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Prediction of Distribution Changes of *Carpinus laxiflora* and *C. tschonoskii* Based on Climate Change Scenarios Using MaxEnt Model in South Korea

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Abstract

Hornbeams (Carpinus spp.), which are widely distributed in South Korea, are recognized as one of the most abundant species at climax stage in the temperate forests. Although the distribution and vegetation structure of the *C. laxiflora* community have been reported, little ecological information of *C. tschonoskii* is available. Little effort was made to examine the distribution shift of these species under the future climate conditions. This study was conducted to predict potential shifts in the distribution of *C. laxiflora* and *C. tschonoskii* in 2050s and 2090s under the two sets of climate change scenarios, RCP4.5 and RCP8.5. The MaxEnt model was used to predict the spatial distribution of two species using the occurrence data derived from the 6th National Forest Inventory data as well as climate and topography data. It was found that the main factors for the distribution of *C. laxiflora* were elevation, temperature seasonality, and mean annual precipitation. The distribution of *C. tschonoskii*, was influenced by temperature seasonality, mean annual precipitation, and mean diurnal rang. It was projected that the total habitat area of the *C. laxiflora* could increase by 1.05% and 1.11% under RCP 4.5 and RCP 8.5 scenarios, respectively. It was also predicted that the distributional area of *C. tschonoskii* could expand under the future climate conditions. These results highlighted that the climate change would have considerable impact on the spatial distribution of *C. laxiflora* and *C. tschonoskii*. These also suggested that ecological information derived from climate change impact assessment study can be used to develop proper forest management practices in response to climate change.
Keywords: *Carpinus laxiflora*, *C. tschonoskii*, Climate change, Distribution change, MaxEnt

Introduction

Over the next 100 years, the Earth's temperature is predicted to rise 1.8°C to 4.0°C, which is expected to have a significant impact on the ecosystems and habitats (IPCC, 2021). Accordingly, the IPCC presented a Representative Concentration Pathways (RCP) scenario in order to evaluate the impact of future climate change and to minimize the damage (IPCC, 2013). The RCP scenario is a future climate prediction model that reflects recent changes in greenhouse gas concentrations and is updated to meet the latest greenhouse gas and resolution rather than the existing Special Report on Emissions Scenario (SRES) greenhouse gas scenarios. Over the past 30 years (1981-2010), the mean annual temperature of the Korean Peninsula has increased by 1.2°C, under the RCP 4.5 and RCP 8.5 scenarios have increased by 1.2 times and 1.4 times, respectively. In this point, RCP 4.5 refers to the implementation of greenhouse gas reduction policies, and RCP 8.5 refers to the emission of greenhouse gases at the current trend (without reduction) (Baek et al. 2011).

Prediction studies of plant habitat distribution by global warming have been done actively around Europe and the United States since the 1990s (Huntley et al. 1995; Iverson et al. 1998; Leathwick et al. 1996; Sykes et al. 1996). In the Korean Peninsula, when temperatures increase due to global warming caused by climate change, the distribution of evergreen broad-leaved forests spread on the southern coast of South Korea will expand, but vegetation in alpine and subalpine regions may experience ecological side effects such as decline or extinction (Lee and Kim, 2007; Chun et al, 2015). Therefore, there is a need for continuous monitoring and research on plant species affected by climate change.

In Korea, ecological research on *Carpinus laxiflora* has been mainly focused on community structure and distribution, such as a study on the characteristics of *C. laxiflora* colony vegetation structure and community structure and vegetation succession of *C. laxiflora* stands (Song et al. 2011; Hong et al. 2012; Byeon and Yoon, 2018). However, in the case of *C. tschonoskii*, research is still lacking, focusing on the analysis of the community structure with other tree species rather than intensive studies at the population level (Won et al. 2016). In addition, there is no study on habitat changes caused by disturbances such as habitat environment, habitat preference, climate and environmental changes for the two species.

Therefore, this study is based on the 6th National Forest Inventory data and the MaxEnt (Maximum Entropy Modeling) model, which is widely used as one of the recent ecological status models. 1) Identification of the relationship between the existing distribution of two species and environmental variables, 2) Evaluation of the relative importance of environmental factors affecting distribution and 3) The future distribution of the two species according to the RCP scenario was comparatively evaluated.

Methodology

1. Species distribution data

In this study, the 6th NFI (2011-2015) data, which is being investigated by the same protocol at about 4,000 points every five years in Korea and is the latest data among the National Forest Inventory (NFI) data, was used to extract the growth and distribution points of *C. laxiflora* and *C. tschonoskii* for identifying their range and predicting its potential distribution (Fig. 1).

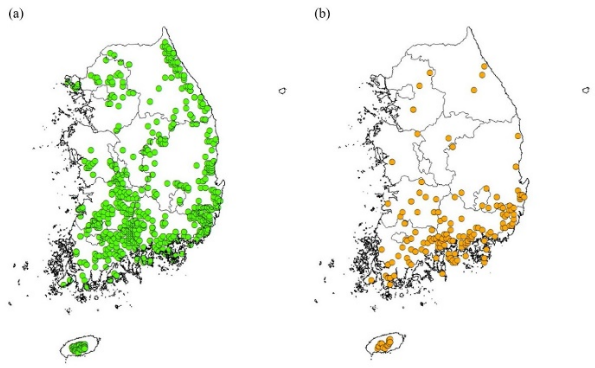

Fig 1: Contemporary distribution of (a) *Carpinus laxiflora* and (b) *C. tschonoskii* based on 6th National Forest Inventory in South Korea.

2. Environmental variables

In this study, Bioclims and elevation, one of the most important factors in the distribution of plant species in Korea, were used as environmental variables to determine the distribution of *C. laxiflora* and *C. tschonoskii* (Chun et al., 2015). Also, to predict the future potential habitat distribution of *C. laxiflora* and *C. tschonoskii*, future distribution changes by two different RCP scenarios were also compared. The average of the 1970–2000 data in RCP 4.5 was derived and set at present (2020s) and compared with 2041-2060 (2050s) and 2081–2100 (2090s) in each scenario. As bioclim factors, 19 bioclimate variables from Bioclim, a global climate data provider (https://www.worldclim.org/) were used. For this purpose, 19 biological climate variables of Bioclim were derived by receiving Worldclim's past climate data and future climate forecast data (HadGEM2-CC, 1km resolution). Correlation analysis was performed to remove the multicollinearity between the 19 variables provided by Bioclim. The analysis included factors that had a significant effect on climate among those with a high correlation number of 0.9 or higher and excluded the remaining factors from the analysis (Lee et al., 2015).

The selected final factor is as Table 1. The geographical elevation was analyzed by receiving the SRTM elevation data of Worldclim (1 km resolution). ArcMap 10.3 was used for bio-climate factors and altitude factor extraction, and R-studio 3.6.3 was used for statistical analysis.

Table 1: Description and equations of climate variables.

Climate variables	Units	Description
Bio1	°C	Mean Annual Temperature
Bio2	°C	Mean Diurnal Range
Bio3	%	Isothermality
Bio4	°C	Temperature Seasonality
Bio5	°C	Max Temperature of Warmest Month
Bio12	mm	Mean Annual Precipitation
Bio13	mm	Precipitation of Wettest Month
Bio14	mm	Precipitation of Driest Month
Bio15	%	Precipitation Seasonality

2.3. Potential Species Distribution Model

In this study, the MaxEnt model was used to predict the distribution of potential habitats for *C. laxiflora* and *C. tschonoskii*. The MaxEnt model is one of the machine-learning models and represents a higher predictive accuracy than other models when only the appearance data are applied (Philips et al. 2006, Seo et al. 2008, Song and Kim, 2012). This study was conducted in five iterations using more than five random location information using the distribution data of *C. laxiflora* and *C. tschonoskii*, nine climatic and elevation factors of Bioclim in Korea, and the verification of the model's explanatory power utilized AUC (Area Under the Curve) values of the ROC (Receiver Operating Characteristics) curve. In addition, the Jackknife test was used to indicate the importance of environmental factors that determine the habitat distribution of each species.

Results

3.1. The predictive power of the potential habitat distribution of two species

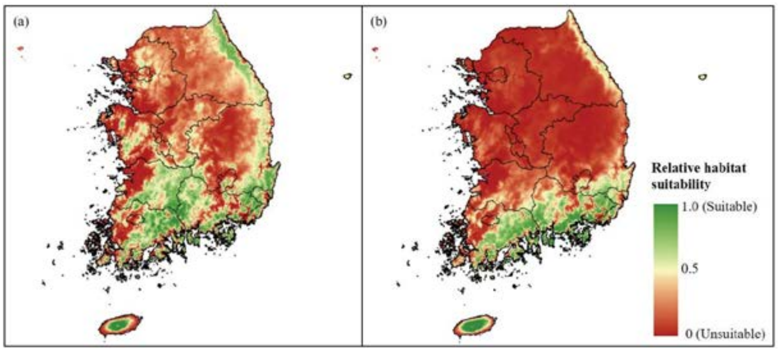

Fig 2: Potential distribution of the present predicted with climate variables and elevation of (a) *Carpinus laxiflora* and (b) *C. tschonoskii*.

The results of the habitat prediction model using the MaxEnt model applied the current (1970s to 2000s) climatic and elevation factors of the *C. laxiflora* and *C. tschonoskii* were shown as Fig .2. Looking at the habitat prediction model and the contribution of the variables to the ROC curve and the explanatory verification power, the Tranning AUC for the *C. laxiflora* and *C. tschonoskii* were 0.806 and 0.879 each, while the Test AUC was 0.792 and 0.861 respectively. In general, AUC has a value of 1.0 for higher classifications on a minimum of 0.5 (Hastie, 1992; Thuiller, 2003). When the AUC value is approximately 0.7 or higher, it is determined that the potential described by the model is meaningful (Seo et al. 2008; Lee, 2010). The potential habitat distribution model of the *C. laxiflora* and *C. tschonoskii* predicted in this study was analyzed to have comparatively meaningful explanatory power, with AUC being 0.793 and 0.861 respectively (Fig. 3).

3.2. The predictive power of the potential habitat distribution of two species

The Jackknife graph of major environmental factors affecting the habitats of *C. laxiflora* and *C. tschonoskii* using MaxEnt model is shown in Fig 4. The Jackknife graph shows the relative importance of ten variables in determining the habitat distribution of *C. laxiflora* and *C. tschonoskii* (Li et al., 2020). The environmental variables involved in the distribution of *C. laxiflora* according to the Jackknife graph were in the order of Mean annual precipitation (Bio12), Elevation, and Temperature seasonality (Bio4) representing year-round temperature change (Donnell and Ignizio, 2012). In addition, environmental variables involved in the distribution of *C. tschonoskii* appeared in the order of Temperature Seasonality (Bio4), Mean annual precipitation (Bio12), and Mean Diurnal Range (Bio2), which is an index representing the degree of change in monthly temperature (Donnell and Ignizio, 2012). As a result of the main response curve, it was found that the habitat fitness of *C. laxiflora* increased gradually from 800 mm or more of mean annual precipitation, and the habitat fitness increased at an elevation of 100 to 1,000 m and decreased from 1,100 m. In addition, when the temperature seasonality value exceeds 950, habitat suitability drops sharply (Fig. 3a, b, c). In the case of *C. tschonoskii*, when the value of temperature seasonality exceeds 700, the habitat suitability was lowered, and it was judged that the higher the annual temperature difference, the lower the habitat suitability. The mean average precipitation started from 800 mm, and as the mean average precipitation increased, the habitat suitability also increased. In addition, when the diurnal temperature difference during the day was 6 degrees or less, the habitat fitness was high, and when the difference was 9 degrees or more, the habitat fitness was lowered (Fig. 3d, e, f).

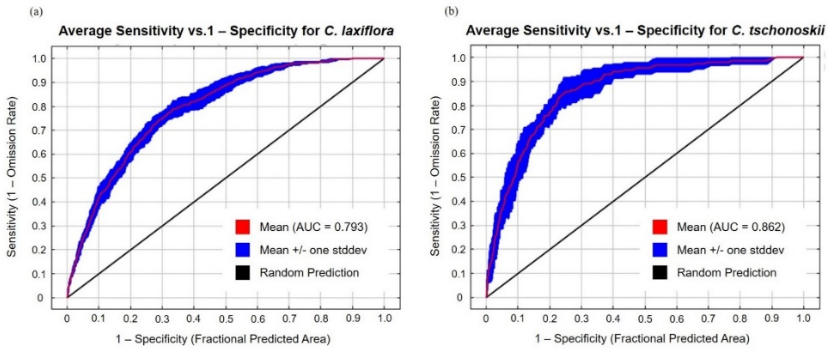

Fig 3: The AUC (area under ROC) curves of the climate suitability model for (a) *Carpinus laxiflora* and (b) *C. tschonoskii*.

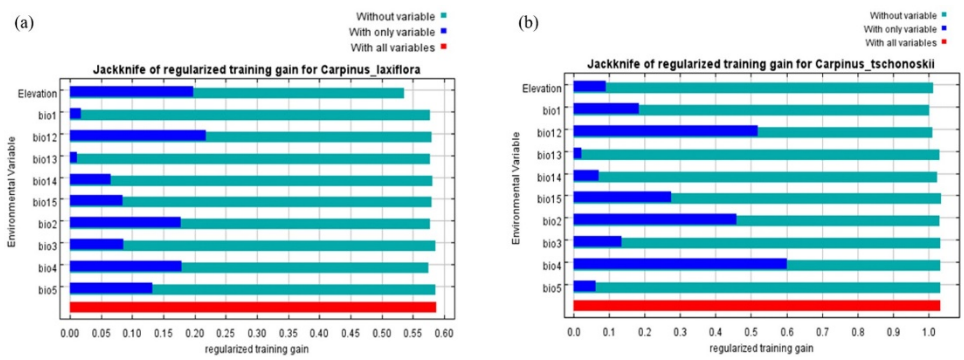

Fig 4: The relative importance (training gain) of 10 environmental variables for (a) *Carpinus laxiflora* and (b) *C. tschonoskii*.

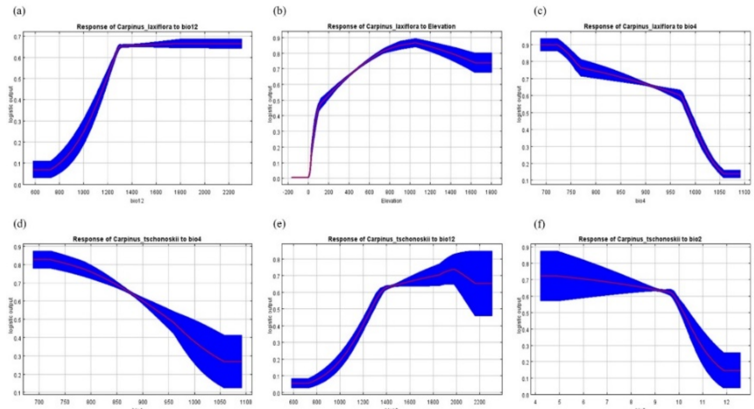

Fig 5: Response curves of variables affecting MaxEnt prediction; (a–c) *Carpinus laxiflora* and (d–f) *C. tschonoskii*.

3.4. Variation of habitat of the *Carpinus laxiflora* and *C. tschonoskii* in accordance with the RCP scenario

The spatial changes of the potential habitats of *C. laxiflora* and *C. tschonoskii* according to the RCP4.5 and RCP8.5 scenarios are shown in Fig. 6 and 7. To identify future potential habitat changes of the *C. laxiflora* and *C. tschonoskii* in accordance with RCP 4.5 and RCP 8.5, each category of area was calculated by dividing it into areas with very high habitat suitability when the probability value of habitat distribution exceeds 0.8; areas with high habitat suitability when over 0.6 and 0.8; areas with medium habitat compatibility when over 0.4 and 0.6; areas with low habitat compatibility when over 0.2 and 0.4; and areas that are unsuitable for habitat under 0.2. As a result, in the RCP4.5 scenario, the area with a habitat distribution probability of 0.8 or higher for *C. laxiflora* increased by 1.15 times compared to the present in the 2050s. Furthermore, in the case of progressing from the 2050s to the 2090s, it is found that the number increases by about 2.02 times compared to the present. In the RCP8.5 scenario, in the 2050s, the area with a potential habitat distribution probability of 0.8 or more decreased in area, but in the 2090s, it increased by about 1.15 times compared to the present (Fig. 8). In the case of *C. tschonoskii*, in the RCP4.5 scenario, the habitat distribution probability of areas with a distribution probability of 0.8 or higher increased significantly to 1.44 times in the 2050s and 1.81 times in the 2050s to 2090s compared to the present. In the RCP8.5 scenario, the area with a habitat distribution probability of 0.8 or higher increased by about 1.76 times in the 2050s but decreased in the 2090s compared to the 2050s (Fig. 9).

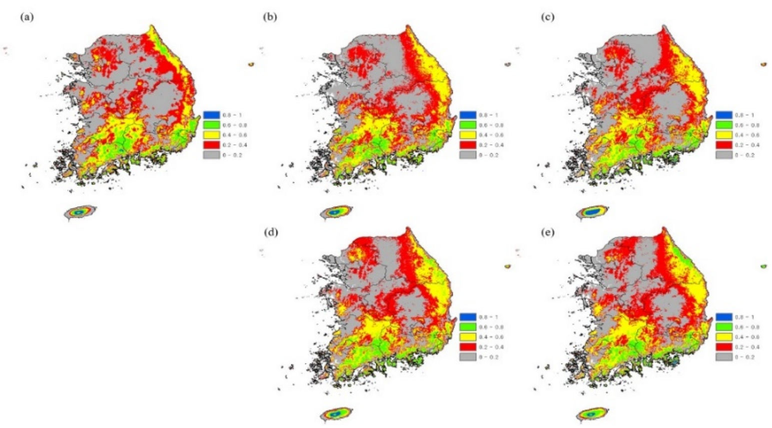

Fig 6: Change of potential distribution of *Carpinus laxiflora*; (a) Present, (b) 2050s with RCP 4.5, (c) 2090s with RCP 4.5, (d) 2050s with RCP 8.5, (e) 2090s with RCP 8.5.

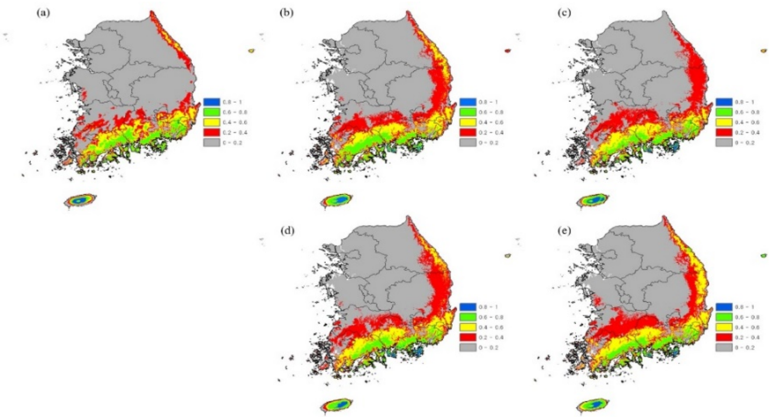

Fig 7: Change of potential distribution of *Carpinus tschonoskii*; (a) Present, (b) 2050s with RCP 4.5, (c) 2090s with RCP 4.5, (d) 2050s with RCP 8.5, (e) 2090s with RCP 8.5.

Fig 8: Change of potential distribution area of *Carpinus laxiflora* under RCP scenarios.

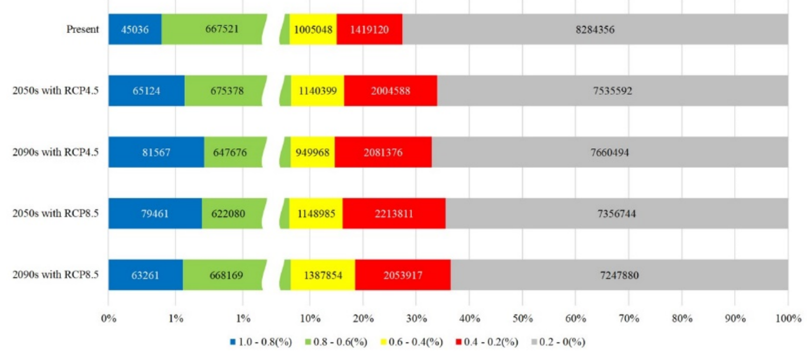

Fig 9: Change of potential distribution area of *Carpinus tschonoskii* under RCP scenarios.

Discussion

In both species, the habitable area was found to be expanding compared to the present in the RCP4.5 and 8.5 scenarios due to climate change. However, in the case of *C. laxiflora*, areas with high habitat suitability (probability value 0.6 to 0.8) showed a sharp decrease compared to the present. In particular, a large decrease was observed in the Taebaek Mountains near the east coast of Gangwon-do, which is thought to be due to elevation among the major environmental variables that determine the habitat of *C. laxiflora* (Lee et al., 2017). According to the RCP scenario, it is predicted that the temperature and precipitation in the highlands will gradually increase as climate change progresses (IPCC, 2013). Therefore, it is expected that the elevation of the point suitable for the habitat of the *C. laxiflora* in response to the climatic factor will gradually increase. However, elevation is a topographical factor and is the only environmental variable that does not change with the progress of climate change scenarios. As a result, even at the preferred elevation of the *C. laxiflora*, the probability of habitat adaptation at that elevation is expected to decrease due to climate change.

The species distribution according to the RCP4.5 and RCP8.5 scenarios was clearly different. In the RCP4.5 scenario, in which the greenhouse gas reduction policy has been substantially realized, from the present to the 2090s, areas suitable as habitats for the two species spread. n the RCP4.5 scenario, the mean annual temperature and precipitation increase and the annual range decreases compared to the present, but compared to the RCP8.5 scenario, the degree is weaker, so it causes a reduction in the distribution of temperate northern and cold temperate tree species such as *Pinus koraiensis*. On the other hand, it is predicted that it may act favorably on temperate and southern temperate tree species, such as wood and hornbeam (Chun et al., 2015; Ministry of Environment, 2020). However, at the same time, in the RCP4.5 2090s scenario, the habitable area of both species decreases slightly compared to the 50s. In the RCP4.5 scenario, it is expected that as time goes by, the regional variation of natural disasters along with extreme climate change will increase. In the RCP8.5 scenario, in which greenhouse gas reduction is not realized, it is somewhat unstable, with areas suitable as habitats for *C. laxiflora* decreasing compared to the present, or areas suitable as habitats for *C. tschonoskii* decreasing in the 2090s compared to the 2050s. This is thought to be due to the extreme climate change of major climate factors affecting the habitat distribution of the two species in the climate change scenario. According to the RCP8.5 climate change scenario, it is predicted that the annual range will decrease and the mean annual precipitation will increase on the Korean Peninsula due to the increase in temperature in the future (Sung et al. 2012). At the same time, it is predicted that regional variations will increase and extremely heavy rains, heat waves, droughts, and typhoons will occur frequently in a short period of time, which may cause continuous and extreme disturbances in the forest succession stage (Moon et al. 2020; Peng et al. 2020). In particular, it is predicted that the more the climate change continues, the more unstable the habitat distribution is due to the nature of the hornbeam, which is a climax.

Conclusions

In Korea, it is difficult to find forests dominated by hornbeams because of the expropriation of forest resources during the Japanese colonial period, the Korean War, and overfishing of heating materials (Hong, 2012; Byeon and Yoon, 2018). However, as a result of using the future climate factors and elevation factors that have a great influence on plant distribution, the habitable area of hornbeams is expected to spread compared to the present, although unstable. Although, in this study, forest succession variables for hornbeam, such as soil conditions, community structure, and environmental changes due to biota, were not included in determining habitat suitability (Lee et al., 2000). However, it is judged to be able to provide meaningful results in predicting potential distribution changes according to the impact of climate change of hornbeams, which are recognized as important in forest succession as climax species. In addition, the RCP scenario used in this study is based on 2013. With the recent IPCC 2021 report, the RCP scenario shows a further increase in temperature and precipitation. However, the Worldclim data used in this study has a limitation in that it does not reflect the latest data because it has not been updated from the 2013 data. In addition, the results of this study are analysis results based on the climate change scenarios RCP4.5 and RCP8.5, and the increase or decrease of the potential distribution area does not mean that the current main habitat suddenly disappears, or the surrounding area becomes a habitat. The potential habitat shown in the MaxEnt model is a place with a high probability of surviving when it becomes a habitat in the future considering current environmental factors (Chun et al., 2015). Therefore, it is unreasonable to conclude that the prediction results of the simulation based on the input data given at the present time are confirmed in the future (Ko et al., 2014). In addition, this study is expected to be helpful in devising a stable management plan for potential habitats of hornbeams, which will be expanded in the future, by understanding the effects of climate change on hornbeams. It is also meaningful in that it can be used as a reference material for decision-making on forest policies for the management and conservation of natural forests in Korea.

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