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Article

Integrating Climate Change and Land Use Impacts to Explore Forest Conservation Policy

Hyeyeong Choe [1,*] and James H. Thorne [2]

[1] Department of Environmental Science and Policy, UC Davis, Davis, CA 95616 USA; hychoe@ucdavis.edu
[2] Department of Environmental Science and Policy, UC Davis, Davis, CA 95616 USA; jhthorne@ucdavis.edu
* Correspondence: hychoe@ucdavis.edu; Tel.: +1-530-217-9578

Abstract: This study uses a scenario-based approach to ask what are the varying impacts to forest extent and biodiversity from sixteen climate change and forest conversion scenario combinations, and what do they suggest about future forest conservation policy directions? We projected these combinations onto existing forests in South Korea and grouped them into four forest categories. We used species distribution models for 1,031 climate vulnerable plant species as a biodiversity index, and found that species richness loss due to forest conversion could be reduced significantly by deploying the scenarios which preserve forest areas that are climatically suitable for these species. Climate-suitable forest areas declined sharply and moved northward as future temperatures increase, and climate-suitable areas lost the highest proportion of forest extent under the current trend of forest conversion. We suggest climate refugia, defined as existing forests with suitable future climates be protected from land use conversion as a way to preserve forest biodiversity. These spatially explicit results can be used for developing forest conservation policies, and the methods may be applicable to other forested regions. However, planners should consider the assumptions and uncertainties of climate projections, species distribution models, and land use trends when addressing forest biodiversity conservation.

Keywords: biodiversity; climate change; climate refugia; forest conservation; forest conversion; land use change; policy scenario-planning; species distribution model

1. Introduction

Direct human modification and conversion of land cover is one of the most evident global changes in the past three centuries [1], and anthropogenic climate change is also modifying land cover and affecting species' habitats [2]. While forests are the most important source of terrestrial biodiversity, diverse factors including deforestation and climate change are threatening nearly half of the world's forests [3]. Climate change and natural habitat destruction from land use are leading factors in decreasing terrestrial biodiversity and can cause uncertainty for forest management and conservation efforts [4-9]. Thus, studies that integrate climate change and land use are necessary for understanding the manner of biodiversity decline, and for understanding of how future climate and land use will affect species distributions at national scales [10-12].

However, while studies on the effects of climate change on biodiversity are increasing, studies that integrate climate change and land use remain scarce. Sirami et al. [13] call for studies to consider multiple drivers at any scale, assess interactions among multiple drivers, and question the role of these processes at species level. In addition, identification of climate change refugia can potentially help to prioritize conservation areas given limited resources [14].

This paper asks whether simulating combinations of future climate change and land use patterns can be used to develop forest conservation policies for forest biodiversity preservation. We used a scenario-based approach of climate change and land use, and projected the results onto existing forests. We applied this approach to South Korea, where around 70% of the land base is in forest, and asked what forest management policies might best protect forest biodiversity.

National and regional policies may be able to influence the spatial patterns of land use and forest conversion, thereby contributing to biodiversity preservation [15,16]. In South Korea, the National

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Reforestation Programme has increased forest cover from 35% of total area in the 1950s to almost 70% [17], and the national forest plan emphasizes the importance of forest functions in responding to climate change. Significant action will be required to offset the impacts of climate change and forest conversion on biodiversity, which may require significant policy changes [6,18]. Recent tree planting projects in South Korea have focused on creating biomass forests and planting rapidly growing trees to supply wood-based materials as carbon sinks [19], but the policies for climate change mitigation may result in threats to biodiversity at local levels. For example, converting natural vegetation types to monoculture plantations to capture greenhouse gas emissions may conflict with biodiversity conservation needs [20]. Therefore, local policy makers should adopt the most appropriate management options for their situation [21], and studies looking at the synergies between biodiversity conservation and climate change mitigation for local situation are important to support decision making by policy makers [22].

South Korea's forest plan emphasizes the identification of climate vulnerable species and ecosystems through long-term monitoring, and special management of rare species. However, this national forest plan does not present specific strategies or plans for implementation, and it lacks specific spatial information for development of effective forest policies at the local government level. Spatial predictions of land use patterns could provide critical information to support environmentally sound development policies and planning strategies [23]. Investigation of the environmental impacts of land use under different policy scenarios by using spatial projections of various scenarios would help in policy formation [24].

The objectives of this study are: (1) to estimate the impacts of climate change and land use policy on the biodiversity of forested areas by exploring the spatial results of different forest conversion and climate models; (2) to stratify current forest areas into four categories of future conditions based on the integration of our forest conversion and climate models; and (3) to suggest options in forest policy and conservation strategies that address both biodiversity conservation and climate mitigation. We estimated the change in species richness in forested areas by using modeled range maps for 1,031 climate-vulnerable species (CVS) under four climate scenarios by 2050 and predicted forest conversions under four scenarios. We combined the two modeling outputs and categorized current forest areas into four classes to examine forest policy alternatives.

2. Materials and Methods

The analysis had four main steps: (1) we estimated the 1,031 CVS richness change under four climate scenarios for 2050; (2) we quantified past forest conversion to other land use by administrative unit; (3) we built four alternative forest conversion scenarios and predicted forest land use change by 2050; and (4) we combined results from the climate-species models and forest conversion models and classified current forest areas to identify forest policy alternatives (Figure 1).

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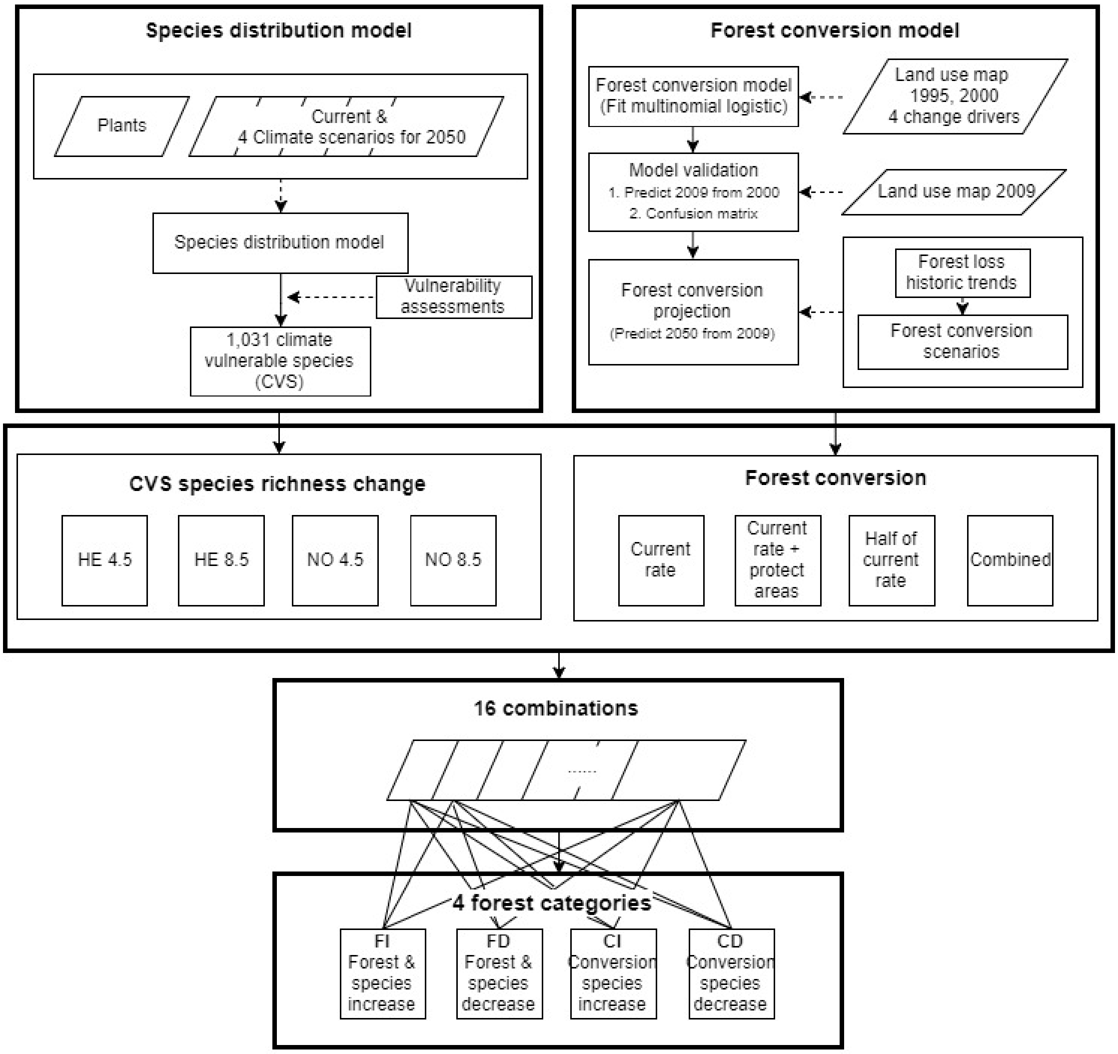

Figure 1. Study flow. (1) We estimated the change in species richness in existing forest areas using the modeled ranges of 1,031 climate vulnerable plant species under four climate scenarios for 2050 (top left); (2) We quantified past forest conversion to other land use by administrative unit to develop a forest conversion model and we built four alternative forest conversion scenarios and predicted forest land use change by 2050 (top right); (3) we combined the spatial results from the climate-species models and forest conversion models, and classified current forest areas to identify forest policy alternatives (bottom).

2.1. Study Area

South Korea constitutes the southern part of the Korean Peninsula with a land mass of 100,033 km^2 (Figure 2). This study is confined to the mainland of South Korea, and the study area is divided into 16 administrative districts currently. South Korea had a population of 50 million in 2014, an increase of 18 million since 1970 [25]. However, the population growth rate has been decelerating since 1970, and zero population growth is expected around 2030. Afterward, the population of South Korea is predicted to decline to 48 million by 2050 [25]. The South Korean population is largely concentrated in the Capital Region. As of 2013 the population of Seoul was 9.9 million and population density was 16,402 inhabitants per km^2 [26].

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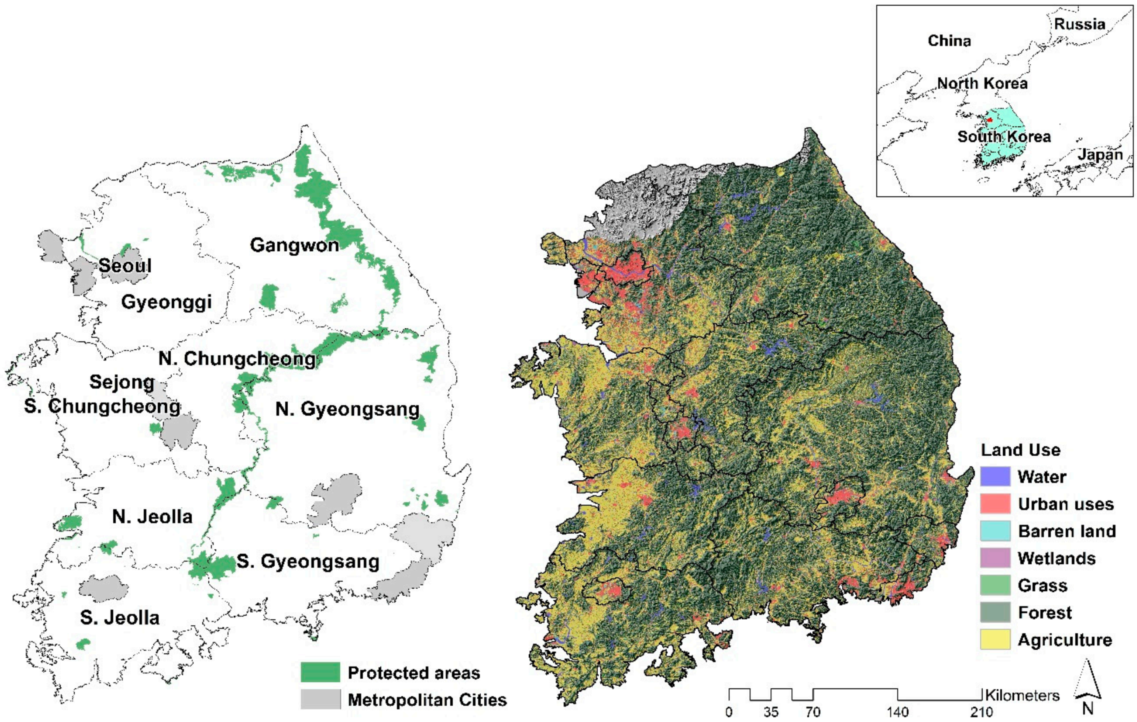

Figure 2. Distribution of the protected areas (left) and land use (2009) and topography of South Korea (right). Land use data for the northwest area is not available, so we excluded it from our study.

Mountains comprise 70% of the Korean Peninsula. The primary mountain range stretches along the eastern coast of South Korea. The mountains interface with southern and western coastal plains where most of South Korea's agricultural crops are grown. Most mountains in South Korea are covered by conifer forests with a few mixed conifer-broadleaf forests. Forests were overused and devastated during Japanese colonization in the early twentieth century and Korean War (1950–1953). The government subsequently implemented forest restoration and planting projects, and legal and institutional strategies were developed for forest management [19]. These actions led to the reestablishment of the Peninsula's forests. The first national forest plan was established in 1973 and has been updated every 10 years. Currently, the fifth national forest plan emphasizes the forest function as a carbon sink in responding to climate change [19]. The total forest area in this study is 57,015 km^2, about 60% of the mainland of the country.

2.2. Estimating Changes in Species Richness under Climate Change

We previously used the MARS multiresponse species distribution model (SDMs) to estimate the current and the future distributions of 2,297 terrestrial plant species [27,28], of which we identified 1,031 species as CVS (Table S1) [27]. For those studies we used 65,491 species occurrence records from the South Korean second and third national ecosystem survey data (available from the ECObank: http://ecobank.nie.re.kr). MARS multiresponse SDMs combine all species data and use information on the presence of other species to supplement information for the modelled species by considering locations of other species as pseudo-absences for each species as it is modelled [29]. The MARS model was appropriate for our use because our data include large numbers of species with few records. Detailed modeling process can be found in [27,28].

The species ranges were predicted using seven climatic variables (annual mean temperature, temperature seasonality, mean temperature of the warmest and coldest quarter of the year, annual precipitation, precipitation of the wettest and driest quarter of the year; obtained from the WorldClim website: http://www.worldclim.org [30]) as environmental predictor variables in the MARS models. For future species' range projections, we used variables derived from the HadGEM2-ES (HE; + 2.7 °C and + 203.9 mm in precipitation (RCP 4.5), + 3.4 °C and + 262.3 mm (RCP 8.5) from the current 5.9 °C

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and 1320.1 mm in South Korea on average) and the NorESM1-M (NO; + 1.9 °C and – 18.9 mm in precipitation (RCP 4.5), + 2.5 °C and + 79.3 mm (RCP 8.5)) global climate models (GCMs) under the emission scenarios for Representative Concentration Pathways (RCP) 4.5 and RCP 8.5 [31], because these two GCMs provide contrasting future climates of South Korea [28]. HE projection represents a hotter and wetter future climate and NO projection represents a warmer and drier future climate in South Korea (Figure 3).

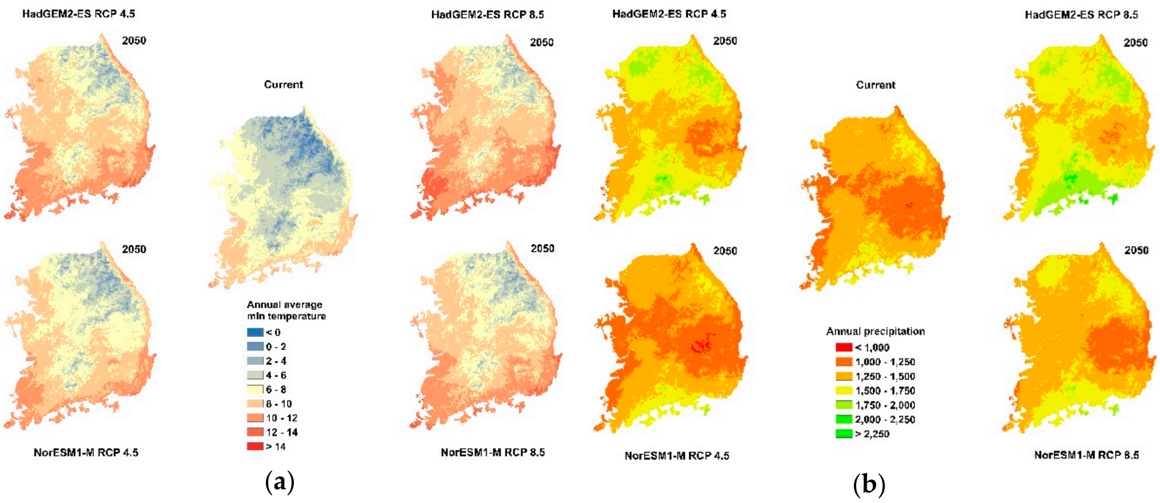

Figure 3. Current climates and 2050 climate projections under four climate scenarios for South Korea: (**a**) Annual average minimum temperature; (**b**) Annual precipitation.

All species were grouped based on their current spatial distribution patterns, and spatial vulnerability components - exposure, spatial disruption, and dispersal pressure – were used to define climatically vulnerable species groups, CVS. Vulnerability values were averaged by group and then defined species groups as vulnerable by comparing their vulnerability scores with the average score for all species [27,28]. We used 1,031 CVS plant species' projected range maps for the current climate and for each of the four future climate projections, and analyzed the shifts in their distribution patterns. We classed the study area's current forested regions into zones of increasing and decreasing CVS richness.

2.3. Determining Historical Forest Conversion Spatial Predictors

We used historical land use maps to build and validate a forest conversion model. The model was built using 1995 and 2000 land use maps, which were the most recent maps developed from the Korean Water Management Information System (WAMIS) [32]. We assessed our model using a 2009 land use map from the Environmental Spatial Information Service [33]. The 1995 and 2000 land use maps have been derived from Landsat 5 TM and Landsat 7 ETM respectively and have eight land use categories: water, urban use, barren land, wetlands, grass, forest, and two agricultural categories (rice paddies and fields) with a spatial resolution of 30 m. The 2009 land use map is a vector-based product that was derived from SPOT 5 and KOMPSAT 2. We combined detailed land use categories from this map into seven categories for model validation (water, urban use, barren land, wetlands, grass, forest, and agriculture), and converted it into a raster surface with a resolution of 30 m. Since urban development patterns differ among South Korea's seven cities and eight provinces, we analyzed past forest transitions for each administrative district separately for further modeling.

We used four criteria for modeling forest conversion: proximity to roads; distance from urban areas (these two continuous variables were log-transformed for symmetrical distribution and we added the size of one cell unit (30 m) to avoid zero distance); slope (classified into four categories: flat, 1–25%, 25–90%, >90%); and a binary map of national protected areas [23,34]. These variable values were calculated by using road data from the Korea Transport Database [35], land use and topographic data from WAMIS, and protected areas data from the ProtectedPlanet website

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(http://www.protectedplanet.net). We identified land use categories in 2000 for areas that were forested in 1995, and, for those areas we computed a multinomial logistic model using the four predictors for each land use category for each administrative district, to fit a model of forest conversion for use in our forward projections. We used the 'raster [36]' package in R (version 3.1.1) to extract values of predictors and the 'nnet [37]' package to run a multinomial logistic model and develop future forest conversion models. Prediction using this fitted forest conversion model yields the probability layer for each land use at a 30 m spatial resolution.

To assess the forest conversion model, we predicted forest conversion by 2009 in each administrative district by applying the values for 2000 as a base year in the fitted model, and assessed the spatial accuracy of our model by comparing predicted forest conversion to the 2009 land use map [38]. We predicted the probability layer of each land use that forest in 2000 converted to other land use with the function 'predict' in the 'raster' package in R, and defined areas that remain in forests as those with the highest probability values as forest land use. We assigned the total extents of remaining forests to the extent measured by historical rates of forest conversion from 2000 to 2009 using the two land use maps. Then, we distributed other land use types with the next highest probability values in the remaining areas. We used the function 'confusionMatrix' in the 'caret [39]' package in R to calculate a cross-tabulation of observed and predicted land use classes and measured the performance of the forest conversion models for each administrative district. We calculated overall accuracy as the total number of correctly classified grid cells of all land use categories divided by the total number of grid cells that were originally forest areas in the base year. Then, the predictor values for 2009 was used to predict the probability for forest conversion by 2050 as the base year for our forest conversion model.

2.4. Future Forest Conversion

Since the national forest plan does not contain specific spatial objectives, we have devised forest conversion scenarios in accordance with the forest conservation and management strategy. We modeled four forest conversion scenarios for 2050, using the calibrated forest conversion models: (1) forest-loss that continues at the current rates and spatial patterns of deforestation; (2) forest loss at the same rate, but with conservation in areas with suitable climates for many vulnerable plant species facing climate change; (3) a reduction of forest loss by 50% from the current rate by administrative unit; and (4) a combination of conservation in areas with suitable climates and reduction of the deforestation rates by 50%.

We assumed that rates of future forest land use will not be significantly different from the recent rates because South Korea has recorded low population growth rate since the mid-1990s [40]. We fitted a linear regression between forest amounts for each year and a continuous number (yearly data) by district using 2000-2010 Forest Service statistics (http://english.forest.go.kr), and projected 2050 forest extents proportionately based on the forest extents from the 2009 land use map.

We projected the probabilities that each grid cell labeled as forest in 2009 would convert to other land use types by 2050 using the fitted forest conversion models. Future forest areas were allocated first, using the calculated forest amounts for each scenario, from the cells having the highest probability values as forest. We distributed other land use types with the next highest probability values in the remaining areas. We assumed that currently protected areas would be maintained through 2050, thus forests in the currently protected areas were set aside as having development restrictions and preserved (Figure 2).

2.5. Combining the Two Simulation Results

We divided future land uses from each forest scenario into binary maps of forest areas and all other land use categories. We also generated four maps of increasing and decreasing CVS species richness from the four climate scenarios. We combined the results from the two simulations to classify areas that are vulnerable to climate change and forest conversion. We identified four forest categories from the 16 combinations: FI (forest preserved and species richness increases, i.e. the most important forest areas as potential climate refugia), FD (forest preserved but species richness decreases), CI

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(forest converted to other land use classes, but species richness increases, i.e. lost future climate suitable habitat), and CD (forest converted to other land use classes and species richness decreases). We calculated the extents and proportions of the 16 case maps representing the combinations of the four climate scenarios and four forest conversion scenarios.

3. Results

3.1. Spatial Shifts in Climate Vulnerable Species Richness

CVS richness varies from 87 to 656 in current climate, and from 70 to 640 among the future climate scenarios (Figure 4). Areas with current high species richness were located at higher elevations in the southern part of South Korea. As future temperatures increase, climate-suitable areas for CVS declined sharply and moved northward, and to higher elevations, particularly in the northeastern and south-central parts of South Korea. Suitable areas for CVS in 2050 were reduced the most by the HE RCP 8.5 scenario.

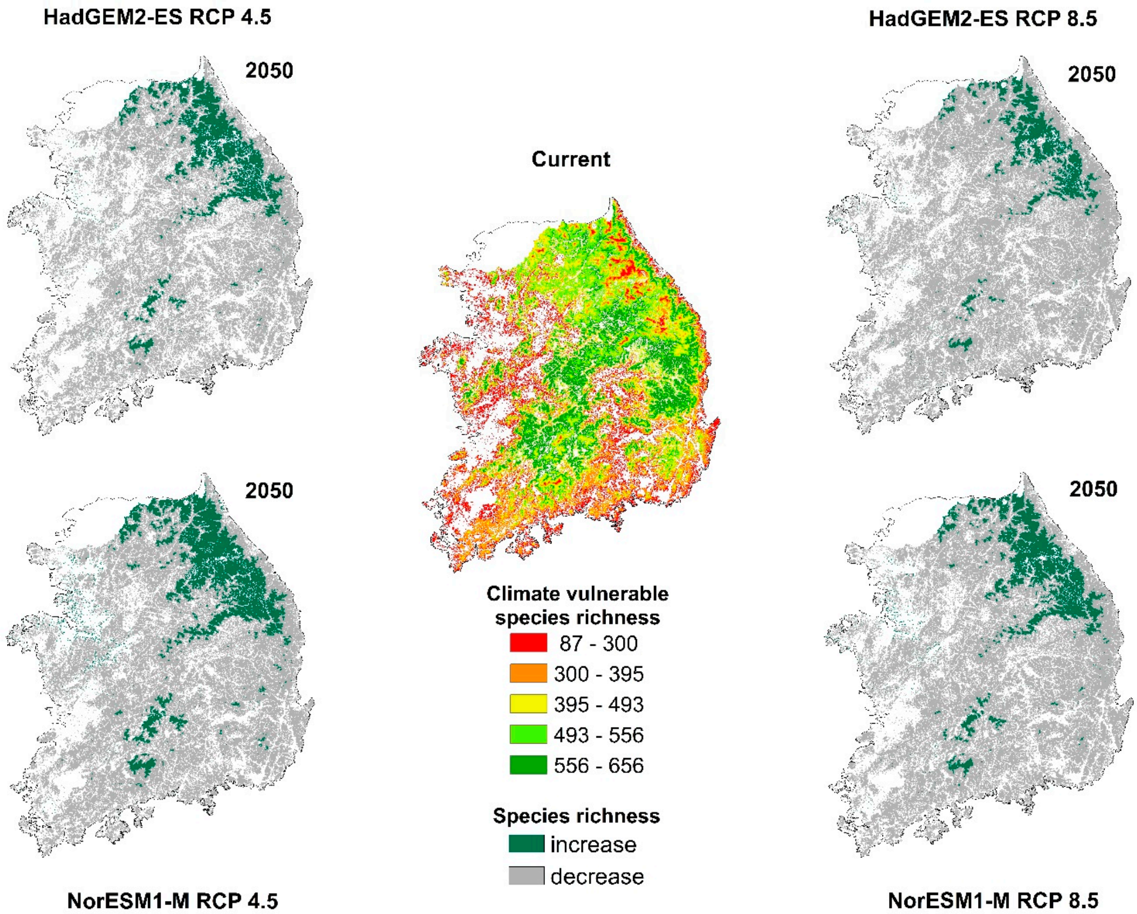

Figure 4. Species richness change for 1,031 CVS (climate-vulnerable species) between the current climate and four climate scenarios. The prediction is simulated for 2050.

3.2. Historical Forest Conversions and Forest Conversion Model Calibration

Historical forest conversion from 1995 to 2000 in the 15 administrative districts showed different conversion trends (Table 1). Considerable portions of forest were maintained in all districts, particularly in Gangwon province (in the northeast), which preserved 97% during this period. The highest land use class which represents conversion from forest, was into agricultural, especially into rice paddies in all districts except Seoul. In Seoul, around 6% of 1995 forest converted to urban use.

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Table 1. Forest conversion from 1995 to 2000 by administrative district (% of forest in 1995 that converted to other land use by 2000).

Administrative district	Forest conversions (% of forest in 1995)							
	Forest	Water	Urban use	Barren land	Wetlands	Grass	Rice paddy	Field
Provinces								
Gyeonggi	85.9	0.2	1.6	0.8	0.12	3.5	4.4	3.5
Gangwon	97.0	0.1	0.1	0.1	0.04	0.7	0.9	1.1
North Chungcheong	93.1	0.1	0.2	0.1	0	1.6	2.5	2.4
South Chungcheong	81.1	0.2	1.0	0.6	0.06	2.6	9.0	5.5
North Jeolla	85.5	0.1	0.9	0.3	0.02	2.6	7.7	2.9
South Jeolla	86.0	0.3	0.7	0.2	0.02	1.8	6.7	4.3
North Gyeongsang	94.6	0.1	0.1	0	0	0.1	4.1	1.0
South Gyeongsang	92.5	0.1	0.2	0	0	0.3	5.6	1.2
Metropolitan Cities								
Seoul	84.9	0.4	5.9	0.6	0	2.9	3.5	3.5
Busan	91.4	0.1	0.7	0	0	0.4	5.8	1.6
Daegu	92.7	0.2	0.6	0	0	0	5.2	1.2
Incheon	80.7	0.1	3.4	0.5	0	1.2	7.0	7.1
Gwangju	80.7	0.3	2.2	0.9	0	0.9	10.4	4.6
Daejeon	84.0	0.1	1.1	0.4	0	4.4	5.5	4.6
Ulsan	91.7	0.1	0.2	0	0	0.4	6.0	1.7

Overall accuracy values of the forest conversion models were more than 0.78 in all districts, and the average of all accuracy values was 0.85 (Table 2). Gangwon Province has the highest overall accuracy of the forest conversion model and Incheon has the lowest accuracy value.

Table 2. The overall accuracy of forest conversion model from 2000 to 2009 (predicted forest conversion by 2009 by applying the values for 2000 as a base year in the fitted model).

Administrative district	Forest conversion model Overall accuracy
Provinces	
Gyeonggi	0.83
Gangwon	0.92
North Chungcheong	0.87
South Chungcheong	0.80
North Jeolla	0.88
South Jeolla	0.86
North Gyeongsang	0.87
South Gyeongsang	0.86
Metropolitan Cities	
Seoul	0.82
Busan	0.83
Daegu	0.88
Incheon	0.78
Gwangju	0.81
Daejeon	0.81
Ulsan	0.86

3.3. Forest Conversion by Scenarios by 2050

Forest loss is expected to continue in all districts using the 2000–2010 trajectory of forest loss (Figure S1). Forest amounts in almost all districts showed a linear decrease by year, and average of R-squared values of linear regressions each district for estimating forest amounts in 2050 were 0.9

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(Table 3). Currently (using a land use map for 2009), the district with the highest proportion of forests is Gangwon province (82.8%) followed by North Gyeongsang (70.3%) and South Gyeongsang (65.5%). According to each forest amount equation by district, Gangwon province will lose the highest proportion of its forest (-23.7%) followed by North Gyeongsang province (-19.1%). Among the cities, Seoul will lose the lowest proportion of its forest (-0.3%) by 2050. The city with the highest loss of remaining forest is Busan (-6.6%) (Table 3 and Figure S2).

Table 3. Test of forest amount linear model and forest amount estimation of each scenario for each district. The numbers in parentheses in the column of "Forest extent in 2009" represent the % of forest to total administrative area. The numbers in parentheses in the columns of "Forest conversion scenarios for 2050" represent the forest decrease ratios compared to the forest extent in 2009. Details about forest conversion scenarios are in the text.

Administrative district	Forest linear estimation model	Forest amounts (km²)				
	R^2	Forest extent in 2009 (% of administrative unit area)	Forest conversion scenarios for 2050 (% of forest decrease from 2009)			
			Scenario 1	Scenario 2	Scenario 3	Scenario 4
Provinces						
Gyeonggi	0.97	3,820.7 (49.0)	3,287.5 (-6.8)	3,123.9 (-8.9)	3,554.1 (-3.4)	3,472.3 (-4.5)
Gangwon	0.99	13,110.1 (82.8)	9,350.6 (-23.7)	11,230.3 (-11.8)	11,230.3 (-11.8)	12,170.2 (-5.9)
North Chungcheong	0.98	4,860.7 (65.4)	4,699. 8 (-2.2)	4,491.7 (-5.0)	4,780.2 (-1.1)	4,676.2 (-2.5)
South Chungcheong	0.99	3,906.4 (46.6)	3,705.9 (-2.4)	3,538.7 (-4.4)	3,806.2 (-1.2)	3,722.5 (-2.2)
North Jeolla	0.96	4,089.5 (51.8)	3,902.0 (-2.4)	3,726.9 (-4.6)	3,995.7 (-1.2)	3,908.2 (-2.3)
South Jeolla	0.98	5,462.3 (54.4)	5,366.7 (-0.9)	5,132.8 (-3.2)	5,414.5 (-0.4)	5,297.6 (-1.6)
North Gyeongsang	0.79	13,271.7 (70.3)	9,663.8 (-19.1)	9,095.6 (-22.1)	11,467.8 (-9.6)	11,183.7 (-11.1)
South Gyeongsang	0.98	6,258.7 (65.5)	6,139.0 (-1.2)	5,871.0 (-4.0)	6,198.8 (-0.6)	6,064.8 (-2.0)
Metropolitan Cities						
Seoul	0.60	143.6 (23.7)	141.7 (-0.3)	135.6 (-1.3)	142.7 (-0.1)	139.6 (-0.6)
Busan	0.98	322.4 (46.4)	276. 9 (-6.6)	263.1 (-8.6)	299.7 (-3.3)	292.8 (-4.3)
Daegu	0.95	466.5 (53.0)	436.1 (-3.5)	416.1 (-5.7)	451.3 (-1.7)	441.3 (-2.9)
Incheon	0.85	184.3 (30.2)	173.2 (-1.8)	165.3 (-3.1)	178.7 (-0.9)	174.8 (-1.6)
Gwangju	0.97	177.8 (35.7)	155.6 (-4.5)	148.0 (-6.0)	166.7 (-2.2)	162.9 (-3.0)
Daejeon	0.94	278.7 (51.7)	262.8 (-2.9)	250.8 (-5.2)	270.7 (-1.5)	264.8 (-2.6)
Ulsan	0.96	661.4 (63.5)	627.8 (-3.2)	599.5 (-5.9)	644.6 (-1.6)	630.4 (-3.0)

Using the current forest extents from the 2009 land use map as the baseline (Figure 2), we established four forest conversion scenarios for 2050 (Table 3 and Figure S2). Scenario 1, the forest loss at historical rates scenario, results in an overall loss of 15.5% (8,825 km²). Scenario 2, the preserve climatically suitable CVS forest areas scenario, identifies land in the northeastern parts of South Korea (Gangwon province). This region accounts for 79% of the increasing species richness areas under HE RCP 8.5, 16,949 km². Therefore, we apportioned half the amount of forest loss in Gangwon province from land use to other districts proportionately by forest area. Scenario 3 aims to reduce forest loss

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to half the current deforestation rates, which results in an overall loss of 7.7% (4,413 km^2). Scenario 4, the combination of scenario 2 and scenario 3, reduced forest loss by half in each district compared to the forest-loss-trend scenario and to reallocated half the forest loss in Gangwon province to other districts proportionately by forest area (Table 3).

3.4. Combined Results from Climate and Forest Change

The proportions of forest in the four categories (FI, FD, CI, and CD) varied by GCM, by RCP, and by forest conversion scenario (Figure 5 and Table 4; We also provide raster layers for this result as Appendix S1.). By deploying the forest conversion scenarios, which preserve climatically suitable forest areas in Gangwon province (scenario 2 and 4), the proportions of FI increased and the proportions of CI declined significantly under all GCM simulations. This effect is similar to the results from forest conversion scenario 3, which reduced deforestation rates in half of the current rates. Moreover, by adopting scenarios preserving forest areas in Gangwon province, the average species richness values of CI and CD, which forests converting to other land use types, reduced significantly. The average species richness values of FI were almost similar between forest conversion scenarios (minimum: 503, maximum: 528) (Table S2).

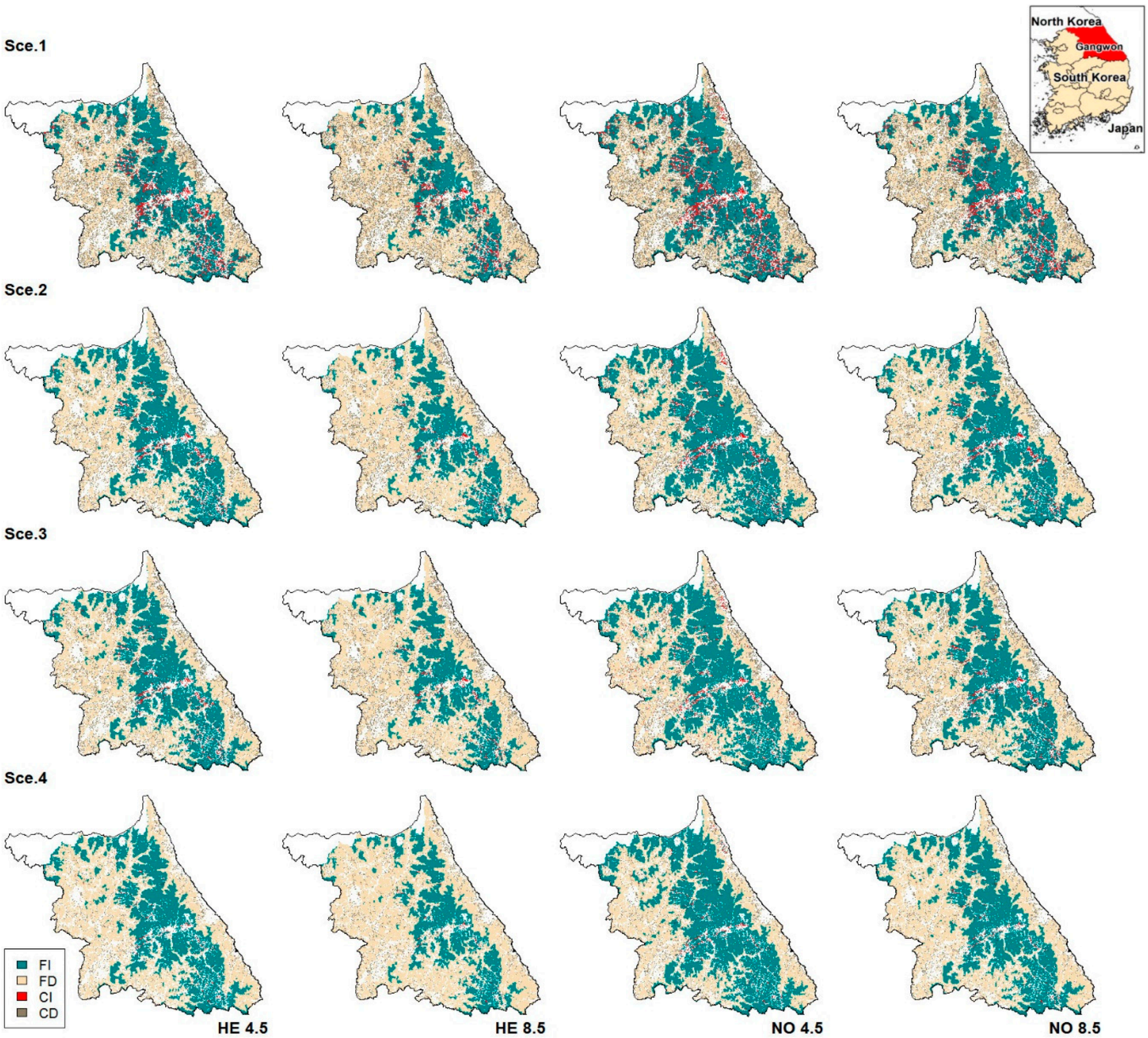

Figure 5. Distributions of four categories (FI: forest preserved, and species richness increase, FD: forest preserved, but species richness decrease, CI: converted to other land use classes, but species richness increase, and CD: converted to other land use classes, and species richness decrease) in 16 case maps. The maps in this figure only describe Gangwon province that contains future species-rich areas for many climate vulnerable species.

Table 4. Extents and proportions to total forest extents of four forest categories (FI: forest preserved, and species richness increase, FD: forest preserved, but species richness decrease, CI: converted to other land use classes, but species richness increase, and CD: converted to other land use classes, and species richness decrease) in 16 case scenarios (km^2, %). Current forest extents is 57,015 km^2.

GCM	Forest conversion scenario	FI	FD	CI	CD
HE 4.5	Scenario 1	7,959 (14.0)	42,231 (74.1)	981 (1.7)	5,844 (10.3)
	Scenario 2	8,592 (15.1)	42,391 (74.4)	331 (0.6)	5,696 (10.0)
	Scenario 3	8,643 (15.2)	45,401 (79.6)	296 (0.5)	2,674 (4.7)
	Scenario 4	8,792 (15.4)	45,703 (80.2)	125 (0.2)	2,395 (4.2)
HE 8.5	Scenario 1	4,886 (8.6)	44,654 (78.3)	582 (1.0)	6,887 (12.1)
	Scenario 2	5,291 (9.3)	44,774 (78.5)	188 (0.3)	6,762 (11.9)
	Scenario 3	5,314 (9.3)	48,263 (84.7)	165 (0.3)	3,273 (5.7)
	Scenario 4	5,394 (9.5)	48,497 (85.1)	68 (0.1)	3,050 (5.4)
NO 4.5	Scenario 1	9,841 (17.3)	39,586 (69.4)	1,363 (2.4)	6,226 (10.9)
	Scenario 2	10,633 (18.7)	39,295 (68.9)	570 (1.0)	6,517 (11.4)
	Scenario 3	10,742 (18.8)	42,761 (75.0)	462 (0.8)	3,045 (5.3)
	Scenario 4	10,964 (19.2)	42,841 (75.1)	239 (0.4)	2,970 (5.2)
NO 8.5	Scenario 1	7,475 (13.1)	42,071 (73.8)	986 (1.7)	6,488 (11.4)
	Scenario 2	8,108 (14.2)	41,957 (73.6)	365 (0.6)	6,585 (11.6)
	Scenario 3	8,159 (14.3)	45,418 (79.7)	314 (0.6)	3,124 (5.5)
	Scenario 4	8,313 (14.6)	45,578 (79.9)	148 (0.3)	2,976 (5.2)

The detailed descriptions of each forest category from the combined model results are as in the following with further information about forest conversion for each scenario in Table S3:

FI (forest preserved, and species richness increase): species richness increases in forest areas were less than 20% even in the most ideal scenario (19.2%, 10,964 km^2) in scenario 4 under NO 4.5. The rates of FI areas were higher in the scenarios assuming lower temperatures—that is, they were highest in the NO 4.5 and lowest in the HE 8.5. In the scenarios that conserve forests in Gangwon province (scenario 2 and 4), the proportions of FI increased under all GCM simulations. Especially, scenario 2, that has the higher level of deforestation, conserves almost as much FI area as scenario 3, which reduced deforestation rates by 50% in all GCM scenarios. FI areas were mostly distributed at higher elevations in Gangwon province but in lower-temperature scenarios FI areas were also distributed in the higher elevations of the southern part of South Korea (near the boundary between North Jeolla and South Gyeongsang provinces).

FD (forest preserved, but species richness decrease): species-decreasing forest areas made up the majority of all scenarios. FD areas increased largely in the scenario 3, which cuts forest loss in half compared to the scenario 1. The rates of FD areas were higher in the scenarios assuming higher temperatures; they were highest in the HE 8.5 and were lowest in the NO 4.5. The proportions of FD were similar under the HE 4.5 and NO 8.5. FD areas were spread throughout South Korea. The western part of South Korea was mainly composed of FD areas.

CI (forest converted to other land use classes, but species richness increase): species increasing non-forest areas made up the smallest part of all scenarios. The rates of CI areas were higher in the scenarios assuming lower temperatures; they were highest in the NO 4.5 and lowest in the HE 8.5. In the scenarios that conserve forests in Gangwon province (scenario 2 and 4), the proportions of CI greatly declined under all GCM simulations. CI areas were mostly distributed in higher elevations of Gangwon province. In the scenario 1, CI areas were also distributed near the boundary between Gyeonggi and South Chungcheong provinces.

CD (forest converted to other land use classes, and species richness decrease): species decreasing non-forest areas were greatly reduced under scenarios that conserve forest (scenario 3 and 4). The

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rates of CD areas were higher in the scenarios assuming higher temperatures; they were highest in the HE 8.5 and lowest in the HE 4.5. CD areas were mostly distributed in North Gyeongsang and Gangwon provinces where many agricultural conversions were expected to occur (Table S3).

4. Discussion

This study modeled forest policy and climate impact scenarios to estimate future forest conditions, which could help inform development of future editions of the national forest plan in South Korea. The overall accuracy of the multinomial logistic forest conversion model for each district was high, and the combined results with the climate-species models can inform forest conservation policies for land use planning at a national scale. Based on our results, protecting forests with future suitable climates that contain the highest species richness as derived from multiple species distribution models emerged as a leading forest conservation policy, and this approach might not need to reduce forest conversion in South Korea, as much as re-direct it away from these priority areas.

4.1. Species' Ranges in Climate Change

Plant species' range shifts in South Korea are expected to be significant during the next 40 years. Many species suited to current climatic environments of high-mountain regions in Gangwon province appear to be highly vulnerable to warmer weather. Our study results showed that plant species richness would increase in higher elevations in Gangwon province, although the increasing area extent varies depending on the RCP scenarios of the GCMs (Figure 4).

Forest conservation strategies are required for biodiversity conservation in South Korea, especially in Gangwon province. Extant viable species could be managed by long-term monitoring, and the threat to them should be limited in these regions. In addition, climate change mitigation should be pushed forward vigorously, as our study showed that areas where species richness is expected to increase were larger under the GCM assuming lower temperatures in the future (Figure 4). Species richness under NO RCP 4.5 also increased in the western coastal areas near the border between Gyeonggi and North Chungcheong provinces. Coastal areas are valuable because various ecosystems interact and transitions occur between adjacent systems [41]. Thus, intensive management is also needed for coastal areas at higher latitudes.

4.2. Forest Conversions in South Korea

Forest conversion causes the reduction and fragmentation of core habitats for many species and brings the construction of more roads and utilities [42,43]. Many animal species rely on large habitats, which could be eliminated by construction activities in forests [44]. Because ecosystems are often complex and interdependent, the decrease or extinction of any one species in an area can alter the stability and biodiversity of the entire community, including the relevant ecosystems [45].

In the forest-loss-trend scenario, most forest conversions in South Korea went into agricultural areas (15.15% of current total forest areas), and these conversions were mostly in Gangwon and North Gyeongsang provinces (Table S3). However, these areas are important for preserving forests, as around 57% of the forest in South Korea grow in Gangwon and North Gyeongsang provinces [46]. Forest areas with favorable environmental conditions, such as good drainage and soil fertility, are the most likely to be converted into agricultural areas [47], and land use conversion to produce food or other agricultural products for human consumption is one of the most serious and widespread threats to global biodiversity [48]. A combination of factors, including increasing demand for food, land fertility, rising market prices for products, and the absence of clear and enforceable land ownership rights can cause forests to be transformed into agricultural areas [47], so multidirectional efforts should be made to reverse the forest loss trends.

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4.3. Suggestions for Forest Conservation under Climate Change in South Korea

We found that the forests in Gangwon province are likely to convert into agricultural areas despite their suitable future climates for vulnerable forest plants. We created policy scenarios that preserve forests in Gangwon province because the increase of CVS richness occurred mostly in Gangwon Province. Scenario 4, the combination scenario aims to reduce forest loss by half and to preserve forests in Gangwon province, was the most effective at conserving species-rich forests (FI) (Figure 5 and Table S2). However, scenario 2, that has the higher level of deforestation but protects future species-rich areas, is also effective at conserving species-rich forests. By adopting scenario 2, FI areas were conserved nearly as much as those in scenario 3, which reduced deforestation rates by 50%, and CI areas were reduced considerably compared to scenario 1, the forest-loss-trend scenario. By protecting forests with future suitable climates (Gangwon province in this study), conversions of species rich forests into other land uses were avoided. This indicates the importance of including biogeographic climate dynamics in forest policy. In the case of South Korea, protecting forests in Gangwon province is as important as reducing national deforestation rates for forest biodiversity conservation. We suggest strong actions to conserve forests in Gangwon province for forest conservation policy under climate change in South Korea.

More specifically, we suggest forest conservation strategies for each category of our combined results:

For the FI category (forest maintained, and species increase): FI areas can act as climate-change refugia [49], as species suited to changed climatic environments are increasing in these areas. Thus, continuous long-term monitoring activities are essential to conserve viable species and to ensure that their environment is not threatened. Designating additional protected areas in FI areas could help to protect the areas [14]. Moreover, FI areas are candidate sites for vulnerable species' assisted colonization (also known as assisted migration or managed relocation), while there are concerns over ethical, legal and policy issues of it [50], especially for species characterized by poor dispersal, a long life-cycle, or low competitive ability [51].

For the FD category (forest maintained, but species decrease): Continuous long-term monitoring is especially important in FD areas for managing potentially climate-sensitive species and helping them to adapt to climate change [7]. Species can be conserved by maintaining habitat connectivity to nearby FI areas and promoting species' movements. Habitat corridors, which are linear strips of vegetation that link isolated habitat fragments, can reduce physical distances among habitats [52], although species that could benefit from this are mostly long-distance seed dispersal plants [51,53]. We suggest the establishment of plantations for climate mitigation activities in FD areas. While there is debate over the benefits and risks of plantations, planting rapidly growing species in FD areas can contribute to the regeneration of natural species in other areas and sequester carbon at a relatively small cost [20,54,55].

For the CI category (converted to other land use classes, but species increase): Identifying potential forest conversion threats and eliminating threatening processes are important in CI areas. Continuous monitoring activities are essential to conserve viable species. Designating additional protected areas in CI areas could help in conserving forests and biodiversity in these regions. If CI areas are not sufficiently stable for species to inhabit, restoration activities as species' climate refugia will be required in CI areas.

For the CD category (converted to other land use classes, and species decrease): Continuous monitoring is important in CD areas for identifying potentially climate-sensitive species and helping them to adapt to climate change. Species can move to suitable areas by maintaining habitat connectivity and dispersal pathways.

4.4. Model assumptions and limitations

The approach used in this study has some limitations. First, because we used the species' range shifts derived from SDM, the limitations of using the SDM should be fully understood for proper use [18,56,57]. In this study, we used the SDM results modeled using only climate parameters, but in reality the distributions of species are confined by interaction with other species [56]. We did not

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consider the capacity of species to reach the future climate suitable regions, and stacking species' ranges may tend to overestimate species richness [58,59]. Therefore, future species richness may be lower than projected, so uncertainties caused by using SDMs for predicting the impacts of climate change should be understood by policy makers. Moreover, in this study we considered only CVS change, but forest conversion has a negative impact on the habitats of all species [3]. Future studies will need to analyze the impact on other species depending on their research objectives.

We also assumed that future forest conversion will not be significantly different from the recent changes and used only one most recent time step data to develop the forest conversion model in this study. We thought the recent drivers of forest conversion would continue and excessive forest conversion would not occur since the population growth rate of South Korea has been decelerating since 1970. However, land use change can be generated based on various drivers such as demographic trends, local and regional policies, socioeconomic development, and land use strategies of local small holders [60] that cannot be grasped by the tendency of short time. Also, these land use change drivers might be different by administrative district. This can be inferred from that the overall accuracy of the forest conversion model for each district was slightly different in this study (Table 2).

Thus, future studies might consider several time steps and various parameters that could explain forest conversion by region to develop a more robust model. In addition, once the direction of forest policy is established, more realistic forest conversion scenarios could be created.

5. Conclusions

As climate changes and species' ranges shift, conservation planning needs to consider the impacts of future climate change [7,51]. Our study showed that species' suitable habitats from climate change are shifting and forest conversions are spatially different. Even though we suggested four broad-scale conservation strategies for forest conservation policy, more subdivision and detailed strategies would be useful for local regional conservation policies. Moreover, land use change largely affects the climate change cycle, and they have a relationship of interdependence [61]. Thus, future studies on the interaction of these two alterations and their interacted impacts on biodiversity could provide important information for conservation planning.

Supplementary Materials: The following are available online at www.mdpi.com/link, Table S1: A list of climate vulnerable species in this study, Figure S1: Recent forest loss percentage versus forest in 2000 by administrative district, Figure S2: Proportion of forest for each district in current time and in each scenario by 2050, Appendix S1: 16 GIS raster layers for the spatial results of this study, Table S2: The average species richness value of each forest category between scenarios, Table S3: Forest Conversion Projection in Each Policy Scenario.

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Author Contributions: H.C. and J.T. conceived and designed the experiments; H.C. performed the experiments; H.C. and J.T. analyzed the data; H.C. and J.T. wrote the paper.

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