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Fine-Scale Species Distribution Modeling of *Abies koreana* across a Subalpine Zone in South Korea for In Situ Species Conservation

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Abstract: Severe declines in the population of *Abies koreana*, a conifer native to the subalpine regions of South Korea, are likely a consequence of climate change. However, local-scale modeling of the species' spatial distribution has seen limited application to in situ conservation policies. Therefore, we intended for this study to examine the applicability of fine-scale species distribution modeling of *A. koreana* in the Mt. Jiri National Park area in S. Korea in order to explore candidate areas for its in situ conservation. We simulated the potential habitat of the species in the area with four separate models using different dominance patterns, then created an index based on habitability probabilities and residual durations to determine priority conservation areas. Under the highest sensitivity of potential habitats to temperature (spatially downscaled based on geomorphological characteristics), rapid habitat reduction occurred under climate warming in all experiments. At the regional scale, hydrological characteristics such as precipitation and slope characterized different secondary habitat distributional patterns among the experiments. Final conservation priority sites were identified based on specified criteria for the designed index. Our results suggest that a fine-scale modeling system with adequate spatial resolution of environmental inputs is advantageous in representing local habitat characteristics of *A. koreana* and can be applied to in situ conservation strategies.

Keywords: subalpine zone; climate change impact; fine-scale species distribution modeling; representation of local habitat characteristics; in situ conservation priority areas

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1. Introduction

Globally, isolated ecosystems such as mountains and islands are expected to be affected most by climate change [1,2]. The adaptability of species within most ecosystems can be diagnosed based on the movement of their habitats in response to the increase in average temperatures. However, regions such as mountains and islands, regardless of the mobility of species, could lose such opportunities for adaptation due to their isolated habitats [3].

The subalpine ecosystem in South Korea is representative of such isolated ecosystems that are vulnerable to the effects of climate change [4–6]. The subalpine zone in South Korea is mainly distributed in mountainous areas such as Mts. Seorak, Jiri, and Halla [6,7]. Subsequently, this subalpine zone is located in regions that are at the highest elevation of the temperate climate zone. This zone mainly comprises specific conifer species such as the Korean needle fir (*Abies holophylla*) and Korean fir (*Abies koreana*) [8]. These species have a short growing season and are sensitive to climate factors, such as continuous snowfall, dry winds, extreme temperatures, soil moisture, and evapotranspiration stress [9]. In particular, the decline of *A. koreana*, a unique conifer species in Korea, has been observed prominently in Mts. Jiri and Halla because of climate change [10,11]. Recent investigations [7,10] have revealed a rapid increase in the decline of *A. koreana* in the Mt. Jiri area over the past five years.

The causes of coniferous forest decline in high-altitude and subalpine zones worldwide are ascribed to climate change and, in particular, the increasing occurrences of winter heatwaves and spring droughts [12]. However, opinions differ as to the cause of the decline of *A. koreana* in the subalpine zone of South Korea. For example, several studies have suggested that the relatively shallow root system of *A. koreana* makes it more sensitive to changes in soil moisture conditions, and the spring droughts caused by strong winds that dry out the soil make the species more susceptible to decline than the other species [10,13,14]. Other studies have proposed the excess water supply derived from increased precipitation as the cause of the decline [15,16]. These differing opinions highlight the possibility that the cause of decline in the subalpine zone could vary according to the regional characteristics of the climate environment, even within a relatively small territory. For instance, the representative regions of coniferous forest decline in Korea, namely Mts. Jiri and Halla, are located approximately 2° apart in latitude (Mt. Jiri 35.33° N, Mt. Halla 33.36° N). However, the climate characteristics of these regions differ markedly, with Mt. Jiri having a continental climate, whereas Mt. Halla has a maritime climate.

To mitigate the decline of subalpine coniferous species, authorities follow two main approaches, namely ex situ and in situ conservation. In ex situ conservation, the surviving members of the species are moved to new habitats with similar environmental conditions. In situ conservation implies identifying the last surviving areas within the current habitat that are affected the least by climate change and implementing protective measures to limit the influence of external factors. In both approaches, species distribution models are typically employed for predicting potential habitats within a given area.

Species distribution modeling techniques have been developed with various approaches such as statistical and machine learning types that define the relationship between observed species distribution and environmental features. Due to their own strength and weakness in their simulating performances and accuracy, ensemble simulation systems using multi-model combination are also popular approaches that intended to reduce technical uncertainties. However, in applying advanced modelling techniques, the suitability of input data into experimental designs such as spatial scale is also critical in affecting modelling accuracy. In Korea, studies on potential habitats mainly employ low-resolution data (spatial resolution ~1 km) for the entire country [17–19]. However, the results of these studies could vary depending on the spatial resolution of the climate data and the information on species distribution, particularly for *A. koreana*, which has an extremely limited habitat range. For instance, Koo et al. (2016) [18] simulated potential habitats for *A. koreana* across the country at a resolution of 1 km, using only 14 observations. The results of applying future climate change scenarios in their study showed an expansion of potential habitat for *A. koreana*. This finding could be ascribed to the limited amount of observation data and low-resolution climate data (1 km), which failed to properly reflect that the actual distribution showed a high correlation with elevation.

Some previous experiments utilized higher resolutions to predict potential habitats. For example, using a climate change factor at a resolution of 1 km and other topographic information at a resolution of 100 m, Park et al. (2015) [20] predicted an overall decrease in the potential habitat of *A. koreana*. Compared with the results of Koo et al. (2016) [18], this finding suggested that a difference in spatial resolution could affect the accuracy of the prediction results. Notably, Manzoor et al. (2018) [21] demonstrated through comparative experiments conducted with environmental climate information at various spatial resolutions that increasing the resolution could not always produce prediction accuracy. However, only the input data corresponding to topographic information were used at a high resolution in their study, and no consideration was given to whether there were adequate observation data for a given species at the particular resolution. Consequently, sufficient observation data for a given species are considered a requisite for reliable prediction results at higher resolutions.

Alternatively, studies employing low-resolution data for potential habitat predictions may be suitable for exploring ex situ alternative habitat candidate areas in response to the effects of climate change in a relatively large area. However, prediction studies for in situ conservation planning in a relatively narrow area require precise predictions. More precise terrain and climate information is required to predict microhabitats that respond to microclimate environmental factors. Accordingly, grid-type high-resolution climate and environmental data are required for such research areas. However, obtaining climate data at a resolution of more than 1 km is challenging. For example, current regional-scale weather or climate prediction models have a maximum resolution of approximately 12.5 km. Although statistical techniques are being developed and applied to downscale data to a higher resolution [22], the current downscaling techniques have a limitation—that uncertainty increases as the resolution increases, owing to a dependence on the availability of ground observations. As the currently available downscaling techniques mainly consider altitude, aspect, slope, and other factors, it is worth applying such techniques to species, such as *A. koreana,* with a clear distribution pattern according to altitude.

In this study, we aimed to examine the applicability of fine-scale distribution modeling to A. koreana across Mt. Jiri National Park in South Korea, using the newly available high-resolution climate data from National Institute of Ecology (NIE). Our goal was to identify candidate areas for the in situ species conservation of *A. koreana* to combat the impact of climate change. The NIE has recently released fine-scale grid-type (100 m spatial resolution; the highest available in Korea) climate data for this area [23]. Our modeling experiments included various simulations of potential habitats of *A. koreana* under the current environmental and climate status and provided predictions for future changes in its distribution. Consequently, based on the simulated outputs, we attempted to develop an index for extracting priority information on in situ conservation areas for *A. koreana*.

2. Materials and Methods

2.1. Study Area

The study area constituted Mt. Jiri National Park, which covers an area of ~483 km^2. Its highest peak, Cheonwangbong, is located on the eastern side of the park at an elevation of 1915 m. The distribution of *A. koreana* clusters in the park accounts for approximately 10% of the total park area. We gathered data from a survey of coniferous forest distributions in the subalpine zone conducted by the Korea National Park Research Institute [7] to determine the distribution of *A. koreana* clusters within the park. These data were acquired as a polygon shapefile with four levels of *A. koreana* dominance (10–25%, 25–50%, 50–75%, and >75%), expressed as the proportion of *A. koreana* stems per total stem count [6]. In this region, *A. koreana* occurs at an elevation of 800 m or higher but is concentrated at elevations above 1400 m. The species has a strong presence along the ridgeline of the highest peaks in the western Banyabong area (~1600 m) and the eastern Yeongsinbong and Cheonwangbong areas (~1700 m) (Figure 1). More than 75% of the total distribution area of *A. koreana* was observed at 1500–1800 m, with a slight decrease in distribution at an elevation above 1800 m (Figure 2a). The increase in *A. koreana* distribution along with elevation was observed in the high-density dominance category of over 75%, suggesting that the elevation, or temperature profile varying with the elevation, would be critical for the selection of environmental inputs for the modeling. In addition, this further suggests that contributions of climate and environmental input variables to the modeling performances may vary depending on the distribution density of species, and thus separate experiments according to the distribution density may be helpful to understand more about the nature of the species' habitat. When extremely simple information is used in model applications on the presence/absence of a species, the results might not accurately reflect the differences in dominance by elevation for species such as *A. koreana.* Therefore, it is crucial for high-resolution prediction experiments in extremely narrow areas, such as our study area, to pay adequate attention to the existence of microhabitats for in situ species conservation.

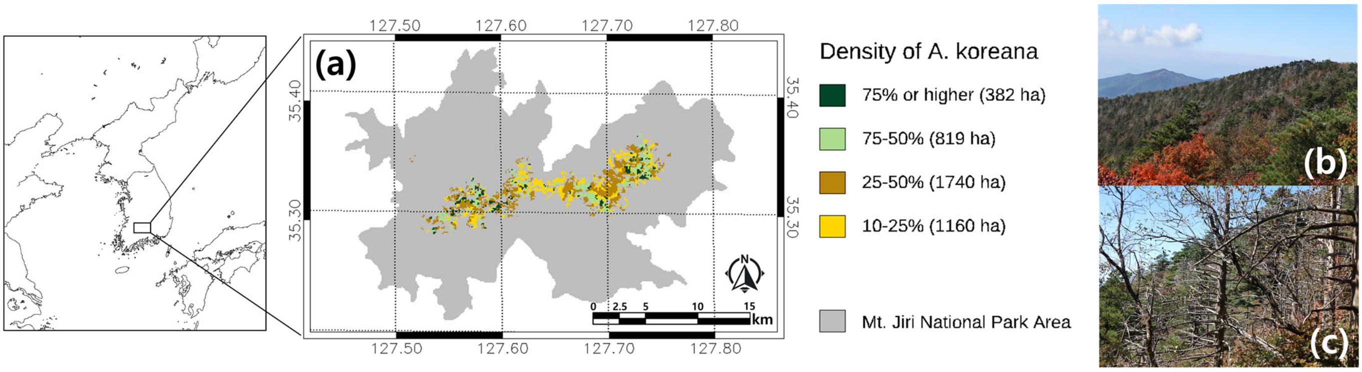

Figure 1. (**a**) Study area and distribution map of *A. koreana* according to dominance level (source: Korea National Park Service), photographs of showing (**b**) the landscape of study area and (**c**) standing dead trees of *A. koreana*.

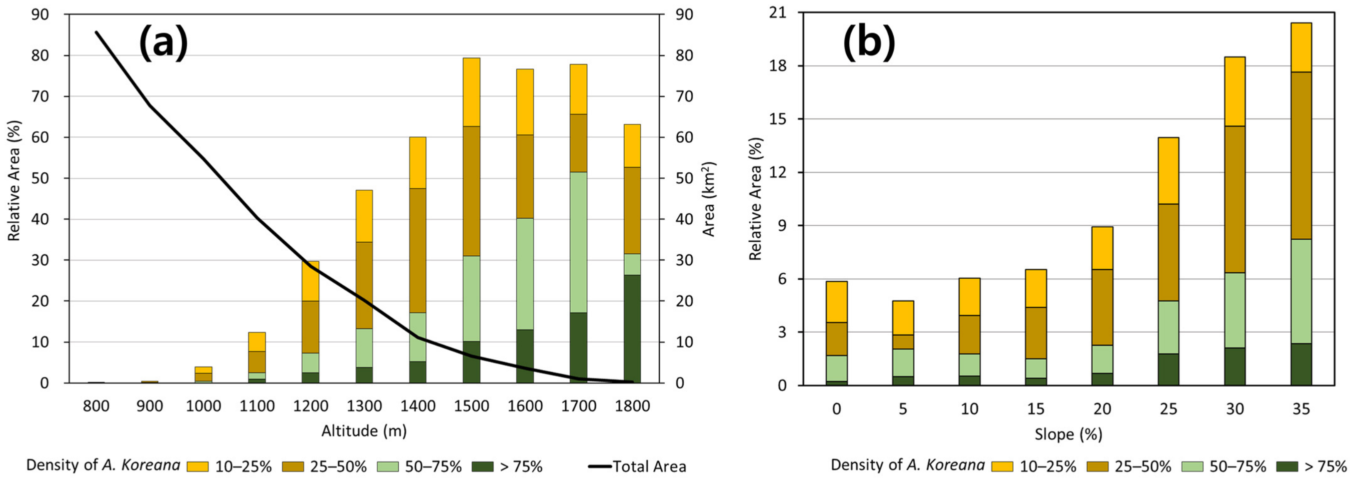

Figure 2. Distribution area of *A. koreana* in the Mt. Jiri National Park area by dominance according to (**a**) altitude (the black line is the total area of *A. koreana*) and (**b**) slope.

Further, the distribution of *A. koreana* varied depending on the slope (Figure 2b). The maximum slope in the area was approximately 40° (based on a resolution of 100 m^2), and the average slope of Mt. Jiri National Park was 17.39°. A comparison of the distribution of the species with the slope showed that the distribution area of *A. koreana* increased up to a certain level. For example, at an average slope of 35° or higher, the distribution area increased up to 20% within the same slope range. The distribution areas of all *A. koreana* dominance levels increased along with an increase in slope; however, the relationship between dominance and slope was unclear. Moreover, no clear relational characteristics were observed between aspects and dominance in the distribution of *A. koreana*.

2.2. Establishment of the High-Resolution Species Distribution Prediction System

2.2.1. Ensemble Prediction System Using Multiple Species Distribution Models

Species distribution models are used to predict the spatial distribution potential of a species, or its abundance, based on the relationship between the observed presence (or occurrence) and absence (non-occurrence) of a species and environmental variables (such as climate, topography, and hydrology). Such models evaluate the effects of various changes in the environment, including climate change, on the distribution of species [24].

Generally, the accuracy of these models is evaluated using a portion of the occurrence input data used to drive the model. Typically, a ratio of 7:3 is used, with 70% of the data used for model training (fitting) and prediction, and the remaining 30% for evaluating the accuracy of the predicted results. However, this internal validation method has limitations for organisms with relatively few occurrence records, as it inevitably reduces the number of information samples [25–27]. Moreover, such little data might not reflect the representativeness of environmental characteristics (climate, terrain, etc.) in the corresponding spatial range [28]. To overcome this limitation, various external validation approaches have been proposed, including independent temporal or polygon data that could reflect the distribution range of a species [29]. Various models are available for predicting the spatial distribution of organisms, broadly classified into statistical techniques (linear regression analysis, multiple regression analysis, etc.) and machine learning techniques (artificial neural network, decision tree technique, etc.). In addition to the uncertainty owing to the physical limitations of species survey information, further uncertainty arising from the technical limitations of the techniques used in each model significantly affect the reliability of the prediction results [30]. Therefore, to minimize the uncertainty of each model, ensemble techniques are widely used to evaluate the performance indicators for multiple model results [31].

Therefore, in this study, we used an ensemble platform for species distribution modeling, BIOMOD species (biomod2 v3.5.1), which allows selective ensemble prediction of ten species distribution models, including three statistical models (generalized linear models, generalized additive models, and multivariate adaptive regression splines) and seven machine learning models (classification tree analysis, flexible discriminant analysis, artificial neural networks, generalized boosted models, surface range envelope, random forest, and maximum entropy algorithm). The BIOMOD ensemble algorithm is based on the evaluation of the predictive performance of each model. After each model is run individually, weights are assigned based on the accuracy evaluation of the prediction results of each model, and the results are combined according to these weights [32].

Training or fitting of models within BIOMOD is carried out individually by each model operating within the system. However, performance diagnosis metrics that determine the optimization of the models are equally applied to all models, such as the area under the curve (AUC) of the receiver operating characteristic (ROC) curve and true skills statistics (TSS). The AUC value is calculated by comparing and validating the predicted distribution probabilities and observed values, representing a curve using a true positive rate (TPR) and false positive rate (FPR) for all threshold values that distinguish predicted results into the presence or absence of a species. The cumulative area distribution value under the ROC curve is used as the final model prediction performance metric, where closer to 100% or 1 represents the ideal prediction performance [33].

TSS is a metric developed to overcome the disadvantage of ROC-AUC, which is influenced by the size of the species distribution area (tendency to decrease as the distribution area widens) [34]. TSS utilizes the matching and non-matching information between the observations used for validation, and it is used in the ensemble of each model in BIOMOD. The weights are assigned and averaged based on the TSS values in the ensemble, after which the ensemble model data are generated. In addition, the TSS value that maximizes the value is also used as the threshold (criterion value). The TSS value ranges from -1 to 1, and the higher the value, the more accurate and reliable is the model.

The future potential habitat distribution is predicted by applying the altered future climate conditions based on the relationship between the distribution of the species derived from the analysis of the potential habitat of current climatic conditions and climate environmental variables. However, due to the characteristics of the species distribution model, only the potential habitat distribution results are derived at a specific point in time. Therefore, to predict the distribution changes over time, the future climate environmental variables are divided into multiple time periods, and the potential habitat is predicted for each period.

2.2.2. Building Input Data

Bioclimatic variables (BIOCLIM) were used as the major environmental model inputs in this study. These variables consider the ecological characteristics of the biological species by combining monthly maximum and minimum temperatures and precipitation values [35]. Other environmental variables could be considered based on habitat characteristics, such as altitude, aspect, slope, and connectivity of habitat patches, as well as hydrological features, depending on the habitat requirements of other species. However, when inputting data for all environmental variables, including climate and environmental factors, a process of selecting input variables based on the correlation analysis results between variables is followed. This process eliminates over- or underestimation of species distribution predictions, which are ascribed to the high correlation between variables, such as between spatially averaged temperature distribution and altitude. This implies that one of the variables is excluded in cases of high correlation between variables. However, this process inevitably involves the researcher's subjective opinion. Furthermore, even if two variables showed high correlation, one might not be excluded depending on its ecological importance, which could be another source of uncertainty in the model prediction results.

In this study, to select input variables for the model, we analyzed the cross-correlation between 19 bioclimatic variables at a resolution of 100 m in the study region [23], as well as geomorphological variables, such as altitude, slope, and aspect in the same area. The final selected variables consisted of four bioclimatic variables related to temperature, and two bioclimatic variables related to precipitation, slope, and aspect (Table 1). Owing to a high correlation with temperature distribution (BIO1), the elevation data were excluded. Future BIOCLIM data were predicted according to the representative concentration pathway (RCP) 4.5 and 8.5 scenarios of the Intergovernmental Panel on Climate. These pathways were employed to predict the potential habitat of *A. koreana* using 20-year mean monthly climatology data for four periods. These periods were 2040s (2021–2040), 2060s (2041–2060), 2080s (2061–2080), and 2100s (2081–2100) [23].

Table 1. Selected BIOCLIM variables that were used as the model inputs.

BIOCLIM	Description	Unit
BIO1	Annual mean temperature	°C
BIO4	Temperature seasonality	
BIO6	Mean minimum temperature of the coldest month	°C
BIO9	Mean temperature of the driest quarter	°C
BIO14	Precipitation in the driest month	mm/month
BIO15	Precipitation seasonality	

BIOCLIM, Bioclimatic variables.

The current average annual temperature in the Mt. Jiri subalpine region is ~9.4 °C, which is approximately 2.5 °C lower than the national average temperature in South Korea. According to the RCP 4.5 scenario, the temperature is expected to increase at a rate of 0.031 °C/year, reaching an average of 11.9 °C by 2100. According to the RCP 8.5 scenario, the temperature is expected to increase at a rate of 0.056 °C/year, reaching an average of 13.8 °C by 2100 [23].

Precipitation over this region is predicted to increase by approximately 100–200 mm annually from the current (2020) average, which is approximately 10–20% of the mean annual precipitation of 2000 mm. However, precipitation varies over an extensive range, unlike the gradual range of temperature increase. In particular, under the RCP 8.5 scenario, rainfall is expected to decrease sharply to 1850 mm until the 2030s and, subsequently, increase by more than 10% to approximately 2050 mm in the 2050s.

2.3. Experimental Design for Potential Habitat Prediction

We investigated various experimental designs for predicting the high-resolution distribution of the BIOMOD model. The predictive performance of each model result was compared and analyzed by dividing the distribution of *A. koreana* into four dominance categories. This was carried out to determine how the differences in the altitude distribution of *A. koreana* by dominance (discussed earlier) would affect the potential habitat prediction within the model. For this purpose, the polygon-formatted *A. koreana* dominance data were divided into areas of 75% or more, 50% or more, 25% or more, and 10% or more. The corresponding grids in the set dominance range were converted into grid-formatted data at 100 m intervals. For example, if the species dominance of 75% covers majorly in a given grid cell, the cell is assigned as species "presence" of 75% dominance. Then, the central coordinates of those cells are input as the *A. koreana* presence location information. Eventually, 382 locations with a dominance of 75% or more, 1201 locations with a dominance of 50% or more, 2941 locations with a dominance of 25% or more, and 4101 locations with a dominance of 10% or more were input into the model. In addition, for areas outside the *A. koreana* occurrence area, random points were extracted and applied to the model as absence data. Finally, the prediction was performed by using all ten species distribution models within BIOMOD and repeated five times to produce the final ensemble prediction result.

3. Results and Discussion

3.1. Prediction Results of Potential Habitats for A. koreana Based on Current Climate Conditions

The prediction results of the potential habitat distribution of *A. koreana* based on current climate conditions by dominance category indicated wider potential habitat distribution areas with lower dominance. The model performance evaluation (AUC = 0.990–0.993, standard deviation = 0.0015; TSS = 0.896–0.908, standard deviation = 0.0054) was consistently high in all experiments (Figure 3). Although TSS was the highest in Experiment 4 (EXP4), the differences in TSS between each experiment were insignificant.

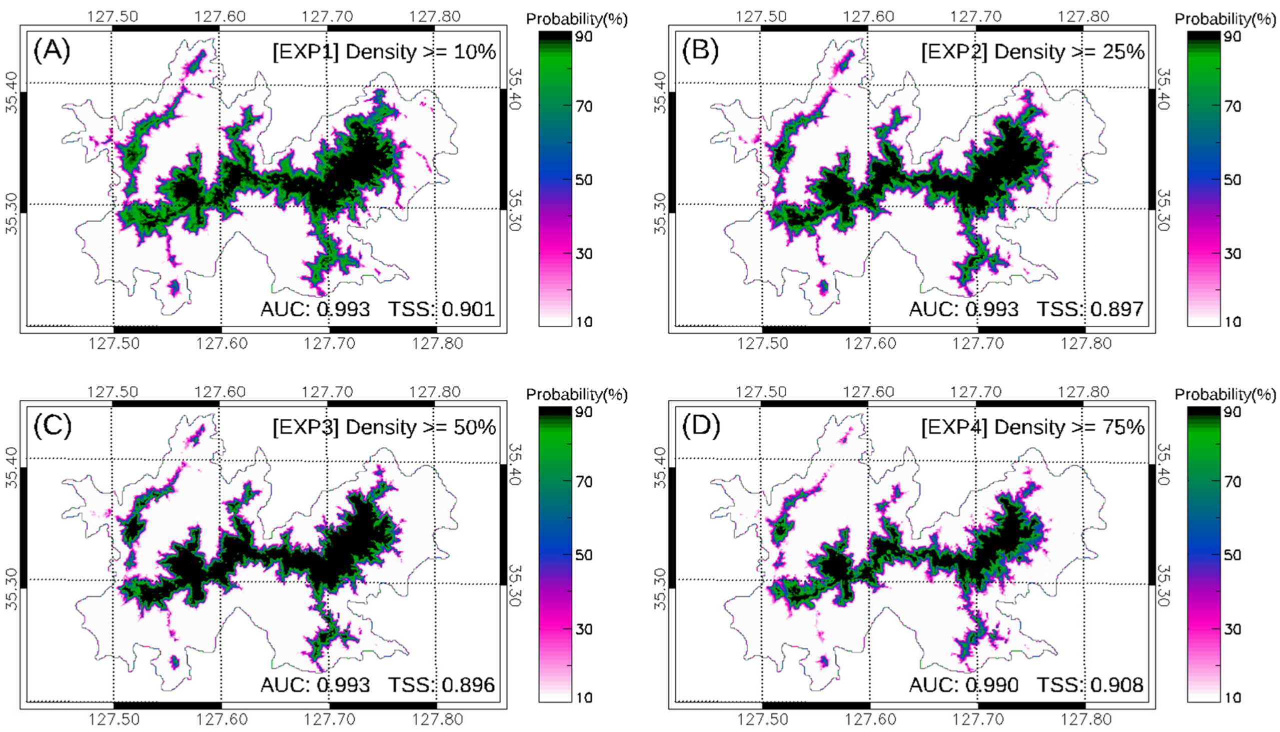

Figure 3. Prediction results of potential habitats of (**A**) the experiment 1(EXP1), (**B**) EXP2, (**C**) EXP3, and (**D**) EXP4 for *A. koreana* based on current climate conditions.; AUC, area under the curve; TSS, true skills statistic.

The percent contribution (PC) and permutation importance (PI) of each input variable for each predictive experiment are shown in Table 2. Contribution refers to the degree to which each variable contributed to the optimal prediction results during the model training process using the observed data. Contribution also represents the relative contribution of variables that could vary depending on the model algorithm [36]. Variable importance measures to what extent a variable influences the dependent variable relative to other variables [36]. In the species distribution prediction experiment for *A. koreana*, PC and PI showed different patterns, but the climate/environmental variables (BIOCLIM) generally had the highest scores. Specifically, variables related to temperature (BIO1 and BIO4) showed the most influence on the prediction performance in both PC and PI. This was particularly observed in experiments with high dominance, where the weight of precipitation-related variables (BIO14 and BIO15) increased in PC. However, in PI, the model was only sensitive to temperature variables, but in EXP4 the weight of BIO6 and BIO9 increased notably. These variables represent the seasonal characteristics of temperature and precipitation, where BIO6, BIO9, and BIO14 represent the winter climate characteristics of the Mt. Jiri area. The implication was that the dominance of *A. koreana* in areas with high dominance was closely related to the temperature and precipitation characteristics of winter, which are in turn closely related to the water stress of the biological species. These findings supported the results of previous studies [37] that identified the cause of the population decline of *A. koreana* in the area. In contrast, the contribution of the topographical variable (slope) decreased notably in areas with high dominance. As the mean temperature variable (BIO1) has a high correlation with altitude, the overall distribution of *A. koreana* was observed to vary according to mean temperature or altitude. Dominance decreased along with a decrease in altitude, but the species distribution tended to be concentrated in areas with gentle slopes. However, areas with high altitudes and relatively low mean temperatures and where the dominance of *A. koreana* was high were more sensitive to precipitation (particularly during the dry spring seasons).

Table 2. Variable contribution of the current potential habitat prediction results of *A. koreana* according to dominance.

BIOCLIM Variables	**EXP1 (≥10%)**		**EXP2 (≥25%)**		**EXP3 (≥50%)**		**EXP4 (≥75%)**	
	PC	**PI**	**PC**	**PI**	**PC**	**PI**	**PC**	**PI**
BIO1	68	77.1	21.4	72	27	77.5	16.3	22
BIO4	0.7	8.8	27.5	13.6	46.3	1.7	22	28.6
BIO6	0.1	1	0	0	0	0	9.1	22.9
BIO9	0	0	0.2	0.7	0.9	6.6	9.2	18.9
BIO14	0.4	8.6	0.8	8.2	1.2	9.9	26.1	3.5
BIO15	0.1	0.	29.4	3.9	24.1	3.2	15.2	2.9
Slope	30.6	3.9	20.7	1.7	0.4	0	1.2	0.9
Aspect	0	0.1	0	0	0	0	0.8	0.4

EXP1–4, experiments 1–4; BIOCLIM, Bioclimatic variables; PC, percentage contribution; PI, permutation importance.

The average predicted distribution probability of potential habitats by altitude was observed to increase as the altitude increased (Figure 4). However, the pattern of probability distribution values varied according to altitude between each experiment and the points where the probability converged differed. EXP1 and EXP2 showed peaks around 1500 m, EXP3 around 1600 m, and the probability value of EXP4 continued to increase after 1800 m. However, in all experiments, probability converged at points where distribution probability was 90% or higher. EXP1 and EXP2 converged around 1400 m, EXP3 around 1300 m, and EXP4 around 1500 m. Generally, the height of the distribution probability is considered as the reference point for a potential habitat, which was 75% at around 1100 m on average in EXP1, 2, and 3, and around 1250 m in EXP4.

Furthermore, when the distribution probability was divided into quartiles (25%, 50%, and 75% or higher) for each experiment and the total area of the corresponding potential habitat was examined (Table 3), the potential habitat area decreased along with an increase in the dominance information used. In the experiment where only the information from areas with a dominance of 75% or higher was used, compared with the current distribution of *A. koreana*, the potential habitat area with a distribution probability of 75% or higher was the closest to the total distribution area of *A. koreana* (4400 ha, areas with dominance of 10% or higher). This result showed the possibility of overestimating the potential habitat when information from areas with low *A. koreana* dominance is also used. Therefore, further analysis is required to determine which experiment among the four dominance information utilization experiments conducted in this study could best represent the current distribution of *A. koreana*. Furthermore, such analysis should explore how the threshold point could be set in the predicted distribution probability for interpreting the potential habitat.

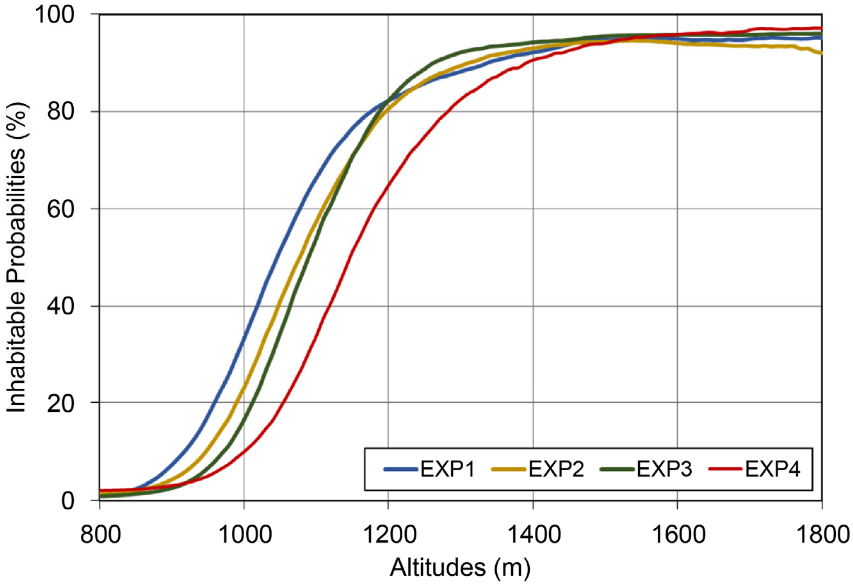

Figure 4. Average distribution probability by experiment according to altitude. EXP1–4, Experiments 1–4.

Table 3. Total area of *A. koreana* distribution estimated in each experiment according to inhabitable probabilities.

Inhabitable Probability	EXP1	EXP2	EXP3	EXP4
≥25%	16,061 ha	14,415 ha	13,032 ha	11,013 ha
≥50%	12,806 ha	11,175 ha	10,693 ha	8094 ha
≥75%	9316 ha	8045 ha	8234 ha	5449 ha

EXP1–4, Experiments 1–4.

For further examination of the predictive performance of each experiment, we analyzed which experiment best represented the actual distribution of *A. koreana* by dominance (Table 4). For example, we considered the accuracy of each experiment in predicting the potential habitat in areas with a dominance of 75%. The experiment with the highest accuracy was EXP3. However, interestingly, EXP4 showed the lowest accuracy. This low accuracy could be ascribed to the inability of EXP4 to adequately represent the decrease in *A. koreana* distribution above an altitude of 1800 m.

Table 4. Average inhabitable probabilities in the areas of the actual distributions of *A. koreana*.

Density of *A. koreana*	Average Inhabitable Probability			
	EXP1	EXP2	EXP3	EXP4
75–100%	89.96	88.91	92.14	88.29
50–75%	89.60	88.82	91.33	84.82
25–50%	86.65	85.44	85.33	77.33
10–25%	85.10	81.75	82.39	71.97

EXP1–4, Experiments 1–4.

3.2. Changes in Potential Habitat Distribution of *A. koreana* under Future Climate Conditions

The predicted potential habitat distribution results under future climate change scenarios showed a rapid decline in the potential habitat over time in the RCP 4.5 and RCP 8.5 scenarios (Appendix A). These results indicated that *A. koreana* was extremely sensitive to temperature increases, with the Cheonwangbong area in the eastern high-altitude region of the study area generally predicted to be the last surviving habitat. Considering only the predicted potential habitat results with a distribution probability of 75% or higher, complete extinction was predicted in all the experiments at the end of the 21st century, with the timing of extinction varying depending on the experiment (Figure 5). The rate of potential habitat decline was generally faster in the RCP 8.5 scenario than that in the RCP 4.5 scenario, and this rate was also faster when using information from areas with high dominance, compared to those with low dominance. The timing of extinction obviously differed depending on the distribution probability used as the judgment criterion for potential habitat; however, the phenomenon of rapid decline in potential habitat over time was observed clearly in all areas.

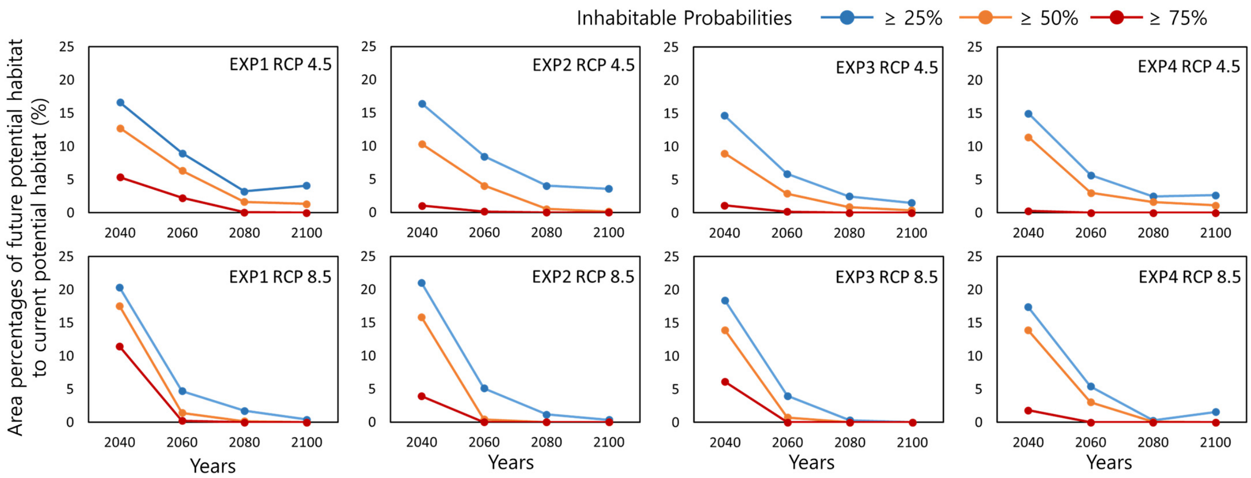

Figure 5. Distribution probability average of potential habitats by time period. EXP1–4, Experiments 1–4; RCP, representative concentration pathway.

This study, however, had a limitation, namely that only species presence information was employed, regardless of the existence of dead individuals. In the Mt. Jiri subalpine zone, a rapid decline in *A. koreana* was recently observed [10]. As our study area included the area where this decline was observed, it was necessary to consider the inclusion of information related to this decline in the species distribution modelling. Additionally, the geographical distribution of biological species is directly related to the climatic and environmental factors of their habitat, but the indirect relationship with climatic and environmental factors associated with competition among different species is also an important consideration. Owing to the significant expansion of *Sasa borealis* in the Mt. Jiri and Mt. Halla subalpine zones, interference with the growth of coniferous trees and the decrease in subsequent tree growth opportunities have become crucial considerations [38]. Accordingly, it was necessary to consider the impact of competition from other species on the potential habitat changes of *A. koreana*.

The significance of this study is that it was a novel attempt to predict the species distribution of *A. koreana* using a species distribution model for limited local areas. This was made possible by the increase in spatial resolution of the modeling system to 100 m, which is approximately 100 times higher than that of previous studies. This increase in resolution facilitated prediction experiments for smaller areas. Thereby, more realistic predictions were calculated by reflecting the distribution of *A. koreana* by altitude, which might be unclear in some previous studies [18]. Our study showed that the distribution pattern of *A. koreana* is much more sensitive to temperature when detailed altitude characteristics are included in the model, leading to a significant effect of the potential habitat decrease under future temperature increases.

3.3. An Index for Extracting In Situ Conservation Areas for A. koreana

Our modeling results could probably be applied for the identification of conservation areas for *A. koreana* in the subalpine zone of Mt. Jiri National Park. However, as a rapid decrease in the potential habitat of this species was predicted in the area based on future climate scenarios, exploring alternative habitats in other areas outside Mt. Jiri should be considered. Nevertheless, delaying the extinction of *A. koreana* in its current habitat for as long as possible would be a valuable conservation measure for preserving ecosystems. Therefore, this study proposes a simple conservation grading method for identifying areas for the in situ conservation of *A. koreana* in the subalpine region. First, the most rational starting point would be selecting the experiment with the highest prediction performance, considering the minimal uncertainty for the predicted results. Therefore, the results of EXP3 could be applied to the conservation grading of *A. koreana*, as these best represent the dominance of *A. koreana* in areas with more than 75% representation. Second, the grading method for conservation could be employed using future prediction results. Collectively, the aim would be to delay the complete extinction of a species occurring in a particular area for as long as possible. Our proposed grading was conducted based on the probability of future distribution presented in the model and information about the areas that could survive the future climate scenarios. Subsequently, starting with areas with the highest grades, employing artificial measures to increase the adaptability of *A. koreana* would be a possibility. Our method proposes a way to determine the areas with the highest probability for the survival of *A. koreana* in response to the impacts of climate change. We attempted to create a conservation grading system based on conservative criteria (Table 5) to increase the success rate of *A. koreana* conservation. The RCP 4.5 scenario was selected to represent the climate change trajectory, and the distribution probability minimum value for potential habitat was set at 20%, with areas with a distribution probability of 50% or more being considered the best fit. Employing the matrix method, the final selected conservation area was classified into four levels: strong recommendation (SR), high recommendation (HR), medium recommendation (MR), and low recommendation (LR). The SR area should be given the highest priority for implementing conservation measures, as it is the area where the survival of *A. koreana* is most likely to last the longest.

Table 5. Matrix approach for the grading of *A. koreana* conservation to mitigate the effects of climate change.

Inhabitable Probability	Residual Period				Conservation Grade	
	2100	2080	2060	2040	Grade	Description
>50%	SR	HR	HR	MR	SR	Strong recommendation
40–50%	HR	HR	MR	MR	HR	High recommendation
30–40%	HR	MR	MR	LR	MR	Medium recommendation
20–30%	MR	MR	LR	LR	LR	Low recommendation

SR, strong recommendation; HR, high recommendation; MR, medium recommendation; LR, low recommendation.

The spatial distribution of each conservation grade is illustrated in Figure 6. Notably, the Cheonwangbong area (42 ha), with elevation >1600 m, was designated with the SR grade. Compared with the current distribution of *A. koreana*, the SR areas included 31 ha (86% of the entire SR area) of distribution areas with a dominance of 50% or more, as well as some areas where *A. koreana* was absent (constituting approximately 14% of the entire SR area).

These priority conservation zones derived from the indexing method proposed in this study can be considered a reasonable approach to aid policy makers in the formulation of a species conservation plan for *A. koreana*. For example, they are useful to set strategic management sites to retard the habitat reduction due to temperature rising. The criteria for distinguishing the recommendation classes, however, can vary according to the importance of policies to conserve *A. koreana* and the effectiveness of policy implementation. If in situ conservation of the species is of policy importance with very high ecological value, the criteria may need to be set more conservatively. On the contrary, if maximizing the effectiveness of policy implementation is the top priority, then the criteria may need be adjusted to lead to more limited conservation areas.

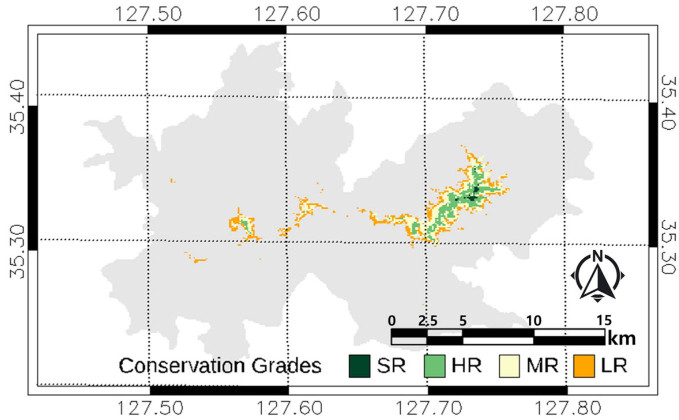

Figure 6. Map of conservation grades of *A. koreana* that are color-coded to represent strong, highly, medium, and low recommendations: SR, HR, MR, and LR, respectively.

4. Conclusions

We conducted a model-based study to develop in situ conservation strategies for the native conifer *Abies koreana* in the subalpine zone of Mt. Jiri that is experiencing severe decline owing to climate change. We constructed a high-resolution species distribution prediction system at a scale of 100 m for precise species distribution prediction in a narrow area, and we performed potential habitat prediction experiments using *A. koreana* distribution information according to their dominance in Mt. Jiri. The predicted results for potential habitats according to current climatic conditions well represented the distribution characteristics according to temperature and consequently, altitude. The experimental results according to dominance showed that the degree of influence of climatic and environmental factors varied depending on the *A. koreana* distribution situation, with differences in the contribution or importance of input variables. For example, in areas where *A. koreana* dominance was high, the altitude of the distribution area was generally high. Furthermore, temperature and precipitation in winter and spring appeared to have a significant influence. Differences in prediction accuracy were observed among the dominance-based experiments. These findings indicate that when a species distribution model is applied in a relatively small area, such as our study area, considering species dominance information could reduce the uncertainty of the predicted results compared with simply using occurrence/non-occurrence information. The predicted *A. koreana* potential habitat under current climate conditions was slightly wider than the actual distribution area; however, the decrease in potential habitat owing to future climate change was extremely rapid. These findings were ascribed to the potential habitat of *A. koreana* being susceptible to rising temperature, and the potential habitat with the highest capacity to survive the effects of climate change was predicted to be located mainly in high-altitude areas. Finally, through an indexing method based on the simulation results, this study suggested spatial information about the recommended areas for *A. koreana* conservation at least to reduce species disappearing over the study region due to warming climate conditions.

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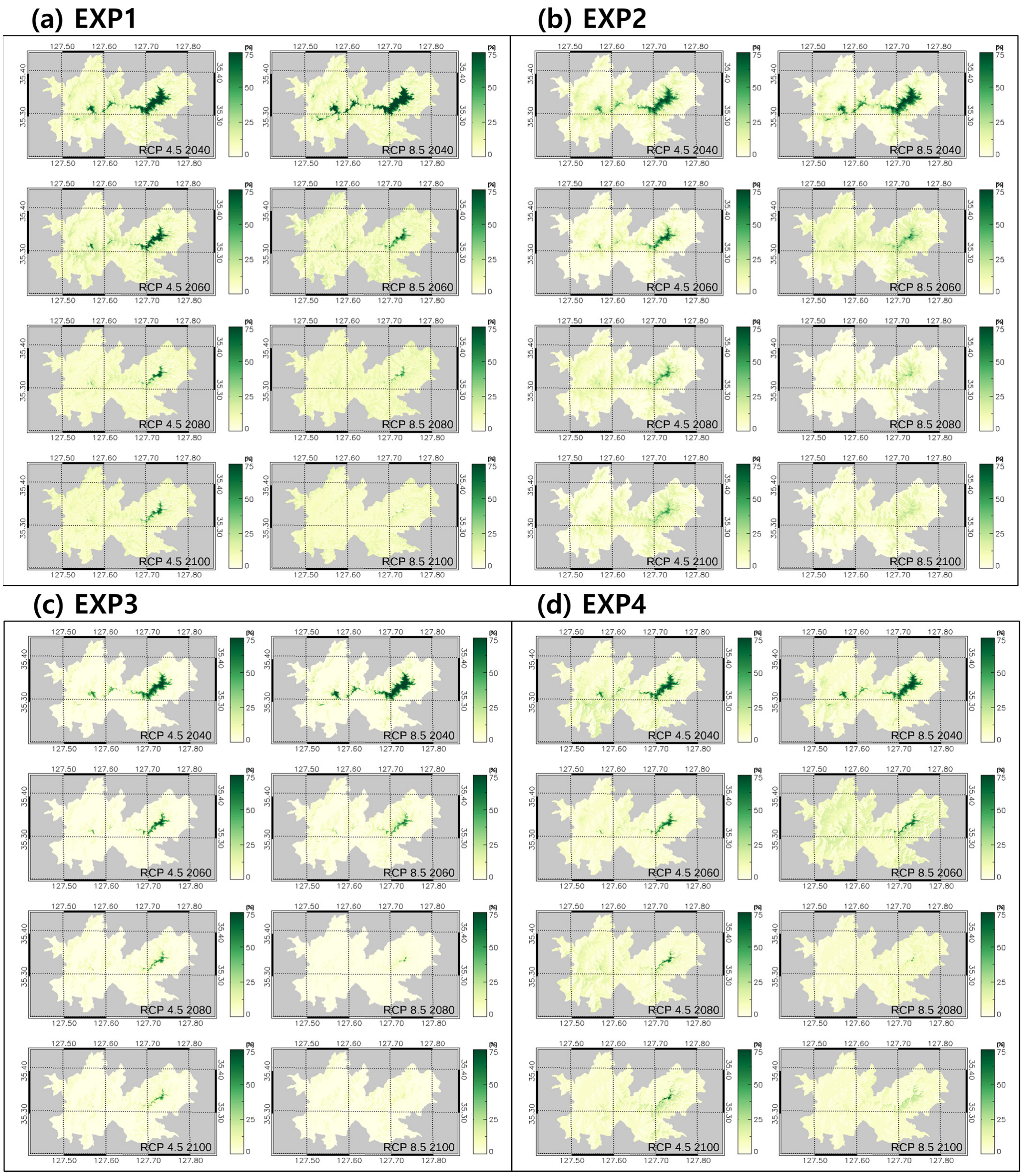
Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

The following images show the future predictions of *A. koreana* habitat distribution. EXP1–4, Experiments 1–4; RCP, representative concentration pathway.



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