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YSSP Report
Young Scientists Summer Program

Assessment of Afforestation Options with Special Emphasis on Forest Productivity and Carbon Storage in North Korea

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Approved by

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Program: Biodiversity and Natural Resources Program (BNR)
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Abstract

North Korea is a country in the Mid-Latitude Ecotone suffering from forest degradation due to climate change and deforestation. An efficient long-term and integrated restoration plan is still missing in the country. In this context, our research addressed the question if we can develop an optimal forest restoration plan for North Korea considering regional and national strategies based on biophysical modeling. This study aims to model afforestation scenarios and assess future management options. We mapped the potential afforestation area and simulated afforestation scenarios by using the Global Forest Model (G4M) being developed at IIASA. The methodology was built upon work and experience gained from modeling afforestation scenarios for South Korea which has been carried out jointly between Korea University (KU) and IIASA's AFE group over the past years. The model used high-resolution of time series satellite data, land cover maps and yield tables provided by KU. For each scenario, we assessed the forest restoration options informed by national forest management strategies in North Korea. The analysis delivers important information to policymakers and technical officials establishing regulations and action plans for forest management in the North Korea.

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1. Introduction

The Mid-Latitude ecotone (MLE) refers to the ecological transition zone where the region is described by complex phenomenon in land degradation (Song et al., 2017). In particular, forest degradation in MLE has great risks on environmental sustainability and human well-being because of low adaptive capacity and large population. In the MLE, about 50 % of the global population and most of the world development and poverty are located (Kummu & Varis, 2011; Moon et al., 2017), and thereby, the levels of adaptive capacity such as economic status or social infrastructure varies within the MLE. Even though there are recent efforts to restore forest and vegetation area for reducing disaster risk, a lack of adaptive capacity and the absence of sufficient restoration planning are resulting in low restoration efficiency and incapability of long-term management.

North Korea is one of the fast-degrading countries in mid-latitude and has been belonging to nation of extreme degradation (Maplecroft, 2012; Lee et al., 2019). Since 1980s North Korea has suffered from forest denudation by climate change and deforestation because of fuel production by human activities (Song et al., 2019). There is a growing interest in restoration of North Korea worldwide. However, it was difficult to derive effective restoration results because most the previous attempts focused on a short-term restoration plan without developing a master plan based on scientific modeling. Therefore, restoration plan based on scientific modelling should be developed at the earliest possible moment to prevent further land degradation and to attain sustainable forest management system in North Korea.

The development of multiple scenarios has a great use on forest management planning in terms of choosing the best possible implementation under the constrained capacity, as afforestation is directly linked to many other national and regional planning (Lee et al., 2018). In this study, we aim to develop multiple afforestation scenarios as a prerequisite for establishing optimal restoration plan mainly focusing on North Korea. Along with restoration plan of North Korea, the quality of life of North Koreans and the sustainability of the East Asian environment will be enhanced. It is necessary to secure diverse restoration scenarios considering climate change scenarios, tree species, disaster risk, land component, regional adaptive capacity, and management level to select utmost restoration plan. Therefore, the future dynamics of restored forest will be assessed.

Research question

The research question of this study is **"Can we establish an optimal restoration plan considering national strategies based on scientific modeling in North Korea?"**.

Objectives

This study aims to develop afforestation scenarios and to assess future afforestation effect in North Korea reflecting environmental factors and management strategies to provide reasonable restoration plan. The process of deriving restoration plan from multiple scenarios is as follows:

a. Select the potential afforestation area using global or regional remote sensed data.

b. Construct geo-spatial afforestation scenario options considering tree species, carbon storage and wood production in terms of multifunctional forest management related to models developed by IIASA, G4M (The Global Forest Model) as a basis for decision making.

c. Assess forest benefit according to the afforestation scenario and derive the optimal forest management plan

2. Material and Method

To identify potential afforestation effect in North Korea, modeling results from the Global Forest Model (G4M) together with the national restoration plan and strategy were considered (Fig.1). In this process, applicable spatial afforestation scenarios were developed and applied for multi-forest management.

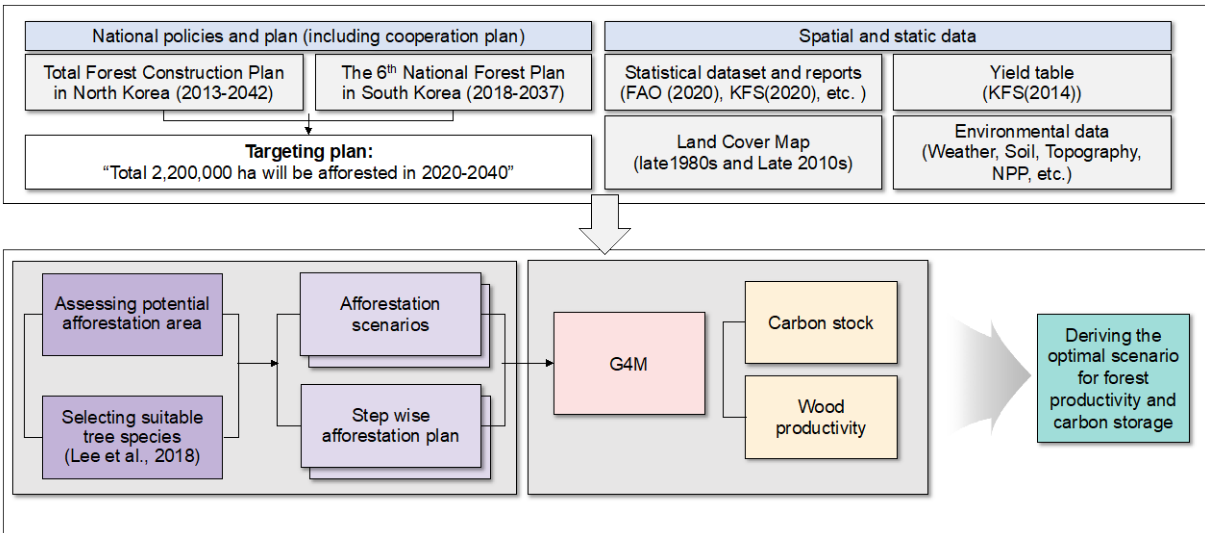


Fig. 1 Research flow for effect of potential afforestation in North Korea

In this study, we set the targeting afforestation plan in North Korea by reviewing national policies and restoration plans for maximum possible afforestation areas. Since there were limitations to collecting statistical and spatial data in North Korea, the global environmental datasets, South Korea's Forest field dataset and land cover map were used.
In order to identify potential afforestation effect in North Korea, afforestation scenarios and stepwise afforestation plan were developed for the potential afforestation area. Afterward, G4M simulated the benefits of forests in terms of future forest biomass and wood productivity. As the result, possible positive effects and possibilities of afforestation in North Korea were presented.

01. Assessing potential afforestation area

Previously, various studies have been conducted on analyzing the degraded land in North Korea. However, there are limitations on understanding actual figures and spatial distribution of area depending on the purpose of study, the definition of forest, etc. Generally, it is known that forest degradation in North Korea accelerated from the mid-1980s to the 1990s (Song et al., 2012).
In order to establish a potential afforestation area, the areas requiring afforestation were divided according to the following definitions:

1. Quantitively degraded area
   : Non-forest converted from forest (agriculture land, grassland, and bareland in mountainous area)
   : Spatially fragmented forest area

2. Qualitatively degraded area
   : Area where the forest productivity has been decreased

The first one is a quantitatively degraded area. This is the area that has been fragmented forest, or an area that has been converted into other land cover such as agriculture land, grassland and bareland in a mountainous area. In order to identify the converted areas, land cover maps (late 1980s and late 2010s), obtained by the Ministry of Environment in South Korea with spatial resolution of 30m were used. Also, forest definition from FAO was referred for extracting spatially fragmented forest area (FAO, 2020). The second one is a qualitatively degraded area. This is the area where forest productivity decreases. The MODIS yearly NPP (Net Primary Production) products and Land cover map (late 2010s) were used to identify areas with reduced forest productivity compared to the current forest areas. The areas were assumed that the same meaning with a highly degraded wooded area (FAO, 2020). After then, we extracted each area, and overlapping areas from the two definitions were excluded.

02. Construct geo-spatial afforestation scenarios of various forest species, afforestation area, and forest management

- **Selecting suitable tree species for afforestation**

To select suitable tree species considering environmental and socio-economic situation in North Korea, we reviewed previous studies and reports on native forest species and species required for afforestation in North Korea. Lee et al. (2018) conducted suitability assessment on 23 tree species considering climate-environmental factors for potential restoration strategies in North Korea. Based on the previous study, we re-selected the suitable species based on a list of yield table (KFS and NIFoS, 2020) which serves as a basis for the forest field survey data in South Korea and re-analyzed tree species suitable priority considering major species with a large area within the same 1km grid.

- **Stepwise afforestation plan**

Based on the potential afforestation area and national polices and plans, we set the total 2,200,000 ha as the afforestation target area during 2020 – 2040. The afforestation priority was designed based on environmental topographic factors to afforestation target area in order (Fig. 2).

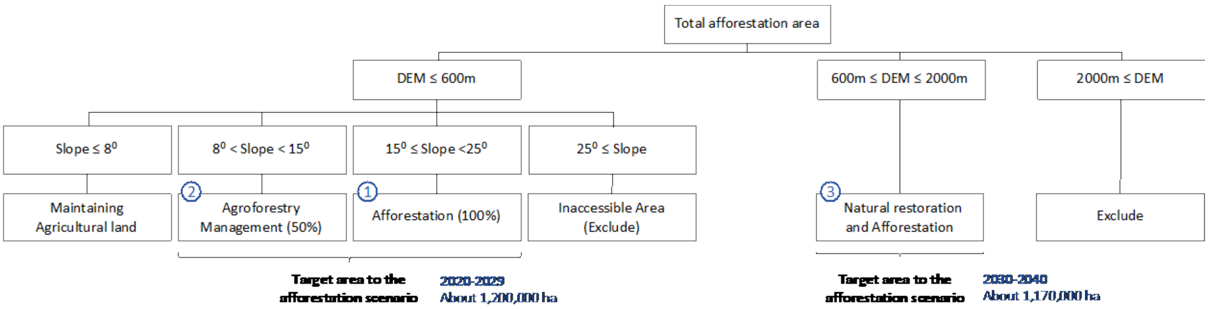


Fig. 2. Afforestation priority considering topographic conditions in North Korea

The 2,000m of altitude is considered as North Korea's tree growth limit line (Kong, 2002), and 600m of altitude is used as a baseline to classify afforestation accessibility. In addition, considering North Korea's past agricultural policy and food security, standards for agricultural policy maintenance and mixed agricultural and forestry policy were set based on 8 and 15 degrees in slope, and accessibility was classified based on 25 degrees. Moreover, we set priorities by considering the accessibility of the neighborhood residents since the continuous logging activities by residents caused acceleration of forest degradation. The SRTM (Shuttle Rader Topography Mission) DEM (Digital Elevation Model) with a 30m spatial resolution was used to produce the slope map.

- **Forest management Scenario**

In this study, two extreme forest management scenarios were designed, to understand the effects of afforestation in North Korea in terms of wood product and carbon absorption (Table 1). The first scenario is leaving the forests in their natural manner after a series of stepwise afforestation. Since forests provide a variety of ecosystem services (biodiversity, habitat conservation) in addition to carbon storage and wood products, the scenario has been designed to minimize ecosystem disturbances. In this scenario, forests continue to accumulate biomass until 2100. The second scenario is harvesting 35,000 ha per year at maximum according to the legal-harvest age of each tree species in South Korea (Kim et al., 2021; KFS, 2018). Forests were harvested for wood, and were re-forested immediately. Both scenarios were designed by using RCP scenarios 4.5 and 8.5, which are available at Korean Meteorological Administration website at a resolution of 12.5 km.

Table 1 Forest management Scenarios for this study

Scenario	Description
1	Future climate change scenario RCP 4.5 and 8.5 No forest management
2	Future climate change scenario RCP 4.5 and 8.5 Final harvest according to the legal final cutting age (~35,000 ha yr^{-1})

- **Methodology for G4M application**

To identify the afforestation effect in terms of carbon storage, G4M was applied in North Korea. G4M is a biophysical model that predicts carbon stock, NPP, potential harvest and optimizes rotation management time (www.iiasa.ac.at/g4m). Based on G4M, we can estimate the impact of forestry actives (afforestation, deforestation, and forest management) on biomass and carbon stocks.
In this study, Site Index (SI) and growth curve of North Korea were derived through 1) NPP model and 2) growth model parameterization based on yield tables, in order to estimate carbon storage per age and to overcome the lack of field data and geo-spatial forest data.

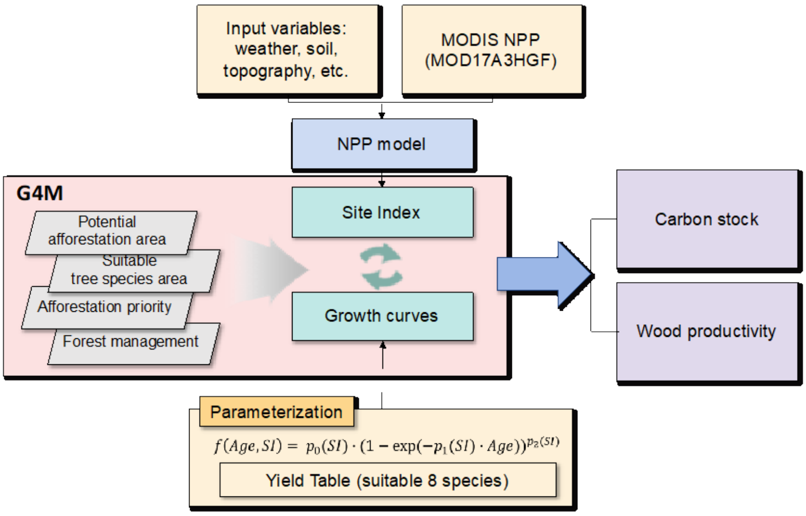


Fig. 3 Methodology for G4M application

In the process of applying the G4M model, the NPP prediction model based on Random Forest algorithm was developed by using monthly precipitation, maximum-minimum-average temperature data of CHELSEA dataset, DEM, Slope, Aspect of SRTM, and soil bulk, soil depth, available water content of Harmonized world soil database v1.2 from FAO to estimate MODIS NPP (MOD17A3HGF) from 2000 to 2018. Then, the model was applied to the RCP 4.5 and RCP 8.5 to estimate future NPPs. All dataset was converted to 1km resolution for modeling.
In addition, in order to parameterize the growth rate by age for each species, a sample of yield table was fitted to Chapman-Richards growth function (Pienaar & Turnbull, 1973) (Equation 1), and predicted NPP values were linked to SI.

$$f(Age,\ SI) = \ p_0(SI) \cdot (1 - \exp{(-p_1(SI) \cdot Age)})^{p_2(SI)}\ (Equation\ 1)$$

where SI is the site index by each tree species, Age is the forest age and p_1, p_2, and p_3 are fitting coefficients for each species.

03. Assess forest benefit according to the afforestation scenario and derive the optimal forest management plan

The amount of carbon storage and CO_2 sequestration in the forest have been calculated for every year until 2100, according to the scenarios designed above. National tree specific coefficients proposed by the Korea Forest Research Institute were used (Equation 2 and Table 2).

$$\mathrm{tCO_2} = \triangle \mathrm{V} \times \mathrm{D} \times \mathrm{BEF} \times (1 + \mathrm{R}) \times \mathrm{CF} \times 44/12 \ \ (Equation\ 2)$$

where $\triangle$V is the growth increment of a stand (m^3), D is the basic density of the wood, BEF is the biomass spreading coefficient, R is the root content ratio, CF is the carbon fraction (biomass to carbon, IPCC default = 0.5), and 44/12 is the stoichiometric ratio of CO_2 and C.

Table 2 Carbon emission factors for each species in South Korea (Korea Forest Research Institute, 2014)

Forest species	Basic wood density (D)	Biomass expansion factor (BEF)	Root/Shoot ratio (R)
Pinus rigida Mill.	0.504	1.325	0.362
Liriodendron tulipifera	0.458	1.26	0.234
Quercus acutissima	0.721	1.45	0.313
Pinus densiflora	0.419	1.483	0.258
Quercus mongolica	0.663	1.603	0.388
Larix kaempferi	0.453	1.335	0.291
Betula platyphyllac	0.558	1.388	0.349
Pinus koraiensis	0.408	1.812	0.283

We can identify and analyze which areas could benefit from effective CO_2 sequestration from afforestation based on the results. Afterwards, to identifying future CO_2 sequestration as a primary result, more diverse options can be added to suggest sustainable forest management options to North Korea. Afterward, in regions with conflicting management measures, policy makers will be presented with various options to choose from.

3. Result and Discussion

01. Assessing potential afforestation area and suitable tree species

A total of 3,215,551 ha was derived according to the potential afforestation area defined in this study (Fig.4). The suitable species that can be planted in potential afforestation areas were selected by those that exist in both the previous study (a) and yield table list (b), as shown in Fig 5. The selected tree species included 4 coniferous trees (*Pinus densiflora*, *Pinus*, *Larix kaempferi*, and *Pinus rigida*) and 4 deciduous trees (*Quercus mongolica*, *Quercus acutissima*, *Betula platyphylla*, and *Liriodendron tulipifera*).

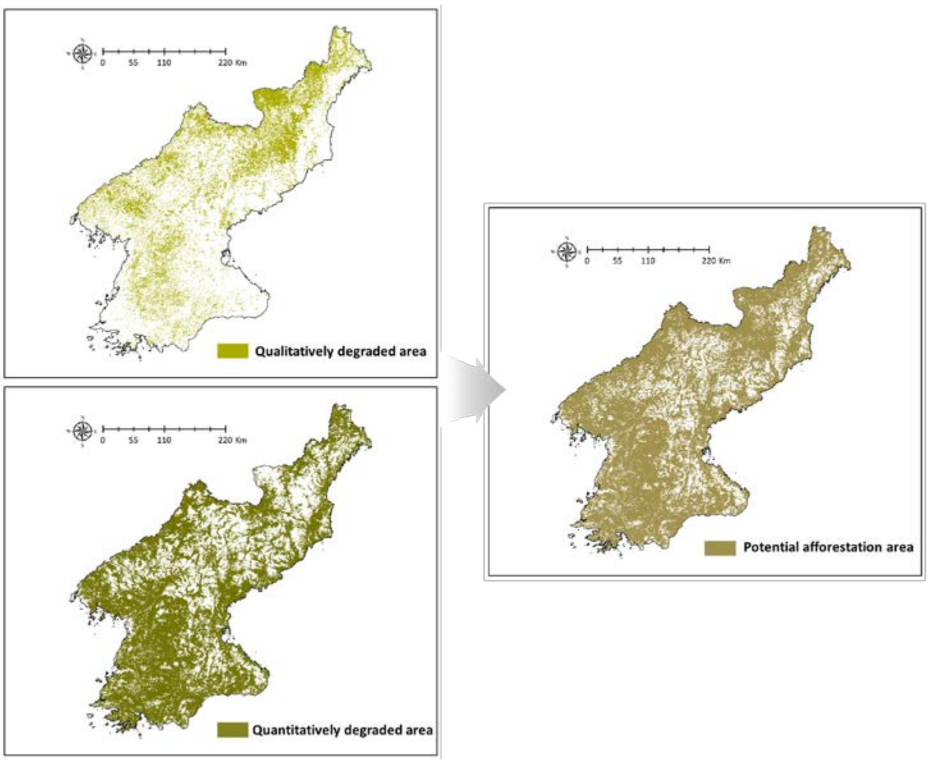


Fig. 4 Potential afforestation area

Type	Native Tree species (Priority)	Introduced Tree species (Priority)
Coniferous Tree	Pinus densiflora Siebold and Zucc.	Larix kaempferi (Lamb.) Carriere
	Pinus koraiensis Siebold and Zucc.	Pinus rigida Mill.
	Larix olgensis var. koreana (Nakai) Nakai	Pinus strobus L.
	Abies holophylla Maxim.	
	Abies nephrolepis (Trautv. ex Maxim.) Maxim.	
	Picea jezoensis	
	Picea koraiensis Nakai	
	Pinus thunbergii Parl.	
Deciduous Tree	Quercus mongolica Fisch. ex Ledeb.	Robinia pseudoacacia L.
	Quercus acutissima Carruth.	Liriodendron tulipifera L.
	Betula platyphylla var. japonica (Miq.) H. Hara	
	Fraxinus rhynchophylla Hance	
	Fraxinus mandshurica Rupr.	
	Tilla amurensis Rupr.	
	Zelkova serrate (Thunb.) Makino	
	Castanea crenata Siebold and Zucc.	
	Juglans regia L.	
	Populus nigra var. italic Koehne	

(a)

Type	Scientific name
coniferous forest	Pinus densiflora (in Kangwon province)
	Pinus densiflora (in the Central region)
	Pinus rigida Mill.
	Pinus koraiensis
	Larix kaempferi
	Chamaecyparis obtusa
deciduous forest	Quercus acutissima
	Quercus variabilis
	Quercus mongolica
	Betula platyphylla
	Liriodendron tulipifera

(b)

Fig. 5 Consideration of suitable tree species in North Korea; (a) Suitable tree species (Lee et al., 2018) and (b) List of tree species in yield table of South Korea (KFS and NIFoS, 2020).

Based on the suitability reanalysis, Fig. 5 showed the results of suitable species distribution by each species. Overall, *Pinus koraiensis* and *Pinus rigida* were widely distributed in North Korea. And *Liridendron tulipifera* and *Larix kaempferi* were distributed in relatively high-altitude regions.

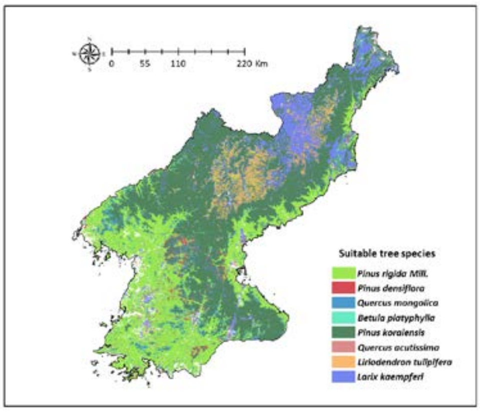
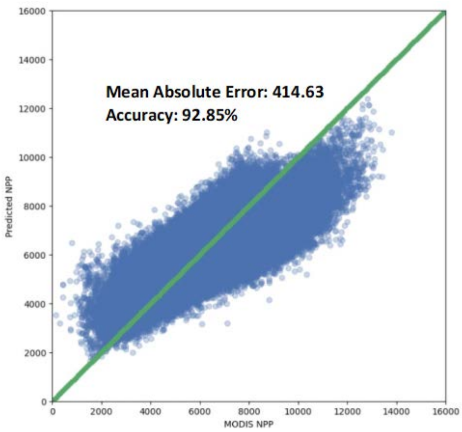
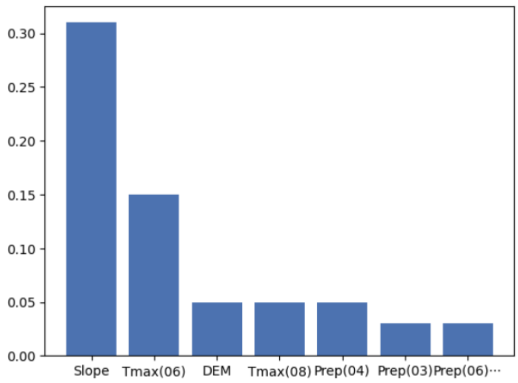


Fig. 6 Potential suitable tree species distribution

02. Estimation of Future NPP for dynamic growth model in afforestation target area

As the first step for the application of the G4M model, the NPP prediction model based on the Random Forest algorithm was developed in the potential afforestation areas (Fig. 7). Based on the result, Fig. 7(a) showed that the lower the MODIS NPP value, the more overestimated the prediction value, and the higher the MODIS NPP value, the more underestimated prediction tendency. The mean absolute error was 414.63 and the accuracy was about 92.85 %. In addition, the NPP was highly related to slope, altitude, max-temperature, and precipitation during vegetation growing season compared other factors.





(a) **(b)**

Fig. 7 Developed NPP model (a) and major factors about the NPP model (b)

Based on the NPP model, we estimated the yearly future NPP values over the 2020-2100 years by using future climate scenarios. Fig.8 and Fig.9 showed every 10-years averaged values of NPP prediction by using RCP 4.5 and RCP 8.5 respectively.

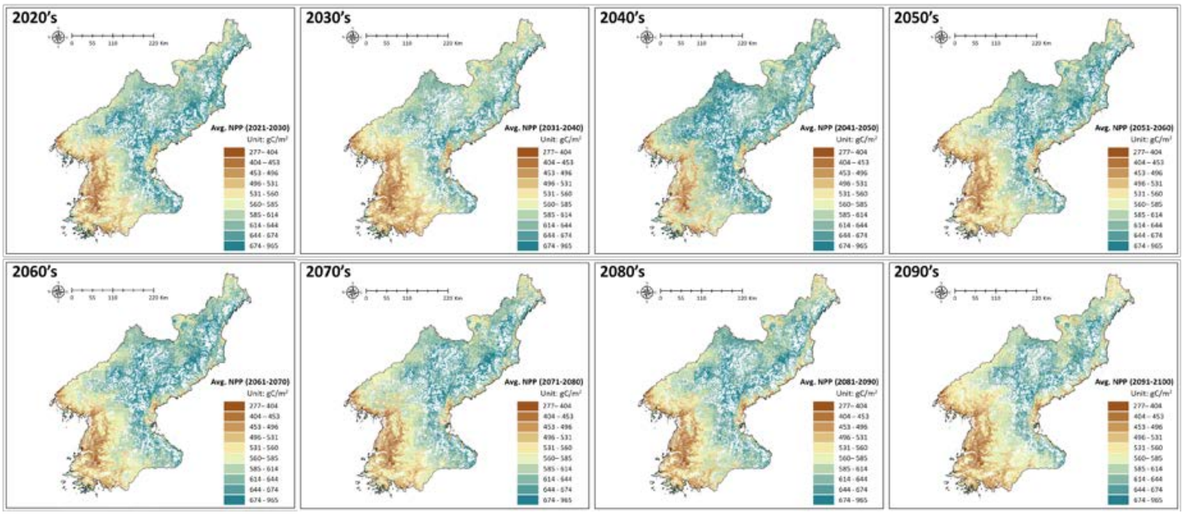


Fig. 8 Predicted NPP according to the RCP 4.5 scenario

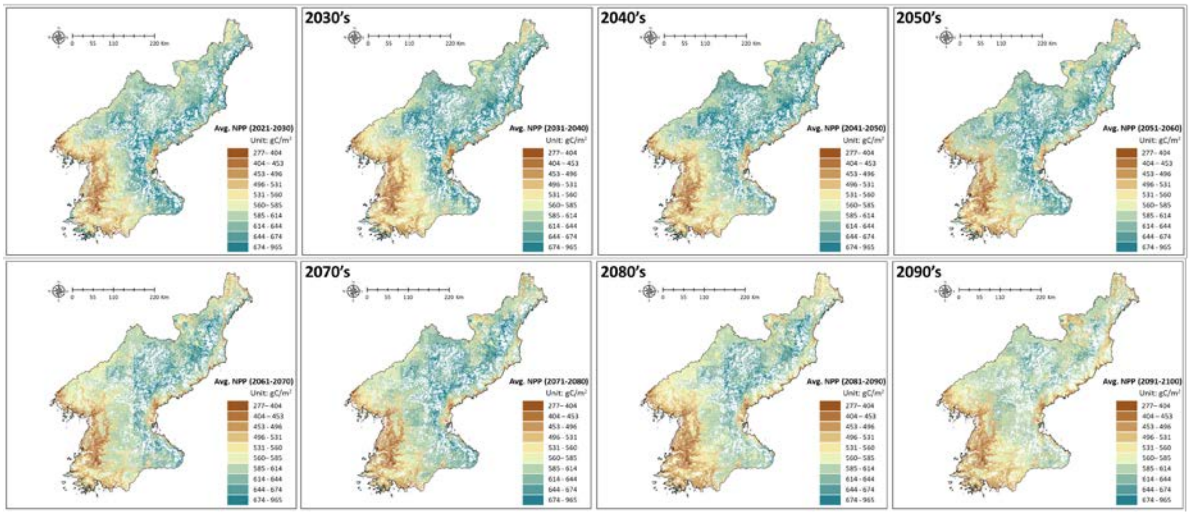


Fig. 9 Predicted NPP according to the RCP 8.5 scenario

Both results showed that the overall tendency of NPP to mainly decrease in under 250 m of altitude region with urban areas (mainly western region), while NPP relatively decreases less in above 1,000m of altitude region (mainly north-eastern region). These patterns were shown due to the impact of topography, especially slope factor and temperature, which were cited as key factors in NPP estimation. In addition, the NPP prediction based on the RCP 8.5 showed that the NPP values were relatively decreased with climate change compared to NPP based on the RCP 4.5. It means that the overall trend of NPP (forest productivity) decreases despite the high fluctuation of the future climate scenario. Therefore, it is important to consider the controlling forest management options such as intensity of forest management and tree species change to adapt to climate change.

03. Parametrization of growth curve for each tree species

Based on the Chapman-Richard growth function and yield tables, tree parameters (p_0, p_1, and p_2) according to age and SI were estimated, and the relationship between stem volume and age were produced by each tree species (Fig. 10).

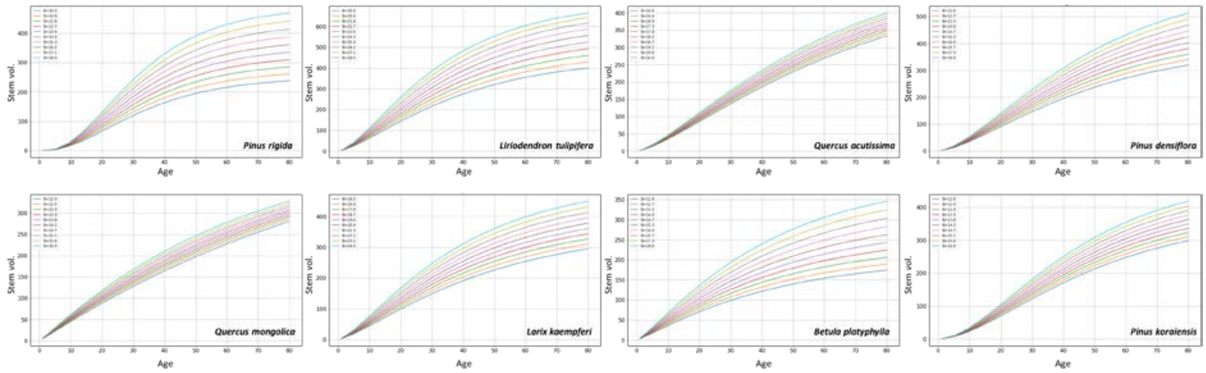


Fig. 10 Parametrization of growth curve for each tree species based on the yield table

04. Estimating CO2 sequestration

The yearly amount of CO_2 sequestration maps were produced by using predicted stem volume and carbon emission coefficient. After simulating the annual stem volume of tree species from g4m model, we estimated the stem volume in each scenario. Accordingly, the average stem volume of 4th age-class (31-40 age) tree is estimated to be 150~200 m^3 per ha after afforestation, which is similar to the average amount of South Korea, about 150m^3 per ha. Fig.11 and Fig.12 showed 10-years averaged values of amount of CO_2 sequestration respectively 2050s, 2070s and 2090s.

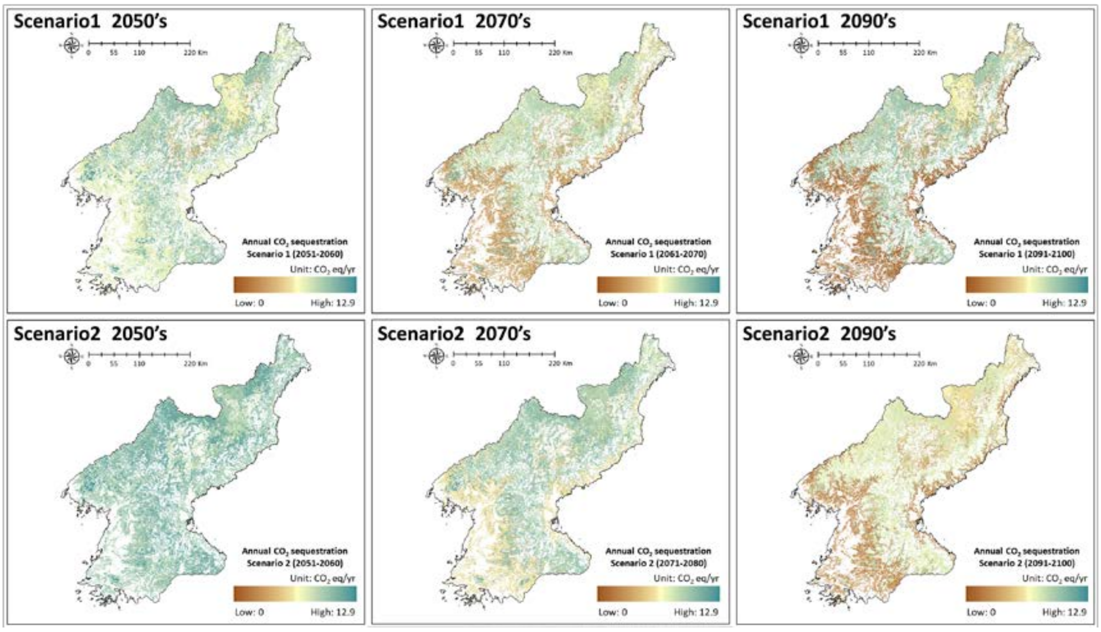


Fig. 11 Average value of annual CO_2 sequestration according to forest management options

The average CO_2 sequestration in Scenario 1 decreased with forest age increment. This can be interpreted as the overall forest stem volume continues to increase when forests are not managed, while the annual growth rate decreases. In addition, the forest growth mainly decreased in the predicted NPP reduction area according to climate scenario. Scenario 2, which manages forest (harvests and re-forestation) according to the legal-harvest age, showed that maintaining relatively high CO_2 sequestration. Since the growth rate is relatively high when forest age reaches about 10-30 years, a large amount of CO_2 can be absorbed in the forest. In particular, average CO_2 sequestration may decrease in the short term in regions with highly concentrated young tree from 2070s to 2100s after re-forestation. However, Scenario 2 has higher potential CO_2 sequestration in the long-term aspect.

Moreover, since we limited the maximum annual management area as 35,000 ha, potential benefits could be expected in term of forest age balance, and ecosystem diversity, etc.

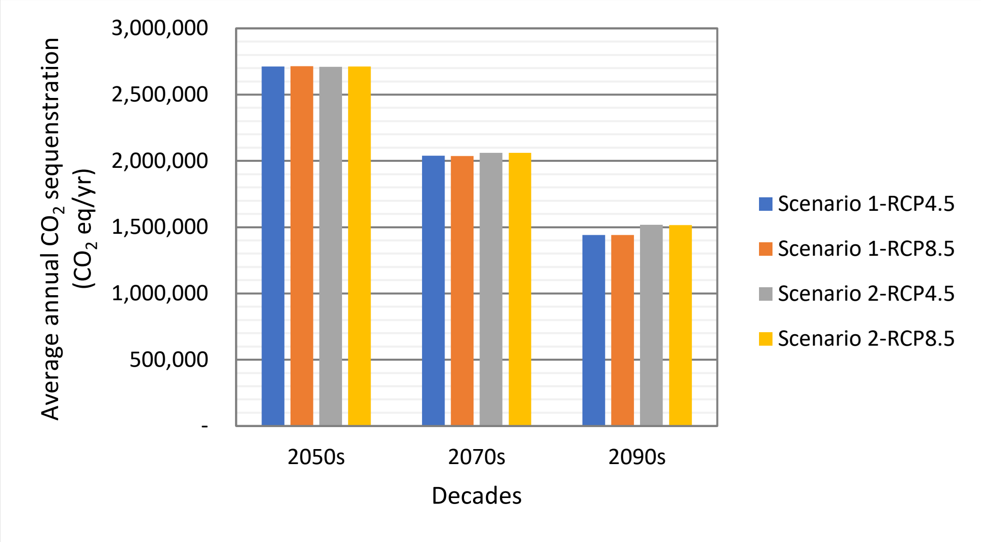


Fig. 12 Comparison of annual CO_2 sequestration according to forest management options (2050s, 2070s, and 2090s)

4. Conclusion and Future work

In this study, G4M was applied in North Korea to present suitable afforestation scenarios considering potential forest benefits. Since the degraded area of North Korea were not precisely known due to the limited access to national data, the potential afforestation areas were redefined and analyzed using spatial data and satellite data. The tree species information, growth curves based on yield table data, and management options for each tree species were spatially mapped. Since the data accessibility was very limited, South Korea's field data and manage strategies were used for G4M modeling. Based on the constructed spatial maps and modeling results from G4M, CO_2 sequestrations from 2021 to 2100 were predicted and differences between scenarios were assessed. In Scenario 2, more carbon dioxides were absorbed at average (about 95,605 CO_2 eq/yr) according to climate scenarios. No significant differences were seen between these scenarios, but RCP 8.5 scenario did show a relatively less absorption compared to RCP 4.5 scenario. Therefore, strategies should be prepared to maintain forest age balance and ecosystem diversity to ensure suitable forest management. Moreover, considering detailed intensity of forest management according to climate change is important. In future studies, various forest management plans will be presented by considering the ongoing part of wood production and additional management option in North Korea, and a spatial (regional) strategy will also be proposed based on the results.

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