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 Jong-Won Lee, Ho-Geun Yun, Tae Young Hwang, Jong-Bin An

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Floristic inventory and distribution characteristics of vascular plants in forest wetlands of South Korea

Jong-Won Lee[‡], Ho-Geun Yun[‡], Tae Young Hwang[‡], Jong-Bin An[‡]

[‡] Korea National Arboretum, DMZ Forest Biological Conservation, Yanggu-gun, Republic of Korea

Corresponding author: Jong-Bin An (ajb8825@korea.kr)

Abstract

This study surveyed the vascular flora present in 455 forest wetlands in South Korea to provide baseline data for conservation, management, and monitoring and to support preparation for climate change. The survey period was from April 2015 to November 2019. The vascular flora of 455 forest wetlands were identified and were found to consist of 143 families, 582 genera, 1,246 species, 26 subsp., 104 var., 12 f., and 1,388 individual taxa. 8 taxa were identified as Grade II endangered wild plants, 220 taxa were identified as northern lineage plants of the Korean Peninsula, 66 taxa were endemic to the Korean Peninsula, and 94 taxa were rare plants as designated by the Korea Forest Service. Among them, 8 taxa were Critically Endangered species, 10 taxa were Endangered species, 31 taxa were Vulnerable species, 31 taxa were Least Concern species, and 14 taxa were Data Deficient species. Further, 411 taxa were floristic target plants, of which 17 taxa were classified as grade V, 70 taxa as grade IV, 110 taxa as grade III, 90 taxa as grade II, and 29 taxa as grade I. There were 64 invasive alien plant taxa. 18 of these species were classed as Widespread species, 9 taxa were Serious Spread species, 13 taxa were Spread Risk species, 18 taxa were Spread Concern species, and 6 taxa were Continuing Spread species. According to wetland preference, 152 taxa (11.0%) were obligate wetland plants, 138 taxa (9.9%) were facultative wetland plants, and 177 (12.77%) taxa were facultative plants. Additionally, 198 taxa (14.3%) were facultative upland plants, and 723 taxa (52.1%) were obligate upland plants.

Keywords

Forest wetland, Korea endemic plants, rare plants, floristic target plants, invasive alien plants, wetland preference

Introduction

A wetland can include swamps, marshes, peatlands, or any area with water, including areas where the depth of water does not exceed 6 m at low tide, whether natural or artificial and permanent or temporary, and whether their waters are purified, running, fresh, brackish, or salty (Ramsar 2021). A wetland is also a depression (Wells and Mundkur 1996) or lowland (Federal Geographic Data Committee 2013) that has been covered with water at various intervals of time. Wetlands are flooded or saturated areas with a frequency and duration that can be sustained by the ground or groundwater (Griffin et al. 2016). Wetlands are also transitional areas between aquatic and terrestrial zones with water on or near the ground surface or with shallow water within several inches or feet of depth (Dahl and Johnson 1991).

The Wetlands Conservation Act (Korea Ministry of Environment 2021b) defines inland and coastal wetlands as areas where freshwater, brackish water, or saltwater covers the surface permanently or temporarily. According to the topography, inland wetlands are classified as river, lake, or hill types. Hill-type wetlands are divided into those that are high moor, low moor, lowland wetland, and marsh, according to their vegetation, soil, and hydrological regime. These wetlands have the following functions: a hydrological function enabling land moisture regulation through naturally formed drainage and irrigation; a biodiversity maintenance function by providing habitats for various organisms; a carbon storage function, for example, peatlands absorb carbon through the remains of emerged plants and aquatic plants around wetlands while accounting for only 3% of the world's land area but containing approximately 30% of all carbon on land; trapping and fixing sediment with the roots of the plants that make up the wetlands; and moderating damage from disasters such as flooding and storms (Ramsar Convention Secretariat 2013).

However, wetlands are widely recognized as one of the most vulnerable ecosystems to climate change and especially the increased severity of drought (Intergovernmental Panel on Climate Change 2007, Johnson et al. 2010, Zedler and Kercher 2005). This is especially true for wetlands in mountainous and alpine areas, where climate change, causing effects such as reduced snow cover, is accelerating (Burkett and Kusler 2000, Carpenter et al. 2007, Erwin 2008). However, despite their importance and sensitivity to climate change, the vulnerability of montane wetlands has not yet been quantified, mainly owing to a lack of research. Montane wetlands are refugia and hotspots of biodiversity (Chatterjee et al. 2010, Son et al. 2014) because they have a relatively low species diversity but provide unique habitats for specific plant species (Omar et al. 2016).

Korea Forest Service has been conducting research on forest wetlands since 2005. According to the Korea Forest Service, forest wetlands are defined as all wetlands (such as swamps, marshes, and peatlands) that are found in areas classified as forests, as well as swamps that are home to woody plants such as tall trees, shrubs, and bushes, even in those areas not classified as forests (Korea Forest Service 2006). Over an eight-year period from 2006 to 2014, the first national survey of forest wetlands covered 6.37 million

hectares of forests within national and private forest areas, which represented one third of the nation's land. Consequently, 1,264 sites (390 ha) of forest wetlands and 1,260 plant taxa (135 families, 545 genera, 1,101 species, 7 subspecies, 136 varieties, and 16 f.) were identified (Korea National Arboretum 2016). This represents 27.15% of the total abundance of vascular flora on the entire Korean Peninsula (Korea National Arboretum 2020b). The large number of taxa identified relative to the area confirms that forest wetlands are an important site of biodiversity and must be preserved.

A total of 1,280 forest wetlands were precisely surveyed for five years between 2015 and 2019, which included 1,264 sites derived from the first survey and 16 new target sites. A second survey of forest wetlands was conducted to grade the sites following evaluation. Consequently, 455 sites functioning as forest wetlands were identified and classified by grade. The 455 sites were categorized as either A, B, C, or D grades with 30, 201, 184, and 40 sites belonging to each grade, respectively. Twenty three sites were reclassified as modified wetlands due to desiccation and a complete clearing of the sites. Consequently, forest genetic resource reserves (FGRRs) and other effective area-based conservation measures (OECMs) should be established as soon as possible to achieve a more systematic management strategy for forest wetlands, which are areas rich in biodiversity.

Additionally, the mountainous terrain accounts for approximately 63% of South Korea's land and is home to a wide range of forest species. The forest wetlands (montane wetlands) also serve as sanctuaries for flora and fauna, buffer zones against climate change, and provide excellent carbon storage, among other functions. Nevertheless, the importance of forest wetlands has been overlooked. On the Korean Peninsula, forest wetlands are a hotspot for biodiversity conservation, and they represent ecosystems that must be protected and managed, but to effectively do this, it is crucial to have a better understanding of their current state. The purpose of the present study was to investigate the vascular flora that must be surveyed to conserve and utilize forest wetlands in the long term, as well as to use this information as the basis for the restoration of forest wetlands in preparation for future climate changes.

Method

Target area

As part of the study, 455 forest wetlands of grades A-D, which were identified in a second survey in 2015-2019, were selected from 1,264 national forest wetlands first surveyed from 2006 to 2014 and 16 newly discovered forest wetlands (Fig. 1, Suppl. material 1). The 455 forest wetlands were classified into grades A, B, C, and D, with 30, 201, 184, and 40 sites accounting for each grade, respectively. The 455 forest wetlands are distributed across 14 administrative districts, excluding Seoul Metropolitan City, Daejeon Metropolitan City, and Sejong Metropolitan Autonomous City. The region with the greatest number of forest wetlands is Gangwon-do with 132 sites (29.0%) covering an area of 875,322 m² (31.7%), followed by Gyeongsangbuk-do with 68 sites (14.9%) covering an area of 711,792 m²

(25.8%) and Jeollanam-do with 56 sites (12.3%) covering an area of 216,910 m² (7.9%). Additionally, 132 sites (29%) were state-owned forests while 323 sites (71%) were privately owned forests. Altitudes range from 20 m to 1,560 m above sea level. However, 342 forest wetlands (approximately 75%), were found to be distributed at elevations below 500 m, 104 (approximately 23%) at elevations between 501 m and 1,000 m, and 9 (approximately 2%) at elevations above 1,001 m (Korea National Arboretum 2019b).

Forest wetlands are classified into four categories: natural forest wetlands, abandoned paddy field forest wetlands, man-made forest wetlands, and modified wetlands (Korea National Arboretum 2020a). The 455 forest wetlands include 193 natural forest wetlands, 237 abandoned paddy field forest wetlands, 2 man-made forest wetlands, and 23 modified forest wetlands.

Research method

Field note was used for survey of flora. The field note includes survey number, survey date, investigators, survey site, altitude, survey route, GPS coordinates, according to the order of plant numbers, plant name, image data, and specimen collection items. A field survey of vascular flora was conducted between April 2015 and November 2019. Plant species were identified in the field as much as possible to prevent disturbance to the plants, and in the case of plants that were difficult to identify in the field, only individuals with reproductive organs were collected for laboratory identification. Identifying plants was based on literature from Lee (1996), Lee (2014a), Lee (2014b), and Lee (2006). Taxonomy of the occurring plants was based on Engler's taxonomy (Melchior 1964), and the list was arranged accordingly (Suppl. material 18). These scientific names and Korean names were derived from the Korea National Plant List (Korea National Arboretum 2020b). The plant list was arranged by family, and the classifications of the genera and below taxa were arranged alphabetically. Listing northern lineage plants followed Amarsana et al. (2020), North Korean plants followed Korea National Arboretum (2019c), endemic plants followed Chung et al. (2017) and Korea National Arboretum (2020b), rare plants and endangered wild species followed Korea National Arboretum (2009) and Korea Ministry of Environment (2021a) respectively, floristic target plants followed Kim (2000) and National Institute of Ecology (2018), plants in the limestone zone followed Korea National Arboretum (2010), and invasive alien species followed Korea National Arboretum (2019a) and Jung et al. (2017). The classification of wetland plants by vascular plant type followed Choung et al. (2012), Choung et al. (2020), Choung et al. (2021).

Results

Distribution characteristics of the total flora of forest wetlands

Total vascular flora

The vascular plants identified in 455 forest wetlands in South Korea belonged to 143 families, 582 genera, 1,246 species, 26 subsp., 104 var., 12 f., and 1,388 taxa (Suppl. material 2). Ferns accounted for 72 taxa, belonging to 19 families, 32 genera, 69 species, and 3 var., gymnosperms for 5 families, 8 genera, and 14 species, angiosperms for 925 taxa, belonging to 101 families, 398 genera, 819 species, 23 subsp., 75 var., and 8 f., and monocotyledons for 377 taxa, belonging to 18 families, 145 genera, 344 species, 3 subsp., 26 var., and 4 f. This accounted for about 29.91% of the 4,641 taxa of vascular plants in South Korea (Korea National Arboretum 2020b). The plant families with the highest number of species recorded were Asteraceae (137 taxa, 9.9% of species recorded), Poaceae (117 taxa, 8.4%), Cyperaceae (113 taxa, 8.1% of species recorded), Rosaceae (63 taxa, 4.5% of species recorded), and Liliaceae (61 taxa, 4.4% of species recorded).

The most frequently occurring species were (in descending order): *Persicaria thunbergii* at 315 sites (69.2%), *Salix pierotii* at 311 sites (68.4%), *Oplismenus undulatifolius* at 269 sites (59.1%), *Artemisia indica* at 249 sites (54.7%), *Impatiens textorii* at 235 sites (51.7%), and *Clematis apiifolia* at 235 sites (50.6%). However, among the 1,388 taxa, 891 taxa including *Syringa reticulata* were observed at only ten or fewer sites, and 295 taxa including *Vicia angustifolia* var. *minor* were recorded at only one site.

Northern lineage plants and North Korean plants of the Korean Peninsula

In total, 220 taxa of plants from the northern Korean Peninsula were identified, and these taxa belonged to 65 families, 141 genera, 208 species, and 4 subspecies (Suppl. material 18). This number represents approximately 35.7% of the 616 taxa of northern lineage plants that occur on the Korean Peninsula, which is 15.9% of the total vascular plant 1,388 taxa observed in the entire forest wetlands. These data can be used as a basis for future research on ecosystem changes related to climate change. The remarkable plants identified northern lineage plants included *Eleutherococcus senticosus*, *Trigonotis radicans*, *Cicuta virosa*, *Lonicera caerulea*, *Carex capricornis*, *Scorzonera albicaulis*, and *Eriophorum gracile* (Fig. 2).

Northern lineage plants are those that migrated to the Korean Peninsula from the north during the Last Inter-Glacial (LIG) of the Last Glacial Maximum (LGM). They are widespread in northern East Asia, including China and Russia but very limited or remnant in the Korean Peninsula (Amarsana et al. 2020). However, if the growing environment becomes poor as a result of global warming or other factors, there will be severe challenges to their growth and a great danger of extinction. Therefore, it is imperative to develop conservation measures both within and outside the local area, as well as active management measures to prevent anthropogenic threats.

North Korean plants are native only to the North Korean region of the Korean Peninsula. A total of 753 taxa of species distributed exclusively in North Korea were selected from the 3,182 taxa included in the North Korean Vascular Plant Checklist (Korea National

Arboretum 2019c). Korea National Plant List (Korea National Arboretum 2020b) and others were consulted for the screening of the data selected above, resulting in a North Korean plant list of 497 taxa including *Lycopodium alpinum* and *Equisetum fluviatile* As with northern plants, the habitats of North Korean plants will be damaged by climate change, which will destroy forest wetland ecosystems as well.

Fourteen North Korean plants were observed in forest wetlands in South Korea, including *Calamagrostis pseudophragmites*, *Equisetum sylvaticum*, *Ranunculus crucilobus*, *Prunus japonica*, *Ligularia intermedia*, *Agrostis canina*, *Stachys oblongifolia*, *Carex idzuroei*, *Juncus filiformis*, *Carex schmidtii*, *Platanthera sachalinensis*, *Elymus gmelinii*, *Lonicera subhispida*, and *Artemisia sacrorum*. It has been determined that additional detailed research on North Korean plants is required as part of conservation measures, among other considerations.

Endemic plants of the Korean Peninsula

A total of 66 taxa of endemic plants belonging to 27 families, 57 genera, 59 species, 6 varieties, and 1 f. were identified in 455 forest wetlands (Suppl. material 3). This accounts for 16.6% of the 398 taxa of endemic plants of the Korean Peninsula (Chung et al. 2017, Korea National Arboretum 2020b). In the 455 forest wetlands, the most frequently occurring endemic plants of the Korean Peninsula were *Weigela subsessilis* and *Salix koriyanagi* (Fig. 3), which were found in 111 sites, followed by *Clematis trichotoma* occurring in 29 sites, *Rhododendron yedoense* f. *poukhanense* in 26 sites, *Populus × tomentiglandulosa* in 23 sites, and *Hemerocallis hakuunensis*, *Aster koraiensis*, and *Carex erythrobasis* in 16 sites.

Rare plants on the IUCN Red List

Ninety-four taxa were identified as rare plants, and they belonged to 46 families, 81 genera, 86 species, 1 subspecies, 5 varieties, and 2 f. (Suppl. material 4). This is approximately 16.5% of the 571 taxa on the rare plant list of South Korea (Korea National Arboretum 2009), which was re-evaluated by the Korea National Arboretum according to the IUCN criteria. Eight Critically Endangered (CR) taxa, ten Endangered (EN) taxa, 31 Vulnerable (VU) taxa, 31 Least Concern (LC) taxa, and 14 Data Deficient (DD) taxa were identified (Suppl. material 4, Fig. 4).

Iris ensata var. *spontanea*, an LC species, was found most frequently of all the rare plants, with 67 occurrences, followed by the LC species *Aristolochia contorta* with 23 occurrences, *Gentiana triflora* var. *japonica* with 18 occurrences, *Utricularia caerulea* with 16 occurrences, and the VU species *Drosera rotundifolia* with 14 occurrences. The frequency of occurrence of rare plants by grade among the CR species was seven for *Mankyua chejuense*, six for *Utricularia uliginosa*, and five for *Cicuta virosa*. Among the EN species, *Hololeion maximowiczii* occurred six times, and *Micranthes octopetala* and *Cynanchum amplexicaule* occurred five times each. Among the VU species, *Drosera rotundifolia* was recorded 14 times, *Utricularia bifida* 13 times, and *Pogonia japonica* 11

times. Among the LC species, *Iris ensata* var. *spontanea* occurred 67 times, *Aristolochia contorta* 23 times, and *Gentiana triflora* var. *japonica* 18 times. Among the DD species, *Sagittaria trifolia* occurred 13 times, *Scrophularia koraiensis* 10 times, and *Eleutherococcus divaricatus* var. *chiisanensis* 8 times.

Endangered wild plants

The term endangered wild organisms refer to species in danger of extinction in the near future, with a very small number of individuals remaining whose population has been severely reduced by natural or human factors (Korea Ministry of Environment 2021a). Eight taxa were identified as endangered wild plants of grade II, including *Menyanthes trifoliata* (Suppl. material 5). Frequency of occurrence of these species can be found in Suppl. material 5. The record of *Eleutherococcus senticosus* from Goseong-gun, Gyeongsangnam-do needs to be re-examined. Because this species is known to mainly grow in northern regions as well (Lee 2014a).

Floristic target plants

A total of 411 taxa were identified as floristic target plants. These belonged to 103 families, 268 genera, 381 species, 5 subspecies, 24 varieties, and 1 f. (Suppl. material 18, Fig. 5), representing about 29.6% of the 1,388 taxa of emergent plants and 27.8% of the 1,476 taxa of floristic target plants.

Grade V plants have discontinuous distributions, such as northern or southern plants that were introduced during glacial periods or are isolated in a limited geographical area. A total of 17 taxa including *Nephrolepis cordifolia*, *Trientalis europaea* var. *arctica*, and *Platanthera hohloglottis* were identified, accounting for 6.6% of the 258 taxa belonging to grade V (Suppl. material 6). Among the grade V plants, the most frequently occurring taxa were *Actaea heracleifolia* (11 records), followed by *Brasenia schreberi* 8 records), *Mankyua chejuense* (7 records), and *Asperula lasiantha* and *Utricularia uliginosa* with 6 records each.

Grade IV plants are distributed in one of the four floristic subregions, the Middle, Jeju, Southern Coast, and Southern Subregions, and to this group belong taxa that grow sporadically and have few individuals or grow in groups and have a relatively large number of individuals. A total of 70 taxa of grade IV floristic regional indicator plants were identified, including *Rhododendron micranthum*, *Hanabusaya asiatica*, and *Trillium camschatcense*. Approximately, 15.9% of the total 440 taxa of grade IV plants was observed in the forest wetlands. The most frequently occurring grade IV plants were *Toxicodendron succedaneum* (22 records), *Hydrocotyle sibthorpioides* (18 records), *Utricularia caerulea* (16 records), and *Utricularia bifida* (13 records) (Suppl. material 7).

Grade III plants occurred in two of the four subregions and include taxa that grow infrequently and have small populations as well as taxa that grow in groups and have relatively large populations. A total of 110 grade III taxa were identified, including *Lysimachia vulgaris* var. *davurica*, *Cynanchum amplexicaule*, and *Scutellaria insignis*.

Approximately, 29.6% of the 371 grade III floristic target plant taxa were present. The most frequently occurring grade III taxa were *Lysimachia vulgaris* var. *davurica* (59 records), *Prunus sargentii* (51 records), *Betula davurica* (29 records), *Vitis coignetiae* (28 records), *Spiraea fritschiana* (22 records), and *Cynanchum nipponicum* (21 records) (Suppl. material 8).

Plants of grade II are either unique to specific environments or are distributed relatively nationwide. However, they include taxa that are generally associated with large populations of 1,000 individuals or more. A total of 90 grade II taxa were identified, including *Bolboschoenus maritimus*, *Maianthemum bifolium*, and *Lobelia sessilifolia*. Approximately, 43.8% of the 207 grade II taxa was observed in the area. *Alnus japonica* and *Glyceria leptolepis* were recorded 84 times each, *Scutellaria dependens* 68 times, *Iris ensata* var. *spontanea* 67 times, and *Tripterygium regelii* 53 times.

Taxa in grade I occur in three of the four subregions and become established sporadically and have relatively small populations or become established in groups and have relatively large populations. For grade I plants, 129 taxa were observed, including *Lycopus maackianus*, *Tricyrtis macropoda*, and *Arisaema heterophyllum*. Of the 200 grade I taxa, 64.5% were recorded. The most frequently recorded were *Carex dispalata* (101 records), *Onoclea interrupta* (100 records), *Lindera erythrocarpa* (88 records), *Salix chaenomeloides* (69 records), and *Eleutherococcus sessiliflorus* (68 records).

Limestone area plants

Limestone area plants include northern alpine flora occurring in lowland areas such as riversides, new species emerging in isolated areas, and isolated distributions of coastal plants (Korea National Arboretum 2010). A total of 31 limestone area taxa were identified, including *Spiraea trichocarpa* and *Stemmacantha uniflora* (Suppl. material 9). The most frequently occurring plants in the limestone area were *Smilax sieboldii* (124 records), followed by *Quercus variabilis* (51 records), *Juniperus rigida* (22 records), and *Euonymus alatus* (16 records). However, *Smilax sieboldii* and *Quercus variabilis* are distributed nationwide, and additional research on plants in limestone areas is needed.

Invasive alien plants

A total of 64 invasive alien plant taxa were identified, belonging to 17 families, 54 genera, 63 species, and 1 subspecies (Suppl. material 10). This represented approximately 17.1% of the 375 taxa in the invasive alien plant inventory (Korea National Arboretum 2019a). The 375 taxa of invasive alien plants in the country were divided into five classes according to the degree of spread: widespread species (WS), serious spread species (SS), spread risk species (SR), spread concern species (SC), and continue spreading species (CS) (Jung et al. 2017). Of these, WS plants are those recorded at 101 sites or more, and 231 (72.2%) of the 375 taxa fall into this category. A total of 18 taxa, including *Robinia pseudoacacia* and *Erigeron annuus*, were identified as WS plants during the survey. SS species are those with 75 to 100 distribution sites, and 38 (11.9%) of the 375 taxa fall into this category. A total of nine taxa were identified as SS in the survey, including *Symphytotrichum pilosum*

and *Festuca arundinacea*. SR species are those with 50 to 74 distribution sites, and 18 (5.6%) out of 375 taxa fall under this category. A total of 13 taxa were identified as SR, including *Quamoclit angulata* and *Crassocephalum crepidioides*. SC species are those with 25 to 49 distribution sites, and 15 (4.7%) of 375 taxa fall into this category. A total of 18 taxa were identified as SC, including *Sicyos angulatus* and *Ambrosia trifida*. The rate of spread of *Sicyos angulatus* and *Ambrosia trifida* is very fast. Therefore, the Ministry of Environment designated them as invasive plants for which management measures should be developed as soon as possible. CS species are those with less than 24 distribution sites, and 18 (5.6%) out of 375 taxa fall into this category, and 6 taxa, including *Erigeron philadelphicus* and *Ageratina altissima*, were identified as CS.

The most frequently recorded invasive alien plants were *Erigeron annuus* (202 records), followed by *Bidens frondosa* (153 records), *Robinia pseudoacacia* (111 records), *Phytolacca americana* (61 records), and *Conyza canadensis* (54 records). A total of 21 taxa, including *Sicyos angulatus* and *Solanum carolinense*, appeared at only one site, and 14 taxa, including *Ambrosia trifida*, *Erigeron philadelphicus*, and *Cerastium glomeratum*, appeared in two or three places. The frequency of occurrence of all 35 taxa was low, but most taxa identified tend to spread rapidly; therefore, further monitoring is required to determine the extent of spread and formulate medium- to long-term management measures to control these species.

Categorization according to wetland preference of vascular plants

Based on Choung et al. (2012), Choung et al. (2020), Choung et al. (2021), the plants identified in the survey were assigned to the following categories according to the frequency of appearance: obligate wetland plant (OBW), facultative wetland plant (FACW), facultative plant (FAC), facultative upland plant (FACU), and obligate upland plant (OBU). Consequently, OBW accounted for 152 taxa (11.0%), FACW 138 taxa (9.9%), FAC 177 taxa (12.7%), FACU 198 taxa (14.3%), and OBU 723 taxa (52.1%) (Suppl. material 11). For each category, the plants with the highest occurrence frequency in forest wetlands were examined. For OBW, *Persicaria thunbergii* appeared 315 times, followed by *Juncus effusus* var. *decipiens* 226 times, *Phragmites japonica* 162 times, *Lycopus lucidus* 154 times, and *Isachne globosa* and *Aneilema keisak* each 124 times. For FACW, *Salix koreensis* appeared 311 times, followed by *Impatiens textorii* 235 times, *Thelypteris palustris* 189 times, *Persicaria sagittata* 186 times, and *Bidens frondosa* 153 times. For FAC, *Oplismenus undulatifolius* appeared 269 times, followed by *Rosa multiflora* 239 times, *Equisetum arvense* 224 times, *Amphicarpaea bracteata* subsp. *edgeworthii* 202 times, and *Acer tataricum* subsp. *Ginnala* 192 times. For FACU, *Clematis apiifolia* appeared 230 times, followed by *Erigeron annuus* 202 times, *Fraxinus rhynchophylla* 170 times, *Commelina communis* 161 times, and *Microstegium vimineum* 152 times. For OBU, *Artemisia princeps* appeared 249 times, followed by *Zanthoxylum schinifolium* 224 times, *Ligustrum obtusifolium* 209 times, *Lindera obtusiloba* 158 times, and *Rubus crataegifolius* 156 times.

Vascular flora by region

The flora of the 455 forest wetland sites in South Korea belonged to 143 families, 582 genera, 1,245 species, 26 subspecies, 104 varieties, and 13 f., with a total of 1,388 taxa recorded. Among them, the flora of 132 sites in the Gangwon area belonged to 927 taxa (66.8%), including 113 families, 423 genera, 819 species, 23 subsp., 78 var., and 7 f., and 151 taxa (about 10.9%), such as *Equisetum ramosissimum*, were found to be endemic to the Gangwon area. The flora of forest wetlands in 38 locations in the Gyeonggi region (including Incheon) was identified to consist of 555 taxa (about 40%), belonging to 98 families, 305 genera, 491 species, 14 subsp., 45 varieties, and 5 f., among which 18 taxa (1.3%) including *Scirpus orientalis* were found to be endemic to the Gyeonggi area. The flora of the 116 forest wetlands in the Gyeongsang region belonged to 121 families, 417 genera, 719 species, 21 subspecies, 64 varieties, and 7 f., with a total of 811 taxa (about 58.4%). Of these, 71 taxa (about 5.1%) including *Parathelypteris beddomei* were surveyed to have appeared in the forest wetlands of the Gyeongsang area. The flora of the 50 forest wetlands in the Chungcheong region consisted of 667 taxa (about 48%) belonging to 104 families, 357 genera, 19 subspecies, 49 varieties, and 7 f., and 43 taxa including *Reynoutria forbesii* were endemic to the forest wetlands of the Chungcheong region. A total of 770 taxa (about 55.5%) of 117 families, 397 genera, 686 species, 16 subspecies, 58 varieties, and 10 f. were identified in the flora of 90 forest wetlands in the Jeolla region. In the Jeolla region alone, 93 taxa (about 6.7%) of endemic plants were identified, including *Lapsanastrum apogonoides*. Finally, the flora of the 29 forest wetlands in the Jeju area belonged to 81 families, 186 genera, 260 species, 4 subspecies, 13 varieties, and 2 f., with a total of 279 taxa (about 20.1%), and 65 taxa (4.7%) including *Potamogeton cristatus* were surveyed to have appeared in the forest wetlands of the Jeju area. Many of the taxa distributed in each region were considered to be region-specific indicator species because their frequency of occurrence was as low as one to five locations, and additional research on forest wetland region-specific indicator species is considered necessary.

Vascular flora in forest wetlands of Gangwon region

A total of 927 taxa, belonging to 113 families, 423 genera, 819 species, 23 subspecies, 78 varieties, and 7 f. were identified as vascular flora of the 132 forest wetlands in the Gangwon area (Suppl. material 18). *Persicaria thunbergii* had the highest frequency of occurrence at 114, followed by *Salix pierotii* Miq. at 103, *Impatiens textorii* at 85, and *Fraxinus rhynchophylla* at 83. A total of 38 endemic plant taxa were identified, including *Pseudostellaria setulosa* and *Angelica purpuraefolia*. Forty seven rare plant taxa were also recorded. Of these, three taxa are classified as CR: *Cicuta virosa*, *Eriophorum gracile*, and *Magnolia kobus*. However, the *M. kobus* as a species native to the Jeju-South region is considered to have been planted. A total of four taxa were EN, including *Micranthes octopetala*, *Menyanthes trifoliata*, *Trientalis europaea* var. *arctica*, and *Megaleranthis saniculifolia*; 15 taxa were VU, including *Galearis cyclochila* and *Tylophora floribunda*; 20 taxa were LC, including *Aristolochia manshuriensis* and *Syringa villosa* subsp. *wolfii* and five taxa were DD, including *Scrophularia koraiensis*. Additionally, 245 taxa were floristic

target plants. There were nine grade V taxa, including *Brasenia schreberi* and *Platanthera holo-glottis*; 41 grade IV taxa, including *Actaea bifida* and *Hanabusaya asiatica*; and 61 grade III taxa, including *Megaleranthis saniculifolia*, *Vicia chosenensis*, and *Carex lasiolepis*; 36 taxa were invasive alien plants, including *Chenopodium album*. and *Dactylis glomerate*.

Of the 927 taxa identified in the forest wetlands of the Gangwon region, 151 taxa (about 16.3%) were confirmed to be endemic to the forest wetlands of the Gangwon region (Suppl. material 12). Of the endemic species in Gangwon-do, the taxon that appeared most frequently was *Carpinus cordata* (19 records), followed by *Tilia amurensis* (18 records), *Acer barbinerve* (10 records), *Impatiens textori* var. *koreana* (9 records), and *Salix rorida* (8 records). The following trees were documented to be distributed in areas considered to be south of central South Korea: *Dryopteris erythrosora* (Seo-myeon, Yangyang-gun), *Carpinus turczaninowii* (Daegwallyeong-myeon, Pyeongchang-gun), *Sinomenium acutum* (Budong-myeon, Wonju-si), *Vicia angustifolia* var. *minor* (Inje-eup, Inje-gun), *Erigeron floribundus* (Wondeok-eup, Samcheok-si), *Arundo donax* (Sacheon-myeon, Gangneung-city), and *Carex lenta* (Gwirae-myeon, Wonju-si). In particular, as *Sinomenium acutum* grows naturally around Jeju, the southern islands, and the coasts, it was considered to have been either planted for medicinal purposes or originated from seeds transported with the sand for snow removal in winter. *Vicia angustifolia* var. *minor* is another species that is distributed mainly along the coast and is likely to have spread along with the snow removal sand. *Sicyos angulatus*, designated as an invasive plant, and other invasive alien plants such as *Cerastium glomeratum* and *Erigeron philadelphicus* have been introduced to one or two forest wetlands. A decrease in water supply due to climate change and terrestrialization of forest wetlands pose a threat to them and will accelerate the spread of invasive alien plants, and management measures are urgently required.

Vascular flora in forest wetlands of Gyeonggi region

A total of 555 taxa belonging to 98 families, 305 genera, 491 species, 14 subspecies, 45 varieties, and 5 f. were identified within the 38 forest wetlands in the Gyeonggi region, which includes Gyeonggi-do and Incheon Metropolitan City. The most frequently occurring taxon was *Salix pierotii* (34 records), followed by *Oplismenus undulatifolius* (33 records), *Acer tataricum* subsp. *Ginnala* (30 records), and *Persicaria thunbergii* and *Ligustrum obtusifolium* with 29 records each. There were 19 endemic taxa, including *Carex sabyensis* var. *leiosperma* and *Polygonatum infundiflorum*. Additionally, 17 rare plant taxa were identified, among which six including *Iris minutoaurea* and *Rhododendron micranthum* were VU, seven including *Arisaema heterophyllum* and *Utricularia caerulea* were LC, and four including *Scirpus orientalis* were DD. A total of 97 floristic target plant taxa were recorded. One grade V taxon was identified, while 13 grade IV taxa including *Rhamnus davurica* and *Epimedium koreanum*, 21 grade III taxa including *Cynanchum nipponicum* and *Centella asiatica*, and 16 invasive alien plants including *Bidens frondosa* and *Phytolacca americana* were recorded.

Of the 555 taxa that appeared in the forest wetlands of the Gyeonggi region, 18 (approximately 3.2%) were documented to be endemic (Suppl. material 14). *Elaeagnus glabra* was recorded three times, *Prunus japonica*, *Magnolia obovata*, *Hosta clausa*, and *Galium tokyoense* were recorded twice each, and the remaining 14 taxa were recorded only once. *Elaeagnus glabra* was observed in Gyeonggi 2019-3 (Yulgil-ri, Sang-myeon, Gapyeong-gun, Gyeonggi-do), Gyeonggi 2019-36 (Sineup-dong, Pocheon-si, Gyeonggi-do), and Gyeonggi 2019-37 (Hwahyeon-ri, Hwahyeon-myeon, Pocheon-si, Gyeonggi-do). In the Gyeonggi 2019-37 area, five taxonomic groups were surveyed, including *Elaeagnus glabra*, *Mukdenia rossii*, *Prunus japonica*, *Carex sabynensis* var. *leiosperma*, *Arabis hirsuta* and *Calamagrostis pseudophragmites* (forest genetic resource reserves, Muui-dong, Jung-gu, Incheon), *Scirpus orientalis*, and *Echinochloa oryzicola* appeared in the mountain valley wetland of Gyeonggi 2019-24 (Dowon-ri, Cheongun-myeon, Yangpyeong-gun, Gyeonggi-do). *Epimedium koreanum* and *Veratrum maackii* var. *parviflorum* were found in Gyeonggi 2019-25 (Sillon-ri, Cheongun-myeon, Yangpyeong-gun, Gyeonggi-do) and *Clematis brachyura* in Gyeonggi 2019-05 (Wigok-ri, Seorak-myeon, Gapyeong-gun, Gyeonggi-do). The designation of forest genetic resource reserves, such as the one in Muui-dong, Incheon Metropolitan City, and other effective regional infrastructure-based conservation measures must be promoted to systematically monitor and manage prime forest wetlands such as Gyeonggi 2019-36.

Vascular flora of Gyeongsang region

A total of 811 taxa belonging to 121 families, 417 genera, 719 species, 21 subspecies, 64 varieties, and 7 f. were identified as the flora of the 116 forest wetlands in the Gyeongsang region. The most frequently occurring species were *Persicaria thunbergii* and *Salix pierotii* (79 records each), followed by *Artemisia indica* (73 records) and *Juncus decipiens* with 72 records. A total of 27 taxa including *Lespedeza maritima* and *Hosta minor* were endemic plants. As for rare plants, 2 taxa *Utricularia uliginosa* and *Eriophorum gracile* were CR, two taxa *Hololeion maximowiczii* and *Trigonotis radicans* were EN, 12 taxa including *Utricularia bifida* and *Inula salicina* were VU, 12 taxa including *Penthorum chinense* and *Ottelia alismoides* were LC, and 5 taxa including *Chloranthus fortunei* were DD. Additionally, 157 taxa were floristic target plants. Five grade V taxa including *Eriophorum gracile* and *Asperula lasiantha* were recorded, along with 17 grade IV taxa including *Mimulus tenellus* and *Cardamine yezoensis*, and 30 grade III taxa including *Cardamine komarovii* and *Parathelypteris beddomei*. Forty-two invasive alien plant taxa including *Briza minor* and *Trifolium pratense* were identified.

Of the 811 taxa identified in the forest wetlands of the Gyeongsang region, 71 taxa (about 8.8%) including *Parathelypteris beddomei* were endemic (Suppl. material 13). The most frequently occurring taxon was *Briza minor* (four records), followed by *Viburnum carlesii*, *Euonymus hamiltonianus* var. *maackii*, and *Lespedeza maritima* with three records each. *Briza minor* is a CS invasive alien plant which was recorded in four locations: Gyeongsangnam-do 2015-49 (Seon-ri, Wondong-myeon, Yangsan-si, Gyeongsangnam-do), Busan 2015-1 (Imgi-ri, Cheolma-myeon, Gijang-gun, Busan), Busan 2015-4 (Oeseok-ri, Sangbuk-myeon, Yangsan-si, Gyeongsangnam-do), and Ulsan 2015-11 (Jungsan-dong,

Buk-gu, Ulsan). Each of these four forest wetlands is considered to have high conservation value because numerous notable plants such as *Eriophorum gracile* and *Utricularia uliginosa* are found there. In particular, the Gyeongsangnam-do 2015-49 area is a high-altitude forest wetland located at 954 m above sea level. The northern lineage plant *Eriophorum gracile* has been documented to occur there, although more precise monitoring is required. *Viburnum carlesii* was recorded in forest wetlands located in three areas in Gunwi-gun, Gyeongsangbuk-do: Gyeongsangbuk-do 2017-9.10 (Unsan-ri, Sanseong-myeon, Gunwi-eup, Gyeongsangbuk-do), Gyeongsangbuk-do 2017-11 (Hwajeon-ri, Sanseong-myeon, Gunwi-gun, Gyeongsangbuk-do), and Gyeongsangbuk-do 2017-15 (Geumyang-ri, Uiheung-myeon, Gunwi-gun, Gyeongsangbuk-do). *Geranium krameri* and *Euonymus hamiltonianus* var. *maackii* appeared in two forest wetlands: Gyeongsangbuk-do 2017-16 (Subuk-ri, Uiheung-myeon, Gunwi-gun, Gyeongsangbuk-do) and Gyeongsangbuk-do 2017 47 (Ibam-ri, Donghae-myeon, Nam-gu, Pohang-si, Gyeongsangbuk-do). *Lespedeza maritima* was observed in three locations: Gyeongsangbuk-do 2017-2 (Nogok-ri, Naenam-myeon, Gyeongju-si, Gyeongsangbuk-do), Gyeongsangbuk-do 2017-9.10 (Unsan-ri, Sanseong-myeon, Gunwi-eup, Gyeongsangbuk-do), and Ulsan 2015-3 (Oegwang-ri, Onyang-eup, Ulju-gun, Ulsan).

A total of ten invasive alien plant taxa were found to be endemic to the Gyeongsang region. Of these, two taxa, *Lepidium virginicum* and *Lolium perenne* were SS, two taxa *Rudbeckia bicolor* and *Cosmos bipinnatus* were SR, four taxa including *Medicago polymorpha* and *Hibiscus trionum* were SC, and two taxa *Elymus repens*, *Briza minor* were CS. Thus, the development of management measures for preventing their spread is urgent.

Vascular flora of Chungcheong region

A total of 667 taxa belonging to 104 families, 357 genera, 592 species, 19 subspecies, 49 varieties, and 7 f. were identified as the flora of the forest wetlands at 50 sites in the Chungcheong region. The frequency of occurrence from highest to lowest was as follows: *Artemisia indica* (41 records), *Persicaria thunbergii* (40 records), *Salix pierotii* (40 records), *Oplismenus undulatifolius* (39 records), and *Equisetum arvense* (37 records). A total of 25 taxa of endemic plants were observed, including *Fraxinus chiisanensis* and *Iris rossii* var. *latifolia* J. As for rare plants, two taxa *Carex capricornis* and *Prunus* × *yedoensis* were CR. However, additional research is considered necessary for *Prunus* × *yedoensis*. Four taxa including *Utricularia japonica* were VU, seven taxa including *Gentiana triflora* var. *japonica* and *Tricyrtis macropoda* were LC, and five taxa including *Eleutherococcus divaricatus* var. *chiisanensis* (Nakai) were DD. A total of 113 taxa were floristic target plants, including two grade V taxa *Utricularia japonica* and *Asperula lasiantha*, ten grade IV taxa including *Rodgersia podophylla* and *Aegopodium alpestre*, and 26 grade III taxa including *Catolobus pendulus* and *Veratrum maackii* var. *japonicum*. Twenty-nine invasive alien plant taxa including *Rumex obtusifolius* and *Carduus crispus* were also recorded.

Of the 667 taxa identified in the Chungcheong region, 43 taxa (about 6.4%), including *Dryopteris sacrosancta*, *Fallopia forbesii*, and *Lonicera harae* were endemic to the Chungcheong region (Suppl. material 15) and were recorded only once or twice. Four taxa

including *Indigofera pseudotinctoria*, *Dryopteris sacrosancta*, and *Primula sieboldii* were recorded twice, and 39 taxa including *Broussonetia papyrifera* and *Tripora divaricata* were recorded only once. The current distribution status of the 43 taxa that were endemic to the Chungcheong region showed that eight taxa were recorded in Chungcheongnam-do 2016 12/13/14 (Daedong-ri, Yeomchi-eup, Asan-si, Chungcheongnam-do), including *Ixeris debilis* and *Solidago gigantea*. Therefore, management measures for *Solidago gigantea* are required. Six taxa including *Themeda triandra*. and *Vicia unijuga* var. *ouensanensis* were recorded in Chungcheongnam-do 2016-05 (Cheongnae-ri, Jewon-myeon, Geumsan-gun, Chungcheongnam-do) and Chungcheongbuk-do 2017-34 (Jidong-ri, Dongnyang-myeon, Chungju-si, Chungcheongbuk-do), respectively.

Vascular flora of Jeolla region

A total of 770 taxa belonging to 117 families, 397 genera, 686 species, 16 subspecies, 58 varieties, and ten f. were recorded in 90 forest wetlands in the Jeolla region. The most frequently occurring taxa were: *Oplismenus undulatifolius* (65 records), *Rosa multiflora* (57 records), *Salix pierotii* (53 records), *Ligustrum obtusifolium* (52 records), and *Styrax japonicus* (51 records). Twenty-eight taxa including *Stewartia koreana* and *Carex erythrobasis* were identified as endemic to the region. A total of 38 rare plant taxa were recorded, of which five including *Utricularia aurea* and *Habenaria radiata* were CR, two including *Hololeion maximowiczii* and *Ophioglossum vulgatum* were EN, 12 including *Pogonia minor* and *Sparganium stoloniferum* were VU, 14 including *Melothria japonica* and *Lindera sericea* were LC, and five including *Hypericum attenuatum* were DD. Additionally, 162 floristic target plant taxa were recorded, including eight grade V taxa including *Arundinaria munsuensis* and *Nephrolepis cordifolia*, 18 grade IV taxa including *Dryopteris tokyoensis* and *Lonicera caerulea*, and 29 grade III taxa including *Salvia japonica* and *Teucrium veronicoides*. Twenty-two invasive alien plant taxa including *Erechtites hieraciifolius* and *Tagetes minuta* were recorded.

Of the 770 taxa found in the Jeolla region, 90 taxa (about 11.7%) including *Cephalotaxus harringtonia* and *Ajuga decumbens* were found to be endemic. *Scleria parvula*, *Hemerocallis thunbergii*, *Vaccinium oldhamii*, and *Hypericum attenuatum* were recorded five times, *Ischaemum antheophoroides*, *Pogonia minor*, and *Melothria japonica* four times, and *Agrostis canina* and *Euscaphis japonica* three times. All taxa recorded three, four, or five times were found to be endemic to the Jeollanam-do region (Suppl. material 16). Eleven taxa including *Carex scabrifolia* were recorded in Jeollanam-do 2016-25 (Hanwoon-ri, Jaeun-myeon, Sinan-gun, Jeollanam-do), nine including *Chionanthus retusus* in Jeollanam-do 2016-15 (Cheongcheon-ri, Cheonggye-myeon, Muan-gun, Jeollanam-do), and seven including *Lophatherum gracile* in Jeollanam-do 2016-01 (Deoknyeon-ri, Doam-myeon, Gangjin-gun, Jeollanam-do).

Vascular flora of Jeju region

A total of 279 taxa belonging to 81 families, 186 genera, 260 species, 4 subspecies, 13 varieties, and 2 f. were identified as the flora of the 29 forest wetlands in the Jeju region.

The most frequently recorded taxa were: *Schoenoplectiella triangulata* (15 records), *Persicaria praetermissa* (15 records), *Rosa multiflora* (14 records), *Carex dimorpholepis* (13 records), and *Isachne globosa* (11 records). Eight taxa including *Maackia fauriei* and *Cirsium rhinoceros* were identified as endemic plants. Fourteen rare plant taxa were recorded, with two taxa *Mankyua chejuensis*, and *Utricularia uliginosa* classified as CR, four taxa including *Cynanchum amplexicaule* and *Nymphoides coreana* as EN, four taxa including *Swertia diluta* var. *tosaensis* and *Tripterospermum japonicum* as VU, one taxon *Acorus calamus* as LC, and three taxa including *Apocynum cannabinum* as DD. Sixty-eight floristic target plant taxa were recorded, of which five grade V taxa including *Brasenia schreberi* were recorded, as well as nine grade IV taxa including *Persicaria taquetii* and *Eleocharis dulcis* and 17 grade III taxa including *Ilex crenata* and *Daphniphyllum macropodum*. Twelve invasive alien plant taxa were identified, including *Ambrosia artemisiifolia* and *Sisyrinchium rosulatum*.

Of the 279 taxa recorded in the forest wetlands of the Jeju region, 65 taxa (about 23.3%) including *Potamogeton cristatus* and *Rubus buergeri* appeared to be endemic (Suppl. material 17). About 23% of taxa endemic to the Jeju region were considered to be floristic target plants. The most frequently occurring of these taxa were: *Mankyua chejuensis*, (seven records), *Ludwigia ovalis* and *Viola lactiflora*, *Maackia fauriei*, *Cynanchum amplexicaule*, and *Nymphoides indica* (five records each), *Cirsium rhinoceros* (four records), and *Potamogeton cristatus*, *Marsilea quadrifolia*, *Sasa quelpaertensis*, and *Allium taquetii* (three records each). By region, 31 taxa including *Viburnum furcatum* were identified in Jeju 2015-28 (Sumeunmulbaengdui, Gwangnyeong-ri, Aewol-eup, Jeju-si), 9 taxa including *Potamogeton cristatus* in Jeju 2015-25 (Geumoreum, Geumak-ri, Hanlim-eup, Jeju-si), and 8 taxa including *Gentiana squarrosa* in Jeju 2015-29 (Bongseong-ri, Aewol-eup, Jeju-si).

Discussion

Plant distribution characteristics of forest wetlands

The most frequently appearing endemic plants in the 455 wetlands were *Weigela subsessilis* and *Salix koriyanagi*, which appeared in 111 wetlands. Wetlands with the most frequent occurrence of endemic plants were Jeollanam-do 2016-32, Chungcheongbuk-do 2017-16, Gangwon-do 2019-30, and Gangwon-do 2019-33, with eight taxa recorded in each region. In Jeollanam-do 2016-32, *Cirsium setidens*, *Scutellaria insignis*, *Weigela subsessilis*, *Thalictrum actaeifolium*, *Lysimachia coreana*, *Salix koriyanagi*, *Scrophularia koraiensis*, and *Chrysosplenium barbatum* were recorded, and in Chungcheongbuk-do 2017-16, *Cirsium setidens*, *Stewartia koreana*, *Fraxinus chiisanensis*, *Weigela subsessilis*, *Viola seoulensis*, *Thalictrum actaeifolium*, *Aconitum pseudolaeve*, and *Carex erythrobasis* were recorded. In Gangwon-do 2019-30, *Asperula lasiantha*, *Angelica reflexa*, *Cirsium setidens*, *Fraxinus chiisanensis*, *Pseudostellaria setulosa*, *Angelica purpuraefolia*, *Lysimachia coreana*, and *Saussurea grandicapitula* were recorded, and in Gangwon-do 2019-33, *Asperula lasiantha*, *Cirsium setidens*, *Pseudostellaria setulosa*, *Angelica*

purpuraefolia, *Aconogonon microcarpum*, *Lysimachia coreana*, *Carex erythrobasis*, and *Chrysosplenium barbatum* were recorded.

The wetlands where the greatest number of rare plants were identified were in Chungcheongbuk-do 2017-23 and Gangwon-do 2018-53. In Chungcheongbuk-do 2017-23, *Carex capricornis* (CR), *Mimulus tenellus* (VU), *Gentiana triflora* var. *japonica* (LC), and *Rumex longifolius* (DD) were found. In Gangwon-do 2018-53, a total of eight taxa appeared: *Megaleranthis saniculifolia* and *Micranthes octopetala* (EN), *Galearis cyclochila* (VU), *Viola albida*, *Gentiana triflora* var. *japonica*, *Parasenecio auriculatus*, *Lilium distichum*, and *Trillium camschatcense*.

Analysis of the distribution characteristics of the rare plants by region and altitude showed that *Mankyua chejuense* classified as CR appeared only in seven forest wetlands at 160 meters or below in Jeju-do, and *Cicuta virosa* appeared only in six forest wetlands in Gangwon-do, although there was no altitude restriction. *Utricularia uliginosa* appeared only in the southern regions of Gyeongsangnam-do and Jeollanam-do. *Eriophorum gracile* appeared only in the forest wetlands of Gangwon-do, which were located at high altitudes. As wetlands with high OBW occurrence rates relative to the occurrence of other species, three forest wetland sites in Jeju-do showed the presence of OBW: Jeju 2015-07, Jeju 2015-10, and Jeju 2015-17. In Jeju 2015-07, ten taxa were identified: *Potamogeton distinctus*, *Trapa japonica*, *Triadenum japonicum*, *Monochoria vaginalis* var. *plantaginea*, *Typha orientalis*, *Schoenoplectiella triangulata*, *Brasenia schreberi*, *Nymphoides indica*, *Schoenoplectus tabernaemontani*, and *Utricularia japonica*. In Jeju 2015-10, two taxa were identified: *Trapa japonica* and *Schoenoplectiella triangulata*. In Jeju 2015-17, three taxa were identified: *Spirodela polyrrhiza*, *Trapa japonica*, and *Wolffia arrhiza*. In contrast, there were eight wetlands with high OBU occurrence rates relative to the occurrence rates of other species sites, where only OBU were recorded: Gyeongsangbuk-do 2017-44 (20 taxa), Gyeongsangbuk-do 2018-09 (24 taxa), Jeollanam-do 2016-07 (14 taxa), Jeollabuk-do 2016-10 (11 taxa), Jeollabuk-do 2016-20 (18 taxa), Jeollabuk-do 2016-21 (36 taxa), Chungcheongbuk-do 2017-02 (47 taxa), and Chungcheongbuk-do 2017-18 (16 taxa). These forest wetlands were located at altitudes of up to 500 m above sea level, which made them highly accessible, and they are considered to be wetlands that are undergoing terrestrialization and losing their function as forest wetlands.

Forest wetland conservation measures

The notable plants recorded in the 455 forest wetlands included 8 taxa of grade II endangered wild plants, 202 taxa of northern plants in the Korean Peninsula, 66 taxa of endemic plants of the Korean Peninsula, 94 taxa of IUCN-designated rare plants, and 411 taxa of floristic regional indicator plants. In forest wetlands where eight taxa of native endangered wild plants (grade II) occur (*Mankyua chejuense*, *Cicuta virosa*, *Utricularia uliginosa*, *Habenaria radiata*, *Menyanthes trifoliata*, *Trientalis europaea* var. *arctica*, *Brasenia schreberi*, and *Eleutherococcus senticosus*), it is necessary to designate the area as a conservation area through an immediate review of its feasibility or to establish a conservation plan by installing information boards and training local observers. In forest

wetlands where native rare plants classified as VU, EN, and CR occur, 1-14 forest wetlands should be designated by Korea Forest Service as Forest Genetic Resources Reserves (FGRR) to be monitored for a cycle of three years. For 197 taxa of floristic target plants of grade III and above, precise monitoring around the native habitat should be conducted periodically.

A total of 64 invasive alien plant taxa were identified in 455 forest wetland sites. The species with the highest frequency of occurrence was *Erigeron annuus* (202 records), followed by *Bidens frondosa* (153 records), *Robinia pseudoacacia* (111 records), *Phytolacca americana* (61 records), and *Conyza canadensis* (54 records). *Erigeron annuus* was identified at 65 (56%) of the 116 sites in the Gyeongsang region, but it was recorded most frequently in the Gyeongsangbuk-do region, occurring at 50 (73.5%) of the 68 sites. In the Chungcheong region, it appeared at 26 (52%) of the 50 sites, 63 (47.7%) of the 132 sites in the Gangwon-do region, and 18 (47.3%) of the 38 sites in the capital area. *Erigeron annuus* was mostly observed around Gyeongsangbuk-do, Chungcheongnam-do, Chungcheongbuk-do, Gyeonggi-do, and Gangwon-do. In the southern regions of Jeju, Jeollanam-do, and Gyeongsangnam-do, *Erigeron annuus* as FACU was considered to have spread slowly owing to the ease of water supply even in winter in southern regions such as Jeju, Jeollanam-do, and Gyeongsangnam-do. However, for forest wetlands in the northern part of the country, the spread is expected to be more active because the moisture supply is insufficient in winter. *Bidens frondosa* had a similar distribution pattern. It was found in 18 (48.6%) of 37 sites in the Gyeonggi region and in 48 (41.4%) of 116 sites in the Gyeongsang region and had spread to 42 sites (61.8%) in the Gyeongsangbuk-do region. It also occurred in the Gangwon-do and Chungcheong-do regions at 36.4% and 30% of the sites in each region, respectively. *Robinia pseudoacacia* was found in the following regions excluding Jeju: Chungcheong (38%), Gangwon (31.1%), capital area (26.3%), Gyeongsang (25%), and Jeolla (13.3%). *Robinia pseudoacacia* is an OBU that often appears at the boundaries of forest wetlands. As it is known not to spread into the interior of forest wetlands, it can serve as an indicator plant for changes in the size of forest wetland areas. In contrast, *Sicyos angulatus* (FACW) was recorded in one location in Gangwon 2019-36 area during the second survey of forest wetlands conducted from 2015 to 2019, but its spreading speed is very fast, and it is necessary to pre-empt its spread through monitoring and control measures.

Among 455 forest wetlands, 23 were classified as deformed wetlands due to natural disasters and terrestrialization; 323 sites (approximately 71%) are privately owned and difficult to manage. Additionally, only 20% (91 sites) are currently designated as forest genetic resource conservation areas (Korea National Arboretum 2019b). Therefore, further designation of FGRRs is required. Application of other effective area-based conservation measures (OECMs) does not involve designating conservation areas but is defined as the management of geographically limited areas over long periods, intending to maintain positive and sustainable in situ conservation of biodiversity, along with relevant ecosystem functions and services, and cultural, spiritual, socio-economic, and other locally relevant values (IUCN World Commission on Protected Areas (WCPA) 2019). In South Korea, seven areas of use including forest wetlands and algal slopes were reported to be suitable

for OECMs. Therefore, it is necessary to pre-emptively designate 140 of the remaining 364 sites as FGRRs and apply OECMs and to seek an integrated management plan with systematic and regular monitoring under the administration of government agencies.

Conclusions

This study was conducted to investigate the customary vascular flora of 455 mountain and forest wetlands in South Korea, to survey for mid-and long-term conservation and utilization, and to prepare basic data necessary for the restoration of the forest wetlands in the future under climate change. The survey was conducted from April 2015 to November 2019. The vascular flora of 455 sites was identified and included 1,388 taxa belonging to 143 families, 582 genera, 1,246 species, 26 subspecies, 104 varieties, and 12 forma. The most frequently occurring species in South Korea's forest wetlands were: *Persicaria thunbergii* (315 records), *Salix pierotii* (311 records), *Oplismenus undulatifolius* (269 records), *Artemisia indica* (249 records), *Impatiens textorii* (235 records), and *Clematis apiifolia* (235 records).

A range of notable plants was also recorded. Eight taxa of grade II endangered wild plants were identified, including *Menyanthes trifoliata* and *Mankyua chejuense*. A total of 220 taxa belonging to 65 families, 141 genera, 208 species, 4 subspecies, and 8 varieties were identified as northern lineage plants. However, it is considered necessary to review the distribution of the list of 616 (Amarsana et al. 2020) northern plants of the Korean Peninsula. A total of 66 taxa belonging to 27 families, 57 genera, 59 species, 6 varieties, and 1 f. were identified as endemic plants of the Korean Peninsula. *Salix koriyanagi* and *Weigela subsessilis* each had 111 records. The rare plants designated by the Korea Forest Service recorded during the survey consisted of 94 taxa belonging to 46 families, 81 genera, 86 species, 1 subspecies, 5 varieties, and 2 forma. A total of 8 taxa including *Carex capricornis* were CR, 10 taxa including *Micranthes octopetala* were EN, 31 taxa including *Utricularia bifida* were VU, 31 taxa including *Streptopus ovalis* were LC, and 14 taxa including *Rumex longifolius* were DD. A conservation strategy for each taxon of grade VU or above should be devised. Moreover, LC or DD classified as threatened species according to the IUCN Red List must be re-evaluated.

A total of 411 floristic target plant taxa belonging to 103 families, 268 genera, 381 species, 5 subspecies, 24 varieties, and 1 f. were recorded. A total of 17 taxa including *Trientalis europaea* var. *arctica* were grade V, 70 taxa including *Hanabusaya asiatica* were grade IV, 110 taxa including *Cynanchum amplexicaule* were grade III, 90 taxa including *Maianthemum bifolium* were grade II, and 129 taxa including *Tricyrtis macropoda* were grade I. Thirty-one limestone area plant taxa were recorded including *Stemmacantha uniflora*, and 64 invasive alien plant taxa belonging to 17 families, 54 genera, 63 species, and 1 subspecies were also recorded. Eighteen taxa including *Erigeron annuus* were WS, nine taxa including *Symphytotrichum pilosum* were SS, 13 taxa including *Quamoclit angulate* were SR, 18 taxa including *Sicyos angulatus* were SC, and six taxa including *Ageratina altissima* were CS. The most frequently occurring invasive alien plants in the 455 mountain forest wetlands were *Erigeron annuus* with 202 records, followed by *Bidens*

frondosa with 153 records, *Robinia pseudoacacia* with 111 records, *Phytolacca americana* L. with 61 records, and *Conyza canadensis* with 54 records.

All vascular plants recorded were classified according to their wetland preference: 152 taxa (11.0%) were OBW, 138 taxa (9.9%) were FACW, 177 taxa (12.7%) were FAC, 198 taxa (14.3%) were FACU, and 723 (52.1%) were OBU.

The distribution of vascular plants by region was also recorded. The flora at 132 sites in the Gangwon region consisted of 927 taxa belonging to 113 families, 423 genera, 819 species, 23 subspecies, 78 varieties, and 7 forma. At 38 sites in the Gyeonggi region, 555 taxa belonging to 98 families, 305 genera, 491 species, 14 subspecies, 45 varieties, and 5 f. were identified. At 116 sites in the Gyeongsang region, 811 taxa belonging to 121 families, 417 genera, 719 species, 21 subspecies, 64 varieties, and 7 f. were identified. At 50 sites in the Chungcheong region, 667 taxa belonging to 104 families, 357 genera, 592 species, 19 subspecies, 49 varieties, and 7 f. were identified. At 90 sites in the Jeolla region, 770 taxa belonging to 117 families, 397 genera, 686 species, 16 subspecies, 58 varieties, and 10 f. were identified. At 29 sites in the Jeju region, 279 taxa belonging to 81 families, 186 genera, 260 species, 4 subspecies, 13 varieties, and 2 f. were identified. At the 140 sites assessed to be much higher degree among the 364 sites, pre-emptive designation as FGRRs and application of OECMs are required. Integrated management measures for the OECMs must be sought through systematic and regular monitoring under the administration of government agencies.

Hosting institution

Korea National Arboretum

Conflicts of interest

The authors declare that they have no conflict of interest.

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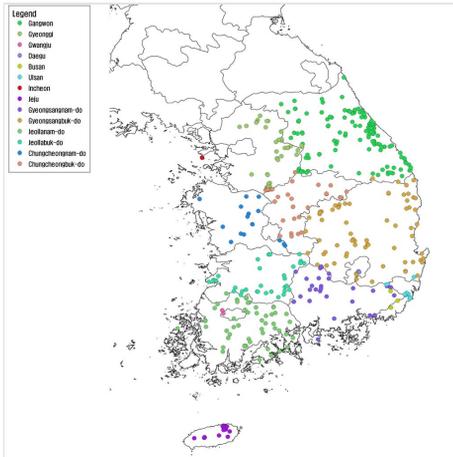


Figure 1.
Map showing the location of forest wetlands by region.



Cicuta virosa L.

Carex capricornis Meinh. ex Maxim

Eriophorum gracile Koch

Figure 2.

The images show northern lineage plants in forest wetlands of Korea.



Figure 3.

Korean endemic plants in forest wetlands of Korea.



Figure 4.

A selection of rare plants by IUCN identified during the survey.

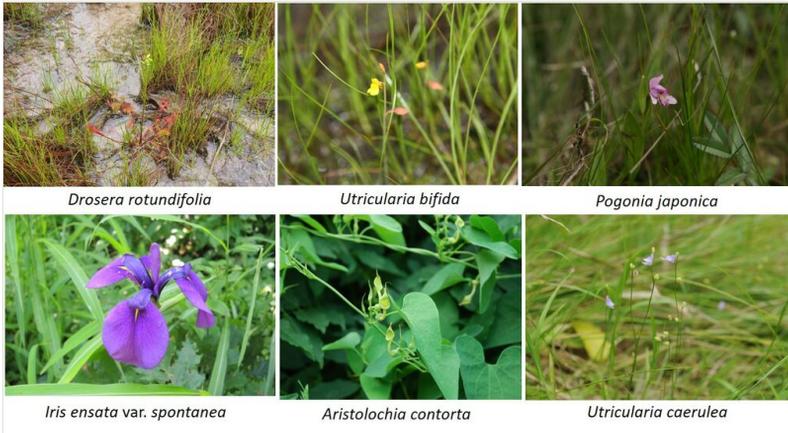


Figure 5.

The pictures show floristic target plants in forest wetlands of Korea.

Supplementary materials

Suppl. material 1: Survey site distribution by region according to grades of forest wetland

Authors: Lee, Jong-Won, Ho-Geun Yun, Tae Young Hwang, Jong Bin An

Data type: etc

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Suppl. material 2: The list of vascular plants in forest wetlands of Korea.

Authors: Lee, Jong-Won, Ho-Geun Yun, Tae Young Hwang, Jong Bin An

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Suppl. material 3: The list of Korean endemic plants in forest wetlands of Korea.

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Suppl. material 4: Rare plants by IUCN identified during the survey.

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Suppl. material 5: The list of endangered wild plants in forest wetlands of Korea.

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Suppl. material 6: Floristic target plants of grade V plants identified in the survey.

Authors: Lee, Jong-Won, Ho-Geun Yun, Tae Young Hwang, Jong Bin An

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Suppl. material 7: Floristic target plants of grade IV plants identified in the survey.

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Suppl. material 10: Invasive alien plants identified in the survey.

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Suppl. material 11: Categorizing vascular plant species occurring in wetland ecosystems of the Korean Peninsula by frequency of occurrence in study area.

Authors: Lee, Jong-Won, Ho-Geun Yun, Tae Young Hwang, Jong Bin An

Data type: etc

Brief description: Choung et al. (2012) Categorizing Vascular Plant Species Occurring in Wetland Ecosystems of the Korean Peninsula. Center for Aquatic Ecosystem Restoration. Chuncheon. 243 pp.

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Suppl. material 12: Vascular plants recorded only in forest wetlands of Gangwon region, Korea.

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Suppl. material 18: The total list of vascular plants of forest wetlands in Korea.

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