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Impact of Climate Change on Species Distribution of *Picea jezoensis* Carrière in Baekdudaegan Using Ensemble Modeling

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Climate change is altering habitat environments, threatening the survival of *Picea jezoensis* (Siebold et Zucc.) Carrière in South Korea. Species distribution models (SDMs) have been considered an effective tool to investigate the impact of climate change on species' potential distributions. We collected occurrence data and bioclimatic data to predict the current and future distributions by ensemble distribution modeling on the BIOMOD2 platform. The predicted distribution habitats of *P. jezoensis* for both current and future climates were shown by ensemble prediction with true skill statistic (TSS) values of over 0.8. Using the random forest (RF) and general linear model (GLM), the natural habitat of *P. jezoensis* was predicted to become extinct in the 2070s under representative concentration pathway (RCP) 4.5. However, the general additive model (GAM) predicted a limited habitat of *P. jezoensis* across the South Korean peninsula in the 2070s. Hence, the natural distribution of *P. jezoensis* is not expected to find alternative habitats to offset their loss of current habitat, placing them at more significant risk of extinction in the future. These findings will aid the effective management and conservation of *P. jezoensis* by providing an understanding of the future impact of climate change on targeted endangered species.

1. Introduction

Picea jezoensis Carrière is widely distributed across Korea, Japan, northeastern China, and far-eastern Russia. It is an economically valuable tree that grows in the cool and subalpine forests of northeast Asia.(1,2) In South Korea, *P. jezoensis* has a very limited distribution, growing only in the upper elevations of Mt. Jiri, Mt. Deogyu, Mt. Seorak, and Mt. Gyebang.(3,4) Isolated populations of *P. jezoensis* might inhibit trait exchange among populations, causing the species to die out within certain limited areas in South Korea.(5,6) Furthermore, *P. jezoensis* is vulnerable to global warming with declining competitiveness in South Korea.(7,8) *P. jezoensis* has been designated as an endangered species in Korea and categorized as of Least Concern

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(LC) in the International Union for Conservation for Nature (IUCN)'s Red List of Threatened Species.[9] Hence, this species is of great conservation importance in South Korea, owing to its restricted distribution and ecological value. Many studies of *P. jezoensis* have focused on structural characteristics, growth conditions, and seed germination, although there is limited data for restoration.[10–12] In particular, research on *P. jezoensis* in South Korea has focused on only certain areas.[8,12]. Thus, it is difficult to overview the comprehensive distribution of *P. jezoensis* across the South Korean peninsula in terms of landscape ecology.

Global temperature is now rapidly rising owing to climate change, with consequent geographic rearrangement of species and recent climate-related extinctions.[13,14] Understanding the impact of climate change on species distributions is essential to establish the potential ecological risk and the design of suitable conservation strategies for adaptive management.[15] Applications of species distribution models (SDMs) use the climate and occasionally the environmental characteristics of locations where species are known to occur and their abundance to estimate the likelihood of occurrence at other locations where no occurrence information is available.[16] There are commonly used SDM algorithms such as generalized linear models (GLMs), generalized additive models (GAMs), maximum entropy modeling (MaxEnt), and other machine learning methods such as artificial neural networks.[17–19] Ensemble modeling has been shown to improve model predictions[20] and reduce overfitting when modeling endangered species,[21] and it has been advocated as a superior alternative to single models for future climate projection modeling with large numbers of species.[22]

Therefore, the main objective of this study is to use ensemble algorithm SDM methods to evaluate the impact of climate change scenarios on the *P. jezoensis* distribution across the South Korean peninsula. These findings will help support effective plans for the management and conservation of *P. jezoensis*, especially in response to climate change.

2. Materials and Methods

2.1 Location data for *P. jezoensis* in South Korea

To acquire the data on *P. jezoensis* in South Korea, we employed databases serviced by Baekdudaegan National Arboretum, Korea Arboreta and Gardens Institute. Four additional field surveys were conducted to determine the current distributions of this species necessary for SDMs (Fig. 1). In total, 84 sites where *P. jezoensis* are present were identified, and maps with binary cell values of presence (1) and absence (0) were produced for each SDM using the threshold value of 0.5 (Fig. 2).

2.2 Environmental parameters

Current climate data, including 19 bioclimatic variables in the WorldClimate data, were used to predict the change in the distribution of potential land suitable for *P. jezoensis* forests.[23] In particular, bioclimatic variables were considered suitable for studying the species distributions under current or possible future conditions using the SDM model. As shown in Table 1, four

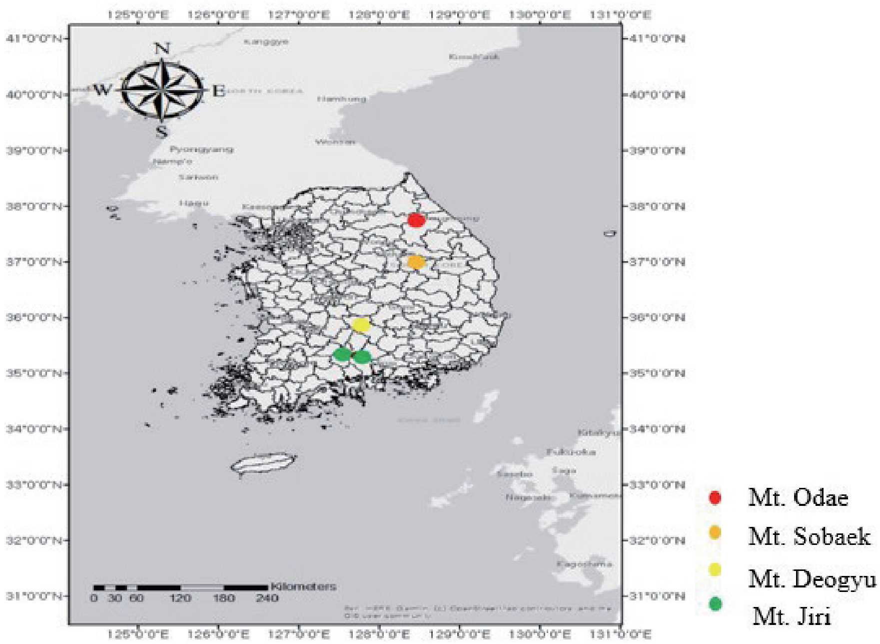

Fig. 1. (Color) Distribution of *Picea jezoensis* Carrière in South Korea.

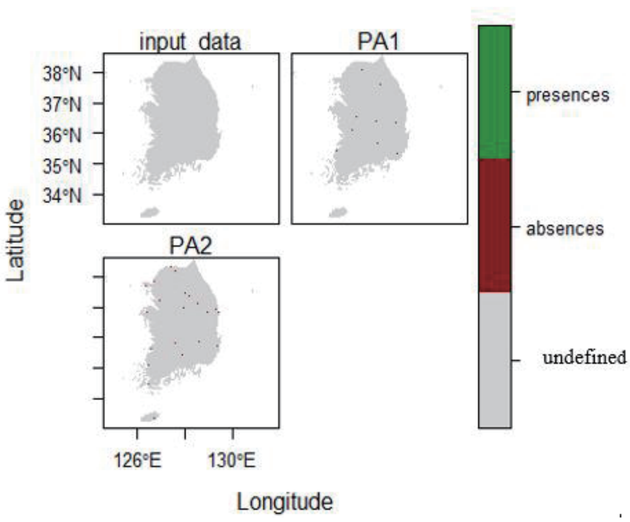

Fig. 2. (Color) Results of presence and absence mapping of *P. jezoensis* distribution (n = 67 presence, n = 500 absence).

Table 1
Selected environmental variables for SDM.

Factor	Variable	Description	Resolution
Climate factor	Bio5	Max Temperature of Warmest Month	30 arcseconds (1 km)
	Bio7	Temperature Annual Range (Bio5-Bio6)	
	Bio11	Mean Temperature of Coldest Quarter	
	Bio19	Prediction of Coldest Quarter	

(max temperature of warmest month, temperature annual range, mean temperature of coldest quarter, and prediction of coldest quarter) of the 19 BioClim variables were considered when investigating the SDM.

For future climate data, we referred to the HadGEM2-AO climate model constructed by the National Institute of Meteorological Science for the publication of IPCC Assessment Report 5 (AR5) for the 2050s (2041–2060) and 2070s (2061–2080) under the RCP 4.5 emission scenario. The HadGEM2-AO climate model is a general circulation model (GCM) with a spatial resolution of 135 km, and its bioclimatic variables were downscaled to a spatial resolution of 30 arcseconds using version 1.4 of WorldClim for the actual analyses conducted for our detailed climate forecast in South Korea.

2.3 Species distribution ensemble modeling

BIOMOD2 provides an ensemble platform of ten SDM algorithms, and we initially used four of these as ensemble candidates. To model the potential land suitability for *P. jezoensis* in the future, the ensemble modeling was designed to consist of three different regression models [GAM, generalized boosted model (GBM), and GLM] and a machine learning model [random forest (RF)] provided by the BIOMOD2 package in R statistical language (Fig. 3). We built individual models using the default settings provided by BIOMOD2 version 3.4.1 and obtained the outcomes of SDM simulations with true skill statistic (TSS) values of over 0.8 to reduce the uncertainty of SDMs. This evaluation metric is an indicator of discrimination capacity, which

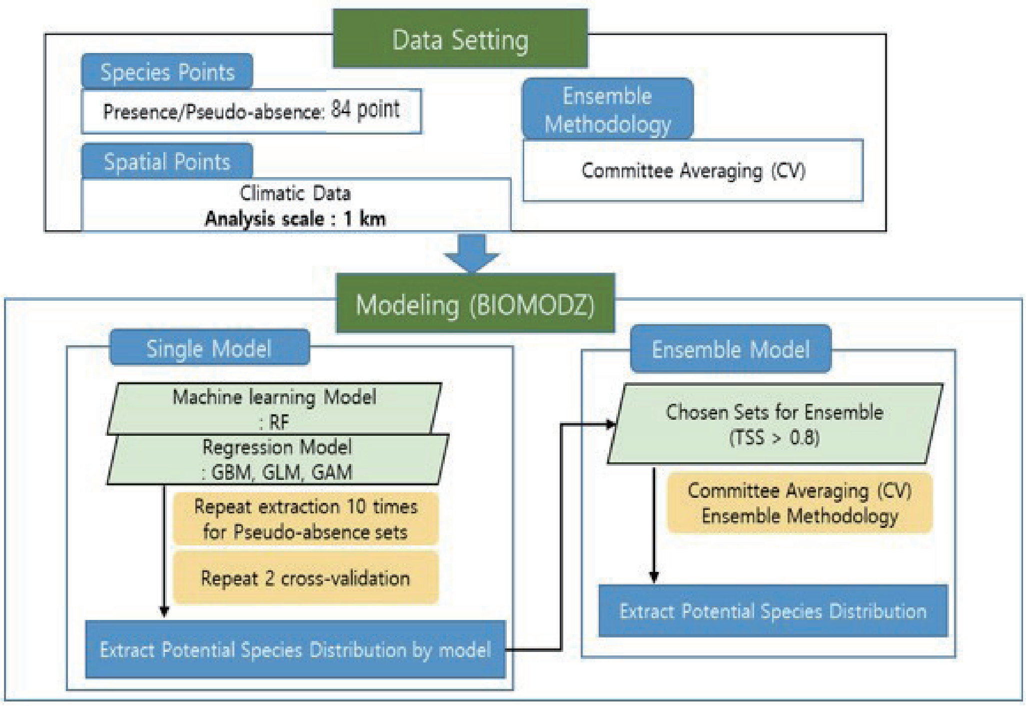

Fig. 3. (Color) Schematic representation of the ensemble species distribution modeling approach.

can quantify how well the model distinguishes presences from absences (or presences from background samples when absences are unavailable). As held-out subsets of the original dataset were used for model evaluation (cross-validation) for partitioning data into subsets, the SDM results represented the possibility of each species' occurrence in the form of a continuous distribution, implying the importance of deciding a threshold to objectively determine the presence of a selected species for the integrity of the modeling results and their interpretation. In BIOMOD2, the cross-validation procedure was repeated five times for each of the 15 presence–absence groups.[24] The accuracy of a committee averaging (CV) ensemble methodology was evaluated using outer validation.

3. Results

3.1 Evaluating the performance of various BIOMOD2 algorithms

We used the ensemble SDM platform and R package BIOMOD2 to explore the potential land suitability for *P. jezoensis* in the future. As shown in Table 2, the performance of models was evaluated using the receiver operating characteristic (ROC) and TSS. The distribution habitats of *P. jezoensis* for both current and future climates were obtained by ensemble forecasting in the BIOMOD2 package by parameterizing TSS > 0.8 for individual models. Specifically, GBM, GLM, and RF performed better than the statistical GAM method according to the TSS values of the models.

3.2 Contribution of four predictor variables used to construct the SDMs for *P. jezoensis*

Among the four predictor variables under the GLM model, Bio 5 (0.993 ± 0.010) contributed the most to the model predictions, followed by Bio 11 (0.938 ± 0.088) and Bio 7 (0.783 ± 0.212) (Table 3). Under the GLM and RF models, Bio 5 contributed the most to the model prediction (0.993 ± 0.010 and 0.345 ± 0.005, respectively), while Bio 11 contributed the most to the model (0.392 ± 0.049 and 0.993 ± 0.006, respectively) under the GBM and GAM models. Furthermore, Bio 19 contributed little to the predictive performance of the models among the four predictor variables under the four algorithms (0.108 ± 0.012 – 0.318 ± 0.051).

Table 2
Mean and standard deviation of ROC and TSS for the SDM.

Species	Model	ROC (0–1) Testing data	TSS (0–1)	ROC cutoff	Sensitivity	Specificity
P. jezoensis	GAM[1]	0.923	0.97	853.5	100	100
	GBM[2]	1	1	854.0	100	100
	GLM[3]	0.99	0.98	795	100	100
	RF[4]	0.98	0.99	798.5	100	100

GAM[1]: General additive model, GBM[2]: Generalized boosted model, GLM[3]: General linear model, RF[4]: Random forest.

Table 3
Importance of variables (environmental parameters) for SDM.

Variable	GAM[1]	GBM[2]	GLM[3]	RF[4]
Bio5	0.839 ± 0.071	0.160 ± 0.033	0.993 ± 0.010	0.345 ± 0.005
Bio7	0.528 ± 0.000	0.365 ± 0.007	0.783 ± 0.212	0.297 ± 0.047
Bio11	0.993 ± 0.006	0.392 ± 0.049	0.938 ± 0.088	0.293 ± 0.014
Bio19	0.318 ± 0.051	0.108 ± 0.012	0.313 ± 0.114	0.154 ± 0.021

GAM[1]: General additive model, GBM[2]: Generalized boosted model, GLM[3]: General linear model, RF[4]: Random forest. Each value is expressed as mean ± SD.

3.3 Current and future potential distributions of *P. jezoensis* under RCP 4.5

Figure 4 presents the predicted ensemble-averaged area loss of currently suitable habitats for *P. jezoensis*, showing the risk of extinction in the future under RCP 4.5. The visualization of the predicted changes in the habitats for *P. jezoensis* during the 2070s shows the loss of their current habitats using the RF and GLM models. Hence, *P. jezoensis* is not expected to find new habitats to offset its loss of current habitat, placing it at an increased risk of extinction in the future. Unlike the RF and GLM models, GAM showed a limited habitat of *P. jezoensis* in the 2070s under RCP 4.5. Specifically, there are natural habitats in the northern Kangwon region in the 2050s. However, the distribution of habitats in this region will gradually decrease in the 2070s.

4. Discussion

The prediction of the distribution of suitable habitats for *P. jezoensis* in South Korea could provide information about its risk of extinction and the possibility of its restoration, which is important for forest management. Many SDM studies have used ensemble approaches to reduce the model uncertainty. In this study, we used multiple SDMs for the ensemble average method, which provided a more accurate simulation performance to predict the suitable habitats for *P. jezoensis* in South Korea. Several algorithms in the BIOMOD2 ensemble performed well with our data, showing that the four methods converged successfully, giving stable TSS results. In general, values of above 0.6 and 0.8 for TSS indicate good and excellent performance for ensemble modeling, respectively.(25) The stable value of TSS results is an important point for an ensemble or consensus method, because it minimizes the uncertainty associated with the situation dependence of environmental data on the predictive performance of individual algorithms.(26,27) We also combined data partitioning (50% training – 50% validation) to produce two random selections from the presence data with each of the 500 balanced absence datasets. Using the climate projections from different GLM and RF models to assess the potential habitat of *P. jezoensis* under RCP 4.5, we found that the species will become extinct in 2070 across the South Korean peninsula. This implies that species are expected to lose some of their current habitats in the 2050s and to become extinct in the 2070s under the RCP 4.5 scenario. Plant species have responded to recent climatic changes by shifting their distribution poleward and to higher elevations.(28) Furthermore, physiological stress caused by various environmental factors, such as the rise in average temperatures in winter and spring, drought, heatwaves, and the

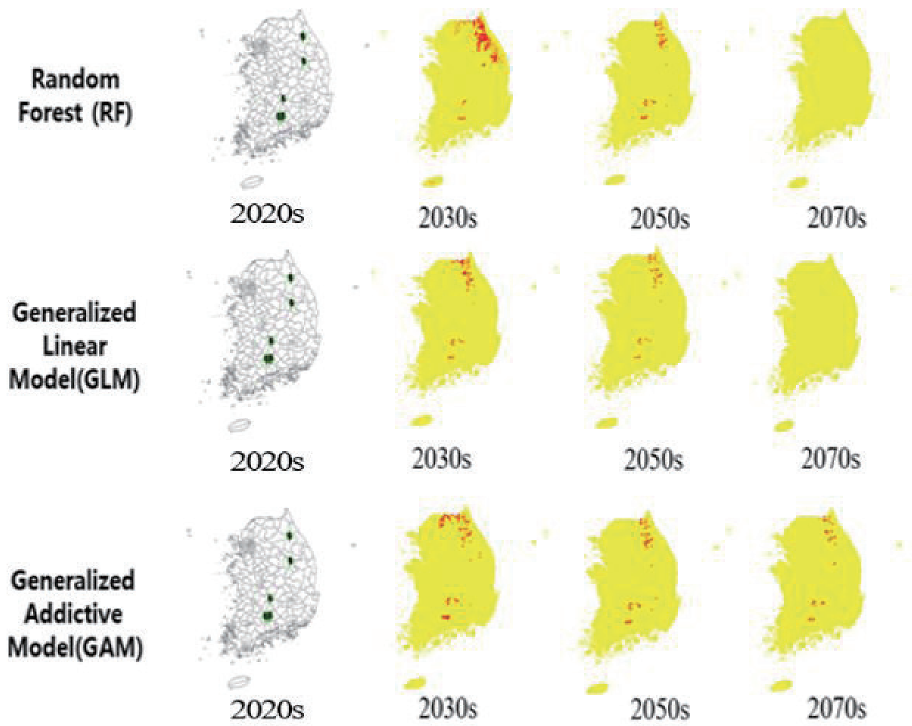

Fig. 4. (Color) Potential habitat distributions of *P. jezoensis* in the 2070s produced by single models under RCP 4.5.

decrease in the amount of snowfall, has been considered to be the major reason for the marked decline of habitat areas.(29) Hence, the natural habitat of *P. jezoensis* is expected to be lost across the South Korean peninsula under future conditions, as shown using the four BioClim variables in the 2070s under the RCP 4.5 scenario. Furthermore, *P. jezoensis* is vulnerable to global warming with declining competitiveness in South Korea.(7,8) In this study, we only considered the climatic factors as environmental parameters. Further study is needed to perform more comprehensive modeling research with various environmental parameters of *P. jezoensis*, such as growth conditions, soil, and altitude.

Limited populations of *P. jezoensis* in South Korea exist in subalpine forests.(5,6) However, *P. jezoensis* in South Korea has not been protected from logging or disturbance and has been subjected to global warming, which is considered to harm montane and subalpine species. On the other hand, *P. jezoensis* populations in Mt. Dokyu and Mt. Jiri have been well preserved in the protected areas of national parks.(30) In recent years, South Korea has been aggressively pursuing conservation efforts, especially by fostering a "green" economy, but also through more direct on-the-ground protection actions.(31) One of the most important aspects of conservation policies is to establish and protect areas of high conservation value. Therefore, it is necessary to expand the natural habitat of *P. jezoensis* as a conservation forest. Furthermore, to minimize the loss of diversity, it is essential to expand the *P. jezoensis* distribution through consideration of its potential suitable habitat in the South Korean peninsula. Other groups studying the changes in land suitability of targeted species using SDM obtained their results by comparing the quantitative habitat loss between current and future changes under climate change scenarios.(32,33) However, we used pixel data, making it difficult to perform a quantitative comparison between current and future changes in habitat area.

Therefore, we investigated the risk of extinction of *P. jezoensis* in South Korea using future climate projections, which would be helpful for forest management and conservation in response to climate change. Our results may suggest forest policy strategies to support target climate change adaptation management in forestry policy and practice.

5. Conclusions

Global warming is accelerating the habitat loss of *P. jezoensis*, suggesting the necessity of efforts to protect this endangered species. We estimated the current habitats of four selected distributions of *P. jezoensis* and constructed models to simulate their future changes under RCP 4.5. Using the climate projections from different RF and GLM models to assess the potential habitat of *P. jezoensis* under RCP 4.5, we found that the species will become extinct in the 2070s. Specifically, several algorithms in the BIOMOD2 ensemble performed well with our data, showing that the four methods converged successfully, giving stable TSS results. To conserve the habitat of *P. jezoensis* in the South Korean peninsula, it is necessary to expand its natural habitat by utilizing the established geospatial data that can confirm potentially suitable habitats for *P. jezoensis.* These findings are expected to be used as the preliminary conservation data of *P. jezoensis* under climate change scenarios in South Korea. Furthermore, monitoring should be performed to realize the effective conservation and management of endangered *P. jezoensis.*

Acknowledgments

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