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Forest succession by space and time based on climate and landuse changes

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Abstract

This research predicted the transition of forest structure by analyzing changes in the dominant vegetation and spatial distribution based on climate and land use changes. The research region involves the mountainous and city vicinity located in Okcheon-gun, Korea. Climate change detailing was carried out until 2100 by employing the SSP2-4.5 scenario and the MaxEnt model was used to predict the land cover change. The data stemming from the above were applied to the Landis-II model. The analysis of forest changes was performed based on the years 2050 and 2100 that showed the most dramatic prediction results of climate changes. Comparing to 2020, the mean minimum temperature fell down by 0.45°C in 2050 and increased by about 0.96°C in 2100. The mean maximum temperature increased by about 0.31°C in 2050 and about 1.96°C in 2100. In the prediction of land cover change, mountainous region exhibited a decreased tendency of agricultural lands in 2050 and 2100, and region city vicinity showed a decrease in residential lands, demonstrating very small land cover changes of the forest in both regions. As for the predicted vegetation change, both regions showed a decrease in the dominant area of *Pinus densiflora*, *Pinus Koraiensis*, and *Pinus rigida*, on the other hand, showing an increase in the dominant area of *Quercus serrate, Quercus variabilis*, and *Quercus aliena*. In conclusion, the future forest vegetation of two regions showed a decreased tendency in the alien species that could not reproduce under natural conditions, tree species that grow in cold climate regions, and the reforestation species that were planted due to a necessity of human beings, whereas the area of *Quercus species*, which are mainly distributed to a relatively warm climate, increased. Therefore, in order to determine tree species for restoration where interfered nature and area that need logging, it should be decided based on the predicted vegetation change in a given area to maximize the forest function.

Keywords: Forest transition; Climate change; Landuse change; LANDIS-II; Sustainable forest management

Introduction

According to the 6th report of the International Panel on Climate Change (IPCC, 2021), the average surface temperature of the entire globe between 2011 and 2020 has increased by 1.09°C compared to that before industrialization (between, 1850 and 1900), and it was also predicted to increase by 1.0~5.7°C depending on the climate change scenarios of the future (IPCC, 2021). In the case of South Korea, it was reported that plants in the zone of mid-latitudes would move about 150km up to the north, which refers to a 150m change in altitude, and many plant species would encounter the crisis of extinction (NGII, 2016).

In the 5th General Assembly of the relevant nation of the Convention on Biological Diversity (CBD), various researches on forest vegetation succession are being progressed as a measure that can preserve the biological diversity and establish the sustainable strategies of each nation in relation to climate change.

Research on forest vegetation succession is one of the basic research categories for analyzing forest succession that is altered according to climate change, securing the carbon neutralization policy of the future and biodiversity, and managing the forest regions in an integrated manner. In the past, the forest succession researches were conducted based on topography, climate, human interference, and site surveys after selecting the survey region and setting the succession period (Mun and Kim 1985) and the recent forest succession researches are typically being progressed employing the Geospatial Information Technology (Scheller et al., 2007).

Choi et al., (2019) applied the LANDIS-II model to the forest vegetation around Yeongdong-gun, South Korea in order to identify the ecological changes in forest vegetation caused by climate change, thereby predicting the long-term changes in forests. It was revealed that most conifer species would become extinct by 2100, whereas *Quercus mongolica* and *Quercus variabilis* were analyzed to increase.

This research aims to predict and analyze the vegetation changes of the future forest in a space-temporal perspective by employing various variables such as temperature, precipitation, and carbon dioxide according to future climate changes.

Methodology

1-Selection of Vegetation Change Model

There was significant progress in the forest vegetation succession analysis for the regions on large scale over 10^6ha by employing various variables based on spatial information technology and vegetation physiology, starting with landscape analysis for small-scale regions in the 1970s. Of those advanced technologies, the LANDscape Disturbance and Succession II (LANDIS-II) has been recently being highlighted as a prediction model for future forest vegetation changes (refer to Fig. 1). It employs not only the Photosynthesis and Evapo-Transpiration (PnET) that applies photosynthesis and evapotranspiration of plants but also the data for land use change and climate change scenarios(USDA Forest Service, 2021).

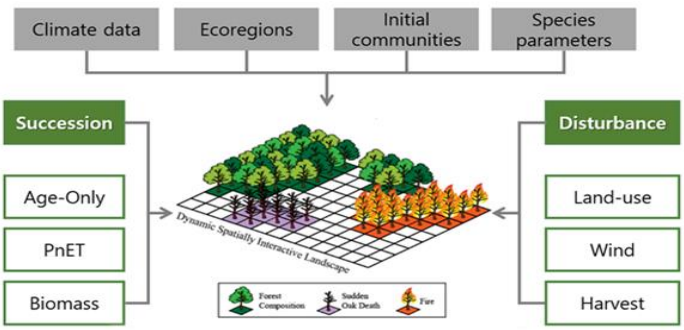

Fig. 1: LANDIS-II model configuration

2-Research sites selection and grid creation

The research site located in Okcheon-gun which occupies the central inland of South Korea. The entire region was classified into the forest of mountainous region (region A) and the forest of city vicinity region (region B) in order to comparatively analyze the forest succession changes according to the climate changes and influence of interference by human beings, and the two regions each have an area of 24km^2 (refer to Fig. 2). Region A is appropriate to the vegetation habitat environment due to its gradual slope and region B includes both residential and commercial sectors that are difficult environments for plants to habitat. The target region was sectored by a unit of 100m×100m for analyzing the forest vegetation changes.

Fig. 2: Research Region

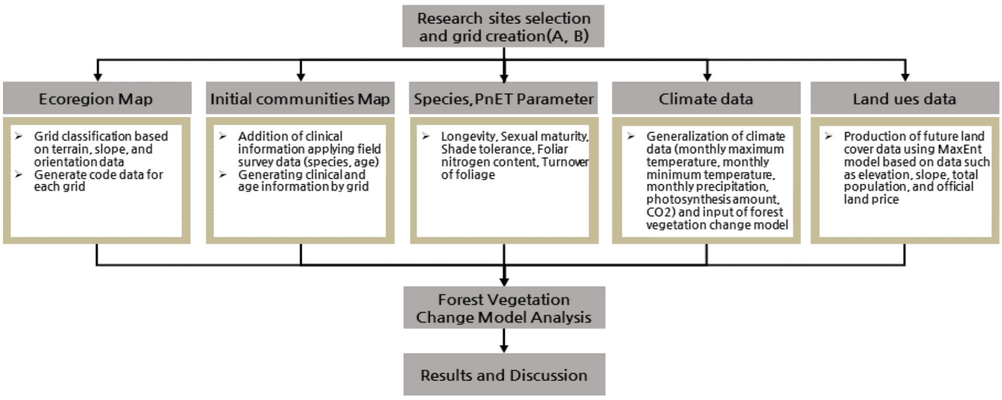

Fig. 3: Main Research Process

3-Preparation for Research process and Input Data

The forest vegetation succession analysis was conducted using the resources necessary for LANDIS-II such as Ecoregion Map, Initial communities Map, Species & PnET, climate data, and land use data, afterward, the dominant area for each tree species was analyzed (refer to Fig. 3).

3-1 Ecoregion Map

Ecoregion Map refers to a map of which regions with ecologically similar habitat environments are grouped together. This research sorted out the habitat environments using the data for slope and slope orientation, which were estimated by employing the digital elevation model and its data created based on the numerical map provided by the National Geographic Information Institute.

3-2 Initial communities Map

Initial communities mean the data that summarized the information on both tree species and their age groups that currently inhabit each cell (100m×100m) in the target region. To get the information on tree species and their age groups, the forest type map, which was created by the Korea Forest Service in 2020, and site survey data were used. Site survey included collecting the information on current vegetation status and potentially dominant tree species in the future targeting the representative stand for tree species and age group, then, thereby fabricating an initial vegetation map.

3-3 Species & PnET

Based on the data collected through the site survey, 24 species of trees inhabit in the site, including Pinus Densiflora, Betula platyphylla, and Pinus rigida. Of those, 10 tree species that are available for input into the forest succession model were selected, for instance, *Larix kaempferi* (Lamb.) Carrière, *Pinus densiflora* Siebold & *Zucc.*, *Pinus koraiensis* Siebold & Zucc., *Pinus rigida* Mill., *Quercus acutissima* Carruth., *Quercus mongolica* Fisch. ex Ledeb., *Quercus serrata* Murray, *Quercus variabilis* Blume, *Quercus aliena* Blume, *Robinia pseudoacacia* L. In order to prepare the species and PnET species parameters that are required for the LANDISII model, the research data and reports from domestic and overseas as well as the data provided by LANDIS were referred to.

1) Species

The following information, which is related to the development and reproduction of trees, is input into the Species.

Longevity, Sexual maturity, Shade tolerance, Fire tolerance, Effective seeding distance, Maximum seeding distance, Vegetative reproduction probability, Minimum resprouting age, Maximum resprouting age, and Post-fire regeneration.

2) PnET Species Parameter

PnET Species Parameters that are the specific details of the Species indicate the data with regard to the chemical properties including KWdLit, which is the annual decomposition rate of a wooden shell, and FolLignin, which is the mass fraction of lignin in leaf tissue, and 19 items were used[1].

3-4 Creation of Climate Data and Input by Cell

This research used the observation data by Automatic Weather System (AWS) for the mountain weather, agriculture and the Meteorological Administration Agency, the ERA5 data from the European Center for Medium-range Weather Forecast (ECMWF), and the Automated Synoptic Observing System (ASOS) data from the Meteorological Administration Agency. All data were interpolated to create climate data in a unit of 100m×100m. Based on the climate data from 1981 to 2010, PRCP(total precipitation in mm of the relevant month), TMAX(maximum temperature in Celsius of the relevant month), and TMIN(minimum temperature in Celsius of the relevant month) were generated by applying the SSP2-4.5 climate change scenario[2] until 2100.

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[1] FolN(Foliar nitrogen content), SLWmax(Maximum specific leaf weight at the top of canopy), SLWDel(Rate of change in specific leaf weight from the top of a canopy layer to the bottom), Tofol(Turnover of foliage - Fraction of foliage bio mass lost per year), AmaxA(Intercept of relationship between foliar N and maximum net photosynthetic rate), Amax B(Slope of relationship between foliar N and maximum net photosynthetic rate, such that Amax), HalfSat(Half satura tion light level for photosynthesis), H2, H3, H4(Water stress parameters according), PsnAgeRed(Reduction factor red ucing leaf photosynthesis rate as cohorts age), PsnTMin(Minimum average daytime temperature for photosynthesi s), PsnTOpt(Optimal average daytime temperature for photosynthesis), k(Canopy light attenuation constant), DNSC (Proportion of NSC relative to total active biomass), FracBelowG(Fraction of non-foliar biomass that is belowground), EstMoist(the maximum expected value of Water to equal 1.0 when computing Pest), FracFol(Fraction of the amoun t of active woody biomass), and FrActWd(Shape parameter of negative exponential function that calculates the amo unt of woody biomass that has active xylem capable of supporting foliage).

[2] SSP: Shared Socioeconomic Pathways (IPCC 2021)

SSP1-2.6: Sustainability, SSP2-4.5: Middle of the Road, SSP3-7.0: Regional Rivalry, SSP5-8.5: Fossil-fueled Development

Photosynthetically Active Radiation (PAR) was created by referring to its monthly average value during daylight hours, and CO2 was created by referring to the data recorded in the IPCC 6th report. The climate data created in this manner were input into each relevant cell (refer to Fig. 4).

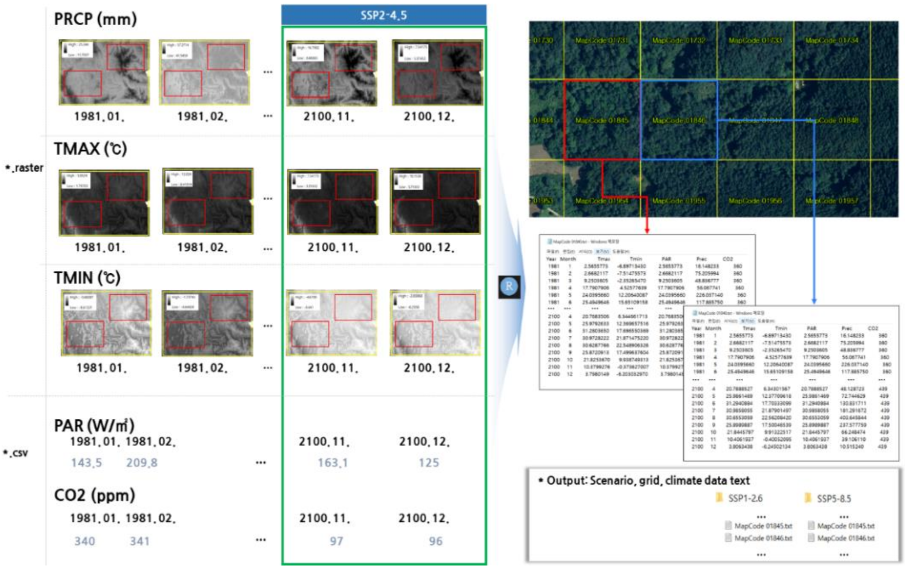

Fig. 4: Climate data input process by cell

3-5 Land Use Data

The MaxEnt (Maximum Entropy Model) based on the 2013 land cover data, which was created by the Ministry of Environment, was used for the future land use data. The variables employed include elevation, slope, total population, officially assessed land price, distance to a city hall or a county office, distance to roads, changing data of urbanized dry zones, data for a restricted region (development restricted region, legally protected region, urban park), and future population and an average number of household members estimated by year 2050 and 2100 based on KOSIS, (2019).

Results

The area of dominant forest of Okcheon-gun in 2020, 2050, and 2100 was comparatively analyzed based on the forest vegetation changes.

1. Climate Change Scenario and Land Cover Change

According to the SSP2-4.5 climate change scenario, compared to 2020, the mean minimum temperature decreased by 0.45°C in 2050, and the mean maximum temperature increased by 0.31°C. In 2100, the mean minimum and mean maximum temperatures both increased by 0.96°C and 1.94°C, respectively.

In terms of the land cover changes until 2100 of the target regions, the area of agricultural land in region A was mainly reduced and that of the residential portion was mainly reduced in region B compared to 2020. It was analyzed that the area of land cover reduced in regions A and B was turned into the grasslands and bare lands, and no change in the area of forest was identified (refer to Fig. 5).

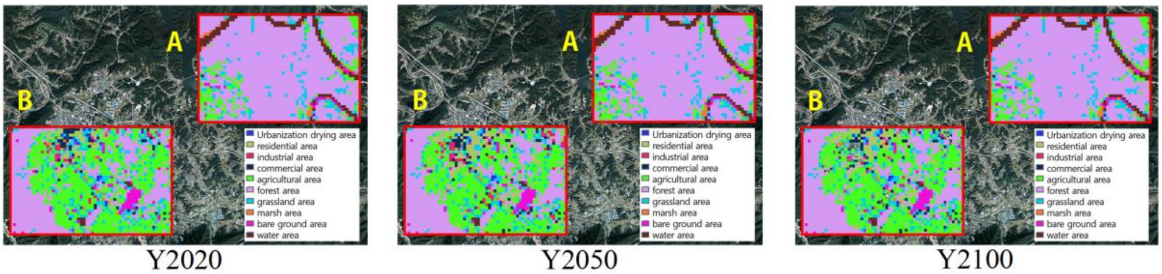

Fig. 5: Land use change data (2020, 2050, 2100)

2. Area Change of Dominant Species in region A (Forest of Mountainous; Table 1)

In region A, a decreasing tendency of the dominant area in conifers, alien species, and plantation species was revealed in 2050. *Quercus mongolica*, an indigenous species, exhibited a high reduction rate of about 95.1%, which is 353ha compared to 2020. All *Quercus* spp. species showed an increasing tendency in the dominant area. It was analyzed, in particular, that the dominant area of *Quercus aliena* increased in 2050 and 2100, unlike in 2020. The dominant areas of conifers and alien species were reduced in 2100 like 2050, and the dominant area of *Quercus* spp. species increased. In addition, the dominant areas of *Quercus serrate* and *Quercus variabilis* increase further, whereas the dominant areas of *Quercus aliena* and *Quercus acutissima* decrease.

Table 1: Area analysis by Tree species in the region A based on SSP2-4.5 scenario

Tree Species	Y2020		Y2050				Y2100			
			Area		Compared to 2020		Area		Compared to 2020	
	Area(ha)	Share(%)	Area(ha)	Share(%)	Area(ha)	Share(%)	Area(ha)	Share(%)	Area(ha)	Share(%)
Larix kaempferi	61	4.6	61	4.6	-	-	60	4.5	-1.0	-1.6
Pinus densiflora	204	15.4	194	14.6	-10.0	-4.9	142	10.7	-62.0	-30.4
Pinus koraiensis	32	2.4	29	2.2	-3.0	-9.4	23	1.7	-9.0	-28.1
Pinus rigida	483	36.4	456	34.3	-27.0	-5.6	226	17.0	-257.0	-53.2
Quercus acutissima	37	2.8	57	4.3	20.0	54.1	52	3.9	15.0	40.5
Quercus mongolica	118	8.9	4	0.3	-114.0	-96.6	75	5.6	-43.0	-36.4
Quercus serrata	7	0.5	39	2.9	32.0	457.1	89	6.7	82.0	1,171.4
Quercus variabilis	305	23.0	436	32.8	131.0	43.0	635	47.8	330.0	108.2
Quercus aliena	0	-	13	1.0	13.0	-	9	0.7	9.0	
Robinia pseudoacacia	81	6.1	39	2.9	-42.0	-51.9	17	1.3	-64.0	-79.0
Total Area	1,328									

3. Area Change in region B (Forest of city vicinity; Table 2)

Like region A, region B exhibited a decreasing tendency of the dominant area for conifers, alien species, and plantation species in 2050 and 2100, and an increasing tendency of *Quercus* spp. species. It was analyzed that the reduction rate in the area of dominant tree species is relatively low compared to region A. In 2100, the dominant area of Larix kaempferi decreased, and the dominant areas of *Quercus serrate* and *Quercus variabilis* exhibited high increase rates.

Table 2: Area analysis by Tree species in the region B based on SSP2-4.5 scenario

Tree Species	Y2020		Y2050				Y2100			
			Area		Compared to 2020		Area		Compared to 2020	
	Area(ha)	Share(%)	Area(ha)	Share(%)	Area(ha)	Share(%)	Area(ha)	Share(%)	Area(ha)	Share(%)
Larix kaempferi	15	0.7	15	0.7	-	-	15	0.7	-	-
Pinus densiflora	512	25.4	476	23.6	-36.0	-7.0	388	19.2	-124.0	-24.2
Pinus koraiensis	20	1.0	14	0.7	-5.0	-30.0	14	0.7	-6.0	-30.0
Pinus rigida	311	15.4	282	14.0	-29.0	-9.3	113	5.6	-198.0	-63.7
Quercus acutissima	20	1.0	65	3.2	45.0	225.0	47	2.3	27.0	135.0
Quercus mongolica	371	18.4	18	0.9	-353.0	-95.1	55	2.7	-316.0	-85.2
Quercus serrata	28	1.4	204	10.1	176.0	628.6	221	11.0	193.0	689.3
Quercus variabilis	677	33.6	872	43.3	195.0	28.8	1150	57.0	473.0	69.9
Quercus aliena	0	-	29	1.4	29.0	-	3	0.1	3.0	-
Robinia pseudoacacia	62	3.1	40	2.0	-22.0	-35.5	10	0.5	-52.0	-83.9
Total Area	2,016									

4. Characteristics of Forest Succession Change in Target Site

The tree species that showed a decreased tendency in the dominant area include as follows; the alien species that cannot reproduce in natural conditions such as *Larix kaempferi, Pinus rigida, Robinia pseudoacacia* (KNA, 2021), the plant species that decrease their distribution as the future climate becomes warmer because of showing the main distribution in cold regions such as *Quercus mongolica*, *Pinus koraiensis* (Kim, 1992), and the plant species that decrease their distribution according to succession because they were planted in a place other than their original natural habitat such as *Pinus densiflora* (Kim, 2006).

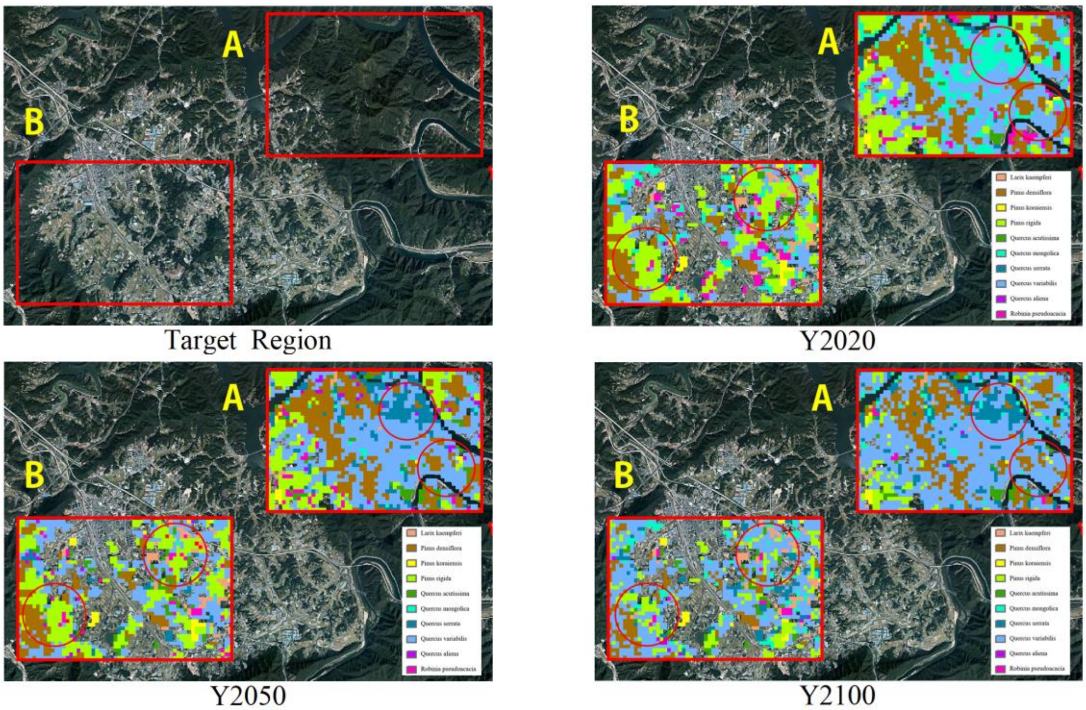

Fig. 6: Status of Forest Type by Major Year based on SSP2-4.5 Scenario

Discussion

The analysis revealed that the tree species showing a decreased tendency in the future dominant area are *Quercus* spp., and their main distribution is cool-temperate southern-submontane and Warm-temperate montane, which are the regions with a relatively warm climate in terms of the syngeographical perspective. These include *Quercus serrata, Quercus variabilis, Quercus aliena*, and *Quercus acutissima* (Kim and Kim, 2017). In particular, it was found that a tree species with the largest dominant area in Okcheon-gun is *Quercus variabilis*, exhibiting a high expansion rate of dominant area in the place where *Pinus densiflora* and *Quercus mongolica* decrease (refer to Fig. 6).

In Okcheon-gun, Region B showed a greater change rate in dominant tree species than region A (Table 2). Such a result seems to be caused by a higher human interference because the artificial land is distributed widely in region B.

the tree species that showed a decreasing tendency in the dominant area include the alien species that cannot reproduce in natural conditions, cold plant species, and plantation tree species, on the other hand, the tree species with an increasing tendency exhibited a distribution status in a relatively warm climate zone and were identified to be *Quercus* spp. species that represents potential natural vegetation in the Korean forest.

Conclusions

The vegetation succession model (LANDIS-II) employed in this research requires the plant physiological data in order to quantify and spatialize both competition between species and dominant distribution, however, the data from currently distributed species in South Korea are limitedly available. When those data are provided more, the accuracy of succession will be increased.

This research has significance in the research results, which can objectify forest planning, by forest change predictions for 2050 and 2100 using vegetation status, physiology of plants, climate changes, and land cover changes, and then mapping those.

Acknowledgements

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