities. *Proceedings of the Royal Society B: Biological Sciences,* 288, 20210212. https://doi.org/10.1098/rspb.2021.0212

Sharp, R., Douglass, J., Wolny, S., Arkema, K., Bernhardt, J., Bierbower, W., *et al.* (2020). *InVEST 3.9.0 User's Guide*. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

Stubbs, C.S., and Drummond, F.A. (2001). Bombus impatiens (Hymenoptera: Apidae): an alternative to Apis mellifera (Hymenoptera: Apidae) for lowbush blueberry pollination. *Journal of Economic Entomology,* 94, 609-616. https://doi.org/10.1603/0022-0493-94.3.609

TEEB. (2010). *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB*. TEEB.

Ulyshen, M., Urban-Mead, K.R., Dorey, J.B., and Rivers, J.W. (2023). Forests are critically important to global pollinator diversity and enhance pollination in adjacent crops. *Biological Reviews,* 98, 1118-1141. https://doi.org/10.1111/brv.12947

van Eck, N.J., and Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics,* 84, 523-538. https://doi.org/10.1007/s11192-009-0146-3

Vicens, N., and Bosch, J. (2000). Weather-dependent pollinator activity in an apple orchard, with special reference to *Osmia cornuta* and *Apis mellifera* (Hymenoptera: Megachilidae and Apidae). *Environmental Entomology,* 29, 413-420. https://doi.org/10.1603/0046-225X-29.3.413

von Frisch, K. (1993). *The Dance Language and Orientation of Bees*. Harvard University Press.

Williams, N.M., Crone, E.E., Roulston, T.H., Minckley, R.L., Packer, L., and Potts, S.G. (2010). Ecological and life-history traits predict bee species responses to environmental disturbances. *Biological Conservation,* 143, 2280-2291. https://doi.org/10.1016/j.biocon.2010.03.024

Winfree, R., Reilly, J.R., Bartomeus, I., Cariveau, D.P., Williams, N.M., and Gibbs, J. (2018). Species turnover promotes the importance of bee diversity for crop pollination at regional scales. *Science (New York, N.Y.),* 359, 791-793. https://doi.org/10.1126/science.aao2117

Winfree, R., Williams, N.M., Dushoff, J., and Kremen, C. (2007). Native bees provide insurance against ongoing honey bee losses. *Ecology Letters,* 10, 1105-1113. https://doi.org/10.1111/j.1461-0248.2007.01110.x

Winfree, R., Williams, N.M., Gaines, H., Ascher, J.S., and Kremen, C. (2008). Wild bee pollinators provide the majority of crop visitation across land-use gradients in New Jersey and Pennsylvania, USA. *Journal of Applied Ecology,* 45, 793-802. https://doi.org/10.1111/j.1365-2664.2007.01418.x

Winston, M.L. (1991). *The Biology of the Honey Bee*. Harvard University Press.

Woo, S.W., and Jung, J.K. (2025). Wild pollinator (Hymenoptera: Aculeata) assemblage structures depending on forest habitat types and trap heights. *Journal of Asia-Pacific Biodiversity,* 18, 737-744. https://doi.org/10.1016/j.japb.2025.03.009

Woodcock, B.A., Garratt, M.P.D., Powney, G.D., Shaw, R.F., Osborne, J.L., Soroka, J., *et al.* (2019). Meta-analysis reveals that pollinator functional diversity and abundance enhance crop pollination and yield. *Nature Communications,* 10, 1481. https://doi.org/10.1038/s41467-019-09393-6

Yachi, S., and Loreau, M. (1999). Biodiversity and ecosystem productivity in a fluctuating environment: the insurance hypothesis. *Proceedings of the National Academy of Sciences of the United States of America,* 96, 1463-1468. https://doi.org/10.1073/pnas.96.4.1463

Zattara, E.E., and Aizen, M.A. (2021). Worldwide occurrence records reflect a global decline in bee species richness. *One Earth,* 4, 114-123. https://doi.org/10.1016/j.oneear.2020.12.005

PNIE PROCEEDINGS OF THE NATIONAL INSTITUTE OF ECOLOGY OF THE REPUBLIC OF KOREA

Original Article

PNIE 2026;7(3):88-97
https://doi.org/10.22920/PNIE.2026.7.3.88
pISSN 2765-2203, eISSN 2765-2211

Moth Community Diversity and Temporal Variation at Mt. Jeombongsan, South Korea

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ABSTRACT

Moths comprise more than 160,000 described species worldwide and are widely used as ecological indicators because of their high diversity and sensitivity to environmental changes. Although long-term monitoring studies on moth communities have been widely conducted in Europe and North America, these studies remain limited to South Korea. To address this gap, we investigated moth community patterns on Mt. Jeombongsan, located in Seoraksan National Park, South Korea. Surveys were conducted at three study sites with different vegetation characteristics (*Pinus densiflora*, *Quercus mongolica*, and *Q. mongolica–Abies*) using bucket light traps once per month from May to October over a three-year period (2023-2025). A total of 34 families, 756 species, and 12,259 individuals were recorded. Species richness and diversity were generally highest at the *Q. mongolica–Abies* site and lowest at the *P. densiflora* site. Community similarity remained relatively low among the sampling occasions, suggesting an apparent temporal variation in species composition. Macro-lepidopteran taxa accounted for approximately 70% of the total species richness, and their similarity patterns closely reflected those of the entire community. These results indicate that moth communities on Mt. Jeombongsan exhibit high diversity with apparent temporal variation, and that overall community patterns are largely reflected by macro-lepidopteran taxa. This study provides baseline data for future long-term ecological monitoring and contributes to our understanding of biodiversity patterns in temperate montane forest ecosystems.

Keywords: Lepidoptera, Long-term monitoring, Moth communities, Similarity analysis, Temporal variation

Introduction

Lepidoptera is one of the largest insect orders worldwide, comprising more than 180,000 described species, of which moths account for approximately 160,000 species and represent the majority of the group (Kristensen *et al*., 2007; Smithsonian Institution, 2025). Moths function as primary consumers in forest ecosystems and provide essential food resources for higher trophic levels, thereby

Received March 24, 2026; **Revised** May 9, 2026; **Accepted** May 11, 2026

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playing a crucial role in maintaining ecosystem structure and stability (Hill *et al*., 2021; Kocsis & Hufnagel, 2011). Owing their sensitivity to environmental changes, moths are widely recognized as suitable indicator taxa for detecting the impacts of environmental changes and ecosystem alterations (Hill *et al*., 2021; Wagner *et al*., 2021).

The long-term monitoring of moth communities has been conducted for several decades in various countries. In Hungary, moth data have been collected for nearly 50 years, while in Finland, monitoring has continued for approximately 40 years (Kocsis & Hufnagel, 2011; Woiwod, 1997). These long-term records have provided the basis for numerous studies examining climate-driven changes in Lepidopteran diversity, shifts in species distribution, and phenological patterns (Keret *et al*., 2020; Valtonen *et al*., 2017). In contrast, long-term ecological studies of moths are relatively limited in South Korea. To date, documented examples include a 5-year survey at Mt. Jirisan (An & Choi, 2013) and a 6-year survey at Mt. Hallasan (Choi & Na, 2020), which represent some of the few long-term moth monitoring efforts in the country.

Mt. Jeombongsan, located within Seoraksan National Park, is designated as a Forest Genetic Resources Reserve and remains well-preserved. The area is characterized by montane temperate forests with diverse vegetation and is one of the core sites within the Korean Long-Term Ecological Research (KLTER) network, where continuous ecological monitoring has been conducted. Because of its protected status, ecological representativeness, and established research infrastructure, Mt. Jeombongsan provides a suitable setting for long-term ecological monitoring and future studies on environmental change (Park *et al*., 2023).

In this study, moth communities were surveyed over a three-year period (May-October) at three study sites in Mt. Jeombongsan, each characterized by distinct vegetation: *Pinus densiflora* (Pd), *Quercus mongolica* (Qm), and *Q. mongolica–Abies* (Qm–Ab). Variations in species composition and abundance among sampling periods and sites were analyzed using similarity indices (Jaccard and Bray–Curtis), and community structure was evaluated using diversity indices including dominance, species diversity (H′), species evenness (Hp), and species richness (Da). Based on these analyses, we assessed the utility of the moth community data as baseline information for future long-term monitoring. Although the present study spans only 3 years, it provides baseline data for future studies on long-term community dynamics in montane temperate forest ecosystems.

Materials and Methods

Survey site

As part of the KLTER program, moth communities were surveyed over a 3-year period at Mt. Jeombongsan, a Forest Genetic Resources Reserve located in Inje-gun, Gangwon Province, South Korea. Surveys were conducted at three study sites, each characterized by distinct vegetation: Pd, Qm, and Qm–Ab forests. Detailed information on the study sites, including their geographic coordinates and site characteristics, is provided in Table 1 and Fig. 1. Because each vegetation type was represented by a single sampling site, the effects of vegetation type could not be separated from site-specific factors, including elevation and microhabitats.

Sampling methods

Sampling was conducted once per month from May to October over the three-year study period (2023-2025), resulting in six surveys per year. No sampling was conducted between October and May; therefore, comparisons between these periods do not represent consecutive monthly transitions but instead reflect differences in community composition due to the absence of sampling during the intervening winter. The moths were collected at night at each study site using bucket light traps equipped with a ultraviolet (UV) black light lamp (12 V, 8 W). Traps were operated for approximately 5 hours after sunset. Ethyl acetate was used as a killing and preserving agent in the traps. All collected samples were retrieved the following day, and all individuals were sorted and identified at the species level. Species names and abundances were recorded in Microsoft Excel (Microsoft, Redmond, WA, USA) and used as the primary dataset for subsequent analyses.

Data analysis methods

The dominance index (DI) was calculated as described by McNaughton (1967). H′ was calculated following Shannon and Weaver (1949), Da was calculated using the Margalef (1963) index, and Hp was calculated according to Heip and Engels (1974).

Community similarity was evaluated using the Jaccard (1908) and Bray and Curtis (1957) indices, which quantify the similarity between sampling units (sites or sampling periods), with values ranging from 0 to 1. The Jaccard

Table 1. Locations of the moth sampling sites in Mt. Jeombongsan

No.	Study site (vegetation type)	GPS	Elevation (m)
1	*Pinus densiflora*	38°04'23.7"N 128°22'53.9"E	600
2	*Quercus mongolica*	38°02'02.9"N 128°26'18.2"E	970
3	*Q. mongolica–Abies*	38°02'16.9"N 128°28'04.9"E	760

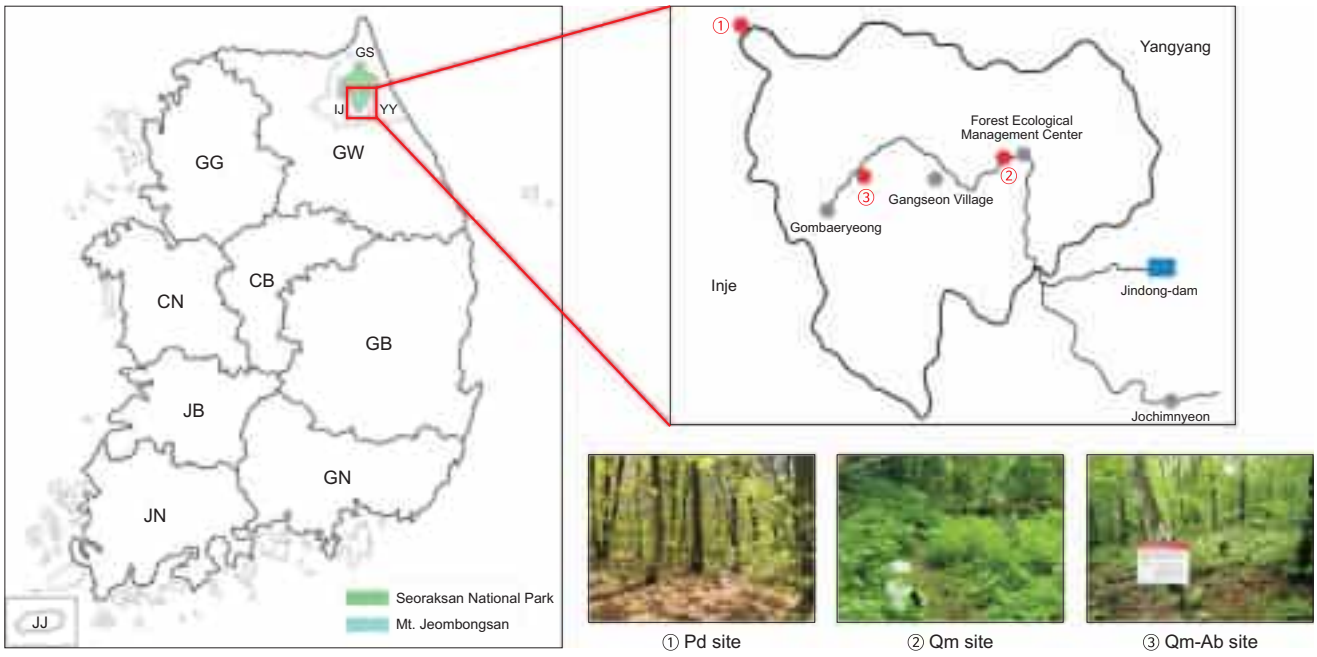

Fig. 1. Locations of moth sampling sites in Mt. Jeombongsan. Pd, *Pinus densiflora*; Qm, *Quercus mongolica*; Qm–Ab, *Q. mongolica–Abies*; GS, Goseong-gun; IJ, Inje-gun; YY, Yangyang-gun; GG, Gyeonggi-do; GW, Gangwon-do; CN, Chungcheongnam-do; CB, Chungcheongbuk-do; GB, Gyeongsangbuk-do; JB, Jeollabuk-do; GN, Gyeongsangnam-do; JN, Jeollanam-do; JJ, Jeju-do.

Table 2. Diversity and similarity indices used in this study

Index	Formula	Description
Dominance index (DI)	$DI = \frac{n1 + n2}{N}$	n1, n2: individuals of the two most abundant species; N: total number of individuals
Species diversity (H')	$H' = -\sum pi \ln pi$	$pi = \frac{ni}{N}$; $ni =$ individuals of species
Species richness (Da)	$Da = \frac{S-1}{\ln N}$	S: total number of species; N: total number of individuals
Species evenness (Hp)	$Hp = \frac{eH\prime - 1}{S-1}$	H': species diversity; S: total number of species
Jaccard index (Jc)	$Jc = \frac{a}{a+b+c}$	a: number of species shared between two samples; b: number of species present only in sample X; c: number of species present only in sample Y
Bray–Curtis index (BC)	$BC = 1 - \frac{\sum\lvert x_i - y_i\rvert}{\sum(x_i + y_i)}$	*xi*: number of individuals of species in sample X; *yi*: number of individuals of species in sample Y

index is based on the presence or absence of shared species, whereas the Bray–Curtis index incorporates species abundance and provides a more quantitative measure of compositional similarity. Even when the same species is present in two samples, the Bray–Curtis index may yield a lower value than the Jaccard index if the species abundance differs substantially.

To calculate these indices, a distance matrix was generated using the pandas, numpy, and scipy libraries in Python (version 3.10). Based on this matrix, figures were generated to illustrate the similarity patterns between sampling periods, including both within-season sampling periods and October-May intervals.

Detailed formulas and descriptions of each index are provided in Table 2.

Results

Species richness and abundance

A total of 34 families, 756 species, and 12,259 individuals were recorded across the three study sites on Mt. Jeombongsan during the three-year study period. The Qm–Ab site consistently exhibited the highest Da and abundance across all sampling years. In contrast, the Pd site showed consistently lower Da than the other sites. Across all study sites, Da increased over the years, with the

highest values recorded in 2025. Detailed Da and abundance values for each site are provided in Table 3.

Taxonomic composition

Among the 756 species recorded during the study period, Geometridae exhibited the highest Da (177 species) and Noctuidae (145 species), Crambidae (59 species), and Notodontidae (44 species) were also among the most species-rich families. In terms of abundance, Erebidae was the most abundant family (3,177 individuals), followed by Geometridae (2,746 individuals) and Noctuidae (1,747 individuals). Macro-lepidopteran families collectively accounted for approximately 70% of the total Da of the moth community. Detailed family-level composition is provided in Table 4.

Diversity patterns (alpha diversity)

DI values decreased from 2023 to 2025 across all the study sites, with the lowest values recorded in 2025, particularly at the Qm–Ab site (DI=0.07). H′ exceeded 3.5 at all study sites throughout the study period and increased consistently from 2023 to 2025, with the highest value observed at the Qm–Ab site in 2025 (H′=5.08). Da showed a similar increasing trend, with all sites recording values above 25 and the highest richness observed at the Qm–Ab site in 2025 (Da=42.91). Hp values generally ranged between 0.7 and 0.9 across sites and years, although evenness at the Qm site was lower in 2023 (Hp=0.66). The detailed alpha diversity indices are provided in Table 5.

Community similarity (beta diversity)

Over the 3-year sampling period, community similarity was generally low across all study sites, suggesting an apparent temporal variation in moth communities at Mt. Jeombongsan.

At the Pd site, Jaccard similarity values ranged from 0.00 to 0.23, while Bray–Curtis values ranged from 0.00 to 0.34. Similarity tended to be higher during early to mid-summer (June-August) but declined toward autumn.

At the Qm site, Jaccard values ranged from 0.00 to 0.24 and Bray–Curtis values from 0.00 to 0.17. This site exhibited a consistently low similarity between adjacent sampling periods, with most comparisons approaching zero except for May-June of 2025.

At the Qm–Ab site, Jaccard values ranged from 0.00 to 0.28 and Bray–Curtis values from 0.00 to 0.46. The similarity was generally higher during the summer months, with the highest similarity recorded between September and October 2025.

Overall, the similarity values remained low across all sites and sampling periods. The detailed similarity indices are provided in Table 6 and Fig. 2.

Similarity comparison between macro-lepidoptera and the entire community

Macro-lepidopteran taxa accounted for approximately 70% of the total moth Da recorded at Mt. Jeombongsan (Table 4). The mean similarity values of macro-lepidoptera were comparable to those of the entire moth community, with minimal differences across all study sites (ΔJaccard<0.02; ΔBray–Curtis<0.02). These results suggest that the overall moth community structure and patterns of temporal variation on Mt. Jeombongsan are largely reflected by the macro-lepidopteran taxa. The detailed similarity indices are listed in Table 7 and shown in Fig. 3.

Discussion

Moth diversity across study sites

In the present study, moth diversity was generally high across all the study sites on Mt. Jeombongsan, although considerable differences were observed. The Qm–Ab site consistently exhibited higher Da than the other sites,

Table 3. Species richness and abundance of moth communities across study sites and years

Study site (vegetation type)	Year	No. of families	No. of species	No. of individuals
Pinus densiflora	2023	19	169	825
	2024	20	243	1,673
	2025	21	245	1,302
Quercus mongolica	2023	22	194	1,422
	2024	19	178	625
	2025	25	261	1,498
Q. mongolica–Abies	2023	19	208	1,109
	2024	19	273	1,766
	2025	24	328	2,039
Total (2023-2025)		34	756	12,259

Table 4. Family-level taxonomic composition of moths in Mt. Jeombongsan

Rank	Group (Macro/Micro)	Family	No. of species	No. of individuals	Species (%)/ individuals(%)
1	Macro-lepidoptera	Geometridae	177	2,746	23.41/22.40
2		Noctuidae	145	1,747	19.18/14.25
3		Erebidae	141	3,177	18.65/25.92
4		Notodontidae	44	734	5.82/5.99
5		Drepanidae	24	592	3.17/4.83
6		Sphingidae	18	347	2.38/2.83
7		Nolidae	17	71	2.25/0.58
8		Lasiocampidae	7	125	0.93/1.02
9		Saturniidae	5	153	0.66/1.25
10		Bombycidae	2	10	0.26/0.08
11		Brahmaeidae	1	3	0.13/0.02
12		Endromidae	1	3	0.13/0.02
13		Uraniidae	1	2	0.13/0.02
1	Micro-lepidoptera	Crambidae	59	1,114	7.80/9.09
2		Pyralidae	42	713	5.56/5.82
3		Tortricidae	27	281	3.57/2.29
4		Limacodidae	9	123	1.19/1.00
5		Thyrididae	6	29	0.79/0.24
6		Ypsolophidae	4	64	0.53/0.52
7		Depressariidae	4	8	0.53/0.07
8		Adelidae	3	25	0.40/0.20
9		Tineidae	3	3	0.40/0.02
10		Yponomeutidae	2	97	0.26/0.79
11		Zygaenidae	2	25	0.26/0.20
12		Gracillariidae	2	4	0.26/0.03
13		Gelechiidae	2	3	0.26/0.02
14		Carposinidae	1	24	0.13/0.20
15		Xyloryctidae	1	13	0.13/0.11
16		Plutellidae	1	10	0.13/0.08
17		Oecophoridae	1	5	0.13/0.04
18		Cosmopterigidae	1	4	0.13/0.03
19		Lecithoceridae	1	2	0.13/0.02
20		Blastobasidae	1	1	0.13/0.01
21		Pterophoridae	1	1	0.13/0.01
Total			756	12,259	100.00/100.00

whereas the Pd site consistently exhibited lower Da. These differences may reflect the combined effects of site-specific conditions, including vegetation structure, plant species composition, and elevation.

Moths are primarily herbivorous insects closely linked to host plant diversity and habitat structure (White, 2013). Mixed forests typically provide a broader range of host plants and more structurally complex environments than single-species stands (Tyler, 2020). This increased structural and botanical diversity could create more ecological niches, thereby supporting a greater number of moth species. In contrast, single-species conifer stands offer fewer

Table 5. Alpha diversity indices of moth communities at three study sites in Mt. Jeombongsan

Study site (vegetation type)	Year	Dominance index	Species diversity	Species richness	Species evenness
Pinus densiflora	2023	0.27	4.00	25.00	0.78
	2024	0.20	4.35	33.42	0.79
	2025	0.09	4.47	34.02	0.86
Quercus mongolica	2023	0.25	3.51	26.58	0.66
	2024	0.14	4.63	28.49	0.89
	2025	0.14	4.69	35.55	0.84
Q. mongolica–Abies	2023	0.17	4.30	28.20	0.83
	2024	0.16	4.65	37.20	0.83
	2025	0.07	5.08	42.91	0.87

Table 6. Community similarity (Jaccard and Bray–Curtis indices) between sampling periods at three study sites in Mt. Jeombongsan

Year_month	*Pinus densiflora*		*Quercus mongolica*		*Q. mongolica–Abies*	
	Jaccard	Bray–Curtis	Jaccard	Bray–Curtis	Jaccard	Bray–Curtis
2023_May-Jun	0.19	0.12	0.11	0.11	0.00	0.00
2023_Jun-Jul	0.00	0.00	0.07	0.06	0.18	0.16
2023_Jul-Aug	0.07	0.03	0.08	0.12	0.28	0.24
2023_Aug-Sep	0.16	0.34	0.00	0.00	0.08	0.04
2023_Sep-Oct	0.00	0.00	0.00	0.00	0.00	0.00
2023_Oct-2024_May	0.03	0.01	0.00	0.00	0.00	0.00
2024_May-Jun	0.08	0.04	0.02	0.00	0.00	0.00
2024_Jun-Jul	0.23	0.29	0.00	0.00	0.05	0.05
2024_Jul-Aug	0.11	0.13	0.01	0.00	0.23	0.29
2024_Aug-Sep	0.06	0.08	0.00	0.00	0.06	0.05
2024_Sep-Oct	0.00	0.00	0.00	0.00	0.00	0.00
2024_Oct-2025_May	0.00	0.00	0.00	0.00	0.00	0.00
2025_May-Jun	0.04	0.07	0.08	0.14	0.01	0.00
2025_Jun-Jul	0.06	0.04	0.24	0.17	0.17	0.20
2025_Jul-Aug	0.06	0.04	0.07	0.05	0.25	0.29
2025_Aug-Sep	0.09	0.09	0.07	0.09	0.08	0.05
2025_Sep-Oct	0.00	0.00	0.00	0.00	0.25	0.46

October-May comparisons represent non-consecutive sampling intervals and are included to characterize differences in community composition between sampling periods.

host plants and reduce structural heterogeneity, potentially limiting insect diversity (Tyler, 2020).

Taken together, these findings suggest that the structural complexity of vegetation may play a role in shaping moth diversity; however, the observed patterns cannot be attributed solely to vegetation type because of the lack of spatial replication. Temporal variability associated with limited within-period sampling may also have influenced the observed community patterns, given that moth assemblages can vary considerably across sampling occasions. Furthermore, the high diversity observed at the Qm–Ab site suggests that this site may function as a potential reservoir of moth biodiversity within Mt. Jeombongsan, although a more comprehensive understanding will require further investigation that incorporates multiple interacting factors and additional spatial and temporal replicat.

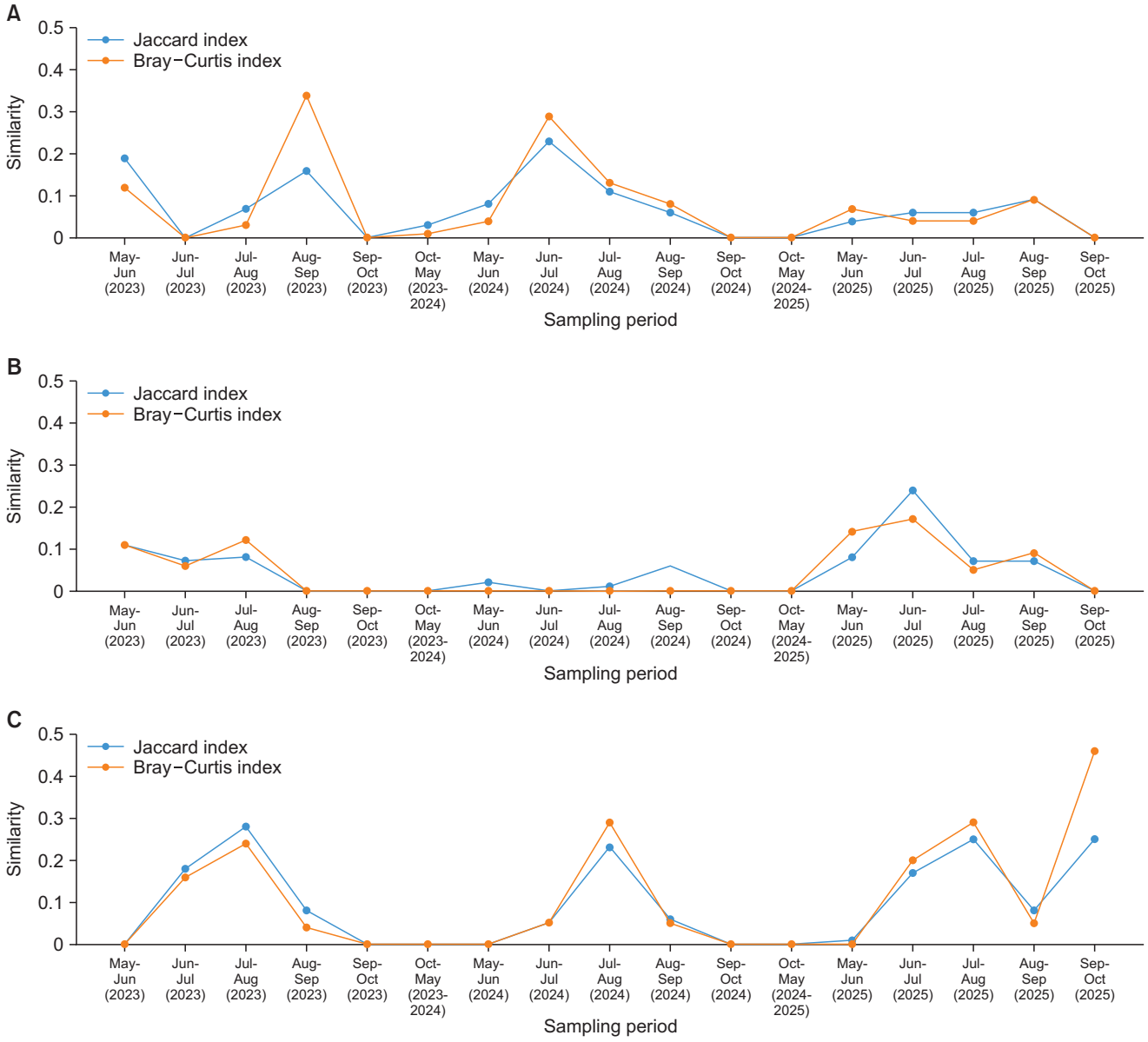

Fig. 2. Community similarity (Jaccard and Bray–Curtis indices) across sampling periods at three study sites in Mt. Jeombongsan. October-May comparisons represent non-consecutive sampling intervals. (A) *Pinus densiflora* site. (B) *Quercus mongolica* site. (C) *Q. mongolica–Abies* site.

Table 7. Mean community similarity (Jaccard and Bray–Curtis indices) of macro-lepidoptera and the entire moth community across study sites

Study site (vegetation type)	Group	Mean Jaccard	Mean Bray–Curtis
Pinus densiflora	Macro	0.074	0.085
	All	0.070	0.075
Quercus mongolica	Macro	0.045	0.047
	All	0.044	0.044
Q. mongolica–Abies	Macro	0.085	0.091
	All	0.096	0.108

"Macro" refers to macro-lepidopteran taxa, and "All" refers to the entire moth community.

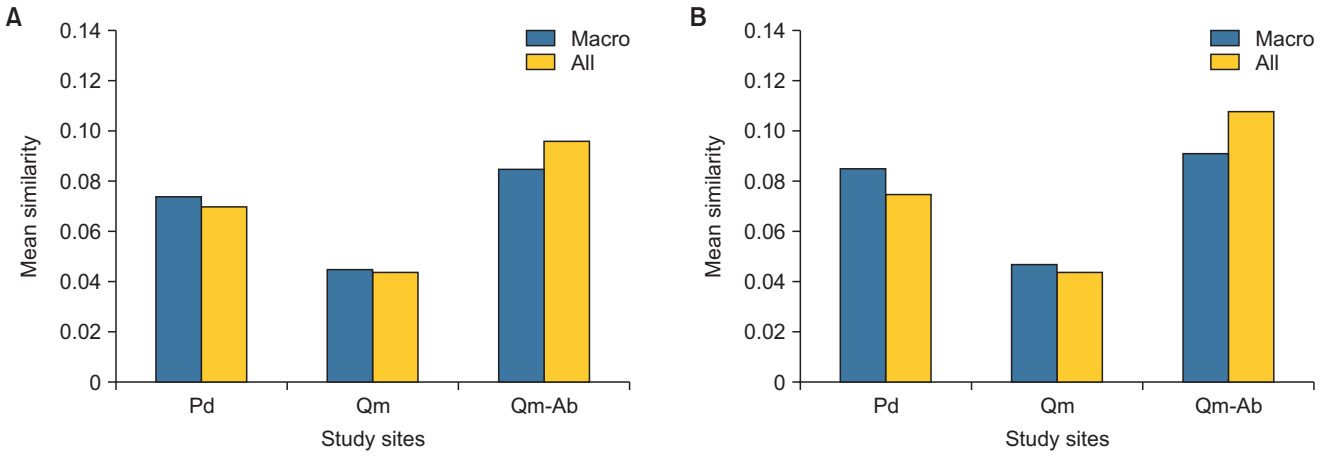

Fig. 3. Comparison of mean community similarity between macro-lepidopteran taxa and the entire moth community across study sites in Mt. Jeombongsan. (A) Mean Jaccard similarity. (B) Mean Bray–Curtis similarity. Bars represent mean values calculated between sampling periods (including both within-season sampling periods and October-May intervals). Pd, *Pinus densiflora*; Qm, *Quercus mongolica*; Qm–Ab, *Q. mongolica–Abies*.

Temporal variation

Our results showed generally low similarity values across all study sites and sampling periods, suggesting an apparent temporal variation in moth communities at Mt. Jeombongsan. The proportion of species shared between adjacent within-season sampling periods was generally low, indicating changes in species composition across sampling periods.

However, because sampling was conducted once per month without within-month temporal replication, the observed patterns may have been influenced by short-term environmental conditions such as weather and temperature. In addition, no sampling was conducted between October and May; therefore, October-May comparisons reflect differences in community composition between late and early-season assemblages, rather than consecutive monthly transitions.

Similarity tended to be higher during mid-summer, likely reflecting the peak emergence period when Da and abundance are the highest, resulting in a greater temporal overlap among communities. However, even during this peak period, the similarity values remained below 0.35. Similar patterns have been reported in montane ecosystems, where moth communities at lower elevations often exhibit more stable temporal patterns, whereas those at higher elevations tend to show lower similarities and more irregular dynamics (Highland *et al*., 2013). These communities are highly sensitive to temperature fluctuations, and the timing of adult emergence can be influenced by precipitation and weather conditions (Highland *et al*., 2013). Furthermore, many montane moth species are univoltine, with relatively short life cycles and high host-plant specificity, traits that may promote species replacement and contribute to temporal variations in community composition (Macgregor *et al*., 2019).

These findings suggest that temporal environmental dynamics contribute to patterns in moth community structure in the montane forests of Mt. Jeombongsan. Because moth communities in high-elevation ecosystems are particularly sensitive to environmental variations, they may provide useful baseline information for future studies investigating ecological responses to environmental changes. Although the present study spans only 3 years and cannot fully capture long-term dynamics, the generally low similarity observed across study sites suggests an apparent temporal variation in moth communities on Mt. Jeombongsan.

Overall, our results underscore the importance of multi-season sampling when assessing moth diversity. Surveys conducted during a single period may underestimate total Da and fail to capture the dynamic nature of moth communities. Therefore, designing monitoring programs that account for temporal variation and key environmental factors is also important for improving biodiversity assessments. Continued long-term monitoring is also necessary to better understand temporal fluctuations in moth communities and their responses to environmental changes in forest ecosystems.

Macro-lepidoptera dominance

Macro-lepidoptera accounted for a large proportion of the moth community on Mt. Jeombongsan and represented approximately 70% of the total Da (Table 4). Similarity values calculated using only macro-lepidopteran taxa were comparable to those obtained from the entire moth community, with minimal differences across all study sites

(Table 7), suggesting that macro-lepidopterans closely reflect the overall similarity patterns of moth communities in this region. However, at the Qm–Ab site, the similarity values for the entire community were slightly higher than those for macro-lepidoptera alone, suggesting a potential contribution of micro-lepidopteran taxa to the overall community similarity at this site.

This pattern may be related to the high Da and abundance of macro-lepidopteran families such as Geometridae, Noctuidae, and Erebidae, which dominate temperate forest moth communities (An & Choi, 2013; Enkhtur *et al*., 2021; Tikoca *et al*., 2017). Because these taxa constitute a substantial proportion of the community, changes in their composition strongly influence overall similarity patterns (An & Choi, 2013; Enkhtur *et al*., 2021).

From a practical perspective, these findings suggest that macro-lepidopterans may serve as a useful proxy for assessing overall moth community patterns in ecological monitoring. Given the taxonomic difficulty and time required to identify many micro-lepidopteran species, focusing on macro-lepidopteran communities may provide an efficient approach for assessing community similarity patterns in montane forest ecosystems.

Implications for long-term monitoring

Mt. Jeombongsan supports highly diverse moth communities across multiple study sites, and high levels of Da and diversity were observed throughout the study period. Alpha diversity increased from 2023 to 2025 across all study sites (Table 5). The Qm–Ab site consistently exhibited the highest Da and diversity values, suggesting that structurally complex montane habitats may support moth biodiversity in this region.

Simultaneously, the moth communities on Mt. Jeombongsan exhibited apparent temporal variation, with generally low similarity values between adjacent sampling periods across all study sites. However, because sampling was conducted once per month without within-month temporal replication, these patterns may have been influenced by short-term environmental conditions. In temperate forest ecosystems, moth life cycles and emergence patterns are influenced by environmental factors such as temperature, precipitation, and host-plant availability, which may contribute to temporal variation in community composition.

In addition, the similarity patterns of macro-lepidopteran communities were comparable to those of the entire moth community across all study sites, suggesting that the overall moth community similarity on Mt. Jeombongsan may be largely reflected by macro-lepidopteran taxa. Therefore, focusing on macro-lepidopteran communities may provide an efficient approach to evaluate community patterns in montane forest ecosystems.

Taken together, these results suggest that Mt. Jeombongsan provides baseline data for the future long-term monitoring of moth communities. Because moth communities may be sensitive to environmental variation, macro-lepidopteran communities, in particular may be useful for future studies aimed at detecting ecological changes in temperate montane forest ecosystems. However, because the present study spans only 3 years and does not include a direct analysis of climate variables, the results cannot be used to infer long-term ecological or climate-driven changes. Therefore, long-term monitoring incorporating both temporal and spatial replication, as well as multiple environmental factors, is important for improving our understanding of ecological dynamics and supporting future studies on long-term ecological change.

Author Contributions

Conceptualization: JHK. Data curation: JHK. Formal analysis: YKK. Funding acquisition: JHK, UB, MK. Investigation: JHK, UB, TGL. Methodology: JHK. Resources: JBL. Visualization: JHK, YKK. Writing – original draft: JHK. Writing – review & editing: YKK.

Conflict of Interest

The authors declare that they have no competing interests.

Acknowledgments

We thank Dr. Dae-Hyun Lee (Dasari Research Institute of BioResources) for assistance with field data collection. We are also grateful to the owners of Kangseon Sanbang for providing accommodation and supporting us in conducting nighttime field surveys during our research stay, and to the staff of the Jeombongsan Forest Management Center for their cooperation and logistical support during the study.

Funding

This work was supported by a grant from the National Institute of Ecology (NIE), funded by the Ministry of Climate, Energy and Environment (MCEE) of the Republic of Korea (NIE-B-2026-02).

References

An, J.S., and Choi, S.W. (2013). Forest moth assemblages as indicators of biodiversity and environmental quality in a temperate deciduous forest. *European Journal of Entomology,* 110, 509-517. https://doi.org/10.14411/eje.2013.067

Bray, J.R., and Curtis, J.T. (1957). An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs,* 27, 325-349. https://doi.org/10.2307/1942268

Choi, S.W., and Na, S.H. (2020). Quantitative data from six years (2013-2018) of light trap sampling of macromoths (Lepidoptera) in Mt. Hallasan National Park, South Korea. *Biodiversity Data Journal,* 8, e51490. https://doi.org/10.3897/BDJ.8.e51490

Enkhtur, K., Brehm, G., Boldgiv, B., and Pfeiffer, M. (2021). Alpha and beta diversity patterns of macro-moths reveal a breakpoint along a latitudinal gradient in Mongolia. *Scientific Reports,* 11, 15018. https://doi.org/10.1038/s41598-021-94471-3

Heip, C., and Engels, P. (1974). Comparing species diversity and evenness indices. *Journal of the Marine Biological Association of the United Kingdom,* 54, 559-563. https://doi.org/10.1017/s0025315400022748

Highland, S.A., Miller, J.C., and Jones, J.A. (2013). Determinants of moth diversity and community in a temperate mountain landscape: vegetation, topography, and seasonality. *Ecosphere,* 4(10), 1-22. https://doi.org/10.1890/es12-00384.1

Hill, G.M., Kawahara, A.Y., Daniels, J.C., Bateman, C.C., and Scheffers, B.R. (2021). Climate change effects on animal ecology: butterflies and moths as a case study. *Biological Reviews of the Cambridge Philosophical Society,* 96, 2113-2126. https://doi.org/10.1111/brv.12746

Jaccard, P. (1908). Nouvelles recherches sur la distribution florale. *Bulletin de la Société Vaudoise des Sciences Naturelles,* 44, 223-270. https://doi.org/10.5169/seals-268384

Keret, N.M., Mutanen, M.J., Orell, M.I., Itämies, J.H., and Välimäki, P.M. (2020). Climate change-driven elevational changes among boreal nocturnal moths. *Oecologia,* 192, 1085-1098. https://doi.org/10.1007/s00442-020-04632-w

Kocsis, M., and Hufnagel, L. (2011). Impacts of climate change on Lepidoptera species and communities. *Applied Ecology and Environmental Research,* 9, 43-72. https://doi.org/10.15666/aeer/0901_043072

Kristensen, N.P., Scoble, M.J., and Karsholt, O. (2007). Lepidoptera phylogeny and systematics: the state of inventorying moth and butterfly diversity. *Zootaxa,* 1668, 699-747. https://doi.org/10.11646/zootaxa.1668.1.30

Macgregor, C.J., Thomas, C.D., Roy, D.B., Beaumont, M.A., Bell, J.R., Brereton, T., *et al*. (2019). Climate-induced phenology shifts linked to range expansions in species with multiple reproductive cycles per year. *Nature Communications,* 10, 4455. https://doi.org/10.1038/s41467-019-12479-w

Margalef, R. (1963). On certain unifying principles in ecology. *The American Naturalist,* 97, 357-374. https://doi.org/10.1086/282286

McNaughton, S.J. (1967). Relationship among functional properties of Californian grassland. *Nature*, 216, 168-169. https://doi.org/10.1038/216168b0

Park, J.S., Joo, S.J., Lee, J., Seo, D., Kim, H.S., Jeon, J., *et al*. (2023). Long-term ecological monitoring in South Korea: progress and perspectives. *Journal of Ecology and Environment,* 47, 1-8. https://doi.org/10.5141/jee.23.077

Shannon, C.E., and Weaver, W. (1949). *The Mathematical Theory of Communication*. University of Illinois Press.

Smithsonian Institution. (2025). Moths. *Smithsonian Institution*. Retrieved Jan 20, 2026 from https://www.si.edu/spotlight/buginfo/moths.

Tikoca, S., Hodge, S., Tuiwawa, M., Pene, S., Clayton, J., and Brodie, G.D. (2017). A comparison of macro-moth assemblages across three types of lowland forest in Fiji. *The Journal of Research on the Lepidoptera,* 49, 69-79. https://doi.org/10.5962/p.266463

Tyler, T. (2020). Relationship between moth (night active Lepidoptera) diversity and vegetation characteristics in southern Sweden. *Journal of Insect Conservation,* 24, 1005-1015. https://doi.org/10.1007/s10841-020-00270-y

Valtonen, A., Hirka, A., Szőcs, L., Ayres, M.P., Roininen, H., and Csóka, G. (2017). Long-term species loss and homogenization of moth communities in Central Europe. *The Journal of Animal Ecology,* 86, 730-738. https://doi.org/10.1111/1365-2656.12687

Wagner, D.L., Fox, R., Salcido, D.M., and Dyer, L.A. (2021). A window to the world of global insect declines: moth biodiversity trends are complex and heterogeneous. *Proceedings of the National Academy of Sciences of the United States of America,* 118, e2002549117. https://doi.org/10.1073/pnas.2002549117

White, P.J. (2013). Testing two methods that relate herbivorous insects to host plants. *Journal of Insect Science (Online),* 13, 92. https://doi.org/10.1673/031.013.9201

Woiwod, I.P. (1997). Detecting the effects of climate change on Lepidoptera. *Journal of Insect Conservation*, 1, 149-158. https://doi.org/10.1023/A:1018451613970

PNIE PROCEEDINGS OF THE NATIONAL INSTITUTE OF ECOLOGY OF THE REPUBLIC OF KOREA

Original Article

PNIE 2026;7(3):98-102
https://doi.org/10.22920/PNIE.2026.7.3.98
pISSN 2765-2203, eISSN 2765-2211

Taxonomic Review of the Genus *Hydrochus* Leach in Korea (Coleoptera: Hydrochidae)

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ABSTRACT

A taxonomic review of the genus *Hydrochus* Leach in Korea is also presented. The genus *Hydrochus* Leach contains approximately 180 described species worldwide, and its members usually inhabit the margins of shallow lentic waters with abundant vegetation. In this study, three species are recognized, one of which is reported for the first time in Korea (*Hydrochus laferi* Shatrovskiy). Habitus and aedeagus photographs, diagnoses, descriptions, and habitat information are provided. A key to the Korean *Hydrochus* species is also provided.

Keywords: Hydrochidae, *Hydrochus*, *Hydrochus laferi*, Korea, Taxonomy

Introduction

While conducting an intensive survey of the national inland wetlands in the Upo-swamp, an unusually small hydrochid species were collected. After detailed studies of their comparative morphology, *Hydrochus laferi* Shatrovskiy was identified.

The genus *Hydrochus* Leach contains about 180 described species worldwide (Hansen, 1991; Hidalgo-Galiana & Ribera, 2011; Short & Fikáček, 2011; Taşar, 2018). Two species of *Hydrochus chubu* Balfour-Browne and Satô and *Hydrochus japonicus* Sharp, have been recorded (Jung *et al*., 2011; Lee *et al*., 2013) in the Korean peninsula, and three species in China, five species in Japan, two species in the Far East of Russia (Hansen, 2004; Hirasawa & Yoshitomi, 2021; Lee *et al*., 2013).

These beetles typically inhabit the margins of shallow lentic waters with abundant vegetation (Lee *et al*., 2013). Mostly, adults are covered by a layer of mud dorsally and are not attracted to light.

They are characterized by a combination of the following characteristics: eyes prominently bulging; maxillary palpomere 4 elongated and uneven, exceeding length of palpomere 3; antenna composed of seven segments; pronotum tapering posteriorly; each elytron bearing ten longitudinal series of punctures; tibiae lacking dorsal fringe of elongated swimming setae; ventral thoracic region and abdominal sternites marked with conspicuous, pit-shaped punctures; and apical area of sternite VII featuring semi-transparent plate (Archangelsky *et al*., 2005; Lee *et al*., 2013).

In this study, one of the three species is reported for the first time in Korea (*H. laferi* Shatrovskiy). Photographs of

Received March 17, 2026; **Revised** April 21, 2026; **Accepted** April 22, 2026

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the habitus and aedeagus, diagnoses, keys, and information on the habitat of the species were also provided.

Materials and Methods

Specimens were collected using a hand net (30×30 cm, mesh size 1 mm) and preserved in 80% ethanol. Identification was performed based on the morphological characteristics using stereoscopy and light microscopy. Images of the dorsal habitus were captured using a digital camera (D90; Nikon, Tokyo, Japan). Image stacks were processed and combined using the Helicon Focus software (ver. 6.8.0 Pro; Helicon Soft Ltd., Kharkiv, Ukraine) and subsequently edited using Adobe Photoshop CS6 (Adobe Inc., San Jose, CA, USA).

The specimens used in this study were deposited at the DASARI Research Institute of BioResources (DRIBR, Daejeon) and in Chungnam National University Insect Collection (CNUIC, Daejeon). The type series and voucher specimens were borrowed from the Natural History Museum (NHM, London) and the Ehime University Museum (EUMJ, Matsuyama). The terminology for taxonomic characteristics and specimen measurements mainly follows Archangelsky *et al*. (2005) and Hirasawa and Yoshitomi (2021). The diagnoses of the median lobe of *H. chubu* is based on the figures provided by Satô and Yoshitomi (2005).

Results

Family Hydrochidae Thomson, 1859.
Genus *Hydrochus* Leach, 1817.
Type species: *Silpha elongata* Schaller, 1783.

Key to the *Hydrochus* species in Korea

1. Head dark brown to black; pronotum and elytra concolorous 2
   - Head metallic blue; pronotum and elytra differ in coloration ..... *H. japonicus*
2. Pronotum and elytra dark reddish brown; pronotum as long as wide ..... *H. chubu*
   - Pronotum and elytra dark brown with metallic bronze; pronotum wider than long ..... *H. laferi*

***Hydrochus chubu* Balfour-Browne and Satô, 1962**

Korean name: Gal-saek-gom-bo-mul-ttang-ttang-i (Figs. 1A, 2B).

Hydrochus chubu Balfour-Browne and Satô, 1962: 3; Satô, 1985: 205; Hansen, 2004: 43; Satô and Yoshitomi, 2005: 4; Lee *et al*., 2013: 249.

Diagnosis

Length 2.6-2.8 mm, elongated, with many punctures. Head black, pronotum and elytra dark reddish brown (Fig. 1A). Ventral surface dark brown. Mentum concave at postero-median part. Pronotum as long as wide. Dorsal part of pronotal ridge flat. Elytral interstriae slightly raised. Median lobe of aedeagus laterally parallel, roundly expanded from the apical one-third, and widest at about one-sixth from the apex; apical part rounded. Paramere nearly as long as median lobe; narrows from the middle, becoming slender toward the apex.; apical margin rounded.

Specimens examined

Holotype: 1♂ (EUMJ), with labels as follows: "Holotype, Obirayama Yokkaichi-City, 1 IX 1957. Coll. Zen. Naruse, *Hydrochus chubu* Balfour-Browne et M. Satô Det. M. Satô, 1963". Paratype: 1♂ (NHM), with labels as follows: "Paratype, Paratype, Obirayama Yokkaichi Mie, Japan VII. 1957. Z Naruse et S.ishida, Brit. Mus. 1962–444., *Hydrochus chubu* Balfour-Browne et M. Satô". SOUTH KOREA: 1♀, Jeju-do: Bukjeju-gun, Gujwa-eup, Deokcheon-ri, 26 Jul 2005, Lee SH, ex pond (on slide, CNUIC); 1♀, same data as former except for, 22 May 2006, Lee DH (CNUIC);

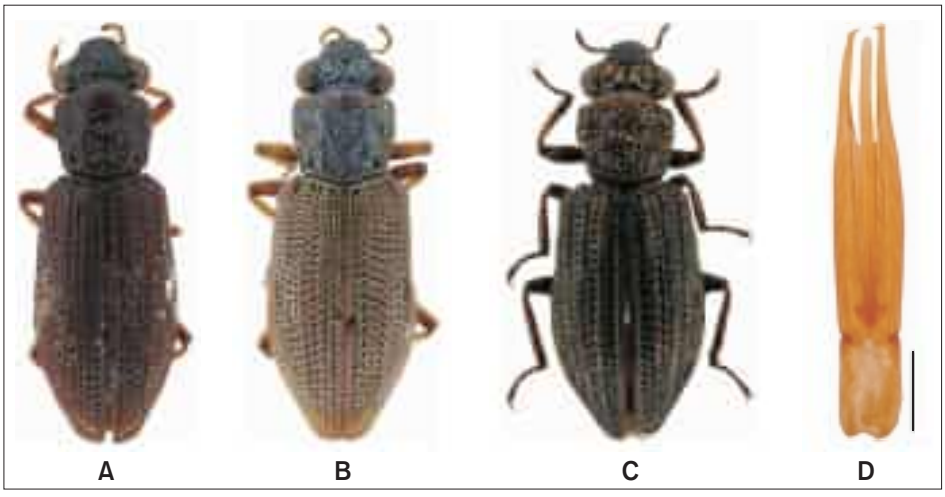

Fig. 1. Habitus and Aedeagus of Korean *Hydrochus* species. (A) *Hydrochus chubu*, 2.8 mm. (B) *Hydrochus japonicus*, 3.2 mm. (C) *Hydrochus laferi*, 2.8 mm. (D) Aedeagus of *H. laferi* (ventral view). Scale bar=0.1 mm.

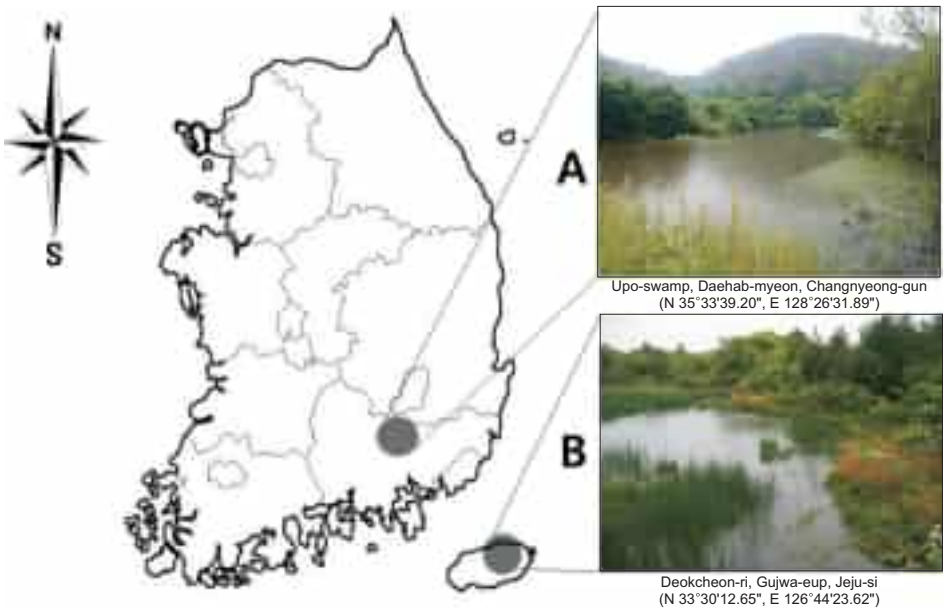

Fig. 2. Habitat. (A) Habitat of *Hydrochus laferi* in reservoir in Upo-swamp. (B) Habitat of *Hydrochus chubu* and *Hydrochus japonicus* in pond in Jejudo.

1♀, same data as former except for, 22 Aug 2007, Lee SH (CNUIC).

Distribution

Korea (South, North), China (Beijing, Fujian, Hainan, Hebei, Hubei, Jiangsu, Jilin, Jiangxi, Liaoning, Shaanxi, Shandong), Japan, Russia (Far East).

Habitat

The species was collected from a small pond formed on a basalt bedrock (approximately 45×11 m; surface area, 852 m^2). The water body is generally clear with low turbidity. The bottom substrate mainly consists of basalt stones with mud, and the surrounding area is largely covered by forests. Abundant marginal vegetation, including *Typha* and *Juncus* species, is present around the pond. Most individuals were found in submerged plant roots and organic debris along the shoreline (Fig. 2B).

Remarks

This species is listed as vulnerable (VU), a category that indicates a high risk of extinction in the wild, on the Japanese Red List (Ministry of the Environment, Japan, 2020). Therefore, a more detailed and accurate Red Data Book assessment is required for this species in Korea.

***Hydrochus japonicus* Sharp, 1873**

Korean name: Gom-bo-mul-ttang-ttang-i (Figs. 1B, 2B).

Hydrochus japonicus Sharp, 1873: 64; Balfour-Browne and Satô, 1962: 4; Nakane *et al*., 1963: 63; Satô, 1985: 205; Jäch, 1995: 182; Hansen, 2004: 43; Satô and Yoshitomi, 2005: 3; Jung *et al*., 2011: 43; Lee *et al*., 2013: 249.

Diagnosis

Length 3.0-3.6 mm, elongated, with many punctures. Head and pronotum metallic blue, elytra brown to yellowish brown with metallic bronze (Fig. 1B). Ventral surface dark brown. Mentum concave at middle. Pronotum as long as wide. Dorsal part of pronotal ridge flat. Elytral interstriae slightly raised. Median lobe slender and curved; apical margin V-shaped. Paramere longer than median lobe; abruptly narrows at basal half; middle to apical part nearly parallel; apical margin rounded.

Specimens examined

Lectotype: 1♂ (NHM), with labels as follows: "Type, Japan. Lewis., Sharp Coll 1905–313., Hydrochus japonicus type D. S. *Hydrochus japonicus* Sharp. Lectotype des. A. u. Berge Heuegoune. 1989". SOUTH KOREA: Jeju-do: 1♂, Jeju, Bukjeju-gun, Gujwa-eup, Deokcheon-ri, 11 VI 2005, DH Lee, *ex* pond (1♂: on slide, CNUIC); 1♂1♀, same data as former except for, 27 VII 2005, SH Lee (1♂1♀: on slides, CNUIC); 1♀, same data as former except for, 28 VII 2005, SH Lee; 1♂1♀, same data as former except for, Dongbaek-pond, 25 IX 2008.

Distribution

Korea (South, North), China (Hunan, Liaoning), Japan, Taiwan.

Habitat

The habitat of this species is the same as that of *H.*

chubu (Fig. 2B).

***Hydrochus laferi* Shatrovskiy, 1989**

Korean name: U-po-gom-bo-mul-ttang-ttang-i (Figs. 1C, D, 2A).

Hydrochus laferi Shatrovskiy, 1989: 275; Satô and Yoshitomi, 2005: 3.

Hydrochus aequalis: Satô, 1985: 205 (misidentification).

Description

Length 2.6-3.0 mm, elongated, with many punctures. Head, pronotum and elytra dark brown with metallic bronze (Fig. 1C). Ventral surface blackish brown with hydrofuse pubescence but leg brown to dark brown. Head depressed at middle part, epicranial suture indistinct. Antennae with 7 antennomeres and 5-7 clubbed with pubescence; 1 as long as 2-4 combined; apical part of 4 dish-shaped; 7 about 2.0 times longer than 6. Mentum concave at postero-median part, with large and sparse punctures, anterior margin rounded. Labrum with many long setae on anterior and lateral parts. Mandible with many short setae on apico-lateral part. Maxillary palpomere 1 with one seta on sub-basal part, 2 slightly shorter than 3 with two setae on sub-basal part, 4 slightly longer than 3 with one seta on sub-apical part. Labial palpomere 1 longer than 2; 3 with one long seta on apical part. Pronotum more or less reversed pentagonal with large seven impressions; lateral margin crenulated. Elytron with 4 large membranous punctures on apical part, diameter as long as elytral punctures. Pro- and mesofemur with hydrofuse pubescence on basal part, metafemur with hydrofuse pubescence on antero-basal fourth. Tarsomere 5 as long as 1-4 combined. Sternite VII with 10 large punctures on middle part, semitransparent plate with many spines on apical margin. Median lobe of aedeagus long and slender; apical margin rounded. Paramere longer than median lobe; gradually narrowing from apical third; apical margin straight and protrude inward (Fig. 1D).

Specimens examined

SOUTH KOREA: Gyeongsangnam-do: 20 exs, Changnyeong-gun, Daehap-myeon, Soya-ri, 24 VI 2025, DH Lee, TK Kim, *ex* reservoir; same data as former except for 10 exs, 19 IX 2025 (1♂: on slide, DRIBR).

Distribution

Korea (South), Japan, Russia (Far East).

Habitat

The species was collected from a small reservoir (approximately 66×25 m, surface area of 2,077 m^2) that received a continuous inflow from a nearby mountain stream. The surrounding environment consists of secondary wetlands and forests with a predominantly muddy bottom substrate and abundant marginal vegetation. Most individuals were found in the submerged plant debris along the shoreline (Fig. 2A).

Biological note

The species was observed only from June to September, corresponding to the summer–autumn period, and was not collected during the spring surveys. During the survey period, the aquatic beetles recorded in association with this species included Haliplidae: *Peltodytes chinensis*; Noteridae: *Noterus japonicus*; Dytiscidae: *Ilybius apicalis*, *Leiodytes nicobaricus*; and Hydrophilidae: *Amphiops mater*, *Enochrus simulans*, *Sternolophus rufipes*.

Remarks

This species can be distinguished from *H. aequalis* Sharp by a pronotum wider than long, and from *Hydrochus mitamurai* Hirasawa and Yoshitomi by the apex of the elytra not circularly excised.

Discussion

Regional species diversity in the genus *Hydrochus* is influenced not only by biogeographical factors but also by research intensity and habitat conditions. The relatively low number of species reported from China and the Russian Far East likely reflects an underestimation due to limited taxonomic efforts, rather than truly low diversity (Hansen, 2004). In contrast, Japan exhibits higher species richness, which may be attributed to its insular geography, complex topography, and geographic isolation, which promote speciation (Hirasawa & Yoshitomi, 2021). In addition, high precipitation and diverse lentic microhabitats, including small wetlands and temporary water bodies, provide suitable environments for *Hydrochus* species. The long-term accumulation of taxonomic studies in Japan has further contributed to a more accurate assessment of its species diversity (Hirasawa & Yoshitomi, 2021; Satô & Yoshitomi, 2005).

In Japan, five *Hydrochus* species have been recorded, most of which are rare or have a restricted distribution (Hirasawa & Yoshitomi, 2021). Three of these species have been previously identified in Korea. Notably, *H. chubu* is classified as VU, indicating a high risk of extinction (Ministry of the Environment, Japan, 2020). Although *H. laferi* is currently listed as data-deficient, its recent rediscovery after a long absence and its highly localized distribution suggest a potentially higher threat status (Hirasawa *et al*., 2025). In addition, *H. japonicus* has shown regional population declines (Satô & Yoshitomi, 2005). Each species occupies distinct microhabitats and co-occurrence is rare, indicating strong habitat specificity and high vulnerability to habitat loss (Hirasawa & Yoshitomi, 2021). These characteristics suggest that *Hydrochus* species are susceptible

to habitat alteration, especially in small lentic ecosystems, and similar patterns are likely to occur on the Korean Peninsula.

Therefore, expanded surveys encompassing diverse lentic habitats and increased taxonomic efforts are essential for reassessing species diversity. Furthermore, the implementation of Red List assessments and the development of conservation strategies targeting small lentic ecosystems are urgently required in Korea.

Author Contributions

Conceptualization: DHL, TKK. Data curation: SWJ, TKK. Funding acquisition: SHK, CSL. Investigation: DHL, TKK. Project administration: DHL, SHK. Resources: SHK, CSL. Supervision: TKK. Validation: CSL. Visualization: DHL. Writing – original draft: DHL. Writing – review & editing: DHL, SWJ, TKK.

Conflict of Interest

The authors declare that they have no competing interests.

Funding

This work was supported by grants from the National Institute of Biological Resources (NIBR), funded by the Ministry of Climate, Energy, and Environment (MCEE) of the Republic of Korea (NIBR201701203) and the National Institute of Ecology Republic of Korea (NIE-A-2025-19).

References

Archangelsky, M., Beutel, R.G., and Komarek, A. (2005). Hydrophiloidea. In R.G. Beutel, and R.A.B. Leschen (Eds.), *Handbook of Zoology, Volume IV, Arthropoda: Insecta, Part 38, Coleoptera, Beetles, Volume 1: Morphology and Systematics (Archostemata, Adephaga, Myxophaga, Polyphaga partim)* (pp. 158-183). Walter de Gruyter.

Balfour-Browne, J., and Satô, M. (1962). On the Japanese species of the genus Hydrochus Leach (Coleoptera, Hydrochidae). *Niponius,* 1, 1-6.

Hansen, M. (1991). *The Hydrophiloid Beetles: Phylogeny, Classification and a Revision of the Genera (Coleoptera, Hydrophiloidea)*. Royal Danish Academy of Sciences and Letters.

Hansen, M. (2004). Hydrochidae. In I. Löbl, and A. Smetana (Eds.), *Catalogue of Palaearctic Coleoptera, Vol. 2, Hydrophiloidea, Histeroidea, Staphylinoidea* (pp. 42-43). Apollo Books.

Hidalgo-Galiana, A., and Ribera, I. (2011). Late Miocene diversification of the genus *Hydrochus* (Coleoptera, Hydrochidae) in the west Mediterranean area. *Molecular Phylogenetics and Evolution,* 59, 377-385. https://doi.org/10.1016/j.ympev.2011.01.018

Hirasawa, K., and Yoshitomi, H. (2021). A new species of the genus *Hydrochus* (Coleoptera, Hydrochidae) from Fukushima, Northeastern Japan. *Elytra, Tokyo, New Series,* 11, 301-305.

Hirasawa, K., Kato, M., and Ueda, S. (2025). [Rediscovery of Hydrochus laferi Shatrovskiy, 1989 (Coleoptera: Hydrochidae) in Hokkaido, Japan for the first time in 31 years]. *Sayabane (New Series),* 59, 44-45. Japanese.

Jäch, M.A. (1995). Hydrochidae (Coleoptera). In M.A. Jäch, and L. Ji (Eds.), *Water Beetles of China, Vol. 1* (pp. 181-184). Wiener Coleopterologen Verein.

Jung, S.W., Lee, D.H., Ham, S.A., Huh, J.M., Hwang, J.M., and Bae, Y.J. (2011). Revised checklist of the Korean aquatic insects. *Entomological Research Bulletin,* 27, 37-52.

Leach, W.E. (1817). *The Zoological Miscellany, Being Descriptions of New, or Interesting Animals. Vol. 3*. E. Nodder & Son.

Lee, D.H., Lee, S.H., and Ahn, K.J. (2013). Taxonomy of the genus *Hydrochus* (Coleoptera: Hydrophilidae: Hydrochinae) in Korea. *Animal Systematics, Evolution and Diversity,* 29, 249-252. https://doi.org/10.5635/ased.2013.29.3.249

Ministry of the Environment, Japan. (2020). Red list 2020 of Japan: threatened wildlife of Japan. *Ministry of the Environment, Japan*. Retrieved Feb 9, 2026 from https://www.env.go.jp/content/900515981.pdf.

Nakane, T., Ohbayashi, K., Nomura, S., and Kurosawa, Y. (1963). *Iconographia insectorum Japonicorum colore naturali edita, Vol. 2 (Coleoptera)*. Hokuryukan.

Satô, M. (1985). Hydrochidae. In Y. Kurosawa, S. Hisamatsu, and H. Sasaji (Eds.), *Colored Illustration of the Coleoptera of Japan, Vol. 2* (pp. 204-205). Hoikusa.

Satô, M., and Yoshitomi, H. (2005). [Taxonomic notes on the aquatic Coleoptera of Japan, IV]. *Coleopterists' News, Tokyo,* 151, 1-6. Japanese.

Schaller, J.G. (1783). Neue Insekten. *Abhandlungen der Hallischen Naturforschenden Gesellschaft,* 1, 217-332.

Sharp, D. (1873). The water beetles of Japan. *Transactions of the Royal Entomological Society of London,* 21, 45-67. https://doi.org/10.1111/j.1365-2311.1873.tb00636.x

Shatrovskiy, A.G. (1989). Hydraenidae, Hydrophilidae. In P.A. Ler (Ed.), *Opredelitel' Nasekomykh Dal'nego Vostoka SSSR v shesti tomakh. Vol. 3. Zhestkokrylye, ili shuki (Part 1)* (pp. 260-293). Nauka.

Short, A.E.Z., and Fikáček, M. (2011). World catalogue of the Hydrophiloidea (Coleoptera): additions and corrections II (2006–2010). *Acta Entomologica Musei Nationalis Pragae,* 51, 83-122.

Taşar, G.E. (2018). Contributions to the knowledge of aquatic Coleoptera fauna (Dryopidae, Helophoridae, Heteroceridae, Hydrochidae, Hydrophilidae, Gyrinidae, Haliplidae and Noteridae) of Diyarbakır, Mardin and Batman Provinces (Turkey). *Turkish Journal of Fisheries and Aquatic Sciences,* 18, 927-936. https://doi.org/10.4194/1303-2712-v18_8_01

Thomson, C.G. (1859). *Skandinaviens Coleoptera, Synoptiskt Bearbetade*. Tryckt Uti Berlingska Boktryckeriet.

PNIE PROCEEDINGS OF THE NATIONAL INSTITUTE OF ECOLOGY OF THE REPUBLIC OF KOREA

Original Article

PNIE 2026;7(3):103-109
https://doi.org/10.22920/PNIE.2026.7.3.103
pISSN 2765-2203, eISSN 2765-2211

Insect Diversity and Conservation Importance of the Wolbong Abandoned Paddy Wetland, a Habitat for an Endangered Korean Dragonfly

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ABSTRACT

A comprehensive insect survey conducted in 2025 in the Wolbong abandoned paddy wetland in South Korea recorded a total of 337 insect species comprising 306 genera, 115 families, and 13 orders, indicating high taxonomic richness within a small agricultural wetland system. Lepidoptera was the most species-rich order, followed by Coleoptera, Hemiptera, and Odonata, reflecting the structural habitat heterogeneity provided by the mosaic of abandoned paddies and adjacent forest margins. Two endemic Korean species (*Cantharis soeulensis* and *Thyris fenestrella seoulensis*) and two newly recorded species in South Korea (*Eutonia satsuma* and *Japonichilo bleszynski*) were observed for the first time. Odonata showed a particularly high conservation value, with 43 species representing approximately 42% of the Korean Odonata fauna. Two endangered Class II species, *Nannophya koreana* and *Libellula angelina*, were consistently observed in both larval and adult stages. In addition, a record of over 2,000 adults of *N. koreana* suggests that this habitat may harbor the largest remaining population in South Korea. In conclusion, this study demonstrates that abandoned paddy wetlands serve as critical biodiversity refugia for endemic and conservation-priority taxa. Long-term monitoring and systematic habitat management are essential to sustain insect diversity in agricultural wetland landscapes.

Keywords: Biodiversity, Endangered species, Gokseong-gun, Odonata, Wetland restoration

Introduction

Wetlands are among the most productive ecosystems and provide essential ecological functions such as biodiversity maintenance, water regulation, and nutrient cycling. They support a wide range of organisms, particularly insects, which play key roles in food webs and ecosystem processes (Åhlén *et al.*, 2024; Dijkstra *et al.*, 2014). However, in recent decades, natural wetlands have been severely reduced or degraded due to changes in land use, agricultural intensification, and urban development, leading to significant declines in wetland-dependent insect species (Nyandwi & Ndikubwimana, 2024).

Abandoned paddy wetlands have emerged as important secondary habitats that partially compensate for the loss of natural wetlands in agricultural landscapes. These habitats often contain shallow water, emergent vegetation,

Received March 2, 2026; **Revised** May 7, 2026; **Accepted** May 8, 2026

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and surrounding terrestrial environments, creating favorable conditions for diverse insect assemblages, especially aquatic and semi-aquatic taxa such as Odonata, Hemiptera, and Coleoptera (Ahn *et al.*, 2017; Kim *et al.*, 2017a). Previous studies have demonstrated that abandoned paddy fields can support high insect diversity and provide critical breeding and foraging habitats for threatened species, highlighting their potential value in biodiversity conservation (Comín *et al.*, 2001; Do *et al.*, 2011; Paik *et al.*, 2009). In South Korea, abandoned paddy wetlands have been increasingly recognized as important refugia, as reduced agricultural disturbance and stable hydrological conditions facilitate the persistence of specialized and sensitive taxa.

The Wolbong abandoned paddy wetland in Gokseong-gun represents a well-preserved example of such a habitat. Characterized by stable water levels and minimal anthropogenic interference, the site offers suitable conditions for aquatic and semi-aquatic insects, particularly Odonata. Dragonflies are widely regarded as reliable bioindicators because their life cycles integrate both aquatic and terrestrial environments, making them highly responsive to environmental changes. Preliminary surveys have documented several legally protected and habitat-specialist species at the site, including endangered *Nannophya koreana* Bae and *Libellula angelina* Selys, highlighting its significance as a regional hotspot for Odonata diversity (Bae *et al.*, 1999; Hong *et al.*, 2023; Yoon *et al.*, 2010).

Despite their ecological significance, comprehensive and long-term assessments of insect fauna of the Wolbong abandoned paddy wetland remain limited. Therefore, this study aimed to document the diversity of Odonata in the Wolbong abandoned paddy wetland and to evaluate its conservation value, thereby providing baseline data for future biodiversity monitoring and sustainable management of abandoned paddy ecosystems.

Materials and Methods

The study was conducted at the Wolbong abandoned paddy wetland (10,460 m^2) located in Wolbong-ri, Gokseong-gun, Jeollanam-do, Republic of Korea (35°15′53.3″N, 127°16′08.6″E) (Fig. 1). The site is characterized by shallow open water, emergent vegetation, and surrounding terrestrial habitats formed through the long-term abandonment of paddy fields, with a stable water level maintained year-round by the continuous inflow of water into the wetland. Insect diversity was investigated using multiple sampling methods to collect a wide range of terrestrial and aquatic insect taxa from February to October 2025. Terrestrial insects were sampled using a sweeping n*et al*ong wetland margins and vegetated areas, direct observation of visually detectable species, and light traps operated at night to attract nocturnal insects. Aquatic insects were collected using a D-frame net (mesh size=0.5 mm) and hand nets (mesh size=1 mm) in the shallow water and vegetated zones of the wetland.

The collected specimens were preserved in 80% ethyl alcohol and identified to the lowest possible taxonomic level using available reference sources (Ahn *et al.*, 2018;

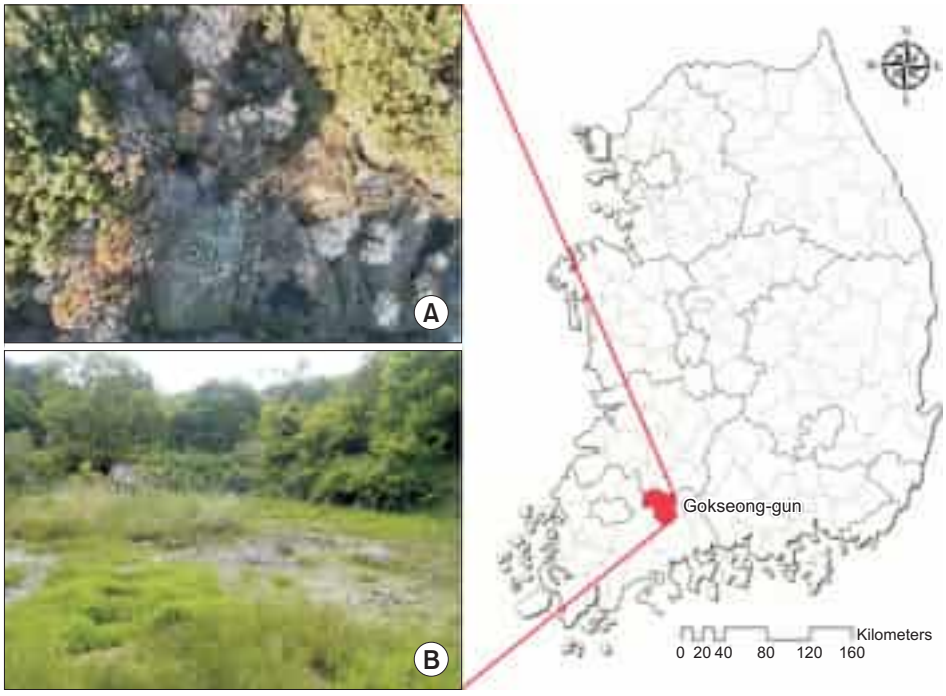

Fig. 1. A map and habitats of Wolbong abandoned paddy wetland in Gokseong-gun, South Korea. (A) Macrohabitat. (B) Microhabitat.

Jung, 2011; Jung & Lee, 2025; Kim & Paek, 2020; Kim *et al.*, 2017b; Kononenko *et al.*, 1998; Kwon *et al.*, 2013; Paek, 2016; Yoon, 1995). Species nomenclature followed the current taxonomic standards, and nationally endangered species were determined according to the designation of Endangered Wildlife Class Species II by the Ministry of Environment of the Republic of Korea. The assessment of Odonata diversity was based on previously published monitoring reports of the Wolbong abandoned paddy wetland carried out in Gokseong-gun.

Results and Discussion

Insect diversity

In total, 337 insect species belonging to 306 genera, 115 families, and 13 orders were recorded from the Wolbong abandoned paddy wetland during the 2025 survey (Table 1, Supplementary Table 1). Among these, the Lepidoptera was the most species-rich group, comprising 126 species from 116 genera and 27 families. Coleoptera was the second most diverse order (86 species, 77 genera, and 26 families), followed by Hemiptera (42 species, 41 genera, and 24 families), Odonata (29 species, 23 genera, and 8 families), Diptera (19 species, 18 genera, and 10 families), Orthoptera (12 species, 11 genera, and 4 families), and Hymenoptera (11 species, 9 genera, and 6 families). Trichoptera (4 species, 4 genera, and 4 families), Mantodea (3 species, 2 genera, and 1 family), and Ephemeroptera (2 species, 2 genera, and 2 families) were represented by relatively few taxa. Dermaptera, Blattodea, and Megaloptera were represented by a single species.

In relative species composition, Lepidoptera accounted for the highest proportion of the total fauna (37.39%), followed by Coleoptera (25.52%), Hemiptera (12.46%), Odonata (8.61), Diptera (5.64%), Orthoptera (3.56%), Hymenoptera (3.26%), Trichoptera (1.19%), Mantodea (0.89%), and Ephemeroptera (0.59%) (Fig. 2). In contrast, Dermaptera, Blattodea, and Megaloptera showed the lowest relative dominance, each representing 0.30% of the total species recorded. Two Korean endemic species, *Cantharis soeulensis* and *Thyris fenestrella seoulensis*, were recorded, along with four wetland-specialist species (*Stenus mercator*, *Stenus comma*, *Geodromicus lestevoides*, and *Paederus fuscipes*). Moreover, two unrecorded species, *Eutonia satsuma* (Diptera: Tipulidae) and *Japonichilo bleszynski* (Lepidoptera: Crambidae) were observed for the first time in the study area (Fig. 3). The occurrence of previously unrecorded species in South Korea further emphasizes the ecological significance of this study site. The presence of such taxa suggests that the habitat may

Table 1. The number of species and relatively dominant ratio in Wolbong abandoned paddy wetland, Gokseong-gun

Order	Family	Genus	Species	Relatively dominant ratio (%)
Lepidoptera	27	116	126	37.39
Coleoptera	26	77	86	25.52
Hemiptera	24	41	42	12.46
Odonata	8	23	29	8.61
Diptera	10	18	19	5.64
Orthoptera	4	11	12	3.56
Hymenoptera	6	9	11	3.26
Trichoptera	4	4	4	1.19
Mantodea	1	2	3	0.89
Ephemeroptera	2	2	2	0.59
Dermaptera	1	1	1	0.30
Blattodea	1	1	1	0.30
Megaloptera	1	1	1	0.30
Total	115	306	337	100.00

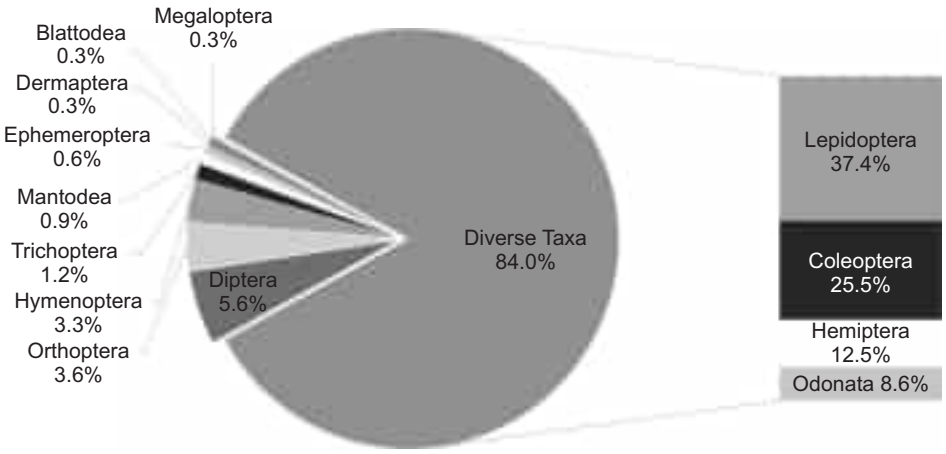

Fig. 2. Percentage composition of insect orders recorded from Wolbong abandoned paddy wetland (Gokseong-gun, South Korea) in 2025.



Fig. 3. Photographs of two unrecorded species from the Wolbong abandoned paddy wetland in South Korea. (A) *Eutonia satsuma* (Westwood) (Diptera: Tipulidae). (B) *Japonichilo bleszynski* Okano (Lepidoptera: Crambidae).

support a higher level of biodiversity than currently documented. Therefore, long-term and detailed investigations are required to understand better the species composition and to inform effective management strategies.

The high species richness of Lepidoptera observed in the study area is likely attributable to the use of nocturnal light trapping, which preferentially captures diverse moth assemblages (Truxa & Fiedler, 2012). The relatively high diversity of Coleoptera and Hemiptera may reflect a heterogeneous habitat structure resulting from a mosaic of abandoned paddy fields and adjacent forest ecosystems (Ahn *et al.*, 2017; Do *et al.*, 2011; Kim *et al.*, 2017a). This pattern is likely associated with residual nutrient accumulation from previous agricultural practices and the gradual progression of ecological succession, which together enhance habitat complexity and resource heterogeneity (Comín *et al.*, 2001).

Similarly, the sustained occurrence and diversity of Odonata can be explained by the continuous inflow of water from the former upstream small pond area, which maintains stable water levels throughout the year. Such hydrological stability is essential for the completion of their life cycles, and likely contributes to the persistence and diversity of dragonflies and damselflies in wetland ecosystems.

Diversity of Odonata and endangered species

Odonata is a major taxonomic group within the insect assemblage of the Wolbong abandoned paddy wetland and is widely recognized as a sensitive bioindicator of wetland ecosystem health (Corbet, 1999; Kadoya & Washitani, 2007). In this study, 43 species of Odonata were recorded (Table 2), representing approximately 42% of the total Odonata fauna documented in South Korea (103 species; Jung & Lee, 2018). This high species richness underscores the ecological significance of habitat as a critical refugia for both dragonflies and damselflies diversity. In addition, two endangered species (Class II), *N. koreana* and *L. angelina*, were consistently observed in both larval and adult stages (Fig. 4) throughout the survey period, confirming their residency since 1999 (Bae *et al.*, 1999). Specifically, observations of over 2,000 adults of *N. koreana* suggest that this site is one of the largest known populations in South Korea. This stenotopic species maintains a stable population within shallow, stagnant water zones characterized by diverse macrophytes, including *Typha latifolia*, *Scirpus triangulatus*, *Phragmites japonica*, *Juncus effusus* var. *decipiens*, *Trapa japonica*, *Potamogeton distinctus*, and *Persicaria thunbergii*. Furthermore, monitoring data from the Green Gokseong21 Council recorded over 200 adults of *L. angelina* in 2024. These findings indicated that the species successfully reproduced and maintained a stable life cycle within its habitat.

As hemimetabolous insects occupy both aquatic and terrestrial environments, Odonata are pivotal for assessing environmental gradients. They provide essential ecosystem services as top-tier invertebrate predators, regulating populations of dipteran pests (e.g., mosquitoes), while serving as a fundamental prey base for higher trophic levels, including fish, amphibians, reptiles, and birds (Córdoba-Aguilar *et al.*, 2021; May, 2013; May, 2019; Samways, 2024).

According to the Korean Red Data Book (2023), 12 Odonata species are currently managed as Vulnerable and Near Threatened: *Paracercion plagiosum*, *Asiagomphus coreanus*, *Asiagomphus melanopsoides*, *Macromia daimoji*, *L. angelina*, *N. koreana*, *Lestes temporalis*, *Aeshna juncea*, *Aeshna mixta*, *Aeschnophlebia anisoptera*, *Boyeria maclachlani*, and *Somatochlora metallica*.

The presence of such conservation-priority species in the Wolbong abandoned paddy wetland highlights the urgent need for systematic management. The transition of abandoned paddies into natural wetlands creates unique ecological niches that support specialized taxa. Therefore, maintaining habitat heterogeneity and minimizing anthropogenic disturbances are likely to be key factors in sustaining insect diversity and Odonata populations. To prevent habitat degradation and ensure the long-term persistence of endangered dragonflies, legal

Table 2. Annual occurrence of Odonata in Wolbong abandoned paddy wetland, Gokseong-gun

No.	Family	Scientific name	2025	2024	2012	2004-2006
1	Calopterygidae	*Atrocalopteryx atrata*	O	O	O	
2	Calopterygidae	*Calopteryx japonica*	O		O	
3	Platycnemididae	*Copera tokyoensis*			O	
4	Platycnemididae	*Platycnemis phyllopoda*	O	O	O	
5	Platycnemididae	*Copera annulata*	O			
6	Coenagrionidae	*Paracercion calamorum*	O		O	O
7	Coenagrionidae	*Paracercion hieroglyphicum*	O		O	O
8	Coenagrionidae	*Coenagrion johanssoni*	O	O	O	
9	Coenagrionidae	*Ischnura asiatica*	O	O	O	O
10	Coenagrionidae	*Ceriagrion melanurum*	O	O	O	O
11	Coenagrionidae	*Ceriagrion nipponicum*	O	O	O	
12	Lestidae	*Sympecma paedisca*		O		
13	Lestidae	*Lestes sponsa*		O		
14	Lestidae	*Indolestes peregrinus*	O		O	O
15	Aeshnidae	*Anax parthenope julius*	O			O
16	Aeshnidae	*Anax nigrofasciatus*	O	O	O	O
17	Libellulidae	*Nannophya koreana**	O	O	O	O
18	Libellulidae	*Libellula angelina**	O	O	O	
19	Libellulidae	*Libellula quadrimaculata*			O	
20	Libellulidae	*Lyriothemis pachygastra*	O	O	O	
21	Libellulidae	*Orthetrum albistylum*	O	O	O	O
22	Libellulidae	*Orthetrum japonicum*	O	O	O	
23	Libellulidae	*Orthetrum melania*	O		O	
24	Libellulidae	*Orthetrum lineostigma*	O			O
25	Libellulidae	*Crocothemis servilia mariannae*	O	O	O	O
26	Libellulidae	*Deielia phaon*			O	
27	Libellulidae	*Sympetrum eroticum*	O	O	O	
28	Libellulidae	*Sympetrum darwinianum*		O		
29	Libellulidae	*Sympetrum frequens*	O	O	O	O
30	Libellulidae	*Sympetrum striolatum*		O		
31	Libellulidae	*Sympetrum infuscatum*		O	O	
32	Libellulidae	*Sympetrum speciosum*			O	
33	Libellulidae	*Sympetrum pedemontanum elatum*		O		
34	Libellulidae	*Pantala flavescens*		O		
35	Libellulidae	*Pseudothemis zonata*	O		O	
36	Libellulidae	*Rhyothemis fuliginosa*	O	O	O	
37	Corduliidae	*Epitheca marginata*	O	O	O	
38	Macromiidae	*Epophthalmia elegans*			O	
39	Gomphidae	*Trigomphus nigripes*	O	O		
40	Gomphidae	*Burmagomphus collaris*			O	
41	Gomphidae	*Sieboldius albardae*	O			
42	Gomphidae	*Davidius lunatus*	O		O	O
43	Gomphidae	*Trigomphus citimus*			O	

*Endangered Wildlife Class Species II.

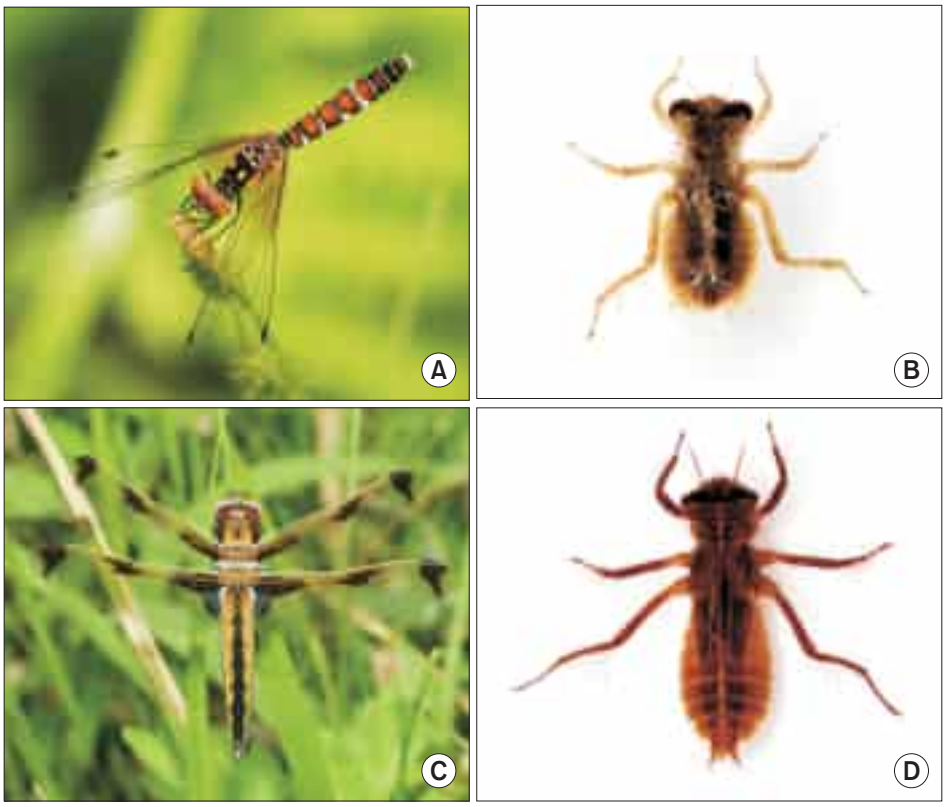

Fig. 4. Endangered Wildlife Class Species II designated by the Ministry of Enviornment, South Korea, observed in the Wolbong abandoned paddy wetland. (A, B) *Nannophya koreana* Bae (A: female; B: larva). (C, D) *Libellula angelina* Selys (C: female; D: larva).

protection and continuous long-term monitoring must be prioritized.

Author Contributions

Conceptualization: SWJ. Data curation: SWJ, YHK, JHK. Formal analysis: SWJ, JHL. Funding acquisition: SWJ. Investigation: SWJ, YHK, JHK, DHL, SBS, JHL. Methodology: SWJ, YSP. Visualization: SBS. Writing – original draft: SWJ. Writing – review & editing: SWJ, YSP.

Conflict of Interest

The authors declare that they have no competing interests.

Acknowledgments

We express our sincere gratitude to Sangrae Cho, the Mayor of Gokseong-gun, and the staff of the Environmental Division of the Gokseong-gun Office for their support in conducting this research at the Wolbong Abandoned Paddy Wetland. We also extend our thanks to Jeong-Su Park (Director of the Green Gokseong 21 Council) for his valuable assistance during the field surveys. We are also grateful to Dr. Jisoo Kim of the Nakdonggang National Institute of Biological Resources (NNIBR) for the identification of the family Tipulidae.

Funding

This study was supported by the Ecosystem Conservation Charge Return Project of Gokseong-gun, Jeollanam-do, funded by the Ministry of Climate, Energy and Environment (MCEE) of the Republic of Korea.

References

Åhlén, D., Jarsjö, J., Jonsell, M., Klatt, B.K., Schneider, L.D., Strand, J., *et al.* (2024). Arthropod diversity in constructed wetlands is affected strongly by shoreline properties but only weakly by grazing. *Journal of Biogeography,* 51, 2323-2333. https://doi.org/10.1111/jbi.14997

Ahn, S.J., Chiluwal, K., Choi, S.H., and Park, C.G. (2017). Diversity of insect fauna in Junam wetland of Korea. *Korean Journal of Applied Entomology,* 56, 135-145.

Ahn, S.J., Kim, W.G., Kim, S.S., and Park, C.G. (2018). *The Terrestrial Heteroptera of Korea*. Nature and Ecology.

Bae, Y.J., Yum, J.H., Cha, J.Y., and Yoon, I.B. (1999). Morphology, habitat, and distributional records of *Nannophya pygmaea* Ramber (Libellulidae, Odonata). *Korean Journal of Entomology,* 29, 287-290.

Comín, F.A., Romero, J.A., Hernández, O., and Menéndez, M. (2001). Restoration of wetlands from abandoned rice fields for nutrient removal, and biological community and landscape diversity. *Restoration Ecology,* 9, 201-208. https://doi.org/10.1046/j.1526-100x.2001.009002201.x

Corbet, P.S. (1999). *Dragonflies: Behavior and Ecology of Odo-*

nata. Comstock Publishing Associates.

Córdoba-Aguilar, A., San Miguel-Rodríguez, M., Rocha-Ortega, M., Lanz-Mendoza, H., Cime-Castillo, J., and Benelli, G. (2021). Adult damselflies as possible regulators of mosquito populations in urban areas. *Pest Management Science,* 77, 4274-4287. https://doi.org/10.1002/ps.6496

Dijkstra, K.D., Monaghan, M.T., and Pauls, S.U. (2014). Freshwater biodiversity and aquatic insect diversification. *Annual Review of Entomology,* 59, 143-163. https://doi.org/10.1146/annurev-ento-011613-161958

Do, Y.N., Jeong, K.S., Lineman, M., Kim, J.Y., Kim, H.A., and Joo, G.J. (2011). Community changes in carabid beetles (Coleoptera: Carabidae) through ecological succession in abandoned paddy fields. *Journal of Ecology and Environment,* 34, 269-278. https://doi.org/10.5141/JEFB.2011.029

Hong, J., Kwon, S.J., Lee, C.S., Choi, J.Y., Cho, K., and Kim, H.G. (2023). Potential distribution of the critically endangered dragonfly *Libellula angelina* (Odonata: Libellulidae) under shared socio-economic pathways. *Entomological Research,* 53, 367-379. https://doi.org/10.1111/1748-5967.12671

Jung, K.S. (2011). *Odonata Larvae of Korea*. Nature and Ecology.

Jung, K.S., and Lee, J.E. (2018). *A Pictorial Key of the Odonata from Korea*. Nature and Ecology.

Jung, S.W., and Lee, D.H. (2025). *A Point Guide Book of Aquatic Coleoptera & Hemiptera in Korea*. Nature and Ecology.

Kadoya, T., and Washitani, I. (2007). An adaptive management scheme for wetland restoration incorporating participatory monitoring into scientific predictions using dragonflies as an indicator taxon. *Global Environmental Research,* 11, 179-185. https://doi.org/10.57466/ger.11.2_179

Kim, M.H., Hwang, J.H., Choi, E.Y., Park, J., and Park, J.K. (2017a). Insect diversity on the paddy field wetland, Gonggeom-ji, Sangju, first designed by Ministry of Environment, Korea. *Journal of Wetlands Research,* 19, 155-163. https://doi.org/10.17663/JWR.2017.19.1.155

Kim, S.S., and Paek, M.K. (2020). *A Photographic Guide to Korean Moths*. Nature and Ecology.

Kim, Y.H., Min, H.K., Jung, S.W., An, J.W., and Paek, W.K. (2017b). *An Identification Guide to Natual Histroy: A Guide Book of Beetles*. Areumwon.

Kononenko, V., Ahn, S.B., and Ronkay, L. (1998). *Insecta of Korea Series 3: Illustrated Catalogue of Noctuidae in Korea (Lepidoptera)*. Korea Research Institute of Bioscience and Biotechnology & Center for Insect Systematics Korea.

Kwon, S.J., Jeon, Y.C., and Park, J.H. (2013). *A Guidebook of Aquatic Fauna: Benthic Macroinvertebrates*. Nature and Ecology.

May, M.L. (2013). A critical overview of progress in studies of migration of dragonflies (Odonata: Anisoptera), with emphasis on North America. *Journal of Insect Conservation,* 17, 1-15. https://doi.org/10.1007/s10841-012-9540-x

May, M.L. (2019). Odonata: who they are and what they have done for us lately: classification and ecosystem services of dragonflies. *Insects,* 10, 62. https://doi.org/10.3390/insects10030062

Nyandwi, O., and Nidikubwimana, I. (2024). The effects of wetland degradation on ecological species. *International Journal of Innovative Science and Research Technology,* 9, 2160-2169. https://doi.org/10.38124/ijisrt/IJISRT24APR1244

Paek, M.K. (2016). *A Point Guide Book of Korean Insects*. Nature and Ecology.

Paik, C.H., Lee, G.H., Kang, J.G., Jeon, Y.K., and Choi, M.Y. (2009). Plant flora and insect fauna in the fallow paddy fields of Jeonnam and Jeonbuk Province. *Korean Journal of Applied Entomology,* 48, 285-294.

Samways, M.J. (2024). *Conservation of Dragonflies: Sentinels for Freshwater Conservation*. CAB International.

Truxa, C., and Fiedler, K. (2012). Attraction to light – from how far do moths (Lepidoptera) return to weak artificial sources of light? *European Journal of Entomology,* 109, 77-84.

Yoon, I.B. (1995). *Aquatic Insects of Korea*. Junghaengsa.

Yoon, J., Nam, J.M., Kim, H., Bae, Y.J., and Kim, J.G. (2010). Nannophya pygmaea (Odonata: Libellulidae), an endangered dragonfly in Korea, prefers abandoned paddy fields in the early seral stage. *Environmental Entomology,* 39, 278-285. https://doi.org/10.1603/EN09103

PNIE PROCEEDINGS OF THE NATIONAL INSTITUTE OF ECOLOGY OF THE REPUBLIC OF KOREA

Original Article

PNIE 2026;7(3):110-122
https://doi.org/10.22920/PNIE.2026.7.3.110
pISSN 2765-2203, eISSN 2765-2211

Vegetation Patterns and Conservation Value Grades of Designated Islands in Jeju Special Self-Governing Province

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ABSTRACT

Vegetation surveys were conducted from May to September 2024 on six designated islands—Heukgeomdo, Cheongdo, Jikgudo, Suryeongseom, Boronseom, and Yeomseom—located around Chuja-myeon, Jeju-si, Jeju Special Self-Governing Province. This study identified major plant communities, including evergreen broad-leaved forests such as the *Machilus thunbergii–Camellia japonica* and the *Machilus thunbergii–Litsea japonica* communities, as well as deciduous broad-leaved forests, montane shrub vegetation, evergreen coniferous forests, and grassland vegetation. The vegetation structure, dominant species, and interrelationships among vegetation types were analyzed to evaluate the conservation value grades of the uninhabited islands. Cheongdo and Boronseom, with well-developed warm-temperate communities, exhibited mature and stable vegetation zones. Vegetation communities distributed along coastal cliffs and escarpments were classified as Grade II in terms of conservation value, indicating very high importance. The *Camellia japonica–Litsea japonica* community covered the largest area (29,073 m^2), followed by the *Pinus thunbergii* community (49,539 m^2). The *Miscanthus sinensis–Carex wahuensis* var. *robusta* community was the most extensive grassland type (69,184 m^2). Evergreen broad-leaved forests were predominant in Heukgeomdo, Jikgudo, and Suryeongseom, whereas grassland vegetation was extensive in Cheongdo and Heukgeomdo. A new evaluation framework, the "Vegetation Conservation Value Assessment Criteria for Uninhabited Islands in Jeju Special Self-Governing Province," was established, and conservation grades were assigned to each island. Heukgeomdo, Jikgudo, Suryeongseom, and Boronseom were classified as Grade I areas, whereas Cheongdo and Yeomseom were Grade II areas. These results provide fundamental baseline data for the future designation of management types and the efficient conservation and management of designated islands.

Keywords: Conservation value grades, Evaluation framework, Evergreen broad-leaved forests, Grassland vegetation, Uninhabited islands, Vegetation surveys

Introduction

Plants distributed in island regions differ from those of mainland floras in that they are adapted to the distinctive environmental conditions of each island. Because these island plants have been isolated from the mainland for long periods and have maintained unique natural envi-

Received January 17, 2026; **Revised** May 10, 2026; **Accepted** May 11, 2026

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ronments, the proportion of endemic and rare species is relatively high. Therefore, such regions are evaluated as areas of high conservation value (Jeollanam-do, 2000). Although island regions generally have limited land areas, which may result in lower species diversity or increased vulnerability to abrupt environmental changes, inhabited islands are subject to continuous anthropogenic interference and disturbances, leading to persistent alterations in natural ecosystems. Nevertheless, the flora of island regions exhibits adaptive characteristics that are distinct from those of mainland areas (Jeollanam-do, 2002). Owing to prolonged geographic isolation and the preservation of unique environmental conditions, island floras support a high proportion of endemic and rare species and are thus regarded as ecologically significant. Consequently, island floras occupy an important position from the perspectives of phytosociology, ecology, species diversity, and biological resource utilization (Kim, 2012; Kim & Oh, 2013).

To date, studies on the characteristics of plant distribution on uninhabited islands in Korea have been relatively limited compared to those on inhabited islands, and have been confined to only a small number of islands (Oh & Beon, 2007). However, following the enactment of the Act on the Conservation and Management of Uninhabited Islands (Act No. 8620) on August 3, 2007, research on the management of uninhabited islands has been actively conducted. These uninhabited islands often possess high ecological and natural conservation value or potential for use and development. Therefore, to establish a systematic and sustainable management framework for uninhabited islands and their surrounding marine areas and to develop management strategies tailored to different categories of conservation, use, and development, it is necessary to classify and grade ecosystem health.

"Specified islands" refer to islands where no people reside or where habitation is extremely limited and which possess outstanding natural ecosystems, landforms, geology, and natural environments, including islands such as Dokdo (Article 2, Paragraph 1 of the Act on the Conservation and Management of Island Ecosystems). The Ministry of Environment conducts nationwide surveys of the natural environment of uninhabited islands each year, including exploratory surveys to identify specified islands, detailed investigations of designated islands, and continuous monitoring of natural ecosystems.

To date, the Ministry of Environment has designated 260 uninhabited islands (8.9%) as specified islands out of 2,918 uninhabited islands in Korea, based on their outstanding natural ecosystems and geomorphological landscapes. The primary reasons for designation as specified islands were geomorphological landscapes (29.4%), vegetation (21.4%), and avifauna (19.0%) (Ministry of Environment, 2024). To systematically manage and conserve uninhabited islands through such designations, objective criteria are required to evaluate their natural environments. Accordingly, the Draft Criteria for Conservation Value Grading of Uninhabited Islands were established by developing objective evaluation standards and differentiated analyses that consider the specific characteristics of designated islands (Ministry of Environment & National Institute of Ecology, 2016). However, as these criteria have been applied in the field over time, it has become necessary to discuss and analyze the appropriateness of the advanced draft criteria for the conservation value grading of uninhabited islands through field verification of evaluation methods and contents under diverse natural environmental conditions, followed by revision and supplementation processes.

This study aims to provide baseline data for the natural environment assessment of specified islands by presenting the current status of vegetation on specified islands in the Jeju Special Self-Governing Province and proposing new draft evaluation criteria for vegetation components.

Materials and Methods

Vegetation surveys in the study area were conducted through field investigations from May to September 2024, focusing on major specified islands around Chujamyeon, Jeju Special Self-Governing Province, including Heukgeomdo (145,884 m^2), Cheongdo (167,603 m^2), Jikgudo (77,160 m^2), Suryeongseom (45,719 m^2), Boronseom (16,552 m^2), and Yeomseom (14,380 m^2) (Table 1, Fig. 1). Heukgeomdo is located approximately 4.8 km east of Sangchujado Port in Chuja-myeon, Jeju-si, Jeju Special Self-Governing Province and approximately 3 km north of the coastal area of Yecho Port on the adjacent Hachujado Island (San 153-1, Daeseori, Chuja-myeon, Jeju-si). The island has a maximum elevation of 106 m above sea level. Cheongdo is located approximately 3.3 km south of Sinyang Port in Chuja-myeon, Jeju-si, Jeju Special Self-Governing Province, and approximately 1.7 km south of the coastal area of Daewangsan (124.9 m above sea level) on the adjacent Hachujado Island (San 150, Sinyang-ri, Chuja-myeon, Jeju-si). The island has a maximum elevation of approximately 100 m above sea level. Jikgudo is located approximately 5.1 km northwest of Sangchujado Port in Chuja-myeon, Jeju-si, Jeju Special Self-Governing Province, and approximately 3.2 km northwest of the Damuraemi coastal area of the adjacent Sangchujado Island (San 150-1, Daeseori, Chuja-myeon, Jeju-si). The island has a maximum elevation of 105 m above sea level. Suryeongseom is located approximately 2.3 km north of Sangchujado Port in Chuja-myeon, Jeju-si, Jeju Special Self-Governing Province, and approximately 1.6 km northeast of the Damuraemi coastal area of the adjacent Sangchujado Island (San 152, Daeseori, Chuja-myeon,

Table 1. Status of specified islands by area category

Is. ID*	Designation number	Coordinate point	Altitude (m)	Area (m^2)
J1	132	33° 58′ 58.95“N 126° 20′ 56.17“E	106	145,884
J2	133	33° 54′ 52.23“N 126° 19′ 22.34“E	100	167,603
J3	205	33° 59′ 17.35“N 126° 15′ 03.98“E	105	77,160
J4	206	33° 59′ 00.77“N 126° 17′ 44.37“E	100	45,719
J5	207	33° 59′ 40.91“N 126° 23′ 31.56“E	65	16,552
J6	208	33° 58′ 29.35“N 126° 18′ 25.15“E	50	14,380

*J1: Heukgeomdo, J2: Cheongdo, J3: Jikgudo, J4: Sureungdo, J5: Boronseom, J6: Yeomseom.

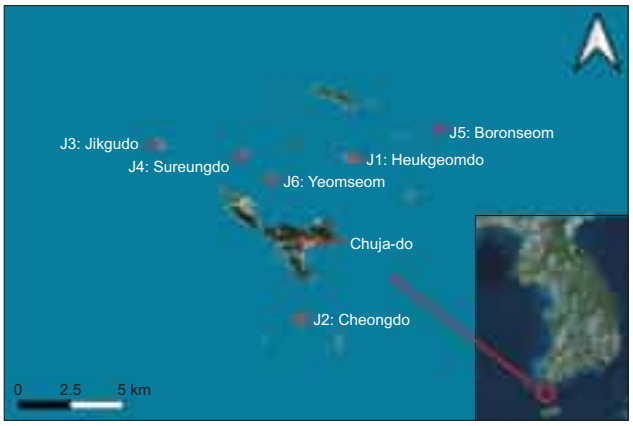

Fig. 1. Surveyed specified islands in Jeju Special Self-Governing Province.

Jeju-si). The island has a maximum elevation of approximately 100 m above sea level. Boronseom is located approximately 9.4 km east of Sangchujado Port in Chuja-myeon, Jeju-si, Jeju Special Self-Governing Province, and approximately 6.6 km east of the coastal area of Yecho Port on Hachujado Island (San 154, Daeseori, Chuja-myeon, Jeju-si). The island has a maximum elevation of 65 m above sea level. Yeomseom is located approximately 1.4 km north of Sangchujado Port in Chuja-myeon, Jeju-si, Jeju Special Self-Governing Province, and approximately 1.3 km northeast of the coastal area of Deungdaesan on the adjacent Sangchujado Island (San 87, Yecho-ri, Chuja-myeon, Jeju-si). The island has a maximum elevation of 50 m above sea level.

The vegetation surveys were conducted in two stages. In the first stage, the islands were circumnavigated by boats, and the major plant communities were preliminarily classified using a physiognomic approach. In the second stage, landings were made at accessible locations to conduct detailed surveys of major plant communities. However, for islands where landing was not possible due to maritime safety constraints, community classification was carried out through physiognomic observation from the vessel at the closest possible offshore distance.

During community surveys, site conditions of occurring species, vertical stratification of communities, and diameter at breast height were measured in the field. The dominance (cover-abundance) of each constituent species was assessed according to the phytosociological method described by Braun-Blanquet (1964). Based on these data, vegetation analyses and descriptions of the dominant communities were conducted for each plant community (National Institute of Ecology, 2023).

To establish the Draft Evaluation of Vegetation Conservation Value Grades for Uninhabited Islands (2026) in Korea, draft assessment criteria were developed based on key evaluation items, scoring systems, and evaluation contents, drawing on previous studies (Kim, 2012; Kim *et al*., 2018; Ministry of Environment & National Institute of Ecology, 2016). During the application of these criteria to the vegetation conservation value grading of uninhabited islands, the need for partial revision and supplementation was identified. Accordingly, a revised Draft Evaluation of Vegetation Conservation Value Grades for Uninhabited Islands (2025) was prepared by incorporating these requirements.

In this study, the evaluation framework for vegetation conservation value grading of uninhabited islands was structured by distinguishing between two assessment components: (1) unit community-level vegetation conservation grade evaluation (25-5 points) and (2) island-level vegetation evaluation (15-3 points).

First, the unit community-level vegetation conservation grade evaluation was conducted in accordance with the Guidelines for the 6th National Natural Environment Survey issued by the Ministry of Environment (2024). For each polygon-based vegetation community unit, five evaluation items—distribution rarity, vegetation restoration potential, integrity of constituent plant species, integrity of vegetation structure, and presence of important species—were assessed using detailed criteria. Evaluation scores were assigned according to five vegetation conservation grades (Grades I to V) for each unit community, corresponding to scores ranging from 25 to 5 points (Grade I: 25 points; Grade II: 20 points; Grade III: 15 points; Grade IV: 10 points; and Grade V: 5 points). After score conversion, the mean value for each uninhabited island was calculated (where the number of unit communities is N, mean value=Σ scores of individual unit communities/N).

Second, the island-level vegetation evaluation included assessment items related to the overall vegetation characteristics of each uninhabited island. The item "island vegetation area" refers to the size of the vegetated area on the target island and was evaluated by classifying islands into three categories based on the area criteria for specified islands (Ministry of Environment & National Institute of Ecology, 2021) (Table 2). In comparison, the Ministry of Oceans and Fisheries classified 2,558 uninhabited islands in Korea into five categories according to island area (Table 2), reporting that islands with an area of 3,000 m^2 or less accounted for the largest proportion, with 909 islands (35.5%) (Ministry of Oceans and Fisheries, 2021).

In addition, the evaluation item "area of alien and planted species" was assessed based on the proportion of the total vegetated area occupied by alien species, planted species, and disturbance-associated species (e.g., Pueraria lobata). The "degree of habitat disturbance" was evaluated by incorporating the extent of factors such as farmland, graves, orchards, logging, livestock grazing, wind damage, and large-scale colonial breeding of birds on uninhabited islands, and corresponding assessment criteria were established accordingly.

Accordingly, the Draft Evaluation of Vegetation Conservation Value Grades for Uninhabited Islands (2026) assessed each surveyed uninhabited island by summing the scores from the unit community-level vegetation conservation grade evaluation (25-5 points) and the island-level vegetation evaluation (15-3 points). Based on the total score, islands were classified into three grades: Grade I (≥30 points), Grade II (20-29 points), and Grade III (≤19 points) (Table 3).

Results and Discussion

Vegetation status by specified island

The major plant communities observed in the study area were evergreen broad-leaved forest vegetation, including the *Machilus thunbergii–Camellia japonica*, *Machilus thunbergii–Litsea japonica*, *Camellia japonica*, *Camellia japonica–Elaeagnus macrophylla*, *Camellia japonica–Pittosporum tobira*, *Camellia japonica–Eurya emarginata*, *Camellia japonica–Litsea japonica*, *Litsea japonica–Eurya emarginata*, *Eurya emarginata*, *Eurya emarginata–Elaeagnus macrophylla*, *Eurya emarginata–Carex wahuensis* var. *robusta*, and *Pittosporum tobira* communities.

In addition, montane deciduous broad-leaved forest vegetation such as the *Carpinus turczaninowii* community, montane coniferous forest vegetation such as the *Pinus thunbergii* community and *Pinus thunbergii–Pittosporum tobira* community, montane shrub vegetation such as the *Sageretia theezans* community, and montane grassland vegetation including the *Miscanthus sinensis*, *Miscanthus sinensis–Carex wahuensis* var. *robusta*, *Miscanthus sinensis–Hemerocallis hakuunensis*, *Hemerocallis hakuunensis–Farfugium japonicum*, *Boehmeria pannosa*, and *Carex wahuensis* var. *robusta* communities were identified. Rocky vegetation and nonvegetated rocky areas were also observed.

The vegetation status of each specified island is as follows.

Heukgeomdo

The major plant communities in Heukgeomdo include evergreen broad-leaved forest vegetation such as the *Camellia japonica–Eurya emarginata*, *Camellia japonica–*

Table 2. Status of domestic specified islands (uninhabited islands) by area category

Island	Region	Area (m^2)					Total
		Less than 3,000	3,000-10,000	10,000-50,000	50,000-100,000	100,000 or more	
Uninhabited island	Nationwide (%)	909 (35.5)	624 (24.4)	683 (26.7)	183 (7.2)	159 (6.2)	2,558
Specified island	Incheon Metropolitan City	5	11	8	2	5	31
	Gyeonggi-do		1	1			2
	Chungcheongnam-do	2	7	13	2	7	31
	Jeollabuk-do	1	1	7	3	4	16
	Jeollanam-do	9	17	46	22	14	108
	Gyeongsangbuk-do					1	1
	Gyeongsangnam-do	4	24	25	4	5	62
	Busan Metropolitan City		1	2			3
	Jeju Special Self-Governing Province			3	1	2	6
	Total (%)	21 (8.1)	62 (23.8)	105 (40.4)	34 (13.1)	38 (14.6)	260
	Sum of the three categories (%)	83 (31.9)		105 (40.4)	72 (27.7)		

Table 3. Evaluation of Vegetation Conservation Value Grades for Uninhabited Islands

Evaluation item		Score allocation	Evaluation criteria	Evaluation description
Unit community–level vegetation conservation grade evaluation (25-5 points)	Distribution rarity	5 3 1	High Moderate Low	• Refers to the distribution pattern of the target plant community within the Korean Peninsula • Communities with a locally restricted distribution area are rated higher, whereas those with nationwide distribution are rated lower
	Vegetation restoration potential	5 3 1	High Moderate Low	• Refers to the time required for the formation of the target plant community (i.e., the formation period of potential natural vegetation) • Communities requiring a long period to develop are rated higher, whereas those forming over a short period are rated lower, reflecting the stage of vegetation development
	Integrity of constituent plant species	5 3 1	High Moderate Low	• Refers to the evaluation of whether the constituent plant species of the target community correspond to those of the plant community that would potentially develop at the given site • Communities dominated by late-successional species are rated higher, whereas those with a high proportion of early-successional species are rated lower
	Integrity of vegetation structure	5 3 1	High Moderate Low	• Assesses how closely the vegetation structure (vertical stratification) of the target plant community resembles the typical structure that develops at the given site • Forest vegetation generally exhibits a four-layered structure, with each layer having characteristic height and cover; communities with well-preserved stratification are therefore rated highly from a conservation ecology perspective
	Habitat of important species	5 3 1	Large community Small community Not observed	• Evaluates the conservation ecological value of the plant species themselves, as plant communities are composed of assemblages of plant species • Communities containing important plant species—such as endangered wild plants or phytogeographically significant species—are rated higher
	Mean value			When the number of unit communities is N, the mean value is calculated as (Σ evaluation scores of individual unit communities/N)
Uninhabited island vegetation evaluation (15-3 points)	Island vegetation area	5 3 1	High Moderate Low	• Refers to the size of the vegetated area of the target uninhabited island • Evaluation is based on a three-level classification according to island area: high (≥50,000 m^2), moderate (5,000-50,000 m^2), and low (<5,000 m^2)
	Area of alien and planted species	5 3 1	<5% 5-30% ≥30%	• Evaluated based on the proportion of the total vegetated area of the target uninhabited island occupied by alien species, planted species, and disturbance-associated species (e.g., Pueraria lobata)
	Degree of habitat disturbance	5 3 1	None <30% ≥30%	• Evaluated according to the degree of habitat disturbance on the target uninhabited island • Farmland, graves, orchards, logging, livestock grazing, wind damage, and impacts from colonial breeding of birds, among others

Vegetation Conservation Value Grades for Uninhabited Islands: Grade I (≥30 points), Grade II (21-29 points), and Grade III (≤19 points). Evaluation score=unit community–level vegetation conservation grade score (25-5 points)+uninhabited island vegetation evaluation score (15-3 points). Score conversion for vegetation conservation grades: Grade I, 25 points; Grade II, 20 points; Grade III, 15 points; Grade IV, 10 points; Grade V, 5 points.

Litsea japonica, and *Litsea japonica–Eurya emarginata* communities; deciduous broad-leaved forest vegetation represented by the *Carpinus turczaninowii* community; montane coniferous forest vegetation represented by the *Pinus thunbergii* community; montane shrub vegetation represented by the *Sageretia theezans* community; and montane grassland vegetation represented by the *Miscanthus sinensis* community (Fig. 2).

The dominant vegetation type in Heukgeomdo, the *Camellia japonica–Eurya emarginata* community, exhibited a shrub layer with a vegetation height of approximately 2.5 m and vegetation cover of 80%. The dominant species in this layer were *Camellia japonica* (cover class 3) and *Eurya emarginata* (cover class 3). The associated woody species included *Euonymus japonicus*, *Clerodendrum trichotomum*, *Smilax china*, *Eurya emarginata*, *Pittosporum tobira*, *Rhus javanica*, *Ampelopsis brevipedunculata*, and *Ficus erecta*. In the herb layer, *Parthenocissus tricuspidata* (cover class 3) was the dominant species, accompanied by *Kadsura japonica*, *Miscanthus sinensis*, *Boehmeria pannosa*, *Ardisia japonica*, *Deparia japonica*, *Cyrtomium falcatum*, *Clematis terniflora*, *Dioscorea polystachya*, *Hemerocallis hakuunensis*, and *Arisaema ringens*.

Around coastal rocky areas, the dominant woody species included *Rhus javanica*, *Clerodendrum trichotomum*, *Grewia parviflora*, *Eurya emarginata*, *Parthenocissus tricuspidata*, and *Ficus erecta*, while the dominant herbaceous species included *Isodon inflexus*, *Oxalis stricta*, *Imperata cylindrica*, *Cocculus trilobus*, *Dioscorea polystachya*, *Carex wahuensis* var. *robusta*, *Clematis terniflora,* and *Cyrtomium falcatum*. Along the coastal cliffs of Heukgeomdo, the cliff vegetation dominated by the *Camellia japonica* community was well developed.

Cheongdo

The major plant communities in Cheongdo include evergreen broad-leaved forest vegetation such as the *Machilus thunbergii–Camellia japonica* community, *Camellia japonica–Eurya emarginata* community, and *Eurya emarginata* community; montane coniferous forest vegetation represented by the *Pinus thunbergii* community; montane grassland vegetation represented by the *Miscanthus sinensis–Carex wahuensis* var. *robusta* community; and the *Boehmeria pannosa* community (Fig. 2).

The dominant vegetation type in Cheongdo, the *Eurya emarginata* community, exhibited a shrub layer with a vegetation height of approximately 3.5 m and vegetation cover of 90%, with *Eurya emarginata* (cover class 5) as the dominant species, accompanied by *Smilax china*. In the herb layer, *Carex wahuensis* var. *robusta* (cover class 3) and *Arisaema ringens* (cover class 3) were dominant, along with *Cynanchum japonicum*, *Boehmeria pannosa*, *Smilax china*, and *Vitis ficifolia* var. *sinuata* as major associated species.

Around coastal rocky areas, dominant woody species included *Camellia japonica*, *Euonymus japonicus*, *Litsea japonica*, *Eurya emarginata*, and *Rosa wichuraiana*, while dominant herbaceous species included *Carex scabrifolia*, *Rumex crispus*, *Barnardia japonica*, *Corydalis heterocarpa*, *Gynostemma pentaphyllum*, *Arisaema ringens*, and *Boehmeria pannosa*. Along the coastal cliffs, cliff vegetation dominated by the *Eurya emarginata* community was well developed.

Cheongdo is a specified island characterized by well-developed warm-temperate vegetation, indicating high conservation value. Therefore, continuous monitoring of natural successional processes is required. In particular, vegetation damage has become severe owing to grazing by feral goats, leading to the simplification of species composition. Accordingly, sustained management measures are necessary to address vegetation degradation and consequent reduction in species diversity.

Jikgudo

The major plant communities in Jikgudo include evergreen broad-leaved forest vegetation such as the *Camellia japonica–Eurya emarginata*, *Camellia japonica*, *Eurya emarginata*, and *Eurya emarginata–Carex wahuensis* var. *robusta* communities; montane coniferous forest vegetation represented by the *Pinus thunbergii* community; and montane grassland vegetation represented by the *Miscanthus sinensis–Carex wahuensis* var. *robusta* community (Fig. 2).

The dominant vegetation type in Jikgudo, the *Eurya emarginata* community, exhibited a subcanopy layer with a tree height of approximately 5 m and vegetation cover of 20%, where *Eurya japonica* was the dominant species. In the shrub layer, the vegetation height was approximately 2.5 m with a cover of 85%. *Eurya emarginata* (cover class 5) was the dominant species, accompanied by *Camellia japonica*, *Elaeagnus macrophylla*, and *Ficus erecta*. In the herb layer, *Arisaema ringens* (cover class 5) and *Carex wahuensis* var. *robusta* (cover class 4) were dominant, with *Pinellia ternata*, *Elaeagnus macrophylla*, *Pittosporum tobira*, *Boehmeria pannosa*, *Rosa wichuraiana*, and *Isodon inflexus* occurring as major associated species.

Along the coastal cliffs, cliff vegetation dominated by the *Eurya emarginata* community was well developed. The dominant woody species are *Rhaphiolepis indica* var. *umbellata*, *Pittosporum tobira*, *Euonymus japonicus*, *Prunus jamasakura*, *Elaeagnus macrophylla*, and *Rosa wichuraiana*. The dominant herbaceous species included *Miscanthus sinensis*, *Carex wahuensis* var. *robusta*, *Rubus parvifolius*, *Isodon inflexus*, *Imperata cylindrica*, *Eupatorium makinoi* var. *oppositifolium*, *Cocculus trilobus*, *Oxalis stricta*, *Themeda triandra*, *Festuca ovina*, and *Scorzonera austriaca*.

Jikgudo is characterized by well-developed warm-

temperate, coastal cliff, and grassland vegetation. As the *Pinus thunbergii* community is expected to undergo successional progression, resulting in changes in species composition among various plant communities, continuous monitoring of successional processes is required.

Suryeongseom

The major plant communities in Suryeongseom include evergreen broad-leaved forest vegetation such as the *Camellia japonica*, *Camellia japonica–Elaeagnus macrophylla*, *Camellia japonica–Litsea japonica*, *Camellia japonica–Pittosporum tobira*, and *Pittosporum tobira* communities; deciduous broad-leaved forest vegetation represented by the *Carpinus turczaninowii* community; montane coniferous forest vegetation represented by the *Pinus thunbergii* and *Pinus thunbergii–Pittosporum tobira* communities; and montane grassland vegetation represented by the *Miscanthus sinensis–Carex wahuensis* var. *robusta* community (Fig. 2).

The dominant vegetation type in Suryeongseom, the *Pinus thunbergii–Pittosporum tobira* community, exhibited a tree layer with a canopy height of approximately 13 m and vegetation cover of 80%, where *Pinus thunbergii* (cover class 5) was the dominant species. In the subcanopy layer, the canopy height was approximately 5 m, with a vegetation cover of 25%, and was dominated by *Pinus thunbergii*. The shrub layer had a vegetation height of approximately 2.5 m and a cover of 90%, dominated by *Pittosporum tobira* (cover class 5), accompanied by *Ficus erecta* and *Stauntonia hexaphylla*. In the herb layer, *Pittosporum tobira* (cover class 4) and *Carex wahuensis* var. *robusta* (cover class 3) were dominant, with *Machilus thunbergii*, *Litsea japonica*, *Dioscorea polystachya*, *Rubus parvifolius*, *Miscanthus sinensis*, *Smilax china*, and *Farfugium japonicum* occurring as major associated species.

Around the coastal rocky areas, the dominant woody species included *Rhaphiolepis indica* var. *umbellata*, *Litsea japonica*, *Pittosporum tobira*, and *Rosa wichuraiana*. The dominant herbaceous species were *Lysimachia mauritiana*, *Aster spathulifolius*, *Crepidiastrum denticulatum*, *Cyperus polystachyos*, *Miscanthus sinensis*, *Barnardia japonica*, *Dendranthema zawadskii* var. *latilobum*, *Peucedanum japonicum*, *Sedum oryzifolium*, *Orostachys japonicus*, *Paederia foetida*, *Zoysia japonica*, *Centella asiatica*, *Oldenlandia strigulosa*, and *Farfugium japonicum*. Along the coastal cliffs, warm-temperate cliff vegetation, such as the *Eurya emarginata* community and the *Eurya emarginata–Pittosporum tobira* community, was well developed.

Boronseom

The major plant communities in Boronseom include evergreen broad-leaved forest vegetation such as the *Machilus thunbergii–Litsea japonica*, *Camellia japonica–Eurya emarginata*, *Eurya emarginat–Elaeagnus macrophylla*, and *Eurya emarginata* communities; montane coniferous forest vegetation represented by the *Pinus thunbergii–Pittosporum tobira* community; and montane grassland vegetation represented by the *Miscanthus sinensis–Hemerocallis hakuunensis*, *Carex wahuensis* var. *robusta* and *Hemerocallis hakuunensis–Farfugium japonicum* communities (Fig. 2).

The dominant vegetation type in Boronseom, the *Pinus thunbergii–Pittosporum tobira* community, exhibited a tree layer with a canopy height of approximately 12 m and vegetation cover of 80%, where *Pinus thunbergii* (cover class 5) was the dominant species. In the subcanopy layer, the canopy height was approximately 5 m, with a vegetation cover of 5%, dominated by *Pittosporum tobira*. The shrub layer had a vegetation height of approximately 2.5 m and a cover of 85%, with *Pittosporum tobira* (cover class 5) as the dominant species, accompanied by *Elaeagnus macrophylla*, *Rhaphiolepis indica* var. *umbellata*, and *Euonymus japonicus*. In the herb layer, *Carex wahuensis* var. *robusta* (cover class 4) and *Trachelospermum asiaticum* (cover class 2) were dominant, along with *Hemerocallis hakuunensis*, *Rubia cordifolia*, *Oxalis stricta*, *Achyranthes bidentata* var. *japonica*, *Ligustrum japonicum*, *Lonicera japonica*, *Clematis terniflora*, and *Rosa wichuraiana* as major associated species.

Near the summit of the island, small patches of the *Machilus thunbergii–Litsea japonica* community were observed, whereas the *Sageretia theezans* community was developed around rocky areas. Along the coastal rocky zones, the dominant woody species included *Rhaphiolepis indica* var. *umbellata*, *Pittosporum tobira*, *Euonymus japonicus*, *Eurya emarginata*, and *Rosa wichuraiana*. The dominant herbaceous species were *Phragmites australis*, *Rumex crispus*, *Zoysia japonica*, *Silene aprica* var. *oldhamiana*, *Hemerocallis fulva*, *Sedum oryzifolium*, *Carex wahuensis* var. *robusta*, *Cynanchum japonicum*, *Miscanthus sinensis*, *Lonicera japonica*, *Asparagus cochinchinensis*, and *Paederia foetida*. Both cliff and grassland vegetation were well developed around the coastal areas of the island.

Yeomseom

The major plant communities in Yeomseom include evergreen broad-leaved forest vegetation (*Eurya emarginata* community), montane coniferous forest vegetation (*Pinus thunbergii* community), and montane grassland vegetation (*Miscanthus sinensis* community) (Fig. 2).

The dominant vegetation type on Yeomseom, the *Eurya emarginata* community, exhibited a shrub layer with a vegetation height of approximately 1.5 m and vegetation cover of 85%, where *Eurya emarginata* (cover class 5) was the dominant species, accompanied by *Euonymus japonicus* and *Pittosporum tobira*. In the herb layer, *Carex wahuensis* var. *robusta* (cover class 3) was the dominant

species, with *Miscanthus sinensis*, *Elaeagnus macrophylla*, *Pittosporum tobira*, *Boehmeria pannosa*, *Rosa wichuraiana*, and *Isodon inflexus* occurring as major associated species.

Around the coastal rocky areas, the dominant woody species included *Rhaphiolepis indica* var. *umbellata*, *Pittosporum tobira*, *Euonymus japonicus*, *Eurya emarginata*, *Parthenocissus tricuspidata*, and *Rosa wichuraiana*. The dominant herbaceous species included *Asparagus rigidulus*, *Barnardia japonica*, *Sedum oryzifolium*, *Cyperus polystachyos*, *Lysimachia mauritiana*, *Carex wahuensis* var. *robusta*, *Miscanthus sinensis*, *Fimbristylis sieboldii*, *Zoysia japonica*, *Eupatorium makinoi* var. *oppositifolium*, *Boehmeria pannosa*, and *Cyrtomium falcatum*.

As the cliff vegetation dominated by the *Eurya emarginata* community was well developed along the coastal cliffs, both the coastal cliff and grassland vegetation were prominent features of Yeomseom.

Characteristics of plant community distribution areas

The distribution area characteristics of plant communities were compared among the six specified islands in Jeju Special Self-Governing Province (Table 4). In total, 12 evergreen broad-leaved forest communities were identified: *Machilus thunbergii–Camellia japonica*, *Machilus thunbergii–Litsea japonica*, *Camellia japonica*, *Camellia japonica–Elaeagnus macrophylla*, *Camellia japonica–Pittosporum tobira*, *Camellia japonica–Eurya emarginata*,

Table 4. Comparison of plant community areas by specified island in Jeju Special Self-Governing Province

Plant community		Community area (m^2)						
Major category	**Community**	**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**Total**
Evergreen broad-leaved forest	*Machilus thunbergii–Camellia japonica*		4,237					4,237
	Machilus thunbergii–Litsea japonica					230		230
	Camellia japonica			4,052	1,373			5,425
	Camellia japonica–Elaeagnus macrophylla				1,402			1,402
	Camellia japonica–Pittosporum tobira				595			595
	Camellia japonica–Eurya emarginata	8,026	966	4,212		483		13,687
	Camellia japonica–Litsea japonica	24,825			4,248			29,073
	Litsea japonica–Eurya emarginata	7,824						7,824
	Eurya emarginata		6,914	5,939		1,335	508	14,696
	Eurya emarginata–Elaeagnus macrophylla					407		407
	Eurya emarginata–Carex wahuensis var. *robusta*			781				781
	Pittosporum tobira				428			428
	Subtotal (%)	40,675 (27.9)	12,117 (7.2)	14,984 (19.4)	8,046 (17.6)	2,455 (14.8)	508 (3.5)	78,785 (16.9)
Montane coniferous forest	*Pinus thunbergii*	18,520	7,929	644	13,401	2,940	6,105	49,539
	Pinus thunbergii–Pittosporum tobira				440	350		790
Montane deciduous broad-leaved forest	*Carpinus turczaninowii*	1,834			3,498			5,332
Montane shrubland	*Sageretia theezans*	7,780						7,780

Table 4. Continued

Plant community		Community area (m^2)						
Major category	**Community**	**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**Total**
Montane grassland vegetation	*Miscanthus sinensis*	33,853					108	33,961
	Miscanthus sinensis–Carex wahuensis var. *robusta*		55,363	13,642	179			69,184
	Miscanthus sinensis–Hemerocallis hakuunensis					770		770
	Boehmeria pannosa		2,513					2,513
	Hemerocallis hakuunensis–Farfugium japonicum					778		778
	Carex wahuensis var. *robusta*					1,380		1,380
	Subtotal (%)	33,853 (23.2)	57,876 (34.5)	13,642 (17.1)	179 (0.4)	2,928 (17.7)	108 (0.7)	108,586 (23.2)
Rocky vegetation	Rocky vegetation	4,658			4,030			8,688
Non-vegetated area	Rocky area	38,564	89,681	47,890	16,125	7,879	7,659	207,800

Camellia japonica–Litsea japonica, *Litsea japonica–Eurya emarginata*, *Eurya emarginata*, *Eurya emarginata–Elaeagnus macrophylla*, *Eurya emarginata–Carex wahuensis* var. *robusta*, and *Pittosporum tobira*.

Among these, the *Camellia japonica–Litsea japonica* community exhibited the largest distribution area (29,073 m^2), followed by the *Eurya emarginata* and *Camellia japonica–Eurya emarginata* communities. Across all surveyed islands, warm-temperate evergreen broad-leaved forests dominated by *Camellia japonica* and *Eurya emarginata* were well developed. The distribution area of evergreen broad-leaved forests was relatively high in Heukgeomdo (40,675 m^2; 27.9%), Jikgudo (14,984 m^2; 19.4%), and Suryeongseom (8,046 m^2; 17.6%).

The montane deciduous broad-leaved forest, represented by the *Carpinus turczaninowii* community, occupied 1,834 m^2 in Heukgeomdo and 3,498 m^2 in Suryeongseom. Montane coniferous forests, represented by the *Pinus thunbergii* community, occurred on all surveyed islands, with a total distribution area of 49,539 m^2, generally forming small, fragmented patches.

Six montane grassland communities were identified: *Miscanthus sinensis*, *Miscanthus sinensis–Carex kobomugi*, *Miscanthus sinensis–Hemerocallis hakuunensis*, *Boehmeria pannosa*, *Hemerocallis hakuunensis–Farfugium japonicum*, and *Carex wahuensis* var. *robusta*. Among them, the *Miscanthus sinensis–Carex wahuensis* var. *robusta* community had the largest distribution area (69,184 m^2), followed by extensive occurrences of the *Miscanthus sinensis* community. The distribution area of grassland vegetation was relatively high in Cheongdo (57,876 m^2; 34.5%) and Heukgeomdo (33,853 m^2; 23.3%).

Evaluation of Vegetation Conservation Value of Uninhabited Islands

In this study, the proposed Evaluation of Vegetation Conservation Value of Uninhabited Islands was applied to specified islands in Jeju Special Self-Governing Province (Table 5).

First, in the unit community-level vegetation conservation grade evaluation, Jikgudo showed the highest mean score (19), followed by Boronseom (18), Suryeongseom (18), and Heukgeomdo (18). On these islands, evergreen broad-leaved forest species such as *Machilus thunbergii*, *Camellia japonica*, *Litsea japonica*, *Pittosporum tobira*, *Elaeagnus macrophylla*, and *Eurya emarginata* formed stable plant communities that are well adapted to habitat conditions along island ridges, slopes, and steep coastal areas, resulting in well-developed and stable vegetation. In addition, the development of the *Carpinus turczaninowii* community, *Sageretia theezans* community, and rocky vegetation on rocky ridges and coastal slopes further indicated the dominance of warm-temperate vegetation, leading to high conservation value as specified islands. Therefore, continuous monitoring of successional processes in the vegetation on these uninhabited islands is required.

Second, in the island-level vegetation evaluation, the

Table 5. Evaluation of Vegetation Conservation Value of Uninhabited Islands by specified island in Jeju Special Self-Governing Province

Evaluation item			Evaluation score					
Category	**Major category**	**Community name**	**J1**	**J2**	**J3**	**J4**	**J5**	**J6**
Unit community–level vegetation conservation grade evaluation	Evergreen broad-leaved forest	*Machilus thunbergii–Camellia japonica* community		20				
		Machilus thunbergii–Litsea japonica community					25	
		Camellia japonica community			20	20		
		Camellia japonica–Elaeagnus macrophylla community				20		
		Camellia japonica–Pittosporum tobira community				20		
		Camellia japonica–Eurya emarginata community	20	20	20		20	
		Camellia japonica–Litsea japonica community	20			20		
		Litsea japonica–Eurya emarginata community	20					
		Eurya emarginata community		20	20		20	20
		Eurya emarginata–Elaeagnus macrophylla community					20	
		Eurya emarginata–Carex wahuensis var. *robusta* community			20			
		Pittosporum tobira community				20		
	Montane coniferous forest	*Pinus thunbergii* community	15	15	15	15	15	15
		Pinus thunbergii–Pittosporum tobira community				20	20	
	Montane deciduous broad-leaved forest	*Carpinus turczaninowii* community	20			20		
	Montane shrubland	*Sageretia theezans* community	20					
	Montane grassland vegetation	*Miscanthus sinensis* community	5					5
		Miscanthus sinensis–Carex wahuensis var. *robusta* community		5	20	5		
		Miscanthus sinensis–Hemerocallis hakuunensis community					5	
		Boehmeria pannosa community		5				
		Hemerocallis hakuunensis–Farfugium japonicum community					20	
		Carex wahuensis var. *robusta* community					20	
	Rocky vegetation	Rocky vegetation	20			20		
	Mean value		18	14	19	18	18	13
Uninhabited island vegetation evaluation	Island vegetation area		5	5	5	3	3	3
	Area of alien and planted species		5	5	5	5	5	5
	Degree of habitat disturbance		5	1	5	5	5	3
Total evaluation score			33	25	34	31	31	24
Vegetation Conservation Value of Uninhabited Islands (Grade)			I	II	I	I	I	II

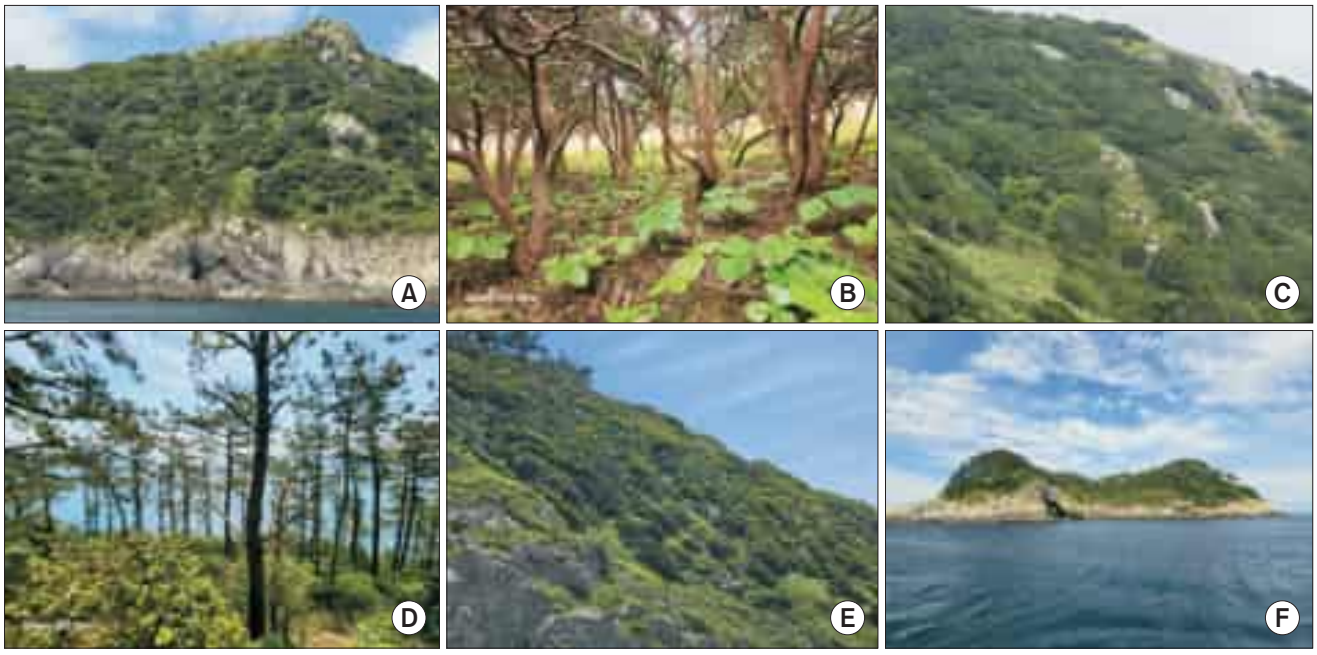

Fig. 2. Major vegetation and landscapes of the specified islands. (A) *Camellia japonica–Eurya emarginata* community on Heukgeomdo. (B) *Eurya emarginata* community on Cheongdo. (C) *Eurya emarginata* community on Jikgudo. (D) *Pinus thunbergii–Pittosporum tobira* community on Suryeongseom. (E) *Eurya emarginata* community on Boronseom. (F) *Pinus thunbergii* community on Yeomseom.

assessment item "island vegetation area" showed high scores for Heukgeomdo (J1; 145,884 m^2), Cheongdo (J2; 167,603 m^2), and Jikgudo (J3; 77,160 m^2), all of which exceeded 50,000 m^2. For the evaluation item "distribution of alien and planted species," all surveyed islands exhibited low proportions (<5%) of alien species, disturbance-associated species, and planted species, resulting in high evaluation scores. Regarding the evaluation item "degree of habitat disturbance," Heukgeomdo, Jikgudo, Suryeongseom, and Boronseom showed minimal habitat disturbance and were therefore rated highly. In contrast, Cheongdo showed vegetation damage due to livestock grazing, and Yeomseom exhibited localized wind damage in the low-lying coastal areas, resulting in lower evaluation scores for these islands.

Based on the Vegetation Conservation Value Grading Criteria for Uninhabited Islands applied in this study, the results of the vegetation conservation value grading indicated that Grade I areas (total evaluation score ≥30 points) included Heukgeomdo, Jikgudo, Suryeongseom, and Boronseom, while Grade II areas (total evaluation score 20-29 points) included Cheongdo and Yeomseom. These results are expected to serve as baseline data for establishing management types for specified islands and for reviewing new vegetation-related evaluation factors to support efficient conservation and management of specified islands in the future.

Conclusion

Vegetation surveys of the study area were conducted through field investigations from May to September 2024, focusing on six specified islands—Heukgeomdo, Cheongdo, Jikgudo, Suryeongseom, Boronseom, and Yeomseom—located around Chuja-myeon, Jeju-si, Jeju Special Self-Governing Province.

The major plant communities identified included evergreen broad-leaved forest vegetation, including the *Machilus thunbergii–Camellia japonica*, *Machilus thunbergii–Litsea japonica*, *Camellia japonica*, *Camellia japonica–Elaeagnus macrophylla*, *Camellia japonica–Pittosporum tobira*, *Camellia japonica–Eurya emarginata*, *Camellia japonica–Litsea japonica*, *Litsea japonica–Eurya emarginata*, *Eurya emarginata*, *Eurya emarginata-Elaeagnus macrophylla*, *Eurya emarginata-Carex wahuensis* var. *robusta*, and *Pittosporum tobira* communities. Deciduous broad-leaved forest vegetation was represented by the *Carpinus turczaninowii* community; montane shrub vegetation by the *Sageretia theezans* community; evergreen coniferous forest vegetation by the *Pinus thunbergii* and the *Pinus thunbergii–Pittosporum tobira* communities; and montane grassland vegetation by the *Miscanthus sinensis*, *Miscanthus sinensis–Carex wahuensis* var. *robusta*, *Miscanthus sinensis–Hemerocallis hakuunensis*, *Boehmeria pannosa*, *Hemerocallis hakuunensis–Farfugium japoni-*

cum, and *Carex wahuensis* var. *robusta* communities. Rocky vegetation was also observed.

Vegetation analyses and descriptions of dominant communities were conducted for each plant community, and baseline data were analyzed to support the evaluation of vegetation conservation grades at each survey site based on vegetation physiognomy and vegetation assessment criteria.

In the areas surrounding Cheongdo and Boronseom, where representative warm-temperate vegetation, such as the *Machilus thunbergii–Camellia japonica* and the *Machilus thunbergii–Litsea japonica* communities, is well developed, vegetation was well established, forming stable vegetation zones. Across all surveyed areas, plant communities developing on coastal rocky areas and cliffs, including *Camellia japonica*, *Camellia japonica–Elaeagnus macrophylla*, *Camellia japonica–Pittosporum tobira*, *Camellia japonica–Eurya emarginata*, *Camellia japonica–Litsea japonica*, *Litsea japonica–Eurya emarginata*, *Eurya emarginata*, *Eurya emarginata–Elaeagnus macrophylla*, *Eurya emarginatas–Carex wahuensis* var. *robusta*, and *Pittosporum tobira* communities, were evaluated as Vegetation Conservation Grade II, indicating a very high conservation value.

At the summits and ridges of Heukgeomdo and Suryeongseom, stable vegetation was represented by well-developed *Carpinus turczaninowii* communities. Montane grassland vegetation, such as the *Miscanthus sinensis–Carex wahuensis* var. *robusta* community in Jikgudo and the *Carex wahuensis* var. *robusta* and *Hemerocallis hakuunensis–Farfugium japonicum* communities on Boronseom, developed in shallow-soil habitats in coastal rocky areas. These communities represent typical and distinctive coastal island vegetation and were classified as Vegetation Conservation Grade II.

In Cheongdo, severe vegetation disturbance caused by grazing goats has led to the simplification of species composition due to damage to natural vegetation. This damage was substantial and was accompanied by soil erosion, indicating ongoing degradation of the natural ecosystem. Consequently, restoration and conservation measures are urgently required. Overall, the surveyed islands exhibited well-developed warm-temperate vegetation and possessed high conservation value as specified islands, highlighting the need for continuous monitoring of natural successional processes. Because Cheongdo exhibits a relatively high proportion of grassland vegetation, it is necessary to establish permanent plots to enable the quantitative assessment of evergreen broad-leaved seedling density, recovery of vertical vegetation structure, and changes in species diversity, thereby supporting a mid- to long-term ecological monitoring framework.

The distribution areas of plant communities in the study area showed that among the evergreen broad-leaved forests, the *Camellia japonica–Litsea japonica* community had the largest area (29,073 m^2), followed by the *Eurya emarginata* and *Camellia japonica–Eurya emarginata* communities. In montane coniferous forests, the *Pinus thunbergii* community occupied an area of 49,539 m^2, whereas in montane grassland vegetation, the *Miscanthus sinensis–Carex wahuensis* var. *robusta* community covered 69,184 m^2.

In terms of vegetation distribution by specified islands, evergreen broad-leaved forests accounted for 40,675 m^2 (27.9%) on Heukgeomdo, 14,984 m^2 (19.4%) on Jikgudo, and 8,046 m^2 (17.6%) on Suryeongseom. Montane grassland vegetation showed relatively high proportions on Cheongdo, with 57,876 m^2 (34.5%), and on Heukgeomdo, with 33,853 m^2 (23.3%).

A comprehensive survey of the natural environment of specified islands in Jeju Special Self-Governing Province was conducted, and the evaluation grades for each specified island were presented in accordance with the Vegetation Conservation Value Grading Criteria for Uninhabited Islands established by the investigator to provide an objective assessment of the ecological conservation value of vegetation and the necessity for conservation at each survey site. Based on these criteria, areas classified as Grade I (total score of ≥30 points across evaluation items) included Heukgeomdo, Jikgudo, Suryeongseom, and Boronseom, while areas classified as Grade II (total score of 21-29 points) included Cheongdo and Yeomseom. No areas were classified as Grade III (total score of ≤19 points).

These evaluation results are expected to serve as baseline data for future natural environment assessments of specified islands by proposing new draft vegetation-related evaluation criteria and to support the establishment of management types and efficient conservation and management of specified islands.

Author Contributions

Conceptualization: HK. Methodology: HK. Resources: HK. Software: HK. Supervision: HK. Writing – original draft: HK. Writing – review & editing: HK, YC.

Conflict of Interest

The authors declare that they have no competing interests. Comparison of Maps for Environmental Policy.

Funding

None.

References

Braun-Blanquet, J. (1964). *Pflanzensoziologie: Grundzüge der*

Vegetationskunde. Springer.
Jeollanam-do. (2000). *Development Strategy for Jeollanam-do Islands in the 21st Century*. Jeollanam-do.
Jeollanam-do. (2002). *Islands of Jeollanam-do*. Jeollanam-do.
Kim, H.S. (2012). Vegetation and vegetation conservation value grades of uninhabited islands. *Korean Journal of Nature Conservation,* 160, 34-45.
Kim, H.S., and Oh, J.G. (2013). Distributed characteristics of big tree and flora of Jisimdo, Geojesi. *Journal of Korean Island,* 25, 205-226.
Kim, H.S., Cho, Y.J., Cho, E.J., Park, J.W., Myeong, H.H., and Oh, J.G. (2018). The conservation value assessment class and vegetation of uninhabited islets on the Goheung-gun, Jeollanamdo, Korea. *Journal of Korean Island,* 30, 195-210. https://doi.org/10.26840/jki.30.1.195
Ministry of Environment. (2024). *The 3rd Basic Plan for the Conservation of Specified Islands*. Ministry of Environment.
Ministry of Environment, and National Institute of Ecology. (2016). *A Study on Establishing Draft Criteria for Conservation Value Grading of Uninhabited Islands and Draft Classification Criteria for Management Types of Specified Islands*. Ministry of Environment, National Institute of Ecology.
Ministry of Environment, and National Institute of Ecology. (2021). *A Study on Ecosystem Status and Management Strategies for the Conservation and Management of Specified Islands*. Ministry of Environment, National Institute of Ecology.
Ministry of Oceans and Fisheries (MOF). (2021). *2021 White Paper on Uninhabited Islands*. MOF.
National Institute of Ecology. (2023). *Guidelines for the 6th National Natural Environment Survey*. National Institute of Ecology.
Oh, H.K., and Beon, M.S. (2007). Distribution of vascular plants on the Mokdo, Gokdudo, Daehangdo and Bulgeundo desert island, Dadohae. *Korean Journal of Plant Resources,* 20, 28-37.

PNIE PROCEEDINGS OF THE NATIONAL INSTITUTE OF ECOLOGY OF THE REPUBLIC OF KOREA

Original Article

PNIE 2026;7(3):123-132
https://doi.org/10.22920/PNIE.2026.7.3.123
pISSN 2765-2203, eISSN 2765-2211

Effects of Plant Traits on Shrub, Climbing, and Lichen Species Composition and CSR Strategies in Hilly Vegetation of Mt. Seungdalsan, Southern Korea

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ABSTRACT

Plant distribution strategies were investigated in the hilly vegetation of Mt. Seungdalsan, Muan-gun, Korea, in relation to plant traits, using competitor (C), stress-tolerator (S), and ruderal (R) analyses. Twenty-three species were classified into CSR strategy types based on their plant traits. Most of the observed species exhibited competitive (C) or competitive–ruderal (CR) strategies. These strategies reflect the functional traits of the species and the local habitat conditions in the study area. In the surveyed region, four species exhibited C strategies: *Mallotus japonicus*, *Rhododendron mucronulatum*, *Rhododendron yedoense*, and *Sasa borealis*. These species are perennial plants with relatively high canopy heights and may possess competitive abilities through aboveground space occupation and lateral spread. Six shrub and climbing species exhibited the CR and C/CR strategies. *Trachelospermum asiaticum* var. *intermedium* exhibited a C/CR strategy. Four lichen species showed S strategies related to drought: *Anzia* sp., *Collema* sp., *Dirinari applanata*, and *Physcia orientalis*. The distribution pattern within the CSR triangle may provide a useful basis for vegetation conservation and restoration in the study area under increasing disturbance.

Keywords: Canonical correspondence analysis, Climbing species, CSR strategy, Hilly vegetation, Lichens, Plant traits

Introduction

Recent trait-based ecological studies (Deng, 2025; Larcher, 2003) demonstrate that the resilience of temperate shrubs is strongly governed by their structural and physiological traits. High leaf dry weight (LDW) per unit area and an elevated root:shoot ratio enhance drought resistance by increasing carbon investment in supportive tissues and belowground water acquisition. Deep root systems enable access to subsurface moisture during dry summers. Unmanned aerial vehicle-based hyperspectral imaging has shown that trait variability is greater in the shrub layer than in the tree canopy, indicating that shrubs are more responsive to fine-scale environmental heterogeneity. Trait–environment models suggest that these

Received March 27, 2026; **Revised** May 22, 2026; **Accepted** May 26, 2026

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functional traits allow deciduous shrubs to outperform evergreen species under fluctuating precipitation regimes, ultimately promoting shrub dominance in post-disturbance forests.

Woody shrubs grow as intermediates between trees and herbaceous plants (Aragón *et al*., 2023; Cao *et al*., 2020; Taiz & Zeiger, 2006). They are commonly found in environments exposed to multiple stressors such as drought, high salinity, and low nutrient availability, including hills, sand dunes, desert fringes, and arid inland regions. In such environments, shrubs often prioritize long-term survival over short-term growth, thereby exhibiting survival strategies. Shrubs typically exhibit a tradeoff between growth and survival. For instance, studies have shown that a higher relative growth rate in shrub saplings is often associated with lower survival rates. A study on saplings in a Brazilian mountain grassland reported that fast-growing species had lower initial survival (Negreiros *et al*., 2016). This indicates that, in high-stress environments, shrubs may adopt a "survive rather than grow" strategy.

Modeling work on *Lycium ruthenicum* (Li *et al*., 2025) illustrates how climate change may reshape shrub distribution. Species distribution models predict range contractions in lowland zones, together with northward and upslope migrations, which are common patterns among temperate shrub taxa. Phenotypic plasticity and enhanced flavonoid synthesis support survival in ultraviolet-exposed, drought-prone microhabitats. Population genetic data indicate that resilience may be reinforced through gene flow and local adaptive selection, enabling persistence under the RCP4.5 climate scenarios. This species performs best in continental climates with low winter precipitation, implying that conservation strategies should consider regional climatic envelopes and future dispersal corridors.

Temperate shrub species exhibit diverse ecological survival strategies shaped by environmental heterogeneity, resource availability, and disturbance regimes. These strategies align well with the CSR model proposed by Grime (1977), which classifies plant strategies along three axes—competitors (C), stress-tolerators (S), and ruderals (R)—each representing a different evolutionary solution to the challenges posed by competition, abiotic stress, and disturbance, respectively (Grime, 1977).

Temperate shrublands are characteristically seasonally dynamic, with intermediate to low nutrient soils, periodic disturbances (e.g., grazing and fire), and variable precipitation. Under these conditions, shrubs often adopt mixed survival strategies and exhibit traits spanning the CSR spectrum. Many temperate shrubs possess competitive traits such as rapid early growth, canopy expansion, and clonal spread, which enable them to outcompete herbaceous vegetation in semi-stable habitats (Grime & Pierce, 2012).

However, in resource-poor or climatically stressful zones, such as higher latitudes or elevations, shrubs may shift toward S strategies featuring slow growth, small sclerophyllous leaves, and high investment in root biomass for drought resistance and nutrient acquisition (Liu *et al*., 2025; Liu & Zheng, 2024; Zhang *et al*., 2024). For instance, *Juniperus communis* and *Vaccinium* spp. exhibit long lifespans and low productivity, consistent with the S strategies that persist in nutrient-depleted acidic soils.

Conversely, in frequently disturbed temperate zones, such as forest edges or post-fire landscapes, R tendencies become apparent. Shrub species, such as *Rubus fruticosus*, exhibit fast regeneration, seed bank formation, and clonal proliferation, reflecting a competitive–ruderal (CR) strategy mix optimized for the rapid exploitation of disturbed gaps (Sjöman *et al*., 2025).

Recent trait-based analyses have indicated that the composition of CSR strategies can shift over successional time or across environmental gradients (Ricotta *et al*., 2023; Zhang *et al*., 2024). Thus, the dominance of shrubs in many temperate biomes may reflect their ecological versatility, combining persistence under stress with opportunistic growth after a disturbance.

In the hilly vegetation of the southern warm-temperate region of Korea, shrubs, woody vines, and lichens often coexist in heterogeneous microsites such as shrub patches, exposed rocks, and tree bark substrates. Although lichens are not vascular plants, they were included in this study as S cryptogamic components occurring on exposed rock surfaces and tree bark substrates, allowing for a comparison with vascular shrubs and climbing species occupying more protected or structurally supported microsites. However, the ecological status and developmental stages of such vegetation have rarely been interpreted using functional traits and CSR strategies. Mt. Seungdalsan, located in Muan-gun, Korea, is a suitable study site for examining these patterns because shrub, climbing, and lichen species occur together within a relatively small hilly area, allowing the comparison of C and S strategies within the same study area. Shrubs and climbing species with greater canopy height (CH) and lateral spread were hypothesized to show more C/CR strategies, reflecting relatively stable vegetation patches or rapid occupation of available space, whereas lichens occurring on exposed substrates would show S strategies associated with drought and resource limitations. Therefore, this study aimed to evaluate the functional traits and CSR strategies of shrub, climbing, and lichen species in the hilly vegetation of Mt. Seungdalsan, and to interpret how these strategies reflect local ecological conditions and community developmental status.

Materials and Methods

Investigated species

Nineteen plant communities were surveyed in the hilly vegetation of Mt. Seungdalsan, Dalsan-ri, Mongtan-myeon, Muan-gun, and Jeollanam-do, Korea (Fig. 1). Phytosociological surveys were used to identify species composition and dominant or frequently occurring taxa within the study area. Based on this vegetation survey, 23 species were selected for trait and CSR analyses, including 19 shrub and climbing species and four lichen species. The lichen species were not treated as vascular plants but were included as a separate S functional group representing exposed substrate microsites within the study area. Species with a very low occurrence frequency or low cover were excluded because they were subordinate taxa, and sufficient plant or substrate samples could not be obtained for trait analysis (Kim, 1984; Kim, 1986; Son *et al*., 2020). Thus, the selected species represent the main shrub, climbing, and lichen components of the hilly vegetation of Mt. Seungdalsan. Field distribution patterns were interpreted based on phytosociological survey records, observed microsite conditions, and substrate types, including shrub patches, supported vegetation structures, exposed rock surfaces, and tree bark substrates.

Plant trait analysis

Plant traits were assessed following Grime (2001) and Hodgson *et al*. (1999). The community attributes (diversity and dominance) were also recorded. The analysis included the following quantitative variables related to plant size and leaf characteristics (Pierce *et al*., 2013; Pierce *et al*., 2007): CH (mm), lateral spread (mm), leaf area (mm^2), LDW (mg), leaf dry matter content (LDMC, %), specific leaf area (SLA, $mm^2\ mg^{-1}$), flowering period (FP), and flowering start (FS). For climbing species, CH was measured as the maximum vertical height reached by shoots climbing on surrounding vegetation or other supports, rather than as the self-supporting stem height. Thus, the CH of climbing species represents their vertical occupation height within the vegetation structure.

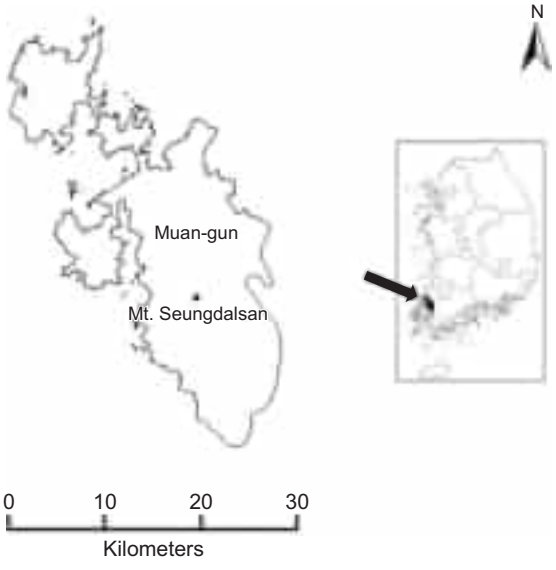

Fig. 1. Map of the study area in Mt. Seungdalsan, Muan-gun, Jeollanam-do, Republic of Korea.

Statistical analysis

(1) Canonical correspondence analysis (CCA): To examine the relationships between species composition and plant traits, CCA was conducted using CANOCO 5.1 (ter Braak, 1986). Plant traits were included to explore the multidimensional relationships.

(2) CSR analysis: Plant functional traits were used to determine CSR strategy types and construct a CSR triangle following Hodgson *et al*. (1999).

Results

A phytosociological survey identified shrubs, climbing vascular plants, and lichen components as the major visible elements of the hilly vegetation of Mt. Seungdalsan. Among the recorded taxa, 23 species with sufficient occurrence and cover were selected for trait and CSR analyses, whereas rare or low-cover subordinate taxa were excluded from quantitative analysis. In the field, shrubs and climbing vascular plants were mainly associated with shrub patches or supported vegetation structures, whereas lichen species were observed on exposed rock surfaces and tree bark substrates.

Table 1 summarizes the functional traits of plants, mainly shrubs, climbing species, and lichens, in the hilly vegetation of Mt. Seungdalsan, Muan-gun, Korea. Shrubs and climbing species show a mean CH of 747 mm, a mean LDMC of 25%, a mean FP of 2 months, a mean lateral spread score of 4, a mean LDW of 113 mg, a mean SLA of 22 $mm^2\ mg^{-1}$, and a mean FS in June. By contrast, lichens exhibited a CH of 1 mm, a mean LDMC of 48%, a mean FP of 3 months, a mean lateral spread score of 2, a mean LDW of 12 mg, a mean SLA of 43 $mm^2\ mg^{-1}$, and an FS in April. These contrasting traits suggest a gradient from taller shrubs and climbing species with greater aboveground or vertical occupation sizes, to low-growing lichens with higher LDMC and SLA values.

Table 2 presents species-level trait values for the 23 surveyed species. Shrubs and climbing species showed wide variation in CH, ranging from 400 to 1,000 mm; LDMC, from 17 to 41%; FP, from 1 to 6 months; lateral spread score, from 3 to 6; LDW, from 5 to 436 mg; SLA, from 5 to 47 $mm^2\ mg^{-1}$; and FS, from April to October. Several shrub, woody vine, or herbaceous climbing spe-

Table 1. Summary statistics of plant traits in the hilly vegetation of Mt. Seungdalsan

Property	Canopy height (mm)	Leaf dry matter content (%)	Flowering period (mo)	Lateral spread (six-point model)	Leaf dry weight (mg)	Specific leaf area ($mm^2 mg^{-1}$)	Flowering start (mo)
Shrubs and climbing species							
Average	747	25	2	4	113	22	6
n	19	19	19	19	19	19	19
SD	276	6	1	1	111	11	2
Max	1,000	41	6	6	436	47	10
Min	400	17	1	3	5	5	4
Lichens							
Average	1	48	3	2	12	43	4
n	4	4	4	4	4	4	4
SD	0	5	0	0	6	15	0
Max	1	52	3	2	20	50	4
Min	1	40	3	2	8	20	4

SD, standard deviation.

cies, including *Clematis apiifolia*, *Hedera rhombea*, *Humulus japonicus*, *Parthenocissus tricuspidata*, *Pueraria thunbergiana*, *Rhododendron mucronulatum*, *Rhododendron yedoense*, and *Trachelospermum asiaticum* var. *intermedium*, reached vertical occupation heights of 1,000 mm. In contrast, all four lichen species had a CH of 1 mm, LDMC values ranging from 40 to 52%, FPs of 3 months, lateral spread scores of 2, LDW values ranging from 8 to 20 mg, SLA values ranging from 20 to 50 $mm^2 mg^{-1}$, and FS in April. These species-level trait data provide the basis for the CSR strategy classification shown in Table 3.

Table 3 shows that shrub and climbing species predominantly exhibited C, CR, and C/CR strategies, with few CSR, R/CR, and CR/CSR types. Highly competitive C-type species included *Mallotus japonicus*, *R. mucronulatum*, *R. yedoense*, and *Sasa borealis*, with C values ranging from 68 to 78%. The C/CR transitional types included *C. apiifolia*, *H. rhombea*, *H. japonicus*, *P. tricuspidata*, *Quercus serrata*, and *T. asiaticum* var. *intermedium*, with C values ranging from 61 to 65% and R values ranging from 33 to 39%. The CR species included *Boehmeria spicata*, *P. thunbergiana*, *Rosa multiflora*, *Rubus coreanus*, *Smilax china*, and *Stephanandra incisa*, with C values ranging from 49 to 60% and R values ranging from 33 to 47%. Other strategy types among shrub and climbing species included *Castanea crenata* as CSR, *Eurya japonica* as R/CR, and *Zanthoxylum schinifolium* as CR/CSR. Lichens, such as *Anzia* sp., *Collema* sp., *Dirinari applanata*, and *Physcia orientalis*, were classified as S-strategists, with S values ranging from 86 to 89%.

Fig. 2 shows a CCA biplot illustrating the relationships among the 23 species (triangles labeled 1-23) and the measured plant traits (arrows). The axes (CCA1 and CCA2) represented the main gradients explaining the variation in species composition based on the measured traits.

Each triangle (1-23) corresponds to a species and is positioned based on its trait profile. The length and direction of the arrows indicate the strength and direction of the association between each trait and the CCA axes.

Species positioned in the direction of an arrow tended to have higher values for this trait. Positions near LDMC, SLA, and FP on the positive side of CCA1 were associated with high LDMC, higher SLA, and a longer FP. Positions near CH and LDW on the negative side of CCA1 were linked to greater CH and higher LDW. The FS points upward, indicating that species positioned higher on CCA2 tend to have an earlier flowering onset. Overall, the ordination highlights trait-based separation among species, suggesting different ecological strategies (e.g., S vs. C types) along the gradients represented by CCA1 and CCA2.

Fig. 3 shows the relationship between CH and CSR strategies.

C strategy: A strong positive correlation indicated that as CH increased, the proportion of competitive traits increased significantly. This suggests that taller plants in the hilly vegetation of Mt. Seungdalsan may have a greater resource acquisition capacity (e.g., light), favoring competitive species in relatively stable microsites.

S strategy: A weak negative relationship suggests that the S component tends to decrease with CH; however, this trend was not statistically significant.

R strategy: The negative trend suggests that species with a higher R component tend to have shorter CH, con-

Table 2. Trait data of selected plant species in the hilly vegetation of Mt. Seungdalsan

	Species	Canopy height (mm)	Leaf dry matter content (%)	Flowering period (mo)	Lateral spread (six-point model)	Leaf dry weight (mg)	Specific leaf area ($mm^2 mg^{-1}$)	Flowering start (mo)
Shrubs and climbing species								
1	*Boehmeria spicata*	900	20	2	3	76	47	7
2	*Castanea crenata*	500	33	2	3	87	24	6
3	*Clematis apiifolia*	1,000	24	3	6	5	30	6
4	*Eurya japonica*	400	28	6	3	80	15	10
5	*Hedera rhombea*	1,000	20	3	6	25	5	7
6	*Humulus japonicus*	1,000	21	3	6	77	11	7
7	*Mallotus japonicus*	900	30	2	3	197	18	6
8	*Parthenocissus tricuspidata*	1,000	17	2	6	150	8	6
9	*Pueraria thunbergiana*	1,000	18	2	6	436	11	8
10	*Quercus serrata*	400	26	2	3	85	30	4
11	*Rhododendron mucronulatum*	1,000	28	2	3	65	21	4
12	*Rhododendron yedoense*	1,000	21	2	3	161	28	4
13	*Rosa multiflora*	400	24	2	3	25	30	5
14	*Rubus coreanus*	400	24	2	3	49	34	5
15	*Sasa borealis*	900	41	1	3	293	14	4
16	*Smilax china*	500	21	2	3	234	21	5
17	*Stephanandra incisa*	500	28	2	3	57	31	5
18	*Trachelospermum asiaticum* var. *intermedium*	1,000	20	2	3	32	16	4
19	*Zanthoxylum schinifolium*	400	26	2	3	6	17	6
Lichens								
20	*Anzia* sp.	1	40	3	2	12	50	4
21	*Collema* sp.	1	50	3	2	8	50	4
22	*Dirinari applanata*	1	50	3	2	20	20	4
23	*Physcia orientalis*	1	52	3	2	8	50	4

sistent with disturbed or early successional microhabitats. However, because the correlation was not statistically significant, this pattern should be interpreted as a tendency rather than a consistent rule.

The increase in C% with CH represents a clear pattern (Fig. 3); taller species tend to be more competitive, whereas shorter species show relatively higher or mixed S and R components. This aligns with Grime's CSR theory, in which C dominate productive and stable environments, whereas R or S are favored under constraints (e.g., drought).

Table 3 and Fig. 4 compare the relative proportions of C and R components across plant species in the hilly vegetation of Mt. Seungdalsan.

Most plant species in the hilly vegetation displayed intermediate to high C% values, consistent with the relatively stable habitat conditions in the study area.

The R% values were generally moderate or low, suggesting a limited ruderal component, possibly due to the low disturbance frequency.

The dominance of C-type components may indicate a relatively mature vegetation structure and adaptation to long-term stability.

This classification (Fig. 5) follows Hodgson *et al*. (1999)

Table 3. Selected plant species, C%, S%, R% values, and CSR strategies in the hilly vegetation of Mt. Seungdalsan

	Species	Percentage			Strategy type
		C%	S%	R%	
Shrubs and climbing species					
1	*Boehmeria spicata*	53	0	47	CR
2	*Castanea crenata*	52	24	24	CSR
3	*Clematis apiifolia*	61	0	39	C/CR
4	*Eurya japonica*	32	6	62	R/CR
5	*Hedera rhombea*	63	0	37	C/CR
6	*Humulus japonicus*	61	0	39	C/CR
7	*Mallotus japonicus*	70	1	29	C
8	*Parthenocissus tricuspidata*	65	0	35	C/CR
9	*Pueraria thunbergiana*	60	0	40	CR
10	*Quercus serrata*	63	4	33	C/CR
11	*Rhododendron mucronulatum*	78	0	22	C
12	*Rhododendron yedoense*	68	0	32	C
13	*Rosa multiflora*	49	4	47	CR
14	*Rubus coreanus*	54	0	45	CR
15	*Sasa borealis*	70	30	0	C
16	*Smilax china*	54	0	46	CR
17	*Stephanandra incisa*	55	12	33	CR
18	*Trachelospermum asiaticum* var. *intermedium*	63	0	37	C/CR
19	*Zanthoxylum schinifolium*	39	15	46	CR/CSR
Lichens					
20	*Anzia* sp.	14	86	0	S
21	*Collema* sp.	11	89	0	S
22	*Dirinari applanata*	13	87	0	S
23	*Physcia orientalis*	11	89	0	S

Source: Hodgson *et al*. (1999).
C, competitor; S, stress-tolerator; R, ruderal.

and Pierce *et al*. (2013) and uses traits such as SLA, LDMC, and canopy structure to determine the CSR type for each species.

Shrub species in hilly vegetation, such as *Rhododendron* spp. and *R. coreanus*, fall mainly within the C or CR types, indicating competitiveness with varying degrees of disturbance tolerance.

Lichens occupy S types, emphasizing stress resistance and persistence under exposed conditions.

The overall pattern suggests a mosaic of C- and S-type adaptations, reflecting the balance between competition and stress in the hilly vegetation of Mt. Seungdalsan.

Discussion

This study examined the functional traits and CSR strategies of shrub, climbing, and lichen communities in the hilly vegetation of Mt. Seungdalsan, Muan-gun, Korea, highlighting the ecological balance between competition, stress tolerance, and disturbance. These results support our hypothesis that non-lichen vascular plants and lichens have contrasting CSR strategies within the study area. Shrub and climbing species were mainly classified as C-, CR-, or C/CR-strategists, whereas lichens were classified as S-strategists, indicating that species composition reflects a gradient from competitive or rapid spatial occupation of relatively stable patches to S persistence on exposed substrates.

The main ecological implication of this study is that shrub, climbing, and lichen species in the hilly vegetation of Mt. Seungdalsan exhibit contrasting functional responses to local habitat heterogeneity. This vegeta-

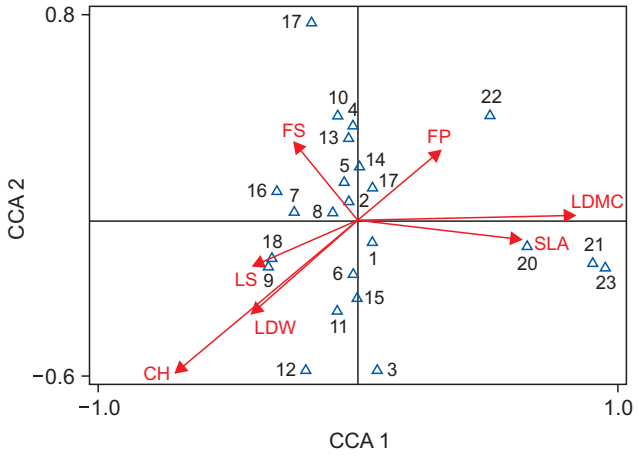

Fig. 2. Canonical correspondence analysis (CCA) biplot diagram. Plant traits are shown as arrows. Species scores (triangles 1-23) are plotted along Axes 1 and 2. FS, flowering start; FP, flowering period; LDMC, leaf dry matter content; SLA, specific leaf area; LS, lateral spread; LDW, leaf dry weight; CH, canopy height.

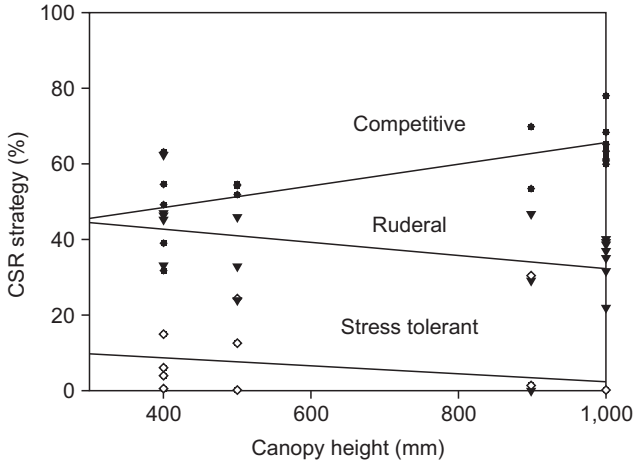

Fig. 3. Relationship between canopy height and competitive, stress-tolerant, and ruderal (CSR) strategies of plant species in the hilly vegetation of Mt. Seungdalsan. C strategy: Y=37.3080+0.0282X (r=0.7099, P<0.01), S strategy: Y=12.8367−0.0104X (r=0.3191, not significant), R strategy: Y=49.8553−0.0178X (r=0.03826, not significant).

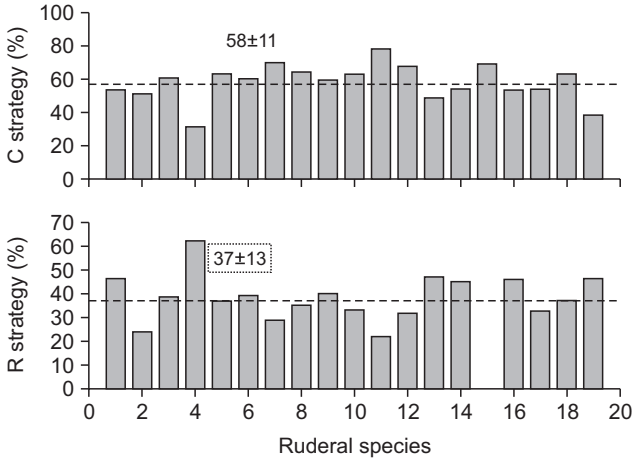

Fig. 4. C% and R% strategy percentages of plant species in the hilly vegetation of Mt. Seungdalsan. C, competitor; R, ruderal.

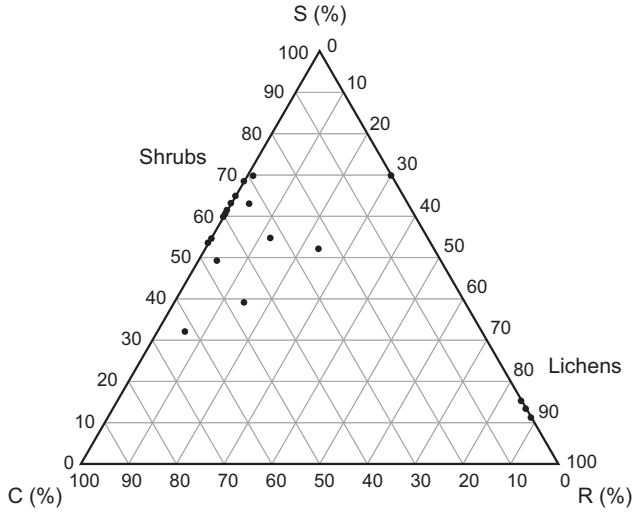

Fig. 5. Competitive, stress-tolerant, and ruderal (CSR) classification of shrub and climbing vascular plant species and lichen species based on plant traits, following Hodgson *et al*. (1999) and Pierce *et al*. (2013). Source: Hodgson *et al*.

tion contains heterogeneous microsites such as relatively protected shrub patches, exposed rock surfaces, and tree bark substrates. These microsite differences may generate contrasting ecological filters that allow C or CR vascular plants and S lichens to coexist within the same study area.

The inclusion of lichens was intended to represent a distinct S functional group, rather than to treat them as vascular plants. Lichens occurred mainly on exposed substrates such as rock surfaces and tree bark, where water availability and nutrient supply are limited and temporally variable. Therefore, their inclusion allowed us to compare the C/CR strategies of vascular shrubs and climbing species with the S strategies of cryptogamic organisms occupying harsher microsites. This comparison helps to clarify the functional heterogeneity within the study area rather than broadening the focus away from vascular plants.

As shown in Table 1, the contrast in functional traits between shrubs, climbing species, and lichens suggests that these groups occupy different microsite conditions within the study area, rather than representing a uniform

vegetation type. Shrub and climbing species exhibited a mean CH of 747 mm, moderate LDMC (25%), and SLA (22 mm^2 mg^{-1}), reflecting moderate growth rates and resource-use efficiency (Pierce *et al*., 2013). In contrast, lichens showed nearly negligible CH (1 mm), extremely high LDMC (48%), and high SLA (43 mm^2 mg^{-1}), indicating an S strategy adapted to harsh, resource-poor environments (Hodgson *et al*., 1999; Sjöman *et al*., 2025). This pattern suggests that taller shrubs and climbing species are favored in relatively protected microsites or supported vegetation where aboveground space acquisition is advantageous, whereas lichens persist on exposed substrates where stress tolerance is more important than competitive growth.

As shown in Table 3 and Fig. 5, shrubs and climbing species were primarily C-, CR-, or C/CR-type species, indicating a shift toward more C/CR strategies as habitat conditions stabilized or available space was rapidly occupied. Lichens such as *Anzia* and *Dirinari* are classified as strict S-strategists, consistent with survival under chronic stress (Grime, 2001). The distribution of CSR strategies observed in the present study is broadly consistent with the classic CSR theory of plant community development, in which S pioneers may be replaced by more R or C species as environmental conditions improve (Garnier *et al*., 2016). Fig. 4 further demonstrates that most plant species in the hilly vegetation exhibited intermediate to high C% values, consistent with adaptation to relatively stable hilly habitats. Low R% values suggest a limited presence of ruderal species, likely reflecting lower disturbance frequencies than those in reclaimed or lowland habitats (Viola *et al*., 2010).

The predominance of C, CR, and C/CR strategies among shrub and climbing species suggests that competition for light and space is an important ecological process in the hilly vegetation of Mt. Seungdalsan. Species with greater CH and lateral spread can occupy the aboveground space more effectively, which may explain the positive relationship between CH and the C component. In this context, the C and CR strategies of shrubs and climbing species not only indicate high competitive ability but also reflect their capacity to persist and expand in relatively stable patches where canopy development, vertical occupation, and lateral growth are advantageous. This interpretation is consistent with the whole-plant perspective of the CSR theory, in which plant strategy expression is linked to coordinated variation in size-related traits, resource acquisition, and stress tolerance (Liu *et al*., 2025).

H. japonicus was classified as a C/CR-type species, which should be interpreted as a boundary between the C and CR strategies rather than as a purely C strategy. Although *H. japonicus* is an annual herbaceous climbing species, it is comparable to woody climbing species in terms of vertical space occupation because climbing shoots use the surrounding vegetation or other support. In this study, the CH for climbing species was assessed based on the height reached by climbing shoots; *H. japonicus* had a CH of 1,000 mm and a lateral spread score of 6. Therefore, the C/CR classification likely reflects both rapid vertical and lateral space occupation and the ruderal component associated with disturbed habitats.

The CSR strategies of the selected species can be interpreted in relation to their field distribution and microsite conditions observed during the vegetation survey. Shrub and climbing vascular plants using the C, CR, or C/CR strategies were mainly associated with shrub patches or structurally supported vegetation, where aboveground space occupation, canopy development, and lateral spread were advantageous. In contrast, lichen species classified as S strategists occurred on exposed rock surfaces and tree bark substrates, where water availability and nutrient supply are limited and temporally variable. Thus, the observed CSR patterns reflect field-level habitat differentiation between relatively protected vascular plant microsites and exposed, stress-prone cryptogamic substrates.

The relationship between the CH and the CSR strategy (Fig. 3) suggests that plant stature is a key trait linking individual morphology to ecological strategies in the study area. Taller plants tend to have greater resource acquisition capacities (e.g., light, nutrients, and space), which is consistent with traits commonly associated with competitive species (Lee *et al*., 2020; Westoby *et al*., 2002; Yang *et al*., 2021), and CSR strategy expression may be linked to broader trait spectra, including plant size-related traits (Ricotta *et al*., 2023). Conversely, the weak negative correlations with the S and R strategies suggest that shorter plants may occupy niches characterized by stress or disturbance, although these trends were not statistically significant. This reinforces the idea that plant stature is a key ecological trait that shapes the expression of functional strategies.

CCA (Fig. 2) indicated that the species distribution patterns were structured by trait gradients related to plant size, leaf economics, and phenology. Traits, such as CH and LDW, were associated with species showing stronger competitive components, whereas LDMC, SLA, and flowering-related traits were associated with species positioned toward more S or mixed strategies. This pattern suggests that species composition in the study area is structured not by a single environmental factor but by combined gradients of plant size, resource acquisition, and stress tolerance. These results support previous findings that habitat structure can act as an ecological filter shaping plant species composition (Bernard-Verdier *et al*., 2012), and further suggest that the field distribution of the selected species reflects microsite-level differences in vegetation structure and substrate exposure.

Our findings suggest that the vegetation of Mt. Seungdalsan forms a mosaic of C/CR- and S-type strategies,

with competitive shrubs and climbing species occupying relatively stable or structurally supported habitats, and S lichens persisting under harsh conditions. In accordance with Grime's (1977) theory, succession may proceed from S- to more C-dominated systems as stability increases. This functional trait-based assessment provides valuable insights for vegetation monitoring and management strategies in the study area.

The shrub and climbing species identified in this study exhibited either predominantly C/CR strategies. This pattern reflected the functional traits associated with C and CR strategies. Drought is a major environmental stress factor for lichens (Ihm & Lee, 1998; Korean National Arboretum, 2015). *T. asiaticum* var. *intermedium* was classified as a C/CR-type species (Table 3). Four lichen species, *Anzia* sp., *Collema* sp., *D. applanata*, and *P. orientalis*, exhibited S strategies associated with drought stress.

In contrast, the S strategies of lichens indicate persistence in resource-limited and physiologically stressful microsites rather than competitive dominance. Lichens occur on substrates, such as exposed rock surfaces and tree bark, where water availability and nutrient supply are likely to be limited and temporally variable. Their high LDMC and S CSR positions suggest a conservative resource-use strategy, allowing them to maintain physiological activity during favorable periods and withstand dry or exposed conditions during unfavorable periods.

The dominance of vegetation by competitors can be disrupted by disturbances, such as air pollution, drought, and agricultural expansion (Li *et al*., 2025). Nevertheless, strategy composition may shift from R- and S-associated types to C-associated types as competitive ability becomes advantageous. The proportion of competitively oriented species may reflect the degree of competition across growth stages or habitats. Furthermore, increased competition may be associated with higher functional and species diversity when no single competitive species dominates strongly, whereas strongly dominant disturbance-adapted species can suppress diversity. This interpretation is consistent with the patterns observed in this study.

Highly competitive plants may appear advantageous even in stressful growth environments (Deng, 2025). However, competitive plants grow rapidly under favorable conditions by rapidly utilizing the available resources. In resource-limited environments, they may grow rapidly during brief periods of resource availability but may suffer tissue damage once resources are depleted. In contrast, S plants grow slowly, even in resource-rich environments, maintaining small sizes and producing well-developed tissues that are resistant to stress and support acclimation to environmental variation.

From a vegetation management perspective, the coexistence of competitive shrubs, climbing species, and S lichens suggests that hilly vegetation should be evaluated at the microsite scale. Management focused only on the dominant vascular plant cover may overlook S organisms that occupy exposed substrates and contribute to local functional diversity. Therefore, CSR-based trait assessment can provide a useful framework for detecting functional differences among species and interpreting how hilly vegetation responds to disturbances, droughts, and habitat heterogeneity.

Author Contributions

Conceptualization: JWK, SYK. Data curation: MJK. Formal analysis: JC. Funding acquisition: JWK. Investigation: JWC, MHP, SSL. Supervision: JWK. Visualization: DHS. Writing – original draft: SYK, JWK. Writing – review & editing: SYK, JWK.

Conflict of Interest

The authors declare that they have no competing interests.

Funding

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education (RS-2018-NR033226).

References

Aragón, L., Messier, J., Atuesta-Escobar, N., and Lasso, E. (2023). Tropical shrubs living in an extreme environment show convergent ecological strategies but divergent ecophysiological strategies. *Annals of Botany,* 131, 491-502. https://doi.org/10.1093/aob/mcad002

Bernard-Verdier, M., Navas, M.L., Vellend, M., Violle, C., Fayolle, A., and Garnier, E. (2012). Community assembly along a soil depth gradient: contrasting patterns of plant trait convergence and divergence in a Mediterranean rangeland. *Journal of Ecology,* 100, 1422-1433. https://doi.org/10.1111/1365-2745.12003

Cao, J.Y., Liu, J.F., Yuan, Q., Xu, D.Y., Fan, H.D., Chen, H.Y., *et al*. (2020). Traits of shrubs in forests and bushes reveal different life strategies. *Chinese Journal of Plant Ecology,* 44, 715-729. https://doi.org/10.17521/cjpe.2020.0024

Deng, X. (2025). *Understanding biodiversity and resilience of forest ecosystems using integrated remote sensing and trait-based approaches*. PhD thesis. University of Oxford.

Garnier, E., Navas, M.L., and Grigulis, K. (2016). *Plant Functional Diversity: Organism Traits, Community Structure, and Ecosystem Properties*. Oxford University Press.

Grime, J.P. (1977). Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *The American Naturalist,* 111, 1169-1194. https://doi.org/10.1086/283244

Grime, J.P. (2001). *Plant Strategies, Vegetation Processes, and*

Ecosystem Properties. 2nd ed. Wiley-Blackwell.
Grime, J.P., and Pierce, S. (2012). *The Evolutionary Strategies that Shape Ecosystems*. Wiley-Blackwell.
Hodgson, J.G., Wilson, P.J., Hunt, R., Grime, J.P., and Thompson, K. (1999). Allocating C-S-R plant functional types: a soft approach to a hard problem. *Oikos,* 85, 282-294. https://doi.org/10.2307/3546494
Ihm, B.S., and Lee, J.S. (1998). Soil factors affecting the plant communities of wetland on southwestern coast of Korea. *Korean Journal of Ecology,* 21, 321-328.
Kim, C.S. (1984). The flora of Huksan-do Archipelago (I) - survey in Taehuksan-do -. *Bulletin of Institute of Littoral Biota,* 1, 67-91.
Kim, C.S. (1986). Studies on the flora and vegetation of Hongdo island. *Bulletin of Institute of Littoral Biota,* 3, 1-34.
Korean National Arboretum. (2015). *A Field Guide to Lichens*. Geobook.
Larcher, W. (2003). *Physiological Plant Ecology*. 4th ed. Springer.
Lee, J.S., Son, D.H., Lee, S.H., Myeong, H.H., Cho, J.S., Lee, J.C., *et al*. (2020). Canonical correspondence analysis ordinations and competitor, stress tolerator, and ruderal strategies of coastal dune plants in South Korea. *Journal of Coastal Research,* 36, 528-535. https://doi.org/10.2112/jcoastres-d-19-00106.1
Li, C., Gu, Y., Liu, B., Chun, K.P., Octavianti, T., Tan, M.L., *et al*. (2025). Assessing the impacts of climate change on the potential geographical distribution of *Lycium ruthenicum* in China. *Biology,* 14, 1379. https://doi.org/10.3390/biology14101379
Liu, R.L., van Kleunen, M., Pierce, S., Chytrý, M., Guo, K., Pyšek, P., *et al*. (2025). Grime's CSR theory revisited: a whole-plant view of vascular plant functioning across contrasting environments. *Journal of Ecology,* 113, 3019-3036. https://doi.org/10.1111/1365-2745.70146
Liu, S., and Zheng, J. (2024). Adaptive strategies based on shrub leaf-stem anatomy and their environmental interpretations in the eastern Qaidam Basin. *BMC Plant Biology,* 24, 323. https://doi.org/10.1186/s12870-024-05026-3
Negreiros, D., Fernandes, G.W., Efremova, A.A., Le Stradic, S., and Neves, A.C.O. (2016). Growth-survival trade-off in shrub saplings from Neotropical mountain grasslands. *South African Journal of Botany*, 106, 17-22. https://doi.org/10.1016/j.sajb.2016.05.015
Pierce, S., Brusa, G., Vagge, I., and Cerabolini, B.E.L. (2013). Allocating CSR plant functional types: the use of leaf economics and size traits to classify woody and herbaceous vascular plants. Functional Ecology, 27, 1002-1010. https://doi.org/10.1111/1365-2435.12095
Pierce, S., Luzzaro, A., Caccianiga, M., Ceriani, R.M., and Cerabolini, B. (2007). Disturbance is the principal α-scale filter determining niche differentiation, coexistence and biodiversity in an alpine community. *Journal of Ecology,* 95, 698-706. https://doi.org/10.1111/j.1365-2745.2007.01242.x
Ricotta, C., Dalle Fratte, M., Pierce, S., Carboni, M., Cerabolini, B.E.L., and Pavoine, S. (2023). Quantifying the extent of plant functional specialization using Grime's CSR strategies. *Ecological Indicators,* 148, 110066. https://doi.org/10.1016/j.ecolind.2023.110066
Sjöman, H., Hirons, A., and Watkins, H. (2025). Using the CSR theory when selecting woody plants for urban forests: evaluation of 342 trees and shrubs. *Arboriculture & Urban Forestry,* 51, 329-354. https://doi.org/10.48044/jauf.2025.014
Son, D.H., Lee, J.S., Kim, D.E., Lee, S.H., Hong, S.K., Myeong, H.H., *et al*. (2020). Importance of biotic and soil factors in determining the distribution strategies of coastal salt marsh plants. *Journal of Marine and Island Cultures,* 9. https://doi.org/10.21463/jmic.2020.09.2.01
Taiz, L., and Zeiger, E. (2006). *Plant Physiology*. 4th ed. Sinauer Associates.
ter Braak, C.J.F. (1986). Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology,* 67, 1167-1179. https://doi.org/10.2307/1938672
Viola, D.V., Mordecai, E.A., Jaramillo, A.G., Sistla, S.A., Albertson, L.K., Gosnell, J.S., *et al*. (2010). Competition-defense tradeoffs and the maintenance of plant diversity. *Proceedings of the National Academy of Sciences of the United States of America,* 107, 17217-17222. https://doi.org/10.1073/pnas.1007745107
Westoby, M., Falster, D.S., Moles, A.T., Vesk, P.A., and Wright, I.J. (2002). Plant ecological strategies: some leading dimensions of variation between species. *Annual Review of Ecology, Evolution, and Systematics,* 33, 125-159. https://doi.org/10.1146/annurev.ecolsys.33.010802.150452
Yang, K.H., Park, S.B., Kim, S.Y., Cho, J.S., Lee, J.S., You, C., *et al*. (2021). Distribution strategies of vascular plants at the reclaimed lands at the Saemangum sea dike. *Journal of Marine and Island Cultures,* 10. https://doi.org/10.21463/jmic.2021.10.2.03
Zhang, Y.S., Meiners, S.J., Meng, Y., Yao, Q., Guo, K., Guo, W.Y., *et al*. (2024). Temporal dynamics of Grime's CSR strategies in plant communities during 60 years of succession. *Ecology Letters,* 27, e14446. https://doi.org/10.1111/ele.14446

PNIE PROCEEDINGS OF THE NATIONAL INSTITUTE OF ECOLOGY OF THE REPUBLIC OF KOREA

Case Report

PNIE 2026;7(3):133-141
https://doi.org/10.22920/PNIE.2026.7.3.133
pISSN 2765-2203, eISSN 2765-2211

Invasion and Management of the Invasive Halophyte *Spartina anglica* at Dongmak-ri on Ganghwa Tidal Flat, South Korea

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ABSTRACT

Coastal tidal flats are highly productive ecosystems vulnerable to colonization by aggressive intertidal plants. *Spartina anglica*, an invasive halophyte listed among the world's worst invasive species, was first recorded in Korea in 2012 at Dongmak-ri on the southern Ganghwa tidal flat and became the largest stand in the country. Driven by clonal rhizome growth, it expanded roughly 9.2-fold between 2015 and 2020, converting open mudflat into vegetated marsh and sharply reducing the richness, diversity, and density of the native benthic community. Removal by mowing and manual uprooting (2016-2020) failed to halt this expansion. From 2021, repeated subsurface tillage applied twice yearly (May and August) fragmented the rhizome network before seed set, reducing the infested area from 55,447 m^2 to approximately 250 m^2 by 2024 (>99%). The case demonstrates the effectiveness of sustained, rhizome-targeted physical removal and the continuing need for surveillance and preventive management on tidal flats.

Keywords: Intertidal ecosystem, Invasive halophyte, Long-term monitoring, Physical control, Tidal-flat restoration

Introduction

Coastal tidal flats are among the most productive ecosystems on Earth, supporting rich benthic and fish communities and providing critical ecosystem services such as sediment stabilization, nutrient cycling (Schutte *et al.*, 2019), and carbon storage (Chen & Lee, 2022; Park *et al.*, 2024). The tidal flats of the Republic of Korea form a key stopover for migratory shorebirds on the East Asian–Australasian Flyway, and a representative portion was inscribed on the UNESCO World Heritage List as "Getbol, Korean Tidal Flats" in 2021 (UNESCO World Heritage Centre, 2021). Because open mudflats are naturally sparsely vegetated, they are highly vulnerable to colonization once aggressive intertidal plants are introduced.

Cordgrasses of the genus *Spartina* are among the most damaging invasive plants of intertidal habitats worldwide. As halophytes adapted to saline, periodically inundated substrates, they readily occupy bare mudflats. Through dense clonal growth from an extensive rhizome system, individual patches coalesce rapidly into continuous meadows (An *et al.*, 2007), while the resulting canopy attenuates tidal energy and traps fine sediment, so that open flats are progressively converted into elevated marshes and the native intertidal biota is displaced (Nehring & Hesse, 2008; Shin *et al.*, 2022). *Spartina anglica* in particular is listed among the "100 of the World's Worst Invasive Alien Species" (Lowe *et al.*, 2000). In South Korea, *S. anglica* and *Spartina alterniflora* have been designated as Ecosys-

Received July 1, 2026; **Revised** July 15, 2026;
Accepted July 16, 2026

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tem Disturbing Species under the Act on the Conservation and Use of Biological Diversity and as harmful marine organisms under the Conservation and Management of Marine Ecosystems Act (Korean Law Information Center, 2025).

The tidal flat at Dongmak-ri, on the southern shore of Ganghwa Island, is unique in the Korean history of this species (Fig. 1). Its invasion and management can be set out as a clear chronology: the species is thought to have colonized the flat around 2008; the first scientific record was published in 2012; the species was designated a harmful marine organism in 2016; the stand reached its maximum recorded extent of 55,447 m^2 in 2020; the removal program was reoriented toward repeated subsurface tillage from 2021; and by 2024 only residual patches totalling approximately 250 m^2 remained under routine surveillance. The site therefore offers an unusually complete record of an intertidal plant invasion, from establishment, through explosive expansion, to large-scale control and ongoing surveillance. Accordingly, this case report aims to (i) synthesize the invasion history and spread dynamics of *S. anglica* at Dongmak-ri, (ii) summarize its impacts on the benthic community and the physical environment of the flat, (iii) document the removal methods applied and evaluate the resulting management outcome, and (iv) derive implications for the future management of invasive halophytes on Korean tidal flats.

Case Report

Spartina anglica as an invasive halophyte

S. anglica is a perennial halophytic grass (Poaceae) found in intertidal zones. It tolerates high salinity through salt-excreting glands and osmotic adjustment, and it withstands anoxic, waterlogged sediments via aerenchymatous tissues that conduct oxygen to the roots (Maricle & Lee, 2002). It reproduces both by seeds and through an extensive rhizome system, the latter driving rapid clonal expansion and the coalescence of isolated patches into continuous meadows (An *et al.*, 2007). Dense stands act as autogenic ecosystem engineers by attenuating tidal energy, trapping fine sediment, and promoting accretion, so that open mudflats are gradually converted into elevated, vegetated marshes (Nehring & Hesse, 2008).

It should be emphasized that these engineering effects are not ecologically neutral or beneficial in the present context. Sediment stabilization and marsh formation may be regarded as functional roles within the species' native range, where cordgrass marshes are a natural component of the intertidal landscape. On the open, unvegetated mudflats of the Korean west coast, however, the same processes constitute ecological disturbance: they eliminate precisely the bare, soft-sediment habitat on which the native macrobenthos depends, and remove the foraging grounds used by migratory shorebirds. In this setting, therefore, ecosystem engineering by *S. anglica* should be

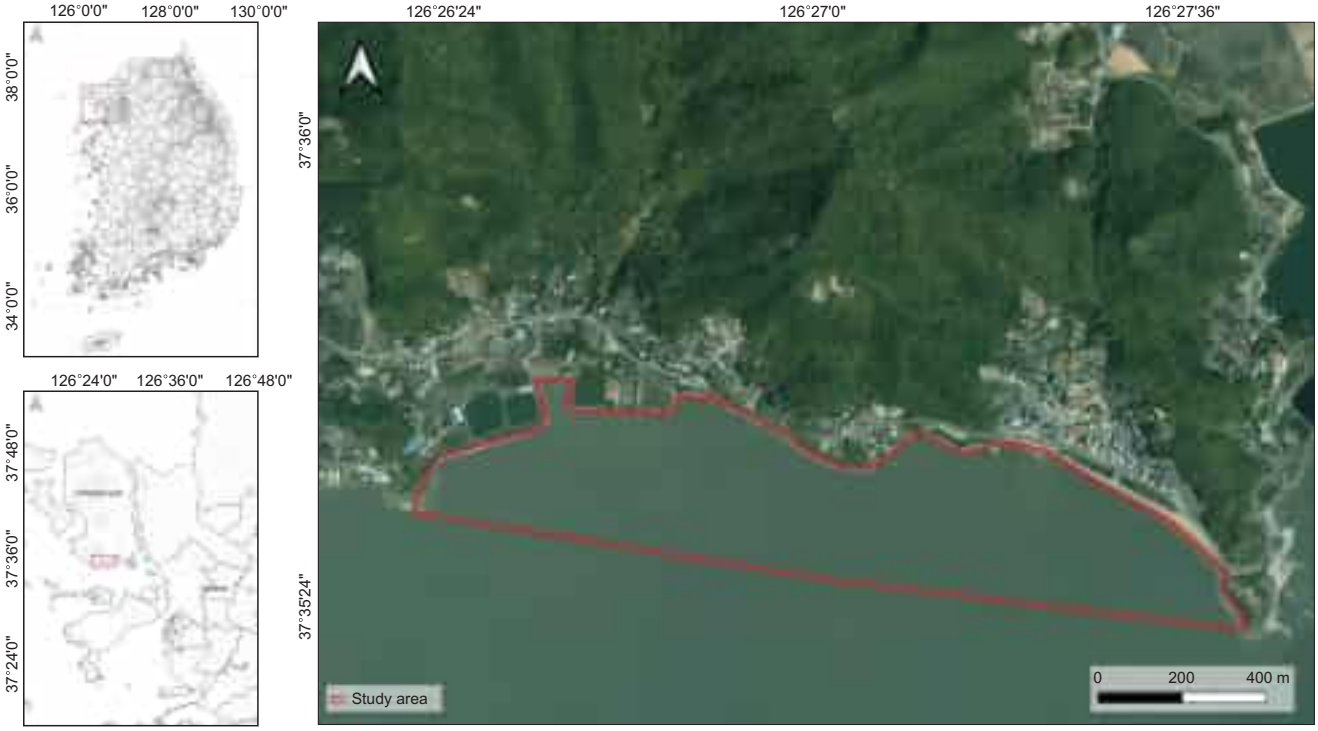

Fig. 1. Location of the study site at Dongmak-ri on the southern Ganghwa tidal flat, Incheon, Korea.

interpreted as the mechanism of habitat loss rather than as habitat creation.

The life history of the species also bears directly on when and how it can be controlled. At Dongmak-ri, new shoots emerge from overwintering rhizomes in May; flowering and seed set follow in July and August; and aboveground biomass, together with the translocation of photosynthate to belowground reserves, peaks around October. Removal is therefore concentrated in May and August: the first treatment suppresses newly emerged shoots before the rhizome reserves are replenished, and the second is completed before seed maturation, thereby limiting both vegetative regeneration and the production of a viable seed bank.

The species is a comparatively young allopolyploid that arose in the late nineteenth century through hybridization of the introduced *S. alterniflora* with the native European *Spartina maritima*; chromosome doubling of the sterile hybrid (*Spartina*×*townsendii*) yielded the fertile, vigorous polyploid (Ainouche *et al.*, 2008). The hybrid vigor and broad tolerance to salinity and inundation associated with its origin make *S. anglica* an effective pioneer of bare mudflats (Nehring & Hesse, 2008). Critically, the same traits that underlie its invasiveness—large belowground rhizome reserves and active sediment stabilization—also make established stands difficult to remove and their removal ecologically disruptive. Consequently, effective control of this polyploid cordgrass requires repeated, rhizome-targeted physical removal sustained over time, together with continued monitoring to suppress regrowth from residual rhizomes.

Invasion history and spread at Dongmak-ri

S. anglica was assumed to have first colonized the salt marshes of southern Ganghwa Island in 2008, with the first scientific record published in 2012 (Kim *et al.*, 2015). Although its introduction pathway remains uncertain, seeds or rhizome fragments are presumed to have been dispersed by ocean currents from the east coast of China, where *Spartina* had been planted extensively for coastal protection and reclamation since the late 1970s (Kim, 2016). At Dongmak-ri the species followed a characteristic two-stage spread pattern: isolated patches were first established on the open flat, and subsequent rhizomatous clonal growth caused these patches to coalesce into a continuous meadow (An *et al.*, 2007).

This process resulted in an explosive increase in area. The Dongmak-ri stand grew from approximately 6,014 m^2 in 2015 to roughly 7,200 m^2 in 2018, continuing to expand despite ongoing removal, and then to 55,447 m^2 in 2020, an increase of approximately 9.2-fold over five years (Fig. 2) (National Institute of Ecology, 2020; Shin *et al.*, 2022). At its peak, the Dongmak-ri stand had the highest *S. anglica* infestation recorded in South Korea (National Institute of Ecology, 2015; 2020). The species was also dispersed to nearby parts of Ganghwa Island, including Buno Harbor, the Seondu-ri shore, and Donggeom-do, such that the shallow surrounding flats remained at risk of further colonization (National Institute of Ecology, 2018; 2020).

Because *S. anglica* reproduces vegetatively, removal itself carries an inherent risk of promoting spread: fragmentation of the rhizome network during cutting or till-



Fig. 2. Year-by-year change in the area of the *Spartina anglica* stand at Dongmak-ri, 2015-2024.

age can generate propagules that are transported by tidal currents and establish new patches elsewhere on the flat. Incomplete or poorly timed removal may therefore aggravate rather than suppress an infestation. Three measures were adopted at Dongmak-ri to minimize this risk. First, all treatments were completed before seed maturation, so that neither seed nor freshly cut material entered the water during the reproductive period. Second, tillage was carried out to a depth sufficient to expose, rather than merely sever, the rhizome mat, and floating fragments were collected from the treated area as far as practicable after each operation. Third, the surrounding flats—including Buno Harbor, the Seondu-ri shore, and Donggeomdo—were placed under routine surveillance, latterly with unmanned aerial vehicle (UAV)-based survey, so that any secondary establishment could be detected and removed while patches remained small. These precautions are integral to the interpretation of the management outcome reported below.

Ecological impact on the tidal flat

Following this extensive spatial expansion, the stand transformed the Dongmak-ri flat both physically and biologically. By trapping fine sediment and raising the surface elevation by up to approximately 5.11 cm per year, dense *S. anglica* cover drove a progressive terrestrialization of the open mudflat while increasing sediment organic matter content and salinity and lowering pH, fundamentally altering the habitat (Shin *et al.*, 2022). Consistent with these engineering effects, earlier work on the Ganghwa tidal flat reported markedly higher iron and sulfur concentrations and anaerobic organic-matter decomposition rates beneath stands than in adjacent unvegetated flat.

These changes were accompanied by a sharp decline in the native benthic community. On the Dongmak-ri flat, macrobenthic species richness, diversity, and density decreased by approximately 70%, 80%, and 67%, respectively, within five years of invasion, and multivariate ordination of the macroinvertebrate assemblage showed that the invaded habitat separated clearly from the adjacent uninvaded tidal flat, indicating a broad restructuring of community composition rather than a uniform, taxon-wide decline (Shin *et al.*, 2022). Against this overall decline, however, several taxa increased in abundance following invasion, including the deposit-feeding polychaete *Perinereis linea* and the epifaunal gastropods *Batillaria cumingi* and *Lactiforis takii* (Shin *et al.*, 2022). These taxon-specific gains likely reflect the same engineering effects that drove the community-wide decline: dense *S. anglica* stems and rhizomes increase structural complexity and provide refuge from predation and desiccation, while the accumulation of plant-derived organic detritus supplies additional food for deposit-feeding and structure-associated invertebrates (An *et al.*, 2007; Nehring & Hesse, 2008).

Taken together, these contrasting responses indicate that *S. anglica* invasion did not act uniformly across taxa, but instead functioned as an ecological filter that favored a small number of structure- and detritus-associated species while displacing the broader assemblage of infaunal deposit- and suspension-feeders characteristic of open mudflats. The net effect at Dongmak-ri was therefore not simply a decline in abundance, but a simplification and homogenization of the benthic community, together with the loss of the open, unvegetated mudflat habitat on which the wider native macrobenthos and migratory shorebirds depend (An *et al.*, 2007; Roberts & Pullin, 2008).

A successful management outcome

Following its designation as a harmful marine organism in 2016, *S. anglica* at Dongmak-ri was the target of a continuous, multi-year removal program, with on-site removal conducted by the Korea Marine Environment Management Corporation and Ganghwa County, and the outcome monitored by the National Institute of Ecology. The management history falls into two clearly distinct phases, and the contrast between them is central to this case (Table 1). Between 2016 and 2020, control relied on mowing and manual uprooting, applied once or at most twice a year. This approach removed aboveground biomass but left the belowground rhizome network intact, and the labour deployed did not keep pace with the rate of clonal expansion; the stand therefore continued to grow throughout this period, from approximately 7,200 m^2 in 2018 to 55,447 m^2 in 2020. Removal of the canopy alone can, moreover, stimulate compensatory shoot production and increase culm density (Roberts & Pullin, 2008), so that the early regime may have been not merely insufficient but locally counterproductive. From 2021, following the peak of 2020, the program was reoriented: repeated subsurface tillage using heavy machinery was adopted as the principal method, applied twice a year (May and August) so as to fragment and expose the rhizome mat directly, with cutting of aboveground shoots retained only as a supplementary measure. Resourcing was concentrated accordingly through cooperation among the Korea Marine Environment Management Corporation, Ganghwa County, and the National Institute of Ecology. It is this shift—from aboveground removal to sustained, rhizome-targeted tillage—rather than the mere continuation of removal effort, that accounts for the reversal described below.

Stand area was quantified consistently throughout the study period by ground-based mapping of patch boundaries during the growing season, and from 2021 this was supplemented by UAV imagery, which improved the

Table 1. Annual stand area, principal removal method, treatment frequency, and management outcome for *Spartina anglica* at Dongmak-ri, Ganghwa tidal flat, 2015-2024

Year	Stand area (m^2)	Principal removal method	Frequency	Outcome and remarks
2015	6,014	Detection and visual survey	-	First national record; baseline survey
2018	7,200	Mowing and manual uprooting	Once a year	Area increased ~20% despite removal
2020	55,447	Mowing-centred (reached its limit)	1-2 times a year	Largest stand recorded in Korea
2021	28,457	Subsurface tillage introduced (heavy machinery)	Twice a year	Onset of decline (48.7% reduction)
2022	857	Intensive tillage and removal of residual plants	Twice a year	97% reduction relative to 2021
2024	250	UAV-based surveillance and immediate removal	Continuous	Residual-patch management stage

UAV, unmanned aerial vehicle.

detection of small residual patches but did not alter the basis on which area was calculated; the annual figures are therefore comparable across the two phases.

The program produced a rapid and sustained contraction of the stand. From its peak of 55,447 m^2 in 2020, the infested area decreased to approximately 28,457 m^2 in 2021 (a 48.7% reduction), to 857 m^2 in 2022 (a 97% reduction relative to 2021), and to approximately 250 m^2 by 2024, by which point the once-continuous meadow had been reduced to a few small patches and scattered individuals (Fig. 3, Table 1). In effect, the two-stage invasion process—patch establishment followed by clonal coalescence into a meadow—was reversed, fragmenting the meadow back into isolated patches. The slight increase recorded between 2023 and 2024 reflects differences in survey timing relative to removal operations and localized regrowth from residual rhizomes, rather than renewed large-scale spread. To the best of our knowledge, this makes Dongmak-ri the first site in South Korea where a major *S. anglica* infestation has been reduced to a residual, manageable level, marking it as an emerging model of successful cordgrass control on Korean tidal flats.

The approach taken at Dongmak-ri is consistent with the wider evidence on *Spartina* control, which helps explain why the sustained tillage program succeeded. Physical removal is the most widely used approach for mudflats; however, its effectiveness depends on disrupting the belowground rhizome system, because mechanical disturbance of the canopy alone is often insufficient to deplete the extensive belowground rhizome reserves that allow the plant to regenerate (Dethier & Hacker, 2004). Indeed, cutting or mowing alone can stimulate compensatory vegetative proliferation in *S. anglica*, substantially increasing culm density (Roberts & Pullin, 2008). Consistent with this, recent work on the Dongmak-ri tidal flat showed that subsurface tillage was far more effective than mowing, with two or more repeated tillage treatments required to destroy the rhizome network and prevent regrowth (Shin *et al*., 2024)—precisely the repeated, rhizome-targeted regime adopted from 2021. The timing of treatment is equally consequential: because photosynthate is translocated to the rhizomes as the season advances, removal carried out at the early flowering stage, before belowground reserves are replenished, is the most effective in suppressing regeneration in the following year, and completing treatment before seed maturation additionally limits recruitment from seed.

Other control options reinforced why the physical program was a practical choice at this site. Post-removal transplantation of native halophytes such as *Suaeda japonica* and *Phragmites australis* was tested to accelerate recovery; however, establishment and spread were limited and did not match the colonizing vigor of *S. anglica* (Shin *et al*., 2024). Chemical control with herbicides such as glyphosate or imazapyr, although effective elsewhere at larger scales (Roberts & Pullin, 2008), is heavily constrained on ecologically sensitive tidal flats; tidal inundation limits contact time, and concerns over collateral toxicity and long-term disruption of non-target marine communities require careful evaluation of the active compound and its delivery (Shimeta *et al*., 2016). Against this background, and despite its considerable demands for labor, time, and budget, the repeated, rhizome-targeted physical removal sustained at Dongmak-ri stands out as an approach that achieved control while maintaining disturbance to the surrounding tidal-flat ecosystem within acceptable limits.

Comparison with *Spartina* management programs elsewhere situates the Dongmak-ri outcome within this broader context. In several well-documented cases abroad, chemical control has been the primary tool for landscape-scale containment, and in some instances has enabled near-complete eradication: a coordinated, herbicide-based program in the San Francisco Estuary reduced *Spartina* cover to residual levels over roughly fifteen years (Kerr *et al*., 2016), and a control effort incorporating herbicide application achieved eradication of *S. anglica* from estuaries in Northern Ireland (Hammond & Cooper, 2002).

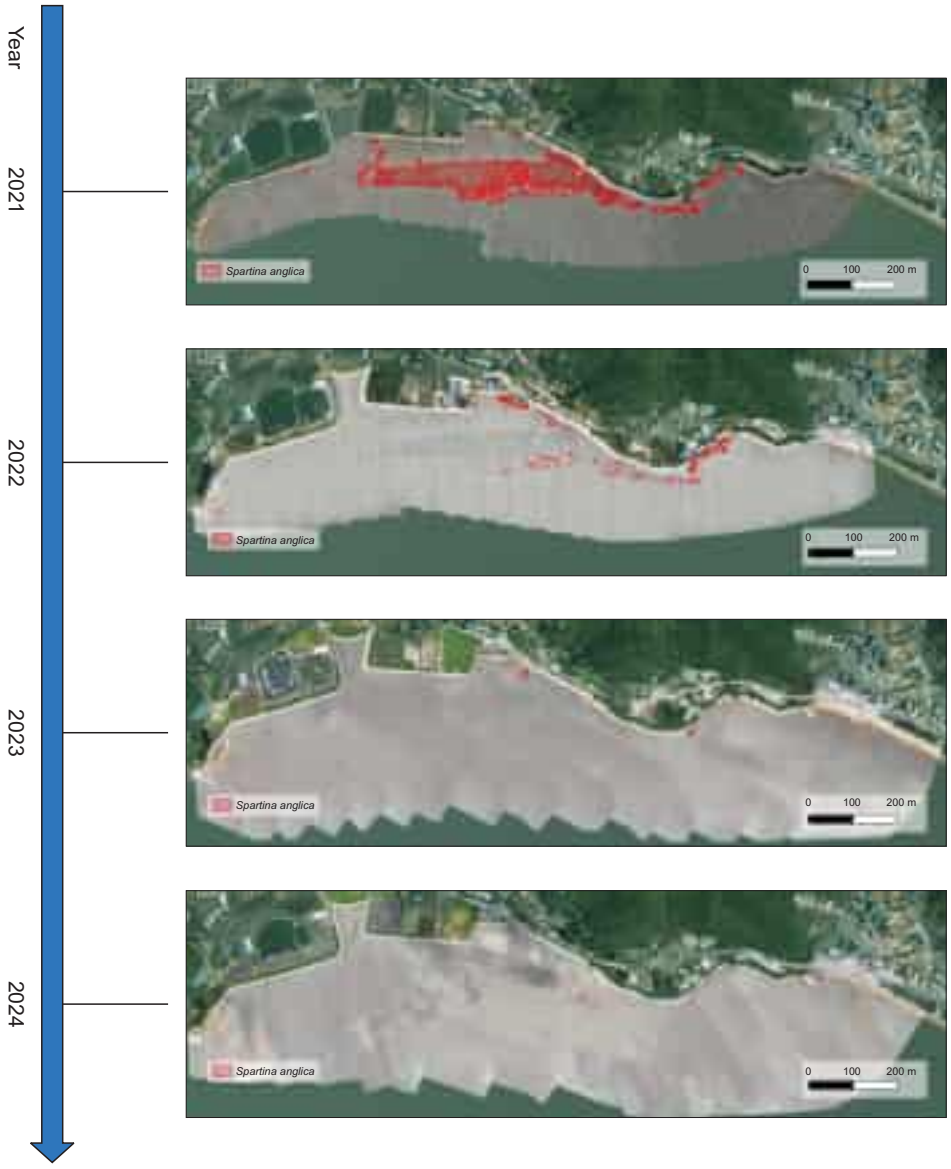

Fig. 3. Drone (unmanned aerial vehicle) imagery of the removal area showing the contraction of *Spartina anglica* cover over the management period, 2021-2024.

Herbicide-based control has also been sustained over the long term in Australia, where repeated treatment of *S. anglica* stands with the herbicide fluazifop-P acid produced no detectable short-term decline in sedimentary macrofaunal abundance or diversity despite the compound's known toxicity to fauna (Shimeta *et al.*, 2016), and in China, where an integrated regime of mowing followed by tilling at the end of the growing season nearly eliminated the related congener *S. alterniflora* within a single growing season, while spraying with the herbicide haloxyfop-r-methyl killed almost all treated plants (Xie *et al.*, 2019).

In South Korea, by contrast, herbicide application is not a viable option on tidal flats designated as ecologically sensitive or protected marine habitat, being constrained under the Enforcement Rule of the Conservation and Management of Marine Ecosystems Act (Korean Law Information Center, 2025); this regulatory context, together with the toxicity and non-target concerns noted above, precluded chemical methods at Dongmak-ri from the outset. Despite this constraint, the physical-only program achieved a reduction comparable in both speed and magnitude to these international, chemically assisted efforts: from a peak of 55,447 m^2 in 2020 to approximately 250 m^2 by 2024, a greater than 99% reduction within four years. This outcome also contrasts with cases in which physical control was applied without adequately targeting belowground rhizome reserves, most notably in coastal China, where mowing alone—rather than the combined mowing-and-tilling regime described above—was reported to stimulate compensatory regrowth rather than suppress the stand (An *et al.*, 2007). Taken together, these comparisons suggest that, where chemical options are legally

or ecologically precluded, a physical protocol explicitly designed around the species' rhizomatous regeneration, and sustained over multiple years, can approach the effectiveness of herbicide-based programs elsewhere, at the cost of greater sustained labor, time, and operational investment.

Management implications

The Dongmak-ri case can be used as a model for the successful management of an invasive halophyte via early detection and sustained control. These two features are particularly instructive. First, the reduction from the country's largest stand to a few residual patches was achieved primarily by repeated, rhizome-targeted physical removal sustained over several years, underscoring that incomplete or one-time treatment is insufficient against a clonal cordgrass. The contrast between the two phases of the program at Dongmak-ri makes this point directly: four years of aboveground removal did not arrest the invasion, whereas a comparable period of rhizome-targeted tillage reduced it by more than 99%. The lesson transferable to other sites is therefore not simply that removal must be sustained, but that it must be directed at the belowground rhizome system and timed to the species' life history. Second, this outcome relies on a stable division of roles sustained over time, combining systematic on-site removal with long-term monitoring.

The practical effectiveness of any such program also depends on the ability of field personnel to identify the target species correctly. On Korean tidal flats *S. anglica* may co-occur with native halophytes and other grasses of superficially similar habit, including *P. australis*, and misidentification would risk both the removal of native vegetation and the survival of overlooked cordgrass patches. Field teams at Dongmak-ri therefore worked from identification materials prepared by the National Institute of Ecology and received site-based training in the diagnostic characters of the species, a component of the program that we regard as integral to the outcome reported here.

At the same time, the case shows that control does not end with clearance of the main stand. Scattered individuals and residual rhizomes persisted, and the program necessarily shifted from large-scale removal to routine surveillance and preventive management of small patches (Kerr *et al.*, 2016). This transition is reflected at the national scale in the Second Mid-term *Spartina* Management Plan (2024-2028), which extends beyond removal to emphasize preventive management and long-term ecological restoration. Such a long-term orientation is warranted because natural habitat recovery and recolonization by native species remain exceptionally slow and limited even after successful *S. anglica* clearance (Hammond & Cooper, 2002), making adaptive, long-term restoration frameworks a priority rather than an afterthought (Kerr *et al.*, 2016).

The success at Dongmak-ri raises the question of whether *S. anglica* might eventually be removed from the lists of Ecosystem Disturbing Species and harmful marine organisms. In our view such a step would be premature. Residual rhizomes and a persistent seed bank remain at the site, from which regrowth has already been observed; the species continues to occur elsewhere on the Korean coast, most extensively in the Garorim Bay Marine Protected Area; and the possibility of re-invasion by waterborne propagules has not been eliminated. Delisting would also withdraw the legal basis for the sustained surveillance on which the present outcome depends. The Dongmak-ri case is therefore better read as evidence that the current designation is working than as an argument for relaxing it.

Technology is another priority. Institutional efforts against terrestrial invaders in South Korea have yielded increasingly sophisticated, and in some cases patented, detection and control tools (Park *et al.*, 2026), whereas comparably specialized toolkits for the dynamic intertidal environment remain largely absent, leaving programs dependent on labour-intensive physical removal. Developing low-disturbance detection and removal methods suited to tidal flats would make the sustained control achieved at Dongmak-ri less expensive and more broadly applicable. Beyond the site itself, the continuing need for vigilance is reinforced by the fact that the largest *S. anglica* stand in the country is now found in the Garorim Bay Marine Protected Area near Doseong-ri, Seosan, indicating that this species remains a live management concern elsewhere on the South Korean coast.

Discussion

The invasion of *S. anglica* at Dongmak-ri from the first national record around 2008-2012, through its expansion into the country's largest stand by 2020, to its reduction to approximately 250 m^2 by 2024 represents one of the most fully documented cases of intertidal plant invasion and control in South Korea. Its central lesson is methodological: removal that addressed only aboveground biomass failed to check the invasion between 2016 and 2020, whereas repeated, rhizome-targeted subsurface tillage, timed to the species' life history and sustained from 2021, reduced the stand by more than 99% within four years. The case demonstrates the severe ecological cost of *S. anglica* invasion on tidal flats, the effectiveness of sustained, rhizome-targeted physical removal, and the importance of surveillance and preventive management once a stand has been cleared. It provides both a practical model for managing invasive halophytes elsewhere on the Korean coast and a baseline against which the ecological recovery of the Dongmak-ri tidal flat can be evaluated as

management continues.

Author Contributions

Conceptualization: SSL, HY. Data curation: SIL, HY. Formal analysis: SSL, HY. Funding acquisition: HY. Investigation: SIL, HY, DC. Writing – original draft: SSL, HY. Writing – review & editing: SSL, HY.

Conflict of Interest

The authors declare that they have no competing interests.

Funding

This work was supported by a grant from the National Institute of Ecology (NIE), funded by the Ministry of Climate, Energy and Environment (MCEE) of the Republic of Korea (NIE-A-2026-12).

References

Ainouche, M.L., Fortune, P.M., Salmon, A., Parisod, C., Grandbastien, M.A., Fukunaga, K., *et al*. (2008). Hybridization, polyploidy and invasion: lessons from *Spartina* (Poaceae). *Biological Invasions,* 11, 1159-1173. https://doi.org/10.1007/s10530-008-9383-2

An, S.Q., Gu, B.H., Zhou, C.F., Wang, Z.S., Deng, Z.F., Zhi, Y.B., *et al*. (2007). *Spartina* invasion in China: implications for invasive species management and future research. *Weed Research,* 47, 183-191. https://doi.org/10.1111/j.1365-3180.2007.00559.x

Chen, Z.L., and Lee, S.Y. (2022). Tidal flats as a significant carbon reservoir in global coastal ecosystems. *Frontiers in Marine Science,* 9, 900896. https://doi.org/10.3389/fmars.2022.900896

Dethier, M.N., and Hacker, S.D. (2004). *Improving Management Practices for Invasive Cordgrass in the Pacific Northwest: A Case Study of Spartina anglica*. Washington Sea Grant Program, University of Washington.

Hammond, M.E.R., and Cooper, A. (2002). *Spartina anglica* eradication and inter-tidal recovery in Northern Ireland estuaries. In C.R. Veitch, and M.N. Clout (Eds.), *Turning the Tide: The Eradication of Invasive Species* (pp. 124-131). International Union for Conservation of Nature.

Kerr, D.W., Hogle, I.B., Ort, B.S., and Thornton, W.J. (2016). A review of 15 years of *Spartina* management in the San Francisco Estuary. *Biological Invasions,* 18, 2247-2266. https://doi.org/10.1007/s10530-016-1178-2

Kim, E.K., Kil, J., Joo, Y.K., and Jung, Y.S. (2015). Distribution and botanical characteristics of unrecorded alien weed Spartina anglica in Korea. *Weed & Turfgrass Science,* 4, 65-70. https://doi.org/10.5660/wts.2015.4.1.65

Kim, J.S. (2016). A research review for establishing effective management practices of the highly invasive cordgrass (Spartina spp.). *Weed & Turfgrass Science,* 5, 111-125. https://doi.org/10.5660/wts.2016.5.3.111

Korean Law Information Center (KLIC). (2025). Enforcement Rule of the Conservation and Management of Marine Ecosystems Act. *KLIC*. Retrieved Jun 26, 2026 from https://www.law.go.kr/%EB%B2%95%EB%A0%B9/%ED%95%B4%EC%96%91%EC%83%9D%ED%83%9C%EA%B3%84%EC%9D%98%EB%B3%B4%EC%A0%84%EB%B0%8F%EA%B4%80%EB%A6%AC%EC%97%90%EA%B4%80%ED%95%9C%EB%B2%95%EB%A5%A0%EC%8B%9C%ED%96%89%EA%B7%9C%EC%B9%99.

Lowe, S., Browne, M., Boudjelas, S., and De Poorter, M. (2000). *100 of the World's Worst Invasive Alien Species: A Selection from the Global Invasive Species Database*. IUCN/SSC Invasive Species Specialist Group.

Maricle, B.R., and Lee, R.W. (2002). Aerenchyma development and oxygen transport in the estuarine cordgrasses *Spartina alterniflora* and *S. anglica*. *Aquatic Botany,* 74, 109-120. https://doi.org/10.1016/s0304-3770(02)00051-7

National Institute of Ecology (NIE). (2015). [*Ecological Studies of Alien Species (II)*]. NIE. Korean.

National Institute of Ecology (NIE). (2018). [*Monitoring of Invasive Alien Species*]. NIE. Korean.

National Institute of Ecology (NIE). (2020). [*Monitoring of Invasive Alien Species*]. NIE. Korean.

Nehring, S., and Hesse, K.J. (2008). Invasive alien plants in marine protected areas: the *Spartina anglica* affair in the European Wadden Sea. *Biological Invasions,* 10, 937-950. https://doi.org/10.1007/s10530-008-9244-z

Park, J., Lee, H., Asselman, J., Janssen, C., Depuydt, S., De Saeger, J., *et al*. (2024). Harnessing the power of tidal flat diatoms to combat climate change. *Critical Reviews in Environmental Science and Technology,* 54, 1395-1416. https://doi.org/10.1080/10643389.2024.2315004

Park, Y.J., Cho, Y.H., and Chae, D.Y. (2026). *A Hydrolysis Probe-Based Primer Composition for Detection of Coptotermes gestroi and Diagnostic Kit Comprising the Same.* Korean Patent No. 10-2963583. National Institute of Ecology.

Roberts, A., and Pullin, A.S. (2008). The effectiveness of management interventions for the control of *Spartina* species: a systematic review and meta-analysis. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 18, 592-618. https://doi.org/10.1002/aqc.889

Schutte, C.A., Ahmerkamp, S., Wu, C.S., Seidel, M., de Beer, D., Cook, P.L.M., *et al*. (2019). Biogeochemical dynamics of coastal tidal flats. In G.M.E. Perillo, E. Wolanski, D.R. Cahoon, and C.S. Hopkinson (Eds.), *Coastal Wetlands: An Integrated Ecosystem Approach* (pp. 407-440). Elsevier.

Shimeta, J., Saint, L., Verspaandonk, E.R., Nugegoda, D., and Howe, S. (2016). Long-term ecological consequences of herbicide treatment to control the invasive grass, *Spartina anglica*, in an Australian saltmarsh. *Estuarine, Coastal and Shelf Science,* 176, 58-66. https://doi.org/10.1016/j.ecss.2016.04.010

Shin, W., Kim, J., Song, Y., Kang, H., and Byun, C. (2024). Soil tillage effect on the control of invasive *Spartina anglica* in a coastal wetland. *Wetlands Ecology and Management,* 32, 397-408. https://doi.org/10.1007/s11273-024-09983-2

Shin, W., Oh, M., Hong, J.S., Byun, C., and Lee, E.J. (2022). Early invasion of common cordgrass (*Spartina anglica*) increases belowground biomass and decreases macrofaunal density and

diversity in a tidal flat marsh. *Biological Invasions,* 24, 3615-3629. https://doi.org/10.1007/s10530-022-02866-8

UNESCO World Heritage Centre. (2021). Getbol, Korean tidal flats. *UNESCO World Heritage Centre*. Retrieved Jun 26, 2026 from https://whc.unesco.org/en/list/1591.

Xie, B., Han, G., Qiao, P., Mei, B., Wang, Q., Zhou, Y., *et al*. (2019). Effects of mechanical and chemical control on invasive *Spartina alterniflora* in the Yellow River Delta, China. *Biodiversity and Conservation,* 7, e7655. https://doi.org/10.7717/peerj.7655

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Enacted August 5, 2020
Revised March 19, 2024
Revised June 23, 2025

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(1) Journal Article
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(2) Book
Chapman, R.F. (1971). *The Insects: Structure and Function*, 3rd ed. Elsevier.

(3) Web Sites
Chapman, K., and Brown, M. (2010). The future of digital library in Asia. *Digital Libraries*, 7, 111-119. Retrieved May 5, 2010 from https://www.diglib.org/publist.htm.
GBIF. (2024). *Global biodiversity information facility*. Retrieved Dec 9, 2024 from www.gbif.org.

(4) Chapter in a Book
Driever, M. (1993). Maternal control of anterior development in the Drosophila embryo. In M. Bate, and A.M. Aris (Eds.), *The Development of Drosophila melanogaster* (pp. 387–424). Cold Spring Harbor Laboratory Press.

(5) Conference Abstract
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Research and Publication Ethics

PNIE PROCEEDINGS OF THE NATIONAL INSTITUTE OF ECOLOGY OF THE REPUBLIC OF KOREA

Enacted August 5, 2020
Revised July 26, 2022
Revised June 23, 2025

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PNIE PROCEEDINGS OF THE NATIONAL INSTITUTE OF ECOLOGY OF THE REPUBLIC OF KOREA

Enacted August 5, 2020
Revised June 23, 2025

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Enacted October 26, 2022
Revised June 23, 2025

1. Name of Journal

The official journal title is *Proceedings of the National Institute of Ecology of the Republic of Korea*. Abbreviated title is PNIE.

2. Website

i. The URL address of official journal website is https://accesson.kr/pnie/.

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It aims to promote, but is not limited to, the achievements of basic ecological research conducted at home and abroad. The prospective audience is researchers conducting global collaborative research as well as ecological studies in the Asia-Pacific region. The scope is not only basic ecological research on terrestrial and aquatic populations, communities, ecosystems and landscapes but also applied issues such as data science and climate change based on ecological research.

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