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Climate Change Vulnerability Assessment and Ecological Characteristics Study of *Abies nephrolepis* in South Korea

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Abstract: *Abies nephrolepis* is a climate-vulnerable species that inhabits high mountains in the Baekdu–Daegan range and is distributed along the southern limit line in South Korea, making it suitable for climate change research. This study aimed to observe spatial distribution changes according to scenarios using species distribution models for *Abies nephrolepis*, analyze the relationship between various environmental factors and *Abies nephrolepis* density, and contribute to the future conservation and management of subalpine coniferous forests. We conducted a field survey to identify the growth environment of *Abies nephrolepis* and observed potentially suitable habitats for *Abies nephrolepis* based on location information obtained through the survey. We also analyzed the relationship between the density of *Abies nephrolepis* and various environmental factors using multiple linear regression models. Based on the field survey results, most *Abies nephrolepis* natural habitats in South Korea showed an unstable form. Vulnerability analysis examining the influence of climate change showed that most of these habitats would be affected. We found that various biological factors were significantly related to the density of *Abies nephrolepis* (diameter at breast height, DBH ≥ 6 cm) and young tree density (stems/ha). We confirmed that species diversity and rock exposure variables had a relatively high impact. Clarifying the relationship between the density of *Abies nephrolepis* and various environmental factors can provide new insights for setting future restoration directions.

Keywords: conservation; ensemble modelling; environmental factor; climate change; South Korea; socio-economic pathway (SSP)

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1. Introduction

Examining 10-year intervals after 1850 has shown that the climate has continuously warmed more than any other time in the last 40 years. In the first 20 years of the 21st century (2001–2020), the Earth's surface temperature increased by 0.84–1.10 °C compared to 1850–1900 [1]. Global warming has caused considerable damage to the habitats of organisms that require unique environmental conditions, such as polar regions and high-altitude mountains. Temperature increases are critical factors in the devastating effects on organisms adapted to cold climates [2]. The National Institute of Forest Science in Korea assessed the growth status of Korean fir (*Abies koreana* E.H. Wilson), Khingan fir (*Abies nephrolepis* (Trautv. ex Maxim.) Maxim.), and Yeddo spruce (*Picea jezoensis* (Siebold and Zucc.) Carrière) that predominantly inhabit the subalpine zone, by calculating the degree of decline. The degree of decline was calculated based on crown vitality, trunk health, and the number of dead trees in the survey area. The degree of decline ranges from 0–1, with 0 being healthy and 1 indicating decline, and based on this, *Abies koreana* had a value of 0.33, *Abies nephrolepis* 0.28, and *Picea jezoensis* 0.25 [3].

Vulnerability assessments of alpine species are considered a key issue for plant conservation because of their isolation in high mountains [3,4]. Among them, *Abies nephrolepis*, which is distributed in the high mountains of the Baekdu–Daegan range, is a suitable species for climate change research because it is located at the southern distribution limit. Given that it is widely distributed in China, comparative research can be conducted. *Abies nephrolepis* research is important for attaining a relatively deep understanding of the decline of *Abies koreana* [5].

As the first step in the conservation of *Abies nephrolepis*, an understanding of the forest and how it should be managed is necessary. To achieve this, a species distribution model (SDM) [6], which is a predictive model for species habitats based on occurrence information, can be used. This has the advantage of being able to predict non-occurrence locations based on occurrence information. It can be used to plan and design conservation priorities by evaluating future distribution changes of *Abies nephrolepis* from climate change [7–9]. However, research using SDM cannot reflect the complex biological interactions that occur in forests, and it is difficult to understand the ecological change processes. To understand the long-term changes in forests, field data are needed. Accurate monitoring for at least several decades provides important ecological information for forest change. This is because sustainability is one of the main goals of modern ecosystem management [10]. Research that clarifies the relationship between species distribution and environmental factors are becoming increasingly important as the impact of global warming accelerates [11]. Such activities provide information on the environmental factors that have a strong impact on species distribution, reducing uncertainty in conservation and restoration activities. In this regard, time series studies targeting multiple individual sites have been found to be useful in understanding patterns in forest ecosystems [12]. This can then contribute to obtaining quantitative and qualitative information on the relationship between *Abies nephrolepis* populations and environmental factors, helping to understand the ecology of *Abies nephrolepis*.

In this study a survey was conducted on *Abies nephrolepis* forests in 18 mountainous areas in South Korea over two years from 2021 to 2022. The first objective was to evaluate the spatial distribution of *Abies nephrolepis* and the change in its distribution in response to climate change based on the new shared socioeconomic pathway (SSP) climate change scenarios presented in the 2021 IPCC 6th Assessment Report. We also aimed to identify the proportion of *Abies nephrolepis* trees and the density of young trees in each mountainous area to contribute to the establishment of priority conservation plans for future climate change. The second objective was to identify the relationship between the density of *Abies nephrolepis* trees and environmental factors including elevation, aspect direction, degree of slope, rock exposure, species diversity, and herbaceous cover in each mountainous area to provide objective information for understanding the plant distribution.

2. Materials and Methods

2.1. Study Area

The study area focused on the distribution of *Abies nephrolepis* within the South Korea region of the Korean Peninsula, and the administrative regions included Gangwon-do, Gyeonggi-do, Gyeongsangbuk-do, and Chungcheongbuk-do. To date, 23 distribution sites of *Abies nephrolepis* have been reported, and field surveys have been conducted at 18 of these sites (Figure 1).

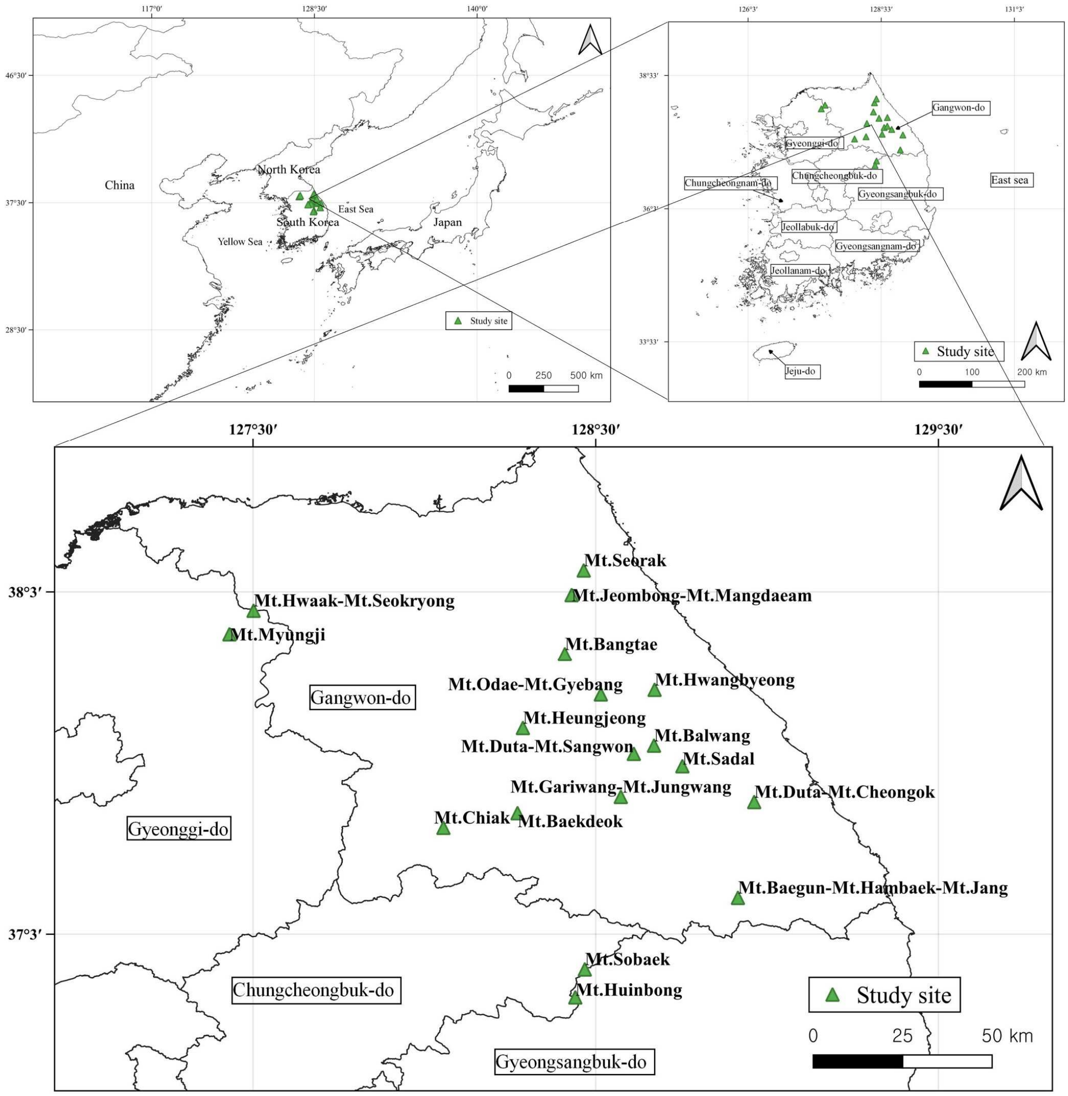

Figure 1. The location of the study sites.

2.2. *Abies Nephrolepis Presence/Absence Data*

For this study, the occurrence data of *Abies nephrolepis* were collected through Global Positioning System (GPS) coordinates from June 2021 to September 2022, targeting 316 *Abies nephrolepis* stands during a monitoring survey of endangered subalpine coniferous forest areas. Additional coordinates were secured by comparing the location conditions of previous research and field survey sites with the points where *Abies nephrolepis* was recorded in the 3rd Actual Vegetation Map of the National Institute of Ecology.

To prevent spatially autocorrelated occurrence points caused by sampling bias, duplicate points were removed to create 211 occurrence points appearing once for each environmental variable grid cell [13–18].

Construction of the absence points was based on the topographical and environmental characteristics of the habitat of *Abies nephrolepis*, which were identified using the presence points and by synthesizing the trends of the species distribution area from previous studies (Table 1). A total of 3097 absence coordinates were constructed around the occurrence points, focusing on areas that did not have these characteristics. We aimed to supplement the limitations of acquiring absence data through field surveys by constructing arbitrary pseudo-absence (PA) data. We generated 6903 random point data points within the study area by repeating the construction of more than 1000 PA location data points ten times to ensure consistency in all models [19].

Table 1. The topographical environmental characteristics of *Abies nephrolepis* using field survey plot and actual vegetation map. (The average temperature and average precipitation value were based on Worldclim data (30 arcsec)).

Distribution Regions	Elevation (m)	Annual Temperature (°C)	Annual Precipitation (mm)
Mt. Duta–Mt.Cheongok	1124–1322	7.14–6.41	1390–1417
Mt. Balwang	1236–1455	5.76–5.48	1419–1429
Mt. Bangtae	1120–1353	5.73–5.21	1362–1413
Mt. Sadal	1132–1302	7.09–6.21	1353–1399
Mt. Gariwang–Mt. Jungwang	1140–1552	7.06–5.11	1394–1455
Mt. Duta-Mt. Sangwon	1024–1383	6.43–5.9	1393–1409
Mt. Baekdeok	1261–1348	7.19–6.24	1375–1418
Mt. Baegun–Mt. Hambaek–Mt. Jang	1174–1538	6.97–5.45	1407–1486
Mt. Odae–Mt. Gyebang	1190–1535	6.27–4.7	1374–1450
Mt. Heungjeong	1168–1186	6.43	1375
Mt. Jeombong–Mt. Mangdaeam	1183–1412	5.8–5.57	1369–1387
Mt. Hwangbyeong	1002–1316	8–6.06	1362–1397
Mt. Chiak	1221–1240	6.74	1423
Mt. Sobaek	1057–1379	7.25–6.2	1394–1478
Mt. Myungji	1024–1246	6.27–6.14	1378–1385
Mt. Huinbong	1066–1209	7.67–7.23	1377–1417
Mt. Hwaak–Mt. Seokryong	1192–1421	6.37–4.92	1345–1417
Mt. Seorak	1048–1664	6.36–4.45	1321–1404

2.3. Environmental Data

Temperature rises and precipitation changes in the Korean Peninsula from climate change have had various effects on organisms and ecosystems that have adapted to the current natural environment [20]. Therefore, to determine the variables that can affect the suitable habitat for a species, we extracted 19 Bioclim variables provided by Worldclim (http://www.worldclim.org, accessed on 3 January 2023) with a resolution of 30 arc seconds (approximately 1 km) based on the average data from 1970 to 2000 and applied them as current values.

Given that the 19 Bioclim variables were correlated with each other, the variables showing a correlation of more than 0.7 using the Pearson correlation method were excluded from one of the two variables. As a result, temperature-related variables Bio1, 2, and 4 and precipitation-related variables Bio12, 13, and 14 were selected, which can affect the growth of *Abies nephrolepis*. The aspect direction data were derived by processing the digital elevation model (DEM) data of SRTMv3. Eight terrain environmental variables were used for the analysis, matching the 30 arc-second meteorological data resolution (Table 2).

Table 2. Description of environmental variables used for the prediction of suitable habitats.

Variables	Variables Name	Unit	Description
Climate Factor	Bio01	°C	Annual mean temperature
	Bio02	°C	Mean diurnal range
	Bio04	°C/month × 100	Temperature seasonality (standard deviation × 100)
	Bio12	mm	Annual precipitation
	Bio13	mm	Precipitation of wettest month
	Bio14	mm	Precipitation of driest month
Topographical Factor	DEM	m	Digital elevation model
	Aspect direction	in degrees	Aspect direction

The future climate data used in this study were based on UKESM1-0-LL climate data under the SSP2-4.5 and SSP5-8.5 scenarios, which were produced through collaboration between South Korea and the UK. The data from 2041 to 2060 have been presented as the average values for the 2050s, and the data from 2061 to 2080 have been presented as the average values for the 2070s. The entire process of constructing environmental variables and evaluating habitats was conducted using ArcGIS 10.8 and QGIS 3.16, and the WGS84 coordinate system was used.

2.4. Species Distribution Modeling

This study aimed to improve the accuracy of models that require only presence/absence point data compared with models that use presence-only data [21]. Six models were selected, that is, statistical models based on generalized linear models (GLM), generalized additive models (GAM), Generalized Boosted Models (GBM), machine learning models based on random forest (RF), Flexible Discriminant Analysis (FDA), and Classification Tree Analysis (CTA). To develop the models, the presence/absence data of *Abies nephrolepis* were used as the dependent variable, and environmental variable data were used as the independent variable. The data were divided into training (80%) and test (20%) data. The training data were used to develop the species distribution model, whereas the test data were used to validate the model. The data were randomly distributed, and model development and validation were repeated 10 times and combined. An ensemble model that combines predictions was applied to reduce the uncertainty in various species distribution models [22–25].

The ensemble modeling was conducted using the R package Biomod2 by assigning weights to the true skill statistic (TSS) values obtained from each individual model. The resulting potential habitat suitability maps were presented as probabilities and setting a threshold was crucial for determining species occurrence. The threshold was set at the point of the sum of sensitivity and specificity, which explains why the accuracy of the presence and absence points, respectively, was maximized. This was performed to convert the maps from presence/absence points to presence/absence maps [26].

Model validation was assessed using the area under the curve (AUC) of the receiver operating characteristic (ROC) curve and TSS. The AUC ranges from a minimum of 0.5 to a maximum of 1.0, where higher values indicate a higher accuracy of the model. An AUC value of $\geq$ 0.8 was considered an indication of strong model performance [27]. However, the AUC values may be low when the occurrence range of the target species is extensive. Alternatively, they may be overly high when the target species is limited to a specific location [28]. Therefore, the model was evaluated using the TSS value, which is not affected by the ratio of presence/absence data. It includes the accuracy of predictions for presence/absence data, as well as the TSS value, which was not affected by the ratio and distribution of data. As the TSS value approaches +1 within the range of −1 to +1, it is considered to have shown excellent performance [29]. The analysis workflow is illustrated in Figure 2.

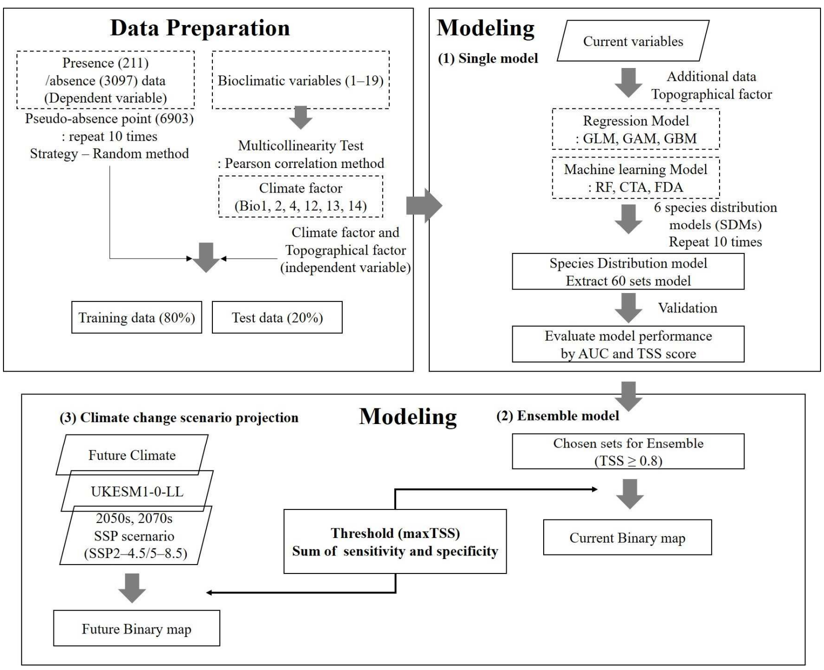

Figure 2. Ensemble species distribution modeling flow chart.

2.5. Field Survey and Analysis Methods

The field surveys followed the guidelines of the Monitoring Survey for Endangered High Mountain Coniferous Trees, Version 1.5, established by the Korea Forest Service. A survey plot with a radius of 11.3 m in the shape of a circular plot was installed with an area of 400 square meters per survey plot. The selection of the survey plot was based on aerial photographs to delineate coniferous forest stands with an elevation of 1000 m or higher. Next, tree information was obtained through stereoscopic reading of aerial photographs, and subalpine coniferous forest stands were classified according to species. Based on the acquired information for precise species classification, the type of tree information was obtained for each tree species and used to identify the location of the coniferous forest. Additionally, among the coniferous forests classified based on crown density and tree morphology differences, the growth areas of *Abies nephrolepis* were identified and classified. The survey plot was determined by comparing the location information obtained from aerial photographs from the field surveys.

The vegetation survey was conducted according to the phytosociological survey method of Braun–Blanquet (1964) [30], in which the degree of cover of each species occurring in the target area was recorded. The diameter at breast height (DBH) of all trees with a DBH greater than or equal to 6 cm within the survey plot was measured for the stand survey. The individual trees were converted into proportions divided into 10 diameter classes (6–10 cm, 10–15 cm, 15–20 cm, 20–25 cm, 25–30 cm, 30–35 cm, 35–40 cm, 40–45 cm, 45–50 cm, D $\geq$ 50 cm) based on their diameter distribution. Mt. Bangtae, Mt. Seorak, Mt. Hwangbyeong, Mt. Hwaak–Mt. Seokryong, Mt. Duta–Mt. Cheongok, Mt. Balwang, Mt. Gariwang–Jungwang, Mt. Odae–Gyebang, and Mt. Baegun–Hambak–Jang had 15 or more survey plots secured. The density of *Abies nephrolepis* (DBH $\geq$ 6 cm, stems/ha) and the density of young trees over 50 cm in height (stems/ha) were calculated for each survey plot. Their relationships with environmental factors were analyzed using stepwise multiple linear regression analysis.

Before the analysis, the Shapiro–Wilk test was performed on the dependent variable. Natural logarithms were used for the dependent variables that did not meet the normality assumption in certain survey areas. The analysis was performed using IBM SPSS Statistics 26. The total herbaceous cover was calculated by adding the degree of herbaceous cover of all species occurring in the understory layer within each survey plot. The elevation, aspect direction, latitude, and longitude were measured using a Garmin GPS 64s. The degree of slope was measured using a clinometer from Suunto. The degree of rock exposure was classified into four categories ($\leq$10%, 11–30%, 31–50%, and 51–75%). The Shannon diversity index was used to calculate the species diversity index for each survey plot and calculated by including both the tree and herbaceous layers. The dominance index of each species was assigned using Braun-Blanquet: r, rare species; +, coverage < 1%; 1, coverage 1–5%; 2, coverage > 5–25%; 3, coverage > 25–50%; 4, coverage > 50–75%; 5, coverage > 75–100%. The dominance indexes were replaced into percentage values as proposed by Canullo et al. (2012) [31] in order to execute numerical and calculate diversity index. Additionally, during the calculation process of the Shannon index, the value of H′ was calculated using the natural logarithm and the statistical software program Pc-ord7 was used for analysis.

3. Results

3.1. Current Suitable Distribution of Abies nephrolepis and Model Evaluation

Ten cross-validation tests were performed on six models based on eight selected variables related to terrain and environmental factors determined through correlation analysis. Consequently, 60 individual models were derived, and their average, maximum, and minimum values were calculated for each model (Table 3). The RF model had the highest values for AUC and TSS, and the performance of most models was found to be excellent.

To apply the ensemble methodology, models with TSS values of 0.8 or higher, among the 60 individual models, were selected as the target models. Weightings were assigned to the TSS values to construct the ensemble model (Figure 3). The AUC and TSS values of the ensemble model constructed were 0.999 and 0.983, respectively, indicating improved accuracy compared with the individual species distribution models. Based on the ensemble model derived, an examination of the spatial distribution showed broad areas suitable for habitats on Mt. Seorak, Mt. Odae–Gyebang, Mt. Baegun–Mt. Hambaek–Mt. Jang, Mt. Gariwang–Mt. Jungwang, Mt. Taebaek, Mt. Hwaak–Seokryong, and Mt. Sobaek. In comparison, relatively narrow areas suitable for habitats were identified on Mt. Chiak, Mt. Heungjeong, Mt. Myungji, Mt. Sadal, and Mt. Baekdeok. Suitable habitats were also identified on Mt. Daeam, Mt. Ilwol, Mt. Yongmun, Mt. Seondal, Mt. Guryong, Mt. Maebong, and Mt. Taegi, where presence data were not available. Their distribution was observed in southern regions, such as Mt. Jiri, Mt. Deogyu, and Mt. Halla, which has appropriate habitat conditions for *Abies koreana* and *Abies nephrolepis*. This finding was consistent with the results reported by Lee et al. (2020) [32]. The variables with the highest contribution to the implementation of the ensemble model were, in descending order, the annual mean temperature (Bio1) at 45%, elevation at 16%, annual mean precipitation (Bio12) at 11%, and precipitation of the wettest month (Bio13) at 5%.

Table 3. Accuracy of the single-species distribution model based on mean, maximum, and minimum values.

Models	AUC			TSS		
	Average (S.D)	**Maximum**	**Minimum**	**Average (S.D)**	**Maximum**	**Minimum**
Generalized linear models (GLM)	0.986 ± 0.019	0.999	0.915	0.936 ± 0.030	0.984	0.830
Random forest (RF)	0.994 ± 0.006	0.999	0.981	0.950 ± 0.022	0.992	0.902
Classification tree analysis (CTA)	0.950 ± 0.022	0.993	0.898	0.907 ± 0.030	0.958	0.849
Flexible discriminant analysis (FDA)	0.957 ± 0.024	0.996	0.910	0.882 ± 0.042	0.955	0.803
Generalized additive models (GAM)	0.946 ± 0.025	0.998	0.899	0.885 ± 0.045	0.992	0.799
Generalized boosted model (GBM)	0.991 ± 0.007	0.999	0.978	0.943 ± 0.024	0.988	0.883

S.D: Standard deviation.

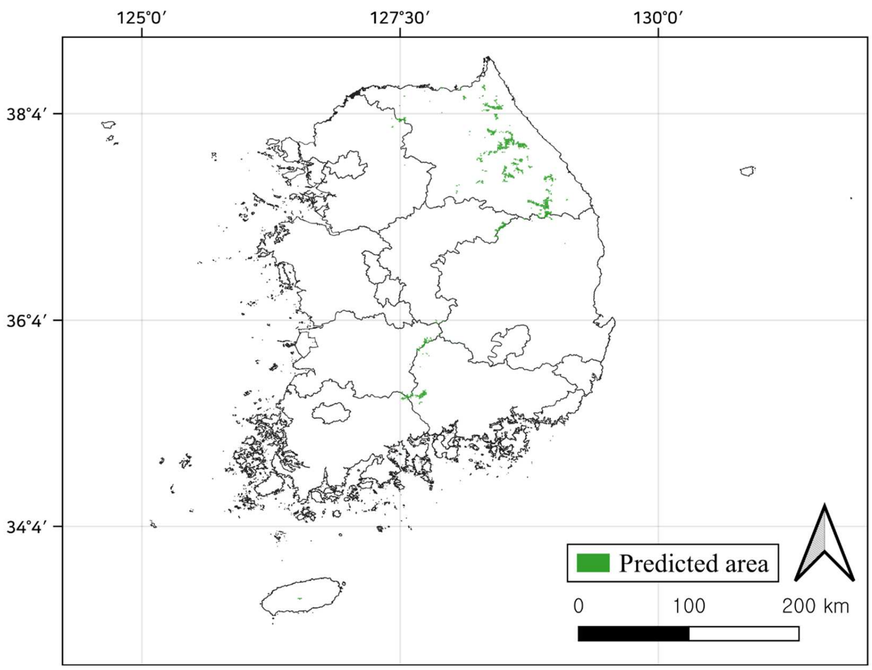

Figure 3. Predicted distribution map of *Abies nephrolepis* by TSS-weighted ensemble model under 1970–2000 climate conditions.

3.2. *Environmental Characteristics of Abies nephrolepis Habitat under 1970–2000 Climate Conditions*

Based on the location data of the *Abies nephrolepis* obtained from field surveys and the Actual Vegetation Map, the environmental characteristics of *Abies nephrolepis* habitats were examined using climate data from a 30-year period (1970–2000). As a result, the annual mean temperature (Bio01) was found to be 5.95 °C, the temperature annual range (Bio02) was 10.19 °C, and the temperature seasonality (Bio04) was 984.71 °C/month × 100. The annual mean precipitation (Bio12) was 1404.8 mm, the precipitation of the wettest month (Bio13) was 323.7 mm, and the precipitation of the driest month (Bio14) was 33.13 mm. Bivariate analysis was conducted based on the eight environmental variables to examine the relationship between the independent variables and the variables that were closely related to each other were identified. As a result of the analysis, it was found that elevation and the Bio1 variable had a major effect on *Abies nephrolepis* habitats. In particular, it was determined that the most suitable habitat for *Abies nephrolepis* was at an elevation of 1200 m or higher with an annual average temperature of 4–6 °C (Figure 4).

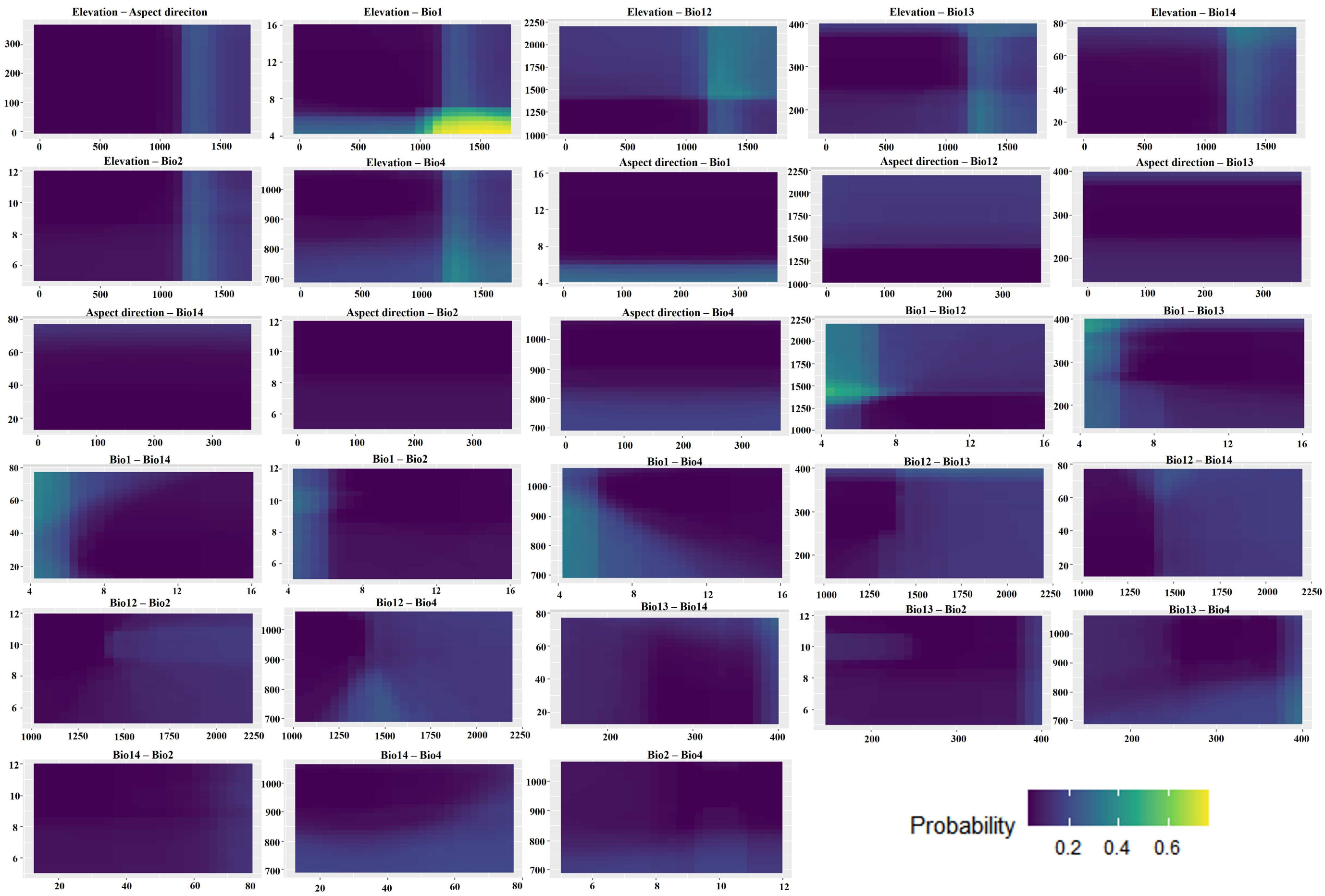

Figure 4. The analysis of relationships between independent variables through bivariate analysis.

3.3. *Suitable Future Distribution of Abies nephrolepis under the SSP Scenario*

We built an ensemble model by applying the shared socioeconomic pathway (SSP) 2–4.5 and 5–8.5 of the UKESM1-0-LL model, weighting the TSS values, to predict changes in potential habitat distribution in the future (Figure 5). As a result, most suitable distribution areas for the species were expected to decrease significantly, and some habitats were predicted to become extinct. Under the SSP 2–4.5 scenario, the suitable habitat area has been projected to decrease by 65% in the 2050s and 71% in the 2070s compared to the current suitable distribution. Under the SSP 5–8.5 scenario, it was predicted that the suitable habitat area will decrease by 74% in the 2050s and 88% in the 2070s compared to the current suitable distribution. Therefore, there is an urgent need to establish measures for the future habitat of the species.

In the model evaluation, the contribution of annual mean temperature (BIO1) was found to be the highest, but relatively extensive areas of suitable habitat for *Abies nephrolepis* were consistently identified in the central and northern regions of Mt. Jiri and Mt. Deogyu and Gangwon-do in the results on distribution changes according to the scenarios. This has highlighted the need to pay attention to precipitation as one of the main factors in regulating the potential habitat for *Abies nephrolepis* in situations where it exceeds its physiological threshold because of global warming in the future. In this regard, although Mt. Halla has been known to record the highest rainfall in South Korea, temperature increases beyond the physiological threshold from global warming were interpreted as being unsuitable for the growth of *Abies nephrolepis* habitats.

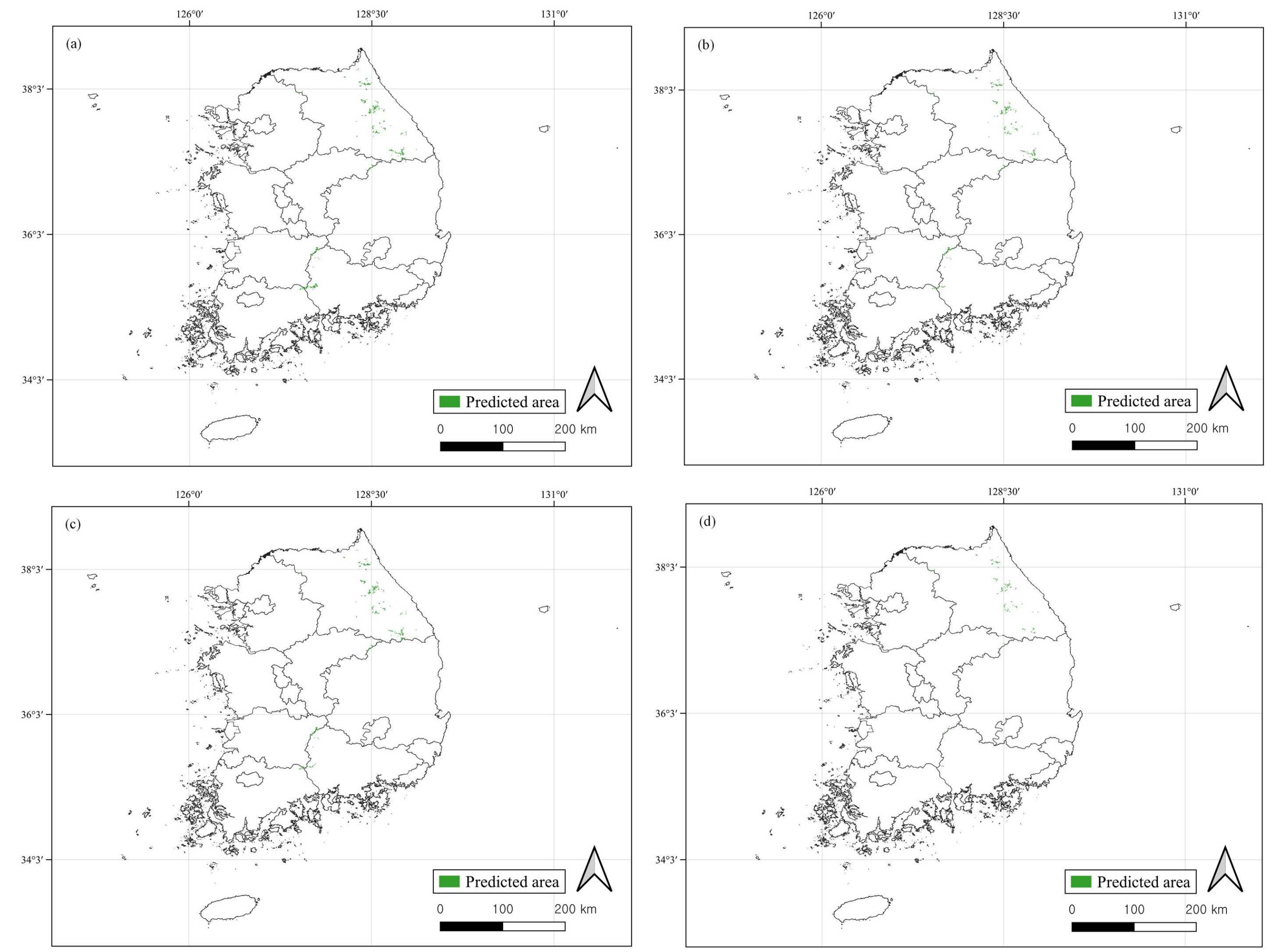

Figure 5. The future potential distribution of *Abies nephrolepis* based on SSP scenario. (**a**) Distribution areas of *Abies nephrolepis* in 2050 (SSP2-4.5). (**b**) Distribution areas of *Abies nephrolepis* in 2050 (SSP5-8.5). (**c**) Distribution areas of *Abies nephrolepis* in 2070 (SSP2-4.5). (**d**) Distribution areas of *Abies nephrolepis* in 2070 (SSP5-8.5).

3.4. Distribution of *Abies nephrolepis* DBH

The structure and sustainability of *Abies nephrolepis* forests were examined by analyzing the diameter class proportions across different forest locations. The results have shown that most forest locations exhibited a left-skewed or normal distribution similar to a bell-shaped curve. Meanwhile, Mt. Seorak and Mt. Balwang showed a distribution closer to a reversed J-shape (Figure 6).

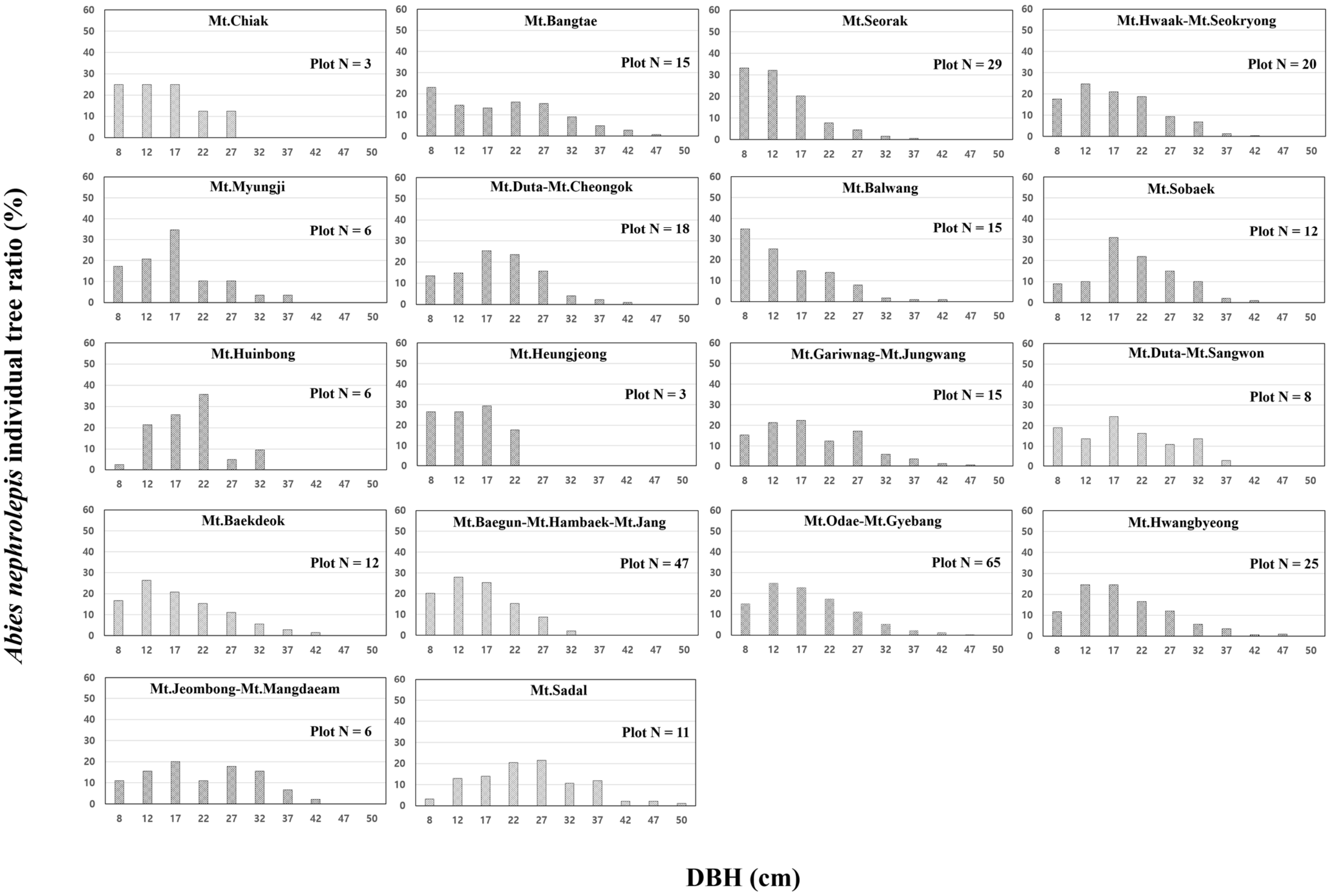

Figure 6. The *Abies nephrolepis* DBH by survey site. DBH classes: 8—(6–9.9 cm), 12—(10–14.9 cm), 17—(15–19.9 cm), 22- (20–24.9 cm), 27—(25–29.9 cm), 32—(30–34.9 cm), 37—(35–39.9 cm), 42—(40–44.9 cm), 47—(45–44.9 cm), 50—(50 ≤ D).

3.5. Relationship between Abies nephrolepis Density (DBH ≥ 6 cm) and Environmental Factors

An analysis of the relationship between *Abies nephrolepis* stem density (stems/ha) and environmental factors was conducted for each forest location, and significant variables were identified in six of the nine locations (Table 4). Among these, species diversity was statistically significant at all six locations, followed by aspect direction, elevation, and slope degree. Stem density, species diversity, and elevation showed a negative relationship, while aspect direction exhibited a higher density in the 170–220° and 250–300° directions. The degree of slope showed a higher density at 25–28°. The standardized coefficients (β values) by forest location showed that species diversity had a higher impact.

Table 4. The relationship between *Abies nephrolepis* density and environmental factors.

Region (Plot N = 15)	Variable	Descriptive statistics		Unstandardized coefficient		Standardized coefficient	t(*p*)
		Average	CV	B	SE	β	
Mt. Gariwang–Mt. Jungwang	(Constant)			8.990	0.743		12.096
	Species diversity	2.45	0.21	−1.050	0.229	−0.659	−4.579 ***
	Aspect direction	130	0.62	0.004	0.001	0.361	2.448 *
	Slope degree	22	0.24	−0.050	0.022	−0.338	−2.305 *
F(*p*)	12.781 ***			adj. R^2		0.716	

Table 4. *Cont.*

Region (Plot N = 15)	Variable	Descriptive statistics		Unstandardized coefficient		Standardized coefficient	t(*p*)
		Average	CV	B	SE	β	
Mt. Balwang	(Constant)			8.346	1.128		7.397
	Species diversity	2.44	0.11	−1.147	0.459	−0.569	−2.497 *
F(*p*)	6.235 *			adj. R^2		0.272	
Region (Plot N = 20)	Variable	Descriptive statistics		Unstandardized coefficient		Standardized coefficient	t(*p*)
		Average	CV	B	SE	β	
Mt.Hwaak–Mt.Seokryong	(Constant)			7.486	0.943		7.941
	Species diversity	2.27	0.13	−0.872	0.413	−0.446	−2.113 *
F(*p*)	4.467 *			adj. R^2		0.154	
Region (Plot N = 65)	Variable	Descriptive statistics		Unstandardized coefficient		Standardized coefficient	t(*p*)
		Average	CV	B	SE	β	
Mt.Odae–Mt.Gyebang	(Constant)			8.805	1.252		7.030
	Species diversity	2.30	0.20	−0.576	0.204	−0.312	−2.824 **
	Aspect direction	196	0.51	0.002	0.001	0.269	2.462 *
	Elevation	1338	0.08	−0.002	0.001	−0.235	−2.133 *
F(*p*)	8.611 **			adj. R^2		0.263	
Region (Plot N = 65)	Variable	Descriptive statistics		Unstandardized coefficient		Standardized coefficient	t(*p*)
		Average	CV	B	SE	β	
Mt.Baegun–Mt.Hambaek–Mt.Jang	(Constant)			8.384	0.711		11.793
	Species diversity	2.62	0.13	−0.956	0.269	−0.468	−3.550 ***
F(*p*)	12.601***			adj. R^2		0.201	
Region (Plot N = 15)	Variable	Descriptive statistics		Unstandardized coefficient		Standardized coefficient	t(*p*)
		Average	CV	B	SE	β	
Mt.Bangtae	(Constant)			7.933	0.696		11.394
	Species diversity	2.63	0.13	−0.965	0.263	−0.713	−3.671 **
F(*p*)	13.475 **			adj. R^2		0.471	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Coefficient of variation: CV.

3.6. Distribution of Abies nephrolepis Young Trees (Young Tree/Ha)

The presence of young trees is crucial for the stable maintenance of forest populations because even a few surviving individuals can contribute to the conservation of continuous *Abies nephrolepis* forests by maintaining the tree line position after the death of mature trees [33,34]. The density of young trees was classified into three categories: h > 50 cm, 10–50 cm, and h < 10 cm. The proportion of young trees >50 cm, which are likely to succeed as mature trees, was compared among forest locations. The highest density was observed at Mt. Seorak and Mt. Balwang, whereas Mt. Jeombong–Mt. Mangdaeam, Mt. Chiak, Mt. Huinbong, Mt. Myungii, Mt. Hwangbyeong, Mt. Duta–Mt. Sangwon, and Mt. Baegun–Mt. Hambaek–Mt. Jang reported a relatively low proportion of young trees (Table 5).

Table 5. Status of *Abies nephrolepis* young tree density by survey site.

Region	**h > 50 cm**	**10 cm ≤ h ≤ 50 cm**	**h < 10 cm**
Mt. Duta–Mt. Cheongok	131	80	29
Mt. Balwang	183	90	63
Mt. Bangtae	158	100	105
Mt. Sadal	75	20	31
Mt. Gariwang–Mt. Jungwang	95	71	78
Mt. Duta–Mt. Sangwon	31	31	25

Table 5. *Cont.*

Region	h > 50 cm	10 cm ≤ h ≤ 50 cm	h < 10 cm
Mt. Baekdeok	68	95	60
Mt. Baegun–Mt. Hambaek–Mt. Jang	44	54	117
Mt. Odae–Mt. Gyebang	116	52	22
Mt. Heungjeong	133	8	208
Mt. Jeombong–Mt. Mangdaeam	8	4	137
Mt. Hwangbyeong	44	44	44
Mt. Chiak	25	25	16
Mt. Sobaek	64	87	75
Mt. Myungji	20	62	62
Mt. Huinbong	35	105	185
Mt. Hwaak–Mt. Seokryong	142	133	33
Mt. Seorak	198	112	69

3.7. Relationship between the Density of Young Trees of Abies nephrolepis (h ≥ 50 cm) and Environmental Factors

Analysis of the relationship between the density of young trees (stems/ha) and environmental factors according to mountain location had significant variables in four out of nine mountains (Table 6). Among them, rock exposure was a statistically significant variable in the three mountains, followed by species diversity, herbaceous cover, aspect direction, and degree of slope. The density of young trees, species diversity, and herbaceous cover were negatively correlated, whereas rock exposure was positively correlated. The density increased as the aspect direction approached 170–220 degrees and the degree of slope was between 20 and 40 degrees. Based on an examination of standardized coefficients according to mountain location, rock exposure was found to have a relatively high influence.

Table 6. The relationship between *Abies nephrolepis* young tree density and environmental factors.

Region (Plot N = 18)	Variable	Descriptive statistics Average	CV	Unstandardized coefficient B	SE	Standardized coefficient β	t(*p*)
Mt. Duta–Mt. Cheongok	(Constant)			8.575	1.922		4.462
	Species diversity	2.29	0.20	−1.990	0.823	−0.517	−2.418 *
F(*p*)		5.847 *		adj. R^2		0.222	
Region (Plot N = 29)	Variable	Descriptive statistics Average	CV	Unstandardized coefficient B	SE	Standardized coefficient β	t(*p*)
Mt. Seorak	(Constant)			3.217	1.116		2.884
	Herbaceous cover	8.96	0.44	−0.183	0.068	−0.405	−2.691 *
	Rock exposure	39	0.46	0.044	0.015	0.447	2.918 **
	Aspect direction	211	0.51	0.005	0.003	0.326	2.126 *
F(*p*)		6.398 **		adj. R^2		0.366	
Region (Plot N = 25)	Variable	Descriptive statistics Average	CV	Unstandardized coefficient B	SE	Standardized coefficient β	t(*p*)
Mt. Hwangbyeong	(Constant)			1.456	0.973		1.496
	Rock exposure	31	0.55	0.085	0.026	0.611	3.295 **
	Slope degree	18	0.55	−0.101	0.044	−0.426	−2.294 *
F(*p*)		6.045 **		adj. R^2		0.296	
Region (Plot N = 47)	Variable	Descriptive statistics Average	CV	Unstandardized coefficient B	SE	Standardized coefficient β	t(*p*)
Mt. Baegun–Mt. Hambaek–Mt. Jang	(Constant)			4.590	2.445		1.877
	Rock exposure	50	0.32	0.050	0.017	0.385	2.900 **
	Species diversity	2.62	0.13	−1.875	0.813	−0.306	−2.307 *
F(*p*)		8.132 ***		adj. R^2		0.245	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Coefficient of variation: CV.

4. Discussion

4.1. Vulnerability Assessment and Conservation Implications of Abies nephrolepis under Climate Change

Among the various factors affecting habitat suitability, BIO1 (annual mean temperature), elevation, and BIO12 (annual precipitation) were found to have significant impacts on the growth of *Abies nephrolepis*. When considering changes in *Abies nephrolepis* distribution under different scenarios, precipitation was identified as one of the main factors in determining habitat suitability for the species. However, precipitation above a certain threshold was unsuitable for the species' growth. Therefore, it is important to understand the climatic threshold suitable for *Abies nephrolepis* habitats. Habitat suitability decreased in the central and northern regions of Gangwon-do, Mt. Jiri, and Mt. Deogyu, but relatively wide areas suitable for the species' habitat were identified compared with other natural habitats. It was found that the habitats of Mt. Jiri, Mt. Deogyu, and Mt. Geumwon were not confirmed as natural habitats of *Abies nephrolepis*. However, they continuously showed suitability for growth, indicating that they play an important role as suitable sites for ex situ conservation of *Abies nephrolepis*.

The ratio of individual trees (DBH $\geq$ 6 cm) and the density of young trees (stems/ha) in each mountain area surveyed were unfavorable for stable population maintenance. Mt. Myungji, Mt. Chiak, Mt. Hwangbyeong, Mt. Jeombong–Mt. Mangdaeam, Mt. Baekdeok, and Mt. Sobeak were predicted to experience habitat extinction or significant population reduction compared to areas suitable for growth because of climate change. The density of young trees (stems/ha) and the size distribution of individual trees showed an unstable form, requiring precise monitoring of these areas in the future. Mt. Heungjeong and Mt. Balwang showed relatively stable ratios of individual trees and densities of young trees. However, the risk of extinction was high because of distribution changes according to the scenarios, requiring long-term observation of changes in population size. Among them, *Abies nephrolepis* on Mt. Sobaek has been confirmed to have a high level of genetic diversity and unique gene types in South Korea [35]. However, it has shown a relatively high level of decline [3] and an unstable distribution for population maintenance, indicating the need to prioritize conservation efforts.

4.2. Relationship between Population Density of Abies nephrolepis and Environmental Factors

According to the results of this study, the variables affecting the density of *Abies nephrolepis* individuals (DBH $\geq$ 6 cm) and young tree density (stems/ha) predominantly showed similar patterns. However, differences were observed in some variables. Rock exposure showed a statistically significant relationship with young tree density and was also observed to have a positive effect. This can provide a microhabitat avoiding direct exposure to the wind and competition with early surrounding vegetation. This is likely to have a positive impact on young tree growth in *Abies nephrolepis*. Bryophytes predominantly inhabit shaded wetlands or rocky surfaces and can effectively retain moisture [36]. Therefore, they are likely to have a positive impact on the growth of *Abies nephrolepis*.

The variability of species diversity has shown a negative relationship. This has been attributed to the formation of competition among various species in response to the expansion of habitat for temperate plant species because of global warming or the temporary increase in light from the opening of canopy gaps caused by the death of dominant trees, such as *Abies nephrolepis*. This has resulted in an influx of various plants.

However, if the decrease in species diversity leads to an improvement in the growth environment of *Abies nephrolepis*, which has a strong shade tolerance, then artificial interventions such as forest management can provide new insights and understanding that the changes in community structure from succession can have a beneficial effect on *Abies nephrolepis*. The area including Mt. Baegun–Hambeak–Jang has many traces of forest management and, unlike the declining trend in other regions, the degree of decline is relatively low in this area [3]. Therefore, in-depth observations are needed to investigate whether continuous forest management will improve the growth of high-altitude coniferous species.

Aspect was correlated with individual tree density and young tree density in the southwest direction. This implies that sufficient light conditions are required for the growth of *Abies nephrolepis*. These results are in line with those of Kim et al. (2019) [12]. On Mt. Odae–Mt. Gyebang, a negative trend was observed according to altitude, which is likely the result of strong winds in the high-altitude ridges where *Abies nephrolepis*, a shallow-rooted tree species, grows. The damage caused by strong winds accompanied by heavy rain on 23 October 2006 [37] affected this area.

This study examined the complex relationships between various environmental factors in *Abies nephrolepis* forests. In contrast with studies that have interpreted specific regions within South Korea, this study provides clearer information that will help in understanding the distribution of *Abies nephrolepis*, and it was discovered that certain environmental factors have a significant impact.

5. Conclusions

Most natural habitats of *Abies nephrolepis* in South Korea were unstable, and vulnerability assessments based on SSP climate change scenarios indicated that most habitats are expected to be lost. Therefore, adequate moisture supply was identified as the most crucial factor for the future distribution of *Abies nephrolepis*. Conservation priority areas were proposed based on field survey data and climate change vulnerability assessments. By identifying the relationship between various environmental factors and the population density of *Abies nephrolepis*, it was found that rock exposure and species diversity were associated. However, further research is necessary to fully understand the complex ecological processes involved.

This study is expected to contribute to the establishment of an important system for the conservation, restoration, and management of subalpine coniferous forests in South Korea, not only for *Abies nephrolepis*, but also for other species.

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