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Establishment of seed zones based on native plant species

Chae young Kim[1], Whee moon Kim[2], Won kyong Song[3], Jae yong Choi[4]

[1] School of Environmental Horticulture and Landscape Architecture, Dankook University, Undergraduate student - cyjjang1011@gmail.com
[2] Dept. of Environmental Horticulture and Landscape Architecture, Dankook University, Postgraduate studen
[3] School of Environmental Horticulture and Landscape Architecture, Dankook University, Professor
[4] Dept. of Environment and Forest Resources, Chungnam National University, Professor

Abstract

Since forest ecosystems constitute a complex ecosystem, the health of the ecosystem must be maintained. Seed zones are areas of relative climatic similarity, and movement of seeds within them should help minimize maladaptation.

This study intends to build Korean seed zones by applying the US seed zone construction method.

In the United States, winter minimum temperature and annual heat: moisture index (AH:M; aridity) were used to construct seed zones. Climate data for the entire Korean Peninsula was provided by Worldclim. Winter minimum temperature was determined as the minimum value per cell from December through February and was classified into 5°F (2.2°C) bands ranging from <-15° to >35°F (-26.1 to 1.6°C). The AH:M data is average temperature (℃) plus 15°C (to obtain positive values) divided by precipitation in meters. The AH:M map was divided into six discrete classes (<–16, 16–19, 19–21, 21–24, 24–27, >27). Korean provisional seed zones of 65 climatic zones were formed by overlapping both maps.

Five native plant species were selected to test correspondence with the provisional seed zones. For Pine(*Pinus Densiflora*), Oak(*Quercus acutissima*), Oyster oak(*Quercus variabilis*), the winter minimum temperature of 15–20℉ and the AH:M of 19–21 and 21–24℃/m accounted for 37%, 43%, and 34%, respectively. Due to the latent habitat area of fern wood(*Acer pictum* subsp. *mono*), the Maxent AUC was 0.844, showing a high fit. The winter minimum temperature of 20–25℉ and AH:M of 16–19℃/m accounted for 42%. Due to the latent habitat of hornbeam(*Carpinus tschonoskii*), Maxent AUC was 0.930, showing high accuracy. The winter minimum temperature of 25–30℉ and AH:M of <16℃/m occupied 33%.

In this study, provisional Korean seed zones were established and their association with five native plant species was identified. This study will be used to define initial seed zones and identify seed zones inhabiting similar climatic zones.

Keywords: Provisional seed zones; Climate variables; Ecosystem; MaxEnt; Korean Peninsula

Introduction, scope and main objectives

Over the past two centuries, the increasing human influences on global ecosystems have resulted in degradation of forest ecosystems and deterioration of natural habitats (Mijinsbrugge et al. 2010). A forest ecosystem is an integrated system, wherein biotic communities and non-living elements co-exist through complex interactions; therefore, maintaining the health of the ecosystem is essential from a global perspective.

Currently, most seeds used in domestic forest restoration projects are imported into Korea from abroad. The settlement and spread of introduced species can cause changes in the biodiversity of the existing ecosystem; therefore, there is an emerging need to restrict the movement of introduced and native species to restore the ecosystem (Cambell 1991).

In the United States, the first provisional study on seed zones accounting for climatic and topographical (soil, slope, etc.) factors was proposed in the 1930s in response to the failure of the U.S. Forest Service to secure afforestation(Bower *et al*., 2014). Since this study, numerous studies that apply climatic analysis to the characteristics of biological distribution are ongoing(Eom 2019).

The US seed zone is a map that depicts an area where plant material can be transferred with little to no risk for proper adaptation to a new location based on climatic factors, which serves as a guideline(Bower et al. 2014). In Korea, studies linking climatic factors and the Species Distribution Model (SDM) are being conducted; however, the focus is on evaluating the same climatic region that reflects domestic characteristics(Lee et al. 2017; sung et al. 2018; Lee et al. 2021), and there is a limit in the identification of the same climatic region for vegetative growth.

Therefore, this study intends to interpret the method involved in the pilot application of US seed zone construction, which has been conducted in previous Korean studies. Furthermore, three commonly found species in Korea (*Pinus Densiflora*, *Quercus*) including two southern tree species were selected, and the classification accuracy was verified through comparative analysis of growth characteristics of five species and the Korean Provisional seed zones. This study is intended to function as a foundation for the establishment of Korean seed zones.

Methodology/approach

1. Study site

For the establishment of provisional seed zones in Korea, the Korean Peninsula that can reflect all climatic characteristics was selected as the target site. The location data available for the native seeds are limited to the South Korean region; therefore, the verification process was only performed for this region. The Korean Peninsula is surrounded by the East Sea, the South Sea, and the Yellow Sea, and it shares a border with China along the Yalu and Tuman Rivers to the north; it has an area of about 220,000 Km^2. The Korean Peninsula has unique climatic characteristics because of its geographical characteristics, being surrounded by seas on three sides; therefore, it is considered a suitable target for pilot establishment of a seed transfer guideline that accounts for the climate.

2. Data collection and analysis

Bower et al. (2014) have constructed provisional seed zones based on minimum winter temperature(MWT) and annual heat:moisture index (AH:M; aridity). The MWT map extracts and merges the minimum temperatures from December, January, and February, and classifies them into a band of 5 °F (2.8 °C). The AH:M index represents the aridity, which is obtained by adding 15 ℃ to the annual average temperature (℃),and dividing it by the annual precipitation in meters (m) to calculate the AH:M (Hamann and Wang 2005); 6 classes were reclassified into 6 grades determined by ArcMap. Thereafter, provisional seed zones were created by overlapping the two datasets, and overlaying them on Omernik's level Ⅲ Ecoregion map to identify regions that may be climatically similar, but ecologically different (Bower et al. 2014).

Provisional seed zones in Korea were constructed using the temperature and precipitation data obtained from WorldClim. WorldClim data is based on monthly data from 1970 to 2000, that are normalized to 4 resolutions ranging from 30" (~1 Km^2) to 10' (~340 Km^2)(O'Donnell and Ignizio 2012). The boundary data for South Korea and North Korea was downloaded from DIVA-GIS, which is based on a global consensus was incorporated with the WorldClim data and used it as the domestic map boundary. In order to construct the Korean MWT map, the minimum temperature (℃) data obtained from historical climate data was used. From the provided data, the smallest 30" (~1 Km^2) resolution was used. Based on the procedure reported in a previous study, the minimum temperature (℃) data for December, January, and February were combined using the Cell statistics tool, ArcGIS 10.7 (Bower et al. 2014). WorldClim data is available in ℃ and USDA plant hardiness zone data is available in ℉; therefore, the Celsius-to-Fahrenheit conversion formula was entered into the raster calculator tool and the values were converted into ℉. Thereafter, the MWT map was classified into bands of 5 °F (2.2 °C) in the range from below −15 to more than 35 °F (−26.1–1.6 °C); the final Korean MWT map containing 12 grades was constructed(Fig.1a).

In order to construct the Korean AH:M map, the annual mean temperature (℃) and annual precipitation (mm) data with a 30" (~1 Km^2) resolution were used from among all the data obtained for Bioclimate variables. A Korean AH:M map was produced by adding 15 ℃ to the annual mean temperature (℃) and then dividing it by the annual precipitation converted into meters (m) (Hamann and Wang, 2005). Subsequently, the Korean AH:M map was divided into 6 scales; the classification interval was set such that the range of each class included almost the same number of values and the change in the interval was constant (Bower *et al*. 2014, Fig.1b).

The Korean MWT map and the Korean AH:M map were merged to create a Korean provisional seed zone (Temperature-aridity) based on the climate.

In order to verify the classification accuracy of the seed zones, the seed zones were normalized by overlapping them with the Ecoregions. The growth characteristics and habitable areas for Acer pictum (*subsp. mono*) were analyzed, and the classification accuracy was reviewed by overlapping them with the Korean provisional seed zones. The species location data was obtained using the National Natural Environment Survey data and 1:5000-scale forest type map; only data for South Korea were available. Accordingly, the accuracy verification was limited to South Korea; the Korean provisional seed zone corresponding to South Korea comprised 34 climate zones. Point data obtained were as follows: Pine (*Pinus Densiflora*) 124,678 point, Oak (*Quercus acutissima*) 106,567 point, Oyster oak (*Quercus variabilis*) 88,991 point, hornbeam (*Carpinus tschonoskii*) 106 point, and fern wood (*Acer pictum subsp. mono*) 1,030 point. Pine, Oak, and Oyster oak that have many habitat distribution points were used to review the emergence of the forest type ratio based on the region of Korean provisional seed zones. For hornbeam and fern wood, the habitat environment was confirmed using SDM to estimate the relationship between emergence data and spatial characteristics. SDM is a method based on predicting the ecological status of a species, and the minimum entropy modeling of species geographic distributions (MaxEnt) is most widely used. MaxEnt is a regression model that estimates the probability distribution in space by estimating the value that can maximize the entropy of a species. When only the appearance data is applied, this model has a higher accuracy than other species distribution models. Habitat probability was expressed as a value between 0 and 1, and an area with a habitat value of 0.5 or higher was determined to have high habitat characteristics. Based on previous studies of major environmental factors that affect species distribution and habitat, environmental factors including altitude, direction, slope, topography, soil map (drainage), and bioclimate variables were selected from the WorldClim data. The bioclimate variables used were Bio1 (annual mean temperature), Bio2 (mean diurnal range), Bio4 (temperature seasonality), Bio8 (mean temperature of wettest quarter), Bio12 (annual precipitation), Bio15 (precipitation seasonality), and Bio18 (precipitation of warmest quarter).

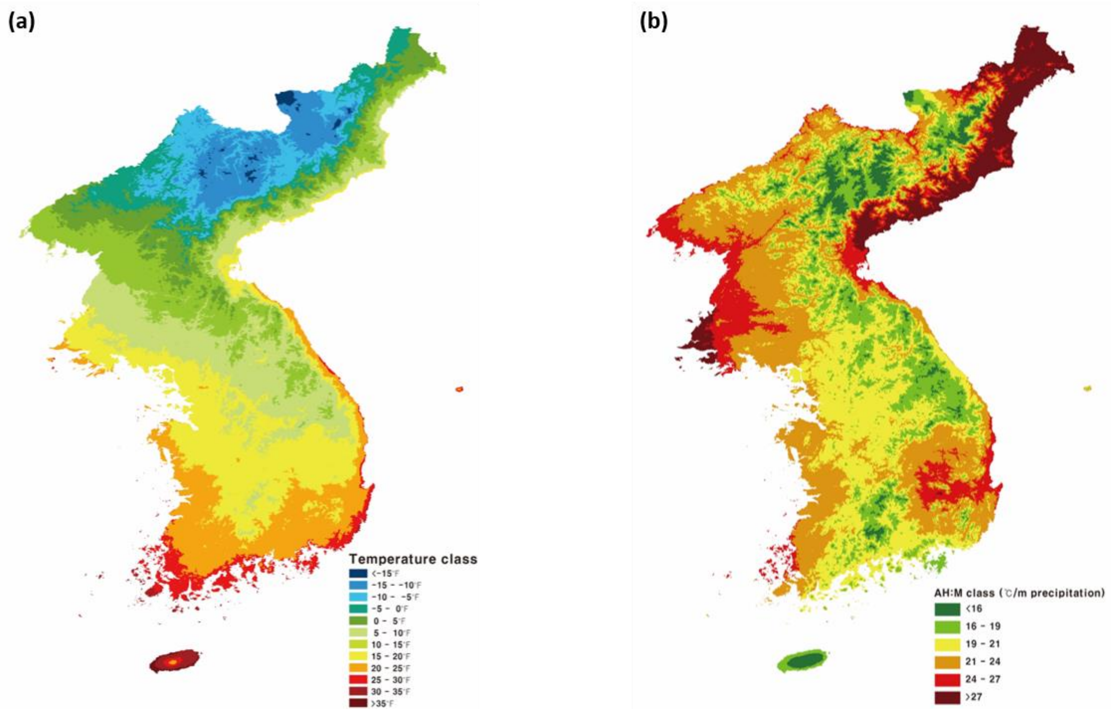

Fig. 1: The climate map needed for the seed zones
(a) Map of the lowest temperature in winter in Korea (b) Domestic drying (annual heat: moisture index) map

Results

The Korean MWT is divided into 5 °F (2.2 °C) bands in the range from below −15 to more than 35 °F (−26.1–1.6 °C), containing 12 grades (<−15, −15~−10, −10~−5, −5~0, 0~5, 5~10, 10~15, 15~20, 20~25, 25~30, 30~35, >35). A Korean MWT map was constructed based on these grades. The largest distribution was confirmed in the 15−20 °F range and the least distributed in the >35 °F grade. Korean AH:M map was constructed and classified into 6 bands (<−16, 16–19, 19–21, 21–24, 24–27, >27). The Korean AH:M map was found to be most distributed in the 21~24 ℃/m precipitation region, and the least in the >27 ℃/m precipitation region. Korean provisional seed zones with 65 climatic zones were formed by overlapping both maps (Fig.2). In the Korean provisional seed zones, the zone with MWT <~15 ˚F, and AH:M 16~19 ℃/m was the least distributed, and the zone MWT of 15~20 ˚F and AH:M 19~21 ℃/m was most distributed.

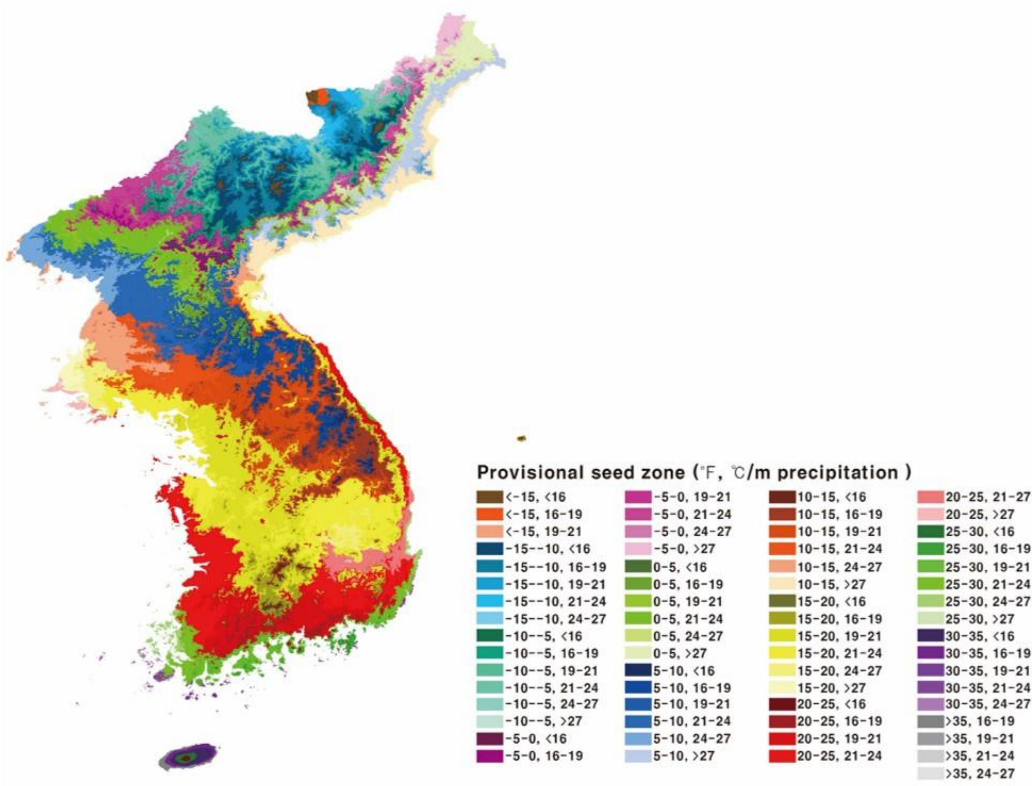

Fig. 2: Domestic provisional seed zones

The habitat potential of Korean provisional seed zones and the five native species (Pine, Oak, Oyster oak, hornbeam, and fern wood) were also examined in this study.

Among the 65 zones, the zone with a MWT of 15~20 ℉ (−9.4~−6.6 ℃) and AH:M of 19~21 ℃/m accounted for the largest proportion of Pine, Oak, and Oyster oak, at 23.46, 36.70, and 22.28 %, respectively(Fig.3a,b,c). Pine were distributed at a high density in the administrative districts of Seoul, southern Gyeonggi-do, Chungcheong-do, and Gyeongsangbuk-do, whereas Oak and Oyster Oak had high densities in Seoul, southern Gyeonggi-do, and Chungcheong-do. The SDM results for hornbeam revealed that the regions with a probability of inhabitation of 0.5 or higher were Jeju Special Self-Governing Province, Yangsan-si in Gyeongsangnam-do, and the east coast of Gangwon-do. The zone with the largest distribution of hornbeam had a MWT of 25~30 ℉ (−3.8~−1.1 ℃) and AH:M of < 16 ℃/m, accounting for 33.34 %(Fig.3d). This area includes the entire Jeju Special Self-Governing Province. The SDM results for fern wood revealed that areas with a habitat probability of 0.5 or higher were distributed in southern coastal areas such as Gokseong-gun, Suncheon-si, and Hadong-gun. Of the 65 zones, the zone with a MWT of 20~25 ℉ (−6.6~−3.8 ℃) and AH:M of 16~19 ℃/m accounted for the highest ratio of fern wood at 42.94 %(Fig.3e). This area includes Gokseong-gun, Jeollanam-do, and Jinju, Gyeongsangbuk-do.

Verifying the accuracy of the boundary classification of Korean provisional seed zones based on species location data and MaxEnt confirmed that the area with high seed density coincided with the area with high density in the Korean provisional seed zones.

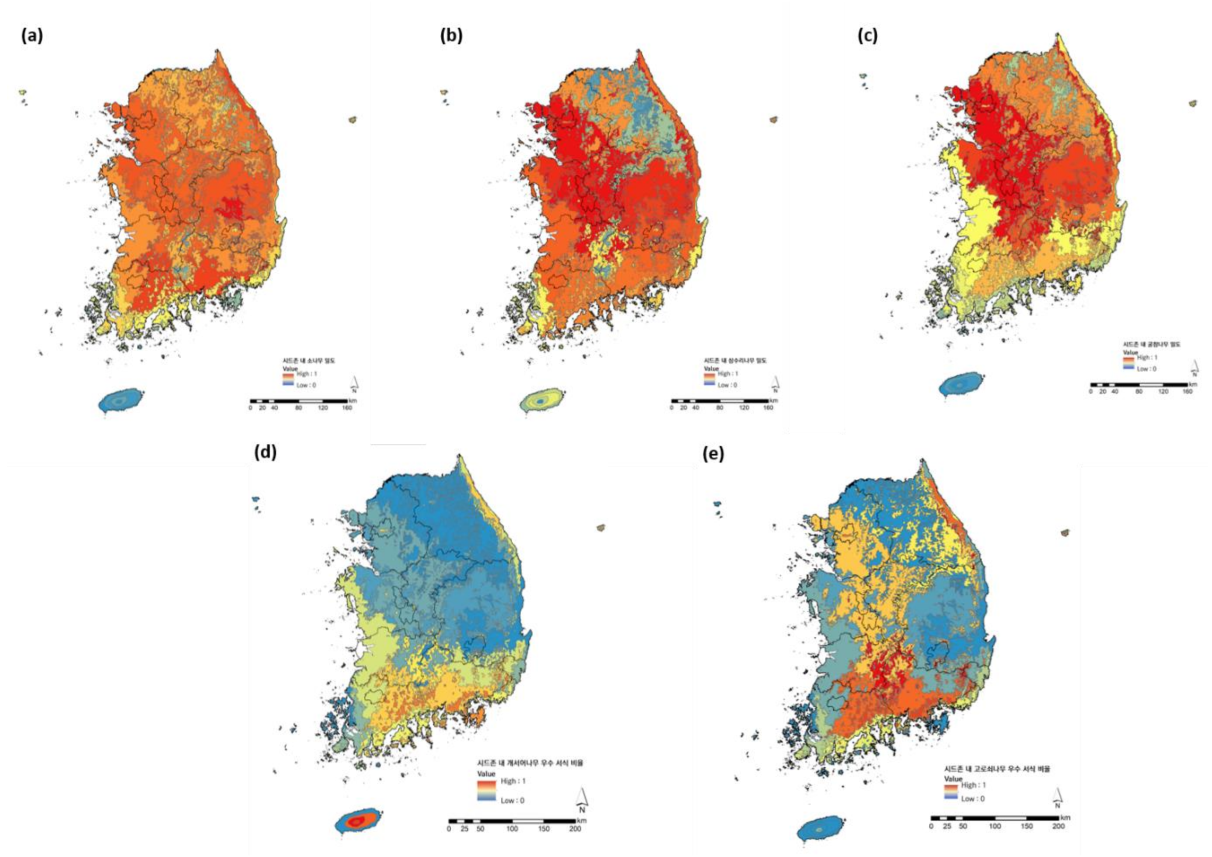

Fig. 3: Density of native seeds in the seed zones
(a) *Pinus Densiflora* (b) *Quercus acutissima* (c) *Quercus variabilis* (d) *Carpinus tschonoskii* (e) *Acer pictum subsp. mono*

Discussion

Korean provisional seed zones defined by this study were confirmed to represent climatically similar regions. Nevertheless, applying the same standards as those used for establishing US seed zones is a limitation because they are different in area or topography in Korea. Furthermore, the accuracy of the boundary classification was confirmed through comparative analysis of seed habitability and seed zones by replacing the Ecoregion defined in the United States; however, it was only conducted in South Korea. There is a possibility that an error may occur in such comparisons.

In order to enhance the accuracy of the established seed zones, it is necessary to develop a method for basic research to create an Ecoregion that can be applied in Korea. Establishing an Ecoregion that is the standard to verify the accuracy of seed zone boundary classification, is expected to be facilitate precise classification of climate zones through accurate boundary adjustment.

For the Korean provisional seed zones identified in this study, utilizing the data of the emergence point of seeds, which is typically used for restoration, or collection of soil environment data can be suggested. Moreover, it is considered useful as reference data for the management of native species at the local level. It can also be used as a basic measure when collecting effective seed movement data by minimizing the side effects of restored species.

Conclusions/ wider implications of findings

Degradation of forest ecosystems and natural habitats has increased the need to develop guidelines for the movement of introduced and native species along with effective ecological restoration of ecosystems. In this study, the MWT and AH:M were used to construct 65 provisional seed migration zones in the Korean Peninsula. Among the Korean provisional seed zones that were established, the zones with MWT of <~15 ℉ and AH:M of 16~19 ℃/m had the least distribution, whereas those with MWT of 15~20 ℉ and AH:M of 19~21 ℃/m had the highest distribution. In order to verify the boundary classification accuracy of Korean provisional seed zones, the habitat locations for Pine, Oak, Oyster oak, hornbeam, and fern wood were identified using the National Natural Environment Survey data and 1:5,000-scale forest type map; the habitat was analyzed through MaxEnt analysis. Areas with a high potential were identified. Subsequently, regions with high density of climate zones were identified by overlapping with Korean provisional seed zones. Consequently, the distribution characteristics of the climate zones of the Korean provisional seed zones and the growth characteristics of each seed were confirmed to be consistent. Although this study is meaningful because it's a leading study on the entire Korean Peninsula based on climate factors, the accuracy of classification in North Korea has not been proven. Moreover, this study has a limitation in applying the same American classification criteria to Korea. Establishing an ecoregion for domestic use in the future is expected to greatly contribute to the development of more accurate Korean seed zones.

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