EGU General Assembly 2020 BG3.23: Mountain forests under climate change

Understanding and predicting species- and elevation-dependent dynamics in East Asian temperate forests

Moonil Kim[1*], Nick Strigul[2], Elena Rovenskaya[1], Florian Kraxner[1], and Woo-Kyun Lee[3]

(kimml@iiasa.ac.at)

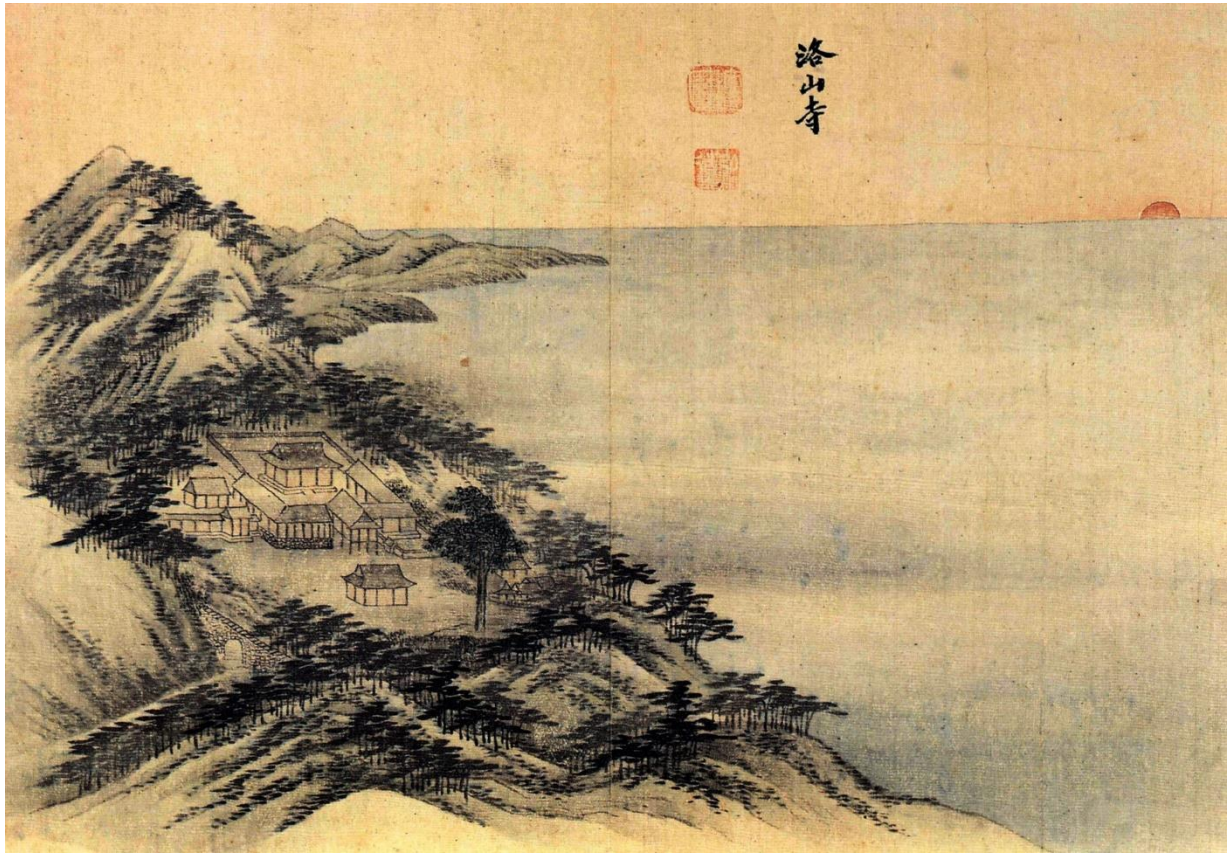
[1]Ecosystems Services and Management Program (ESM), International Institute for Applied Systems Analysis, A-2361 Laxenburg, Austria
[2]Department of Mathematics and Statistics, Washington State University, 14204 Salmon Creek Avenue, Vancouver, WA, 98686, USA
[3]Department of Environmental Science and Ecological Engineering, Korea University, Seoul, 136-701, Republic of Korea

This work was also supported under the framework of international cooperation program managed by the National Research Foundation of Korea (Project No. 2019K2A9A1A02094860).

Introduction

South Korean forests in the past (16-17c)

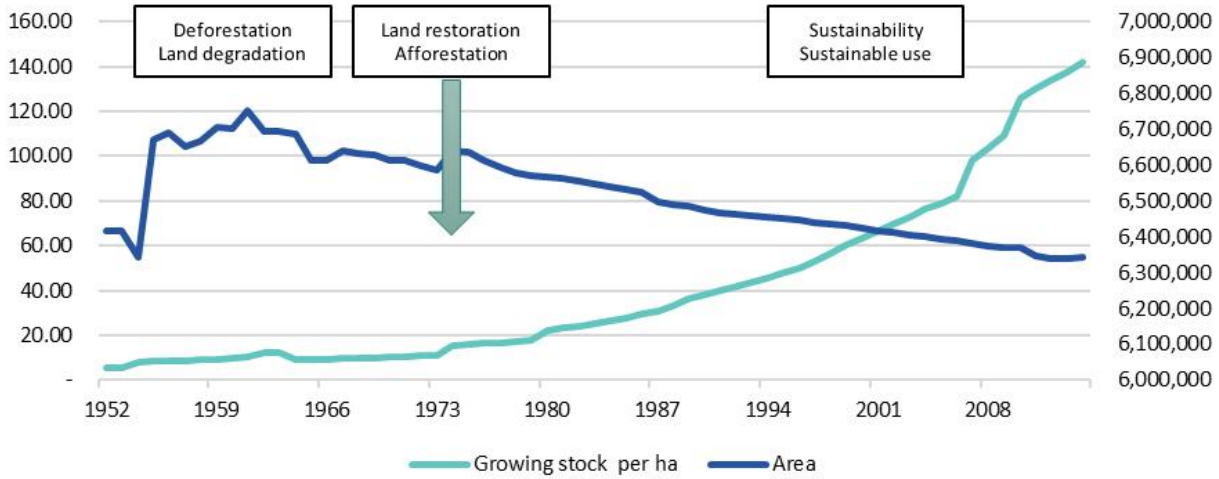
< Sun Jung, Misting in Seoul [長安烟雨] (1676~1759) >

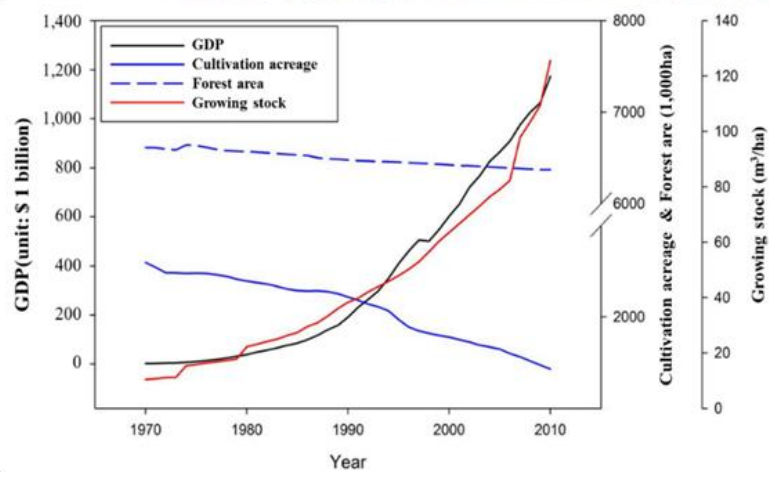


< Hongdo Kim, Naksan Temple [洛山寺] (1745~1810) >

Introduction

South Korean forest (1950-2015) – Deforestation and reforestation (more than 2.5M ha)

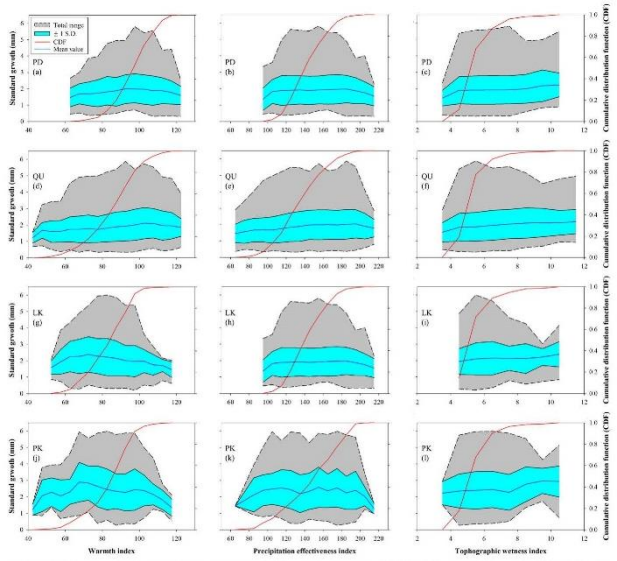




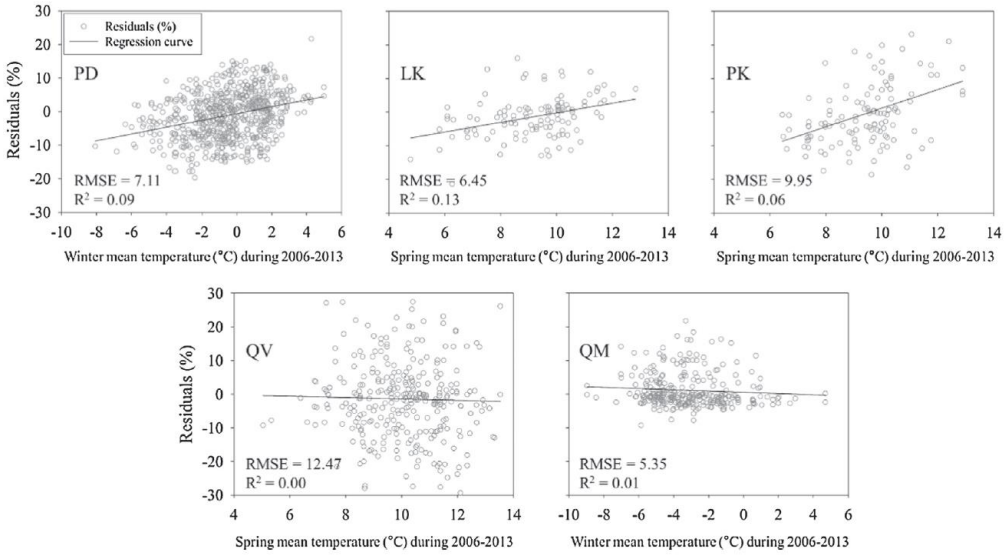
Introduction

Climate change (CC) & South Korean forests

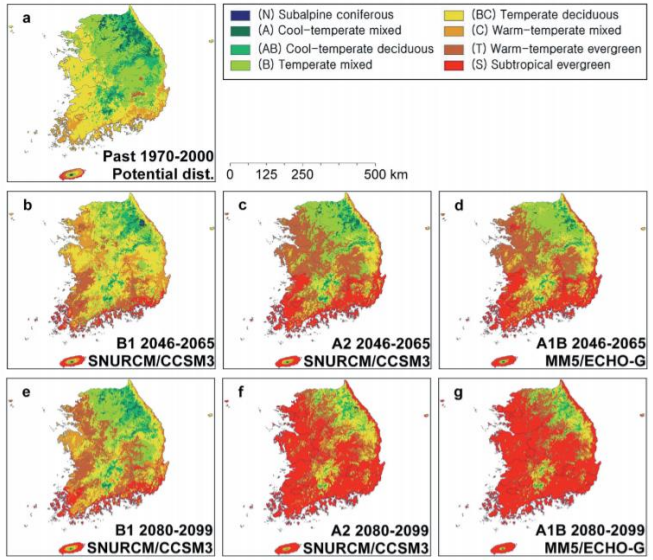
- The average temperature in Korea has risen by more than 2˚C over the last 100 years.
- The impacts of climate change on forest dynamics have been observed differently by tree species and types.



< Impact of CC on tree growth,
Source: Kim et al., 2017 >



< Impact of CC on tree mortality,
Source: Kim et al., 2017 >



< Impact of CC on potential forest distribution,
Source: Choi et al., 2014 >

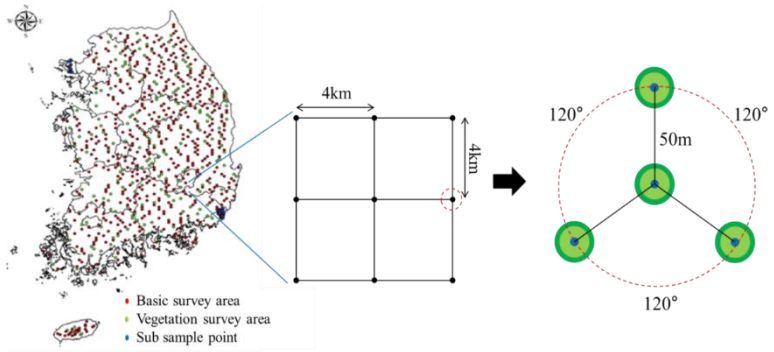
Purpose & Objectives

- **Purpose**
  - ✓ Analysis of species- and elevation-dependent dynamics in East Asian temperate forests
- **Objectives**
  - ✓ Assessment of changes in forest productivity
  - ✓ Assessment of changes in dominant tree species
  - ✓ Assessment and prediction of forest dynamics from stand-scale to national-scale

Data

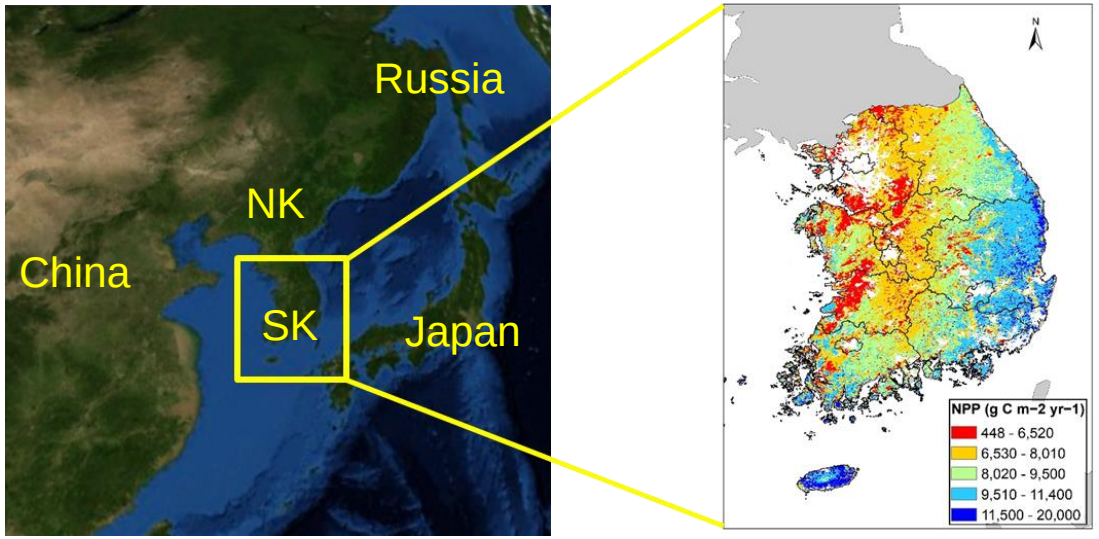
Korean National Forest Inventory (NFI)

- Systematic design on 4 x 4 km national grid
- Identify plot locations on digital photo map
- Total forested plots : 4,000 (16,000 sub plots)
  - sampling intensity : 0.01%
- Five panel system
  - one panel : 800 plots
  - five-year terms [5th (2006-2010), 6th (2011-2015)]



MODIS NPP

- NPP algorithms (MOD17A3) derived from MODIS sensor.
- The data had a spatial resolution of 1 km and were obtained from the materials of the NTSG at the University of Montana (resource link: http://ntsg.umt.edu/data).



Methods

Assessment of productivity

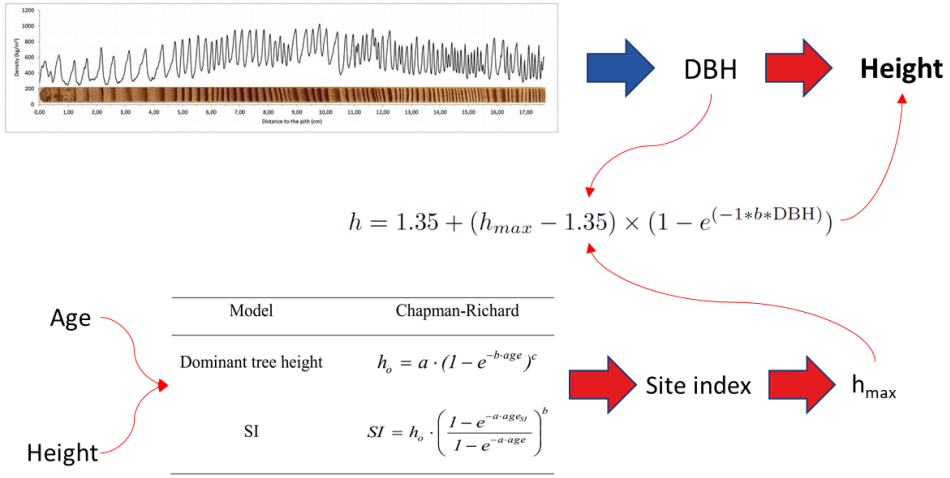
- Inventory plot-based forest productivity
  - Comparing data between 5th and 6th NFI
  - $SAI_i = \left(\frac{V_2 - V_1 - V_{removed}}{t_2 - t_1}\right)$
- Tree-ring based forest productivity
  - C-method (Biondi and Qeadan, 2008)
- Satellite based forest productivity – MODIS NPP
  - NPP

$$\mathrm{NPP} = \sum_{i=1}^{365} GPP - R_m - R_g$$

$$\mathrm{GPP} = LUE_{max} \times 0.45 \times SW_{rad} \times FPAR \times f_{VPD} \times f_{Tmin}$$

Changes in dominant tree species

- The growth of dominant trees heights are estimated by tree increment cores.
  - The increment cores were obtained from six dominant trees of each permanent plot in NFI.



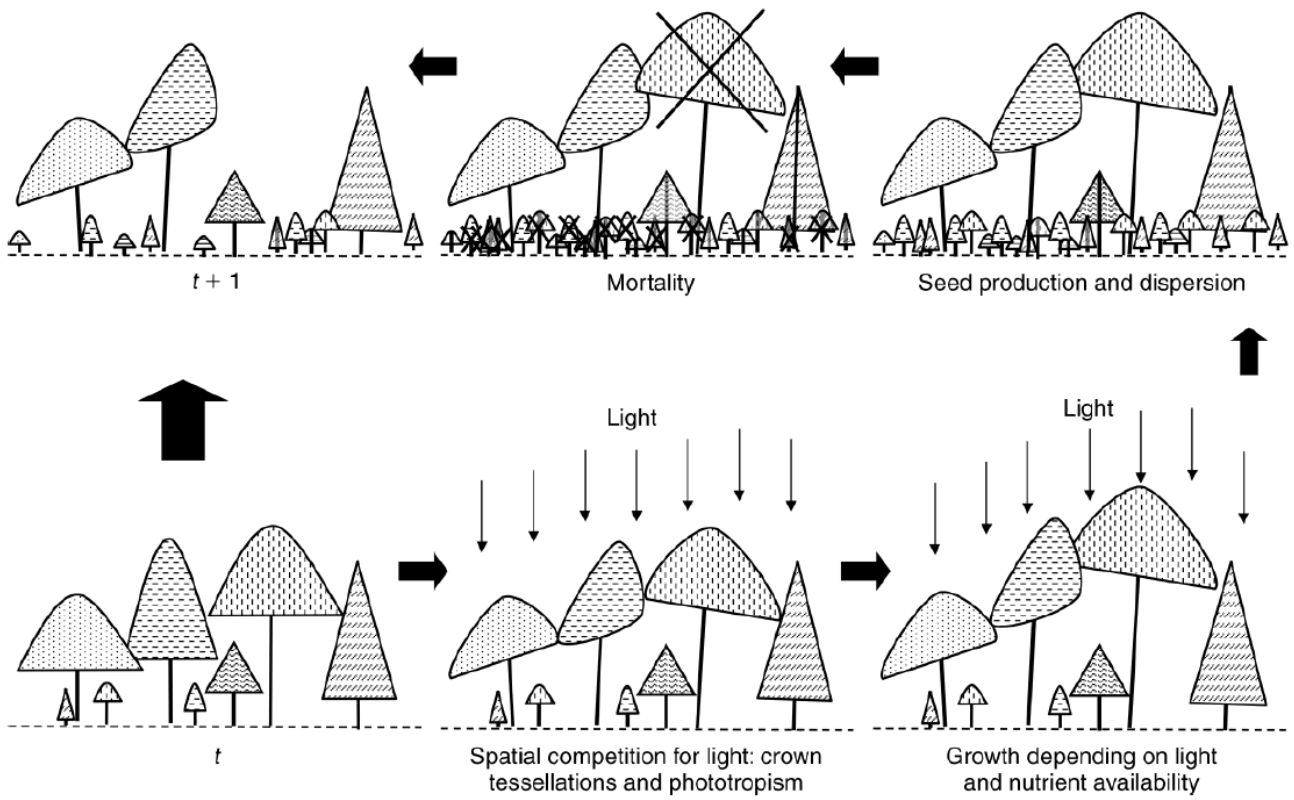
< Flowchart of estimation for tree height growth >

- Model for changes in dominant tree species
  - Logistic regression

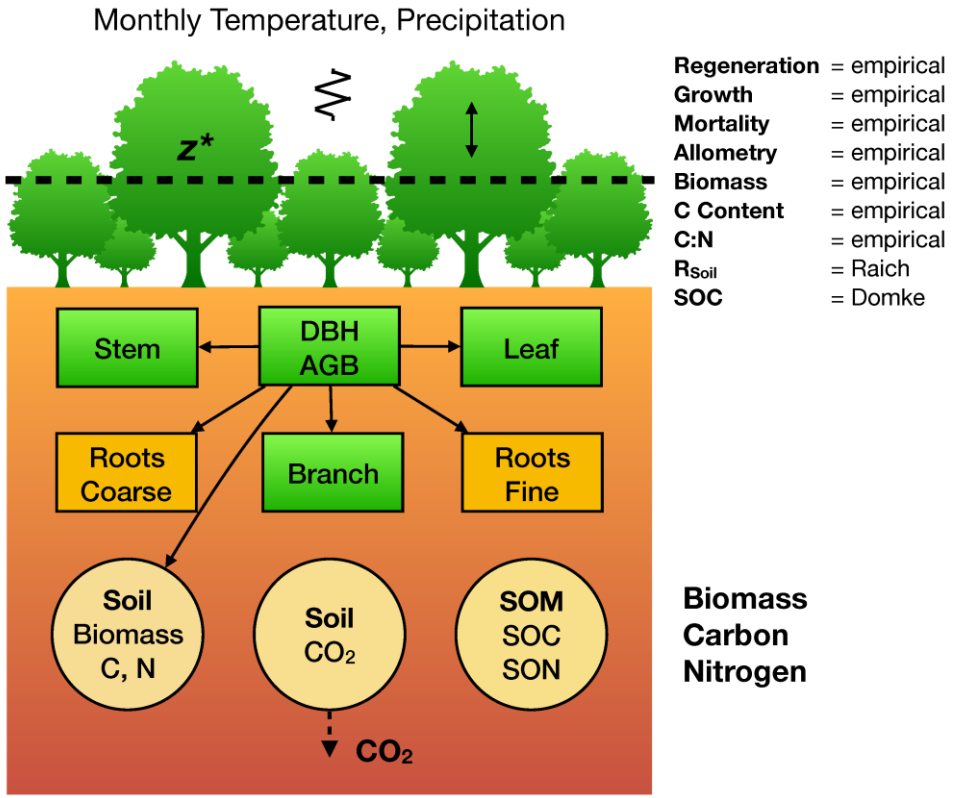
Methods

Estimation and Prediction of forest dynamics

- PPA-SiBGC model used to estimate and predict forest dynamics from 2005-2020



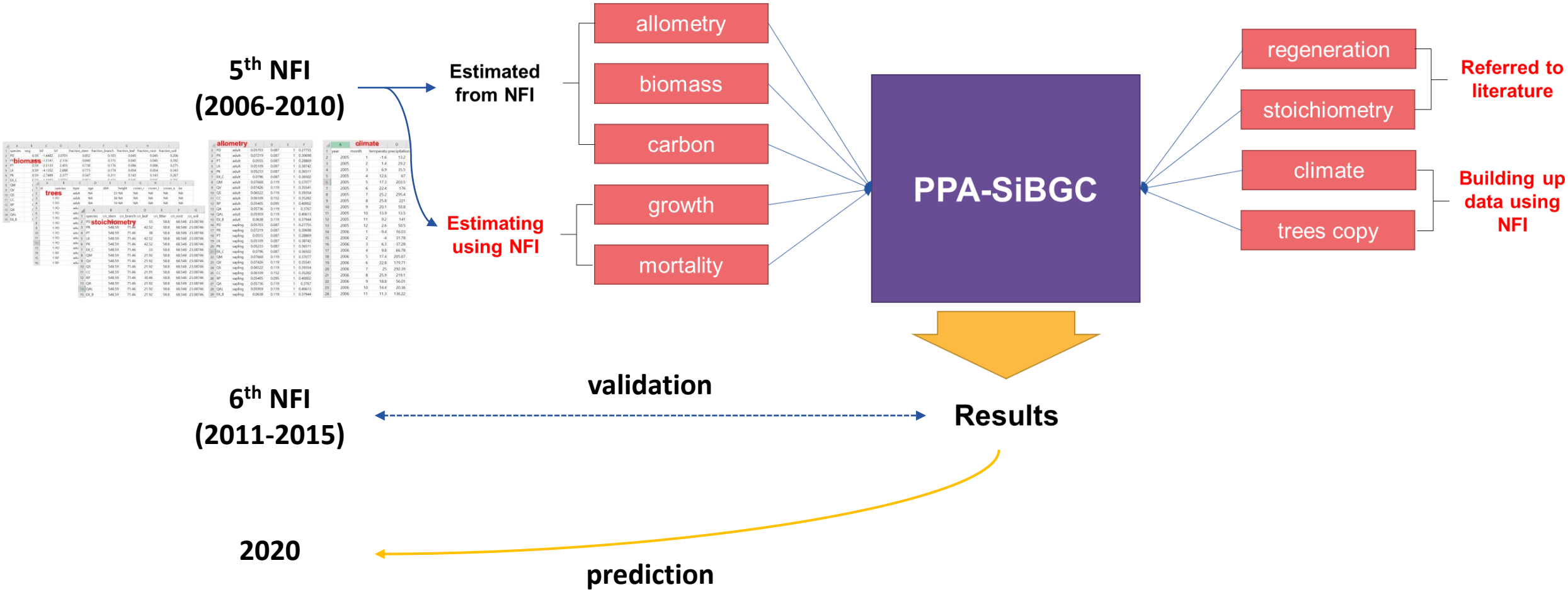
< Individual-based model of forest growth a spatial stochastic process, Strigul et al. 2008 >



< PPA-SiBGC model structure, Raich et al. 2002; Domke et al. 2017.>

Methods

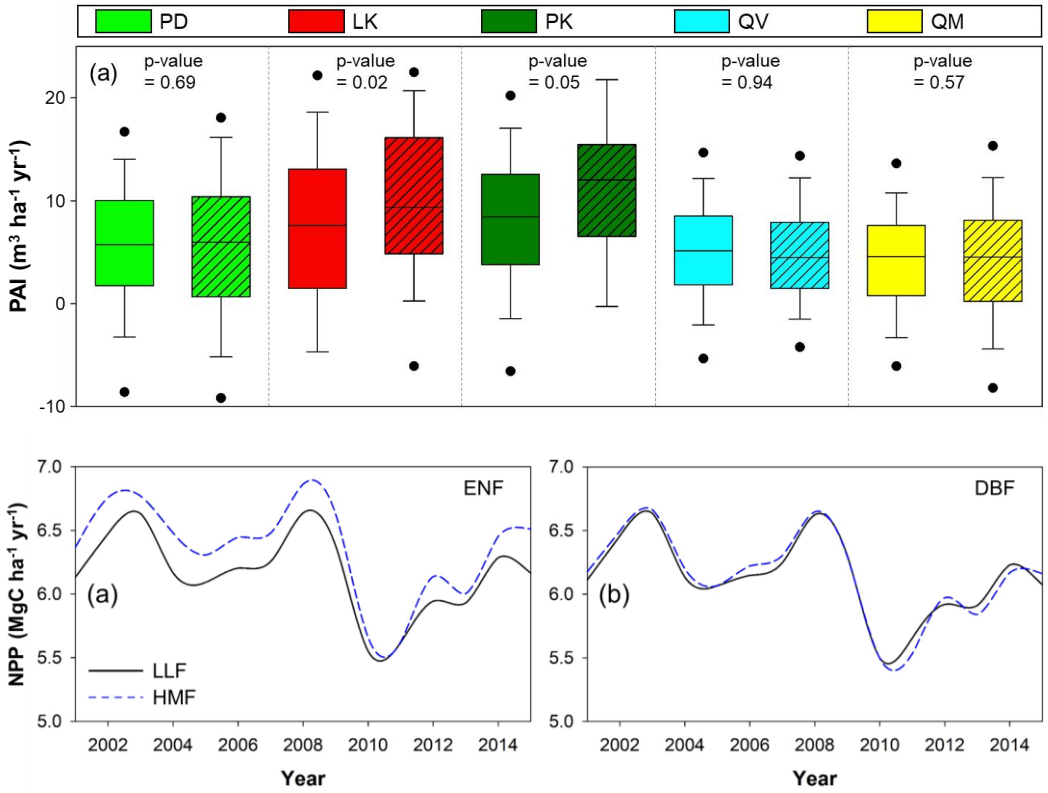
Build the lookup table (LUT) files to run the `PPA-SiBGC'



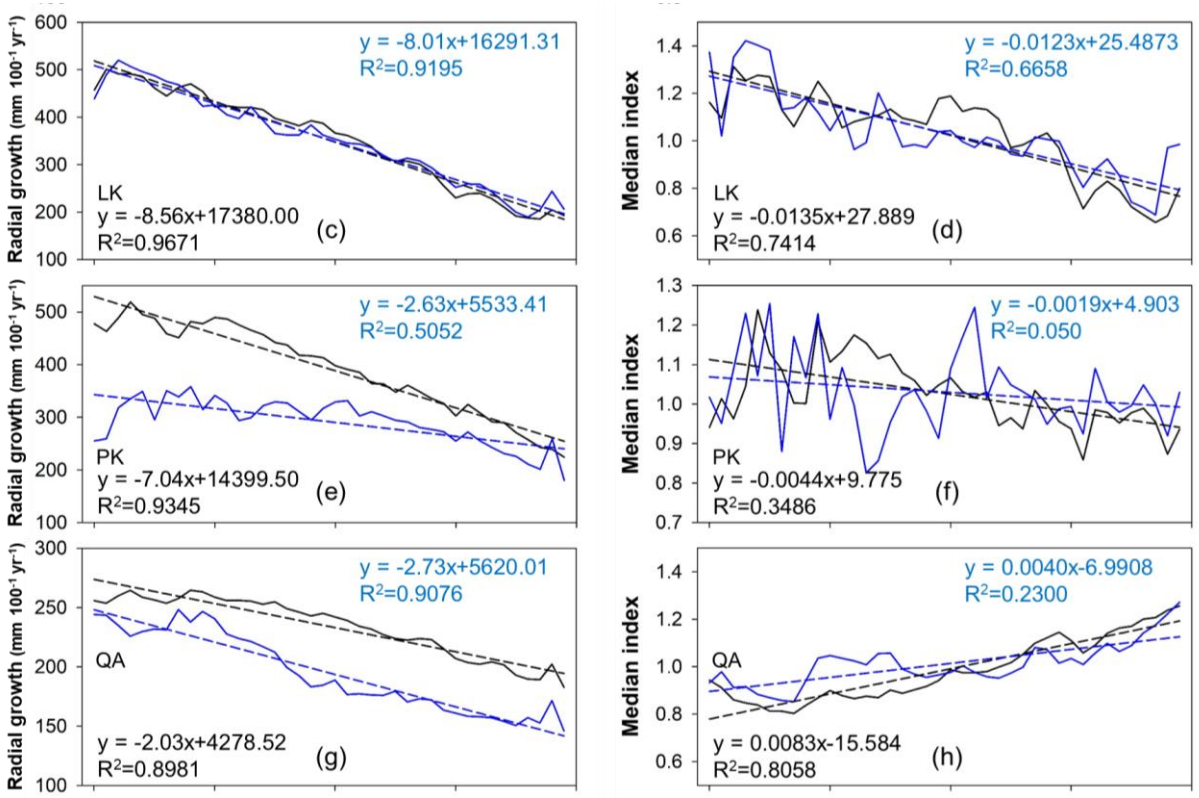
Results – 1) Changes in productivity

- Change in patterns of annual growth are found different depending on tree species and altitude.
- These results (Kim et al., 2020) imply that we should make a management strategy and policy for each tree species and their location.

Source: Kim et al, Species- and elevation-dependent productivity changes in East Asian temperate forests. *ERL* **2020**, 15(3). https://iopscience.iop.org/article/10.1088/1748-9326/ab71a2



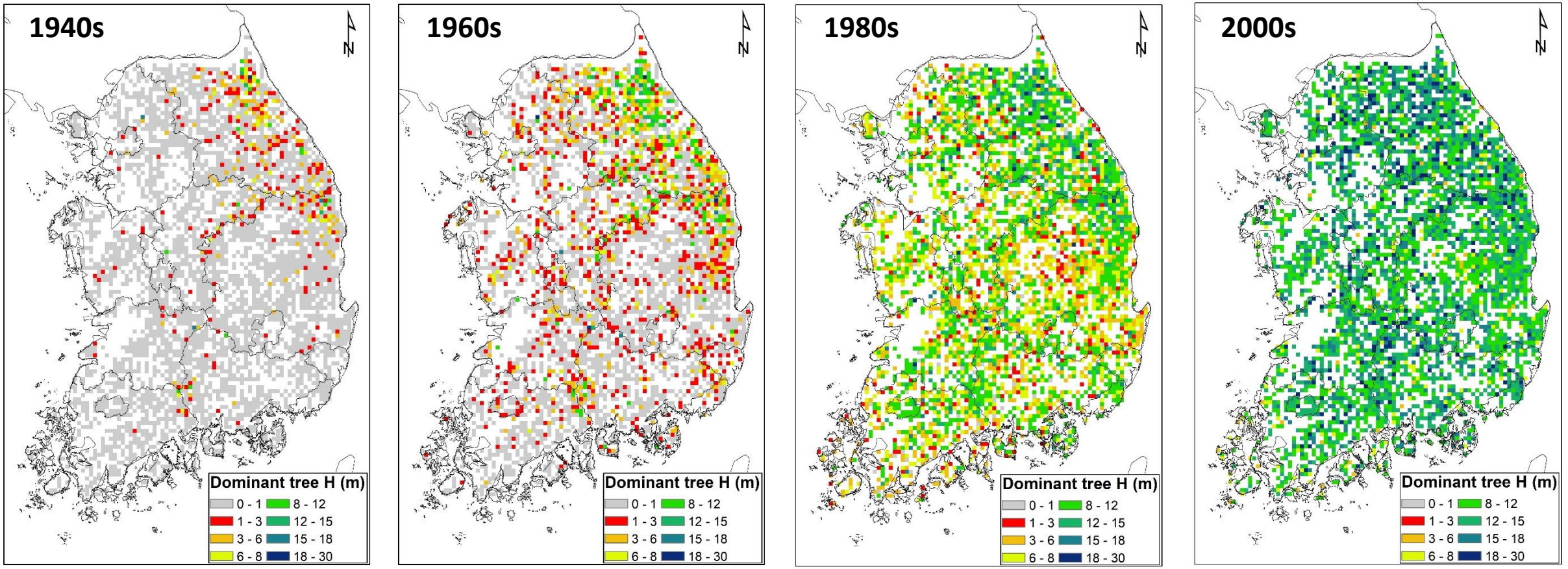
< Growth index of Korean major tree species >



< Tree-ring chronologies and growth index for major Korean tree species >

Results – 2) Changes in the distribution of tree species

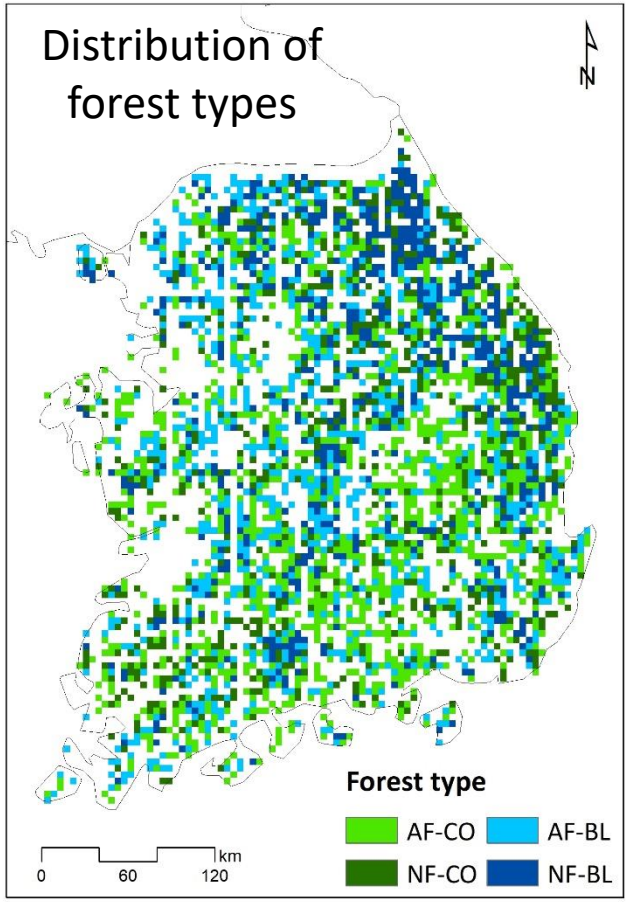
- Our results reveal that the forest area and dominant tree height have been changed dramatically from the 1940s to the 2000s by the national reforestation project with great momentum.
- The high mountain forests are older and higher than at lowland forest.

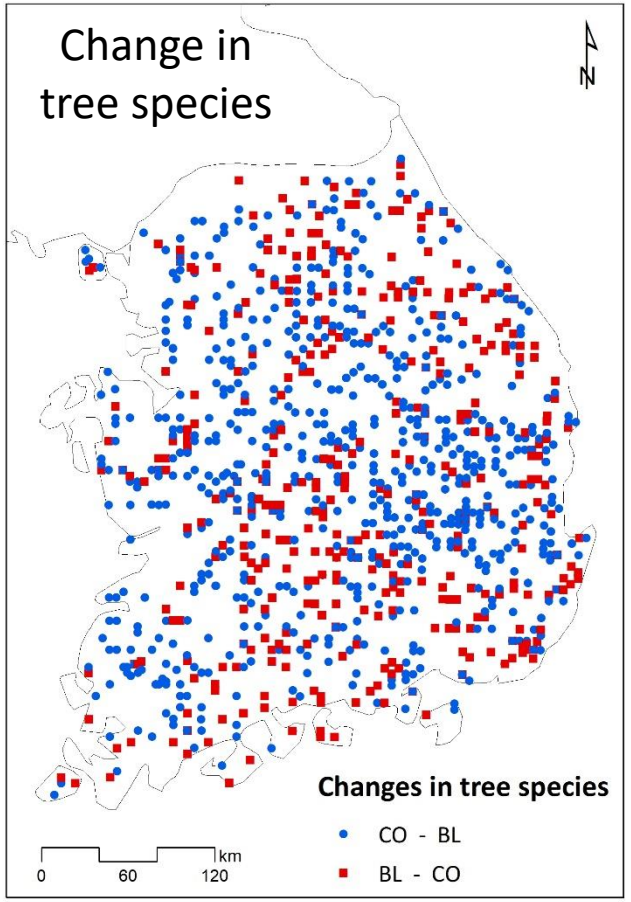


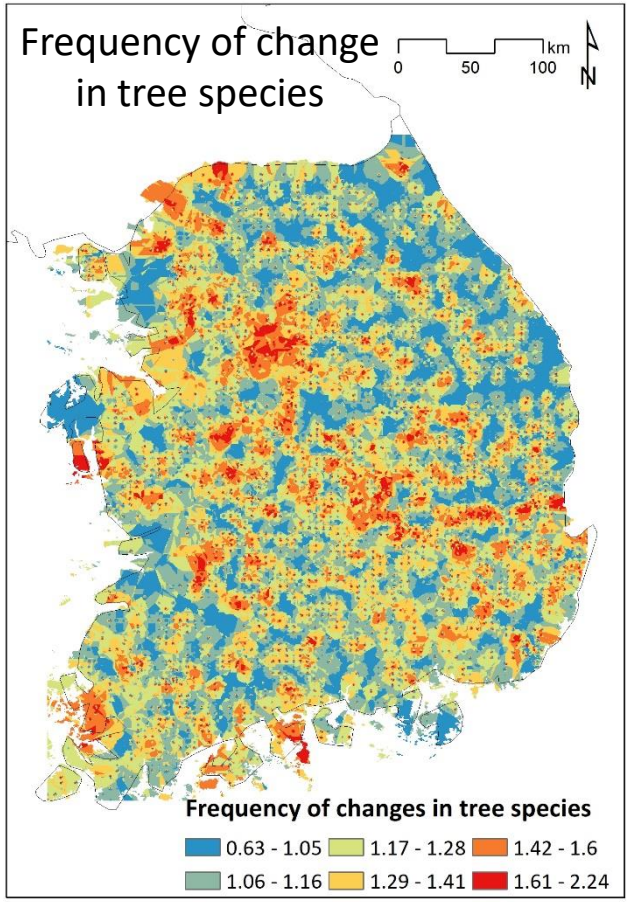
< Estimation of forest area and dominant tree height based on NFI data >

Results – 2) Changes in the distribution of tree species

- The NFI plots are categorized as the artificial/natural forest (AF&NF) and the coniferous/broad-leaved forest (CO&BL). We checked and selected the plots that the dominant tree species of plot changed from CO/BL to BL/CO. The map of changes in tree species is produced using the interpolation method.







Results – 2) Changes in the distribution of tree species

- Logistic models are developed to estimate changes in the dominant tree species using environmental, climatic, and topographic factors.

< Model for AF – CO >

Indicator	Estimate	Std.	Error	z-value	Pr(>|z|)
(Intercept)	-7.8370	9.2190	-0.8500	0.3953	
AGE_S	-0.0604	0.0146	-4.1360	0.0000	***
TEM_DIF	23.1100	8.3130	2.7800	0.0054	**
T_SP_80	2.1200	0.9018	2.3510	0.0187	*
T_SU_80	-1.6260	0.7019	-2.3160	0.0205	*
T_AU_80	1.8640	1.0370	1.7970	0.0723	.
T_WI_80	-2.2550	0.6911	-3.2630	0.0011	**
T_D_SP	-4.9790	2.4780	-2.0090	0.0445	*
T_D_SU	-7.8620	2.7730	-2.8350	0.0046	**
T_D_WI	-14.3300	3.7170	-3.8550	0.0001	***
PRE_80	0.0225	0.0053	4.2580	0.0000	***
PR_SP_80	-0.0264	0.0070	-3.7920	0.0001	***
PR_SU_80	-0.0211	0.0050	-4.1860	0.0000	***
PR_AU_80	-0.0259	0.0059	-4.3570	0.0000	***
PRE_DIF	0.0013	0.0006	2.0660	0.0389	*

< Model for NF – CO >

Indicator	Estimate	Std.	Error	z-value	Pr(>|z|)
(Intercept)	-2.95263	0.88104	-3.351	0.000804	***
ELE	-0.00166	0.000417	-3.984	6.78E-05	***
SL	0.017777	0.008168	2.176	0.029533	*
T_D_AU	4.068589	1.208997	3.365	0.000765	***
T_D_WI	-2.52614	1.190878	-2.121	0.033901	*
PRE_DIF	0.019202	0.007883	2.436	0.014849	*
PR_DI_SP	-0.0284	0.009311	-3.05	0.002287	**
PR_DI_SU	-0.01576	0.007896	-1.996	0.045963	*
PR_DI_AU	-0.01873	0.008645	-2.166	0.030289	*

Results – 2) Changes in the distribution of tree species

- Logistic models are developed to estimate changes in the dominant tree species using environmental, climatic, and topographic factors.

< Model for AF – BL >

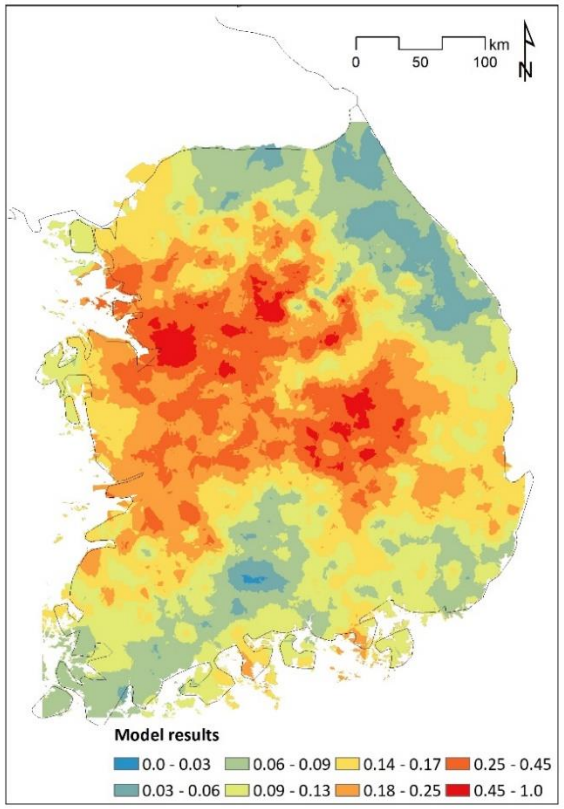
Indicator	Estimate	Std.	Error	z-value	Pr(>|z|)
(Intercept)	-3.6379	1.8902	-1.9250	0.0543	.
AGE_S	-0.0443	0.0158	-2.8130	0.0049	**
DIST	-0.0004	0.0002	-2.3960	0.0166	*
ELE	0.0018	0.0008	2.3850	0.0171	*
T_80	-0.5776	0.3242	-1.7820	0.0748	.
TEM_DIF	-6.3972	2.0412	-3.1340	0.0017	**
T_SP_80	0.9596	0.3807	2.5200	0.0117	*
T_D_SP	3.4276	1.1791	2.9070	0.0037	**
PRE_DIF	-0.0018	0.0006	-2.8950	0.0038	**
PR_DI_SP	0.0117	0.0034	3.4500	0.0006	***

< Model for NF – BL >

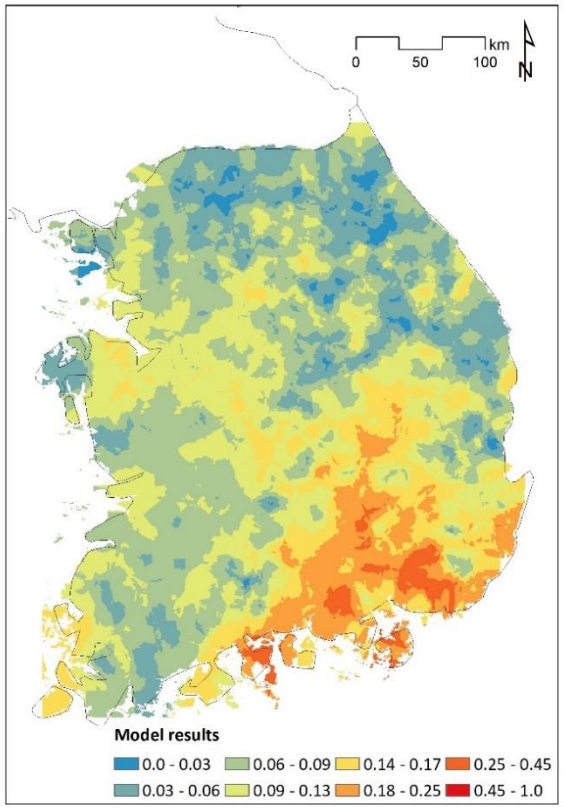
Indicator	Estimate	Std.	Error	z-value	Pr(>|z|)
(Intercept)	15.31943	6.290893	2.435	0.014885	*
AGE_S	-0.04579	0.015316	-2.99	2.79E-03	**
DIST	-0.00039	0.000183	-2.112	0.034716	*
T_SP_80	0.889491	0.377048	2.359	0.01832	*
T_AU_80	-2.02011	0.750021	-2.693	0.007073	**
T_WI_80	1.300431	0.471555	2.758	0.00582	**
T_D_SU	10.26991	2.944954	3.487	0.000488	***
PRE_DIF	-0.00166	0.000816	-2.039	0.04148	*
PR_DI_SP	0.008986	0.004984	1.803	0.071396	.
GTS0_DIF	-0.00172	0.000859	-2.005	0.045003	*

Results – 2) Changes in the distribution of tree species

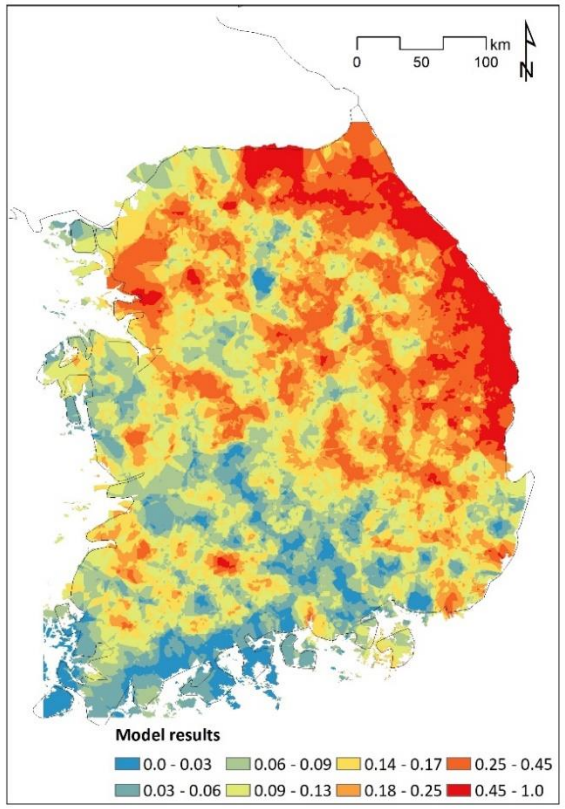
- The chances of changes in tree species of NFI plots are figured out using the logistic model.
- The results from each model for each forest type are different.
- These results implied that climate change can accelerate the changes in the distribution and composition of tree species.



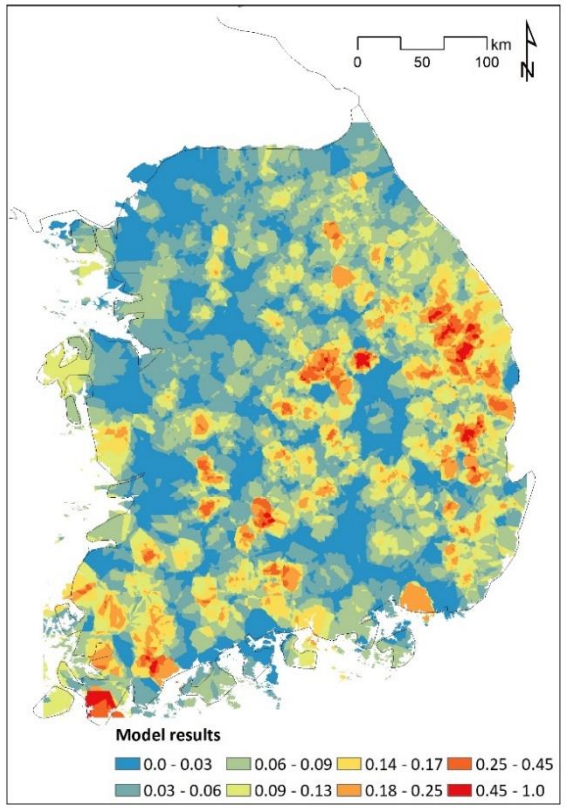
< CO: 1980s-2000s >



< BL: 1980s-2000s >



< CO: 2000s-2040s >

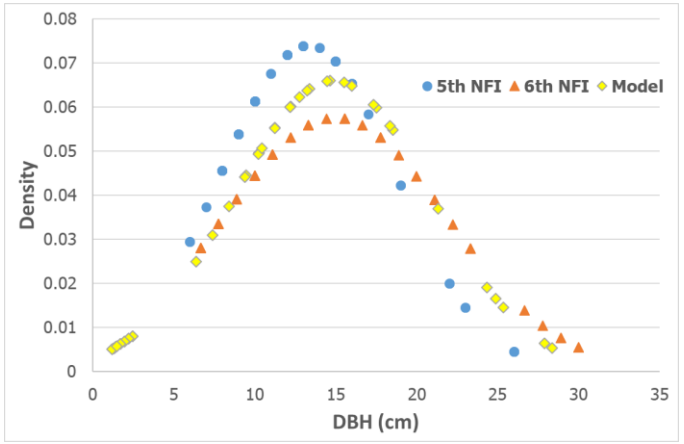


< BL: 2000s-2040s >

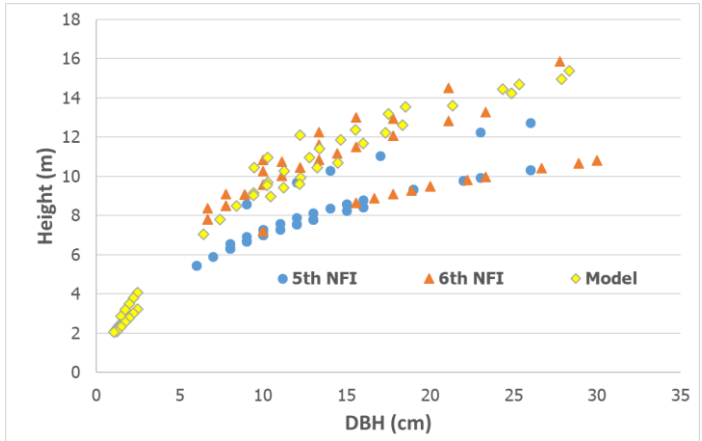
Results – 3) Assessment and prediction of forest dynamics

- PPA-SiBGC showed a strong performance to estimate forest dynamics for each type.

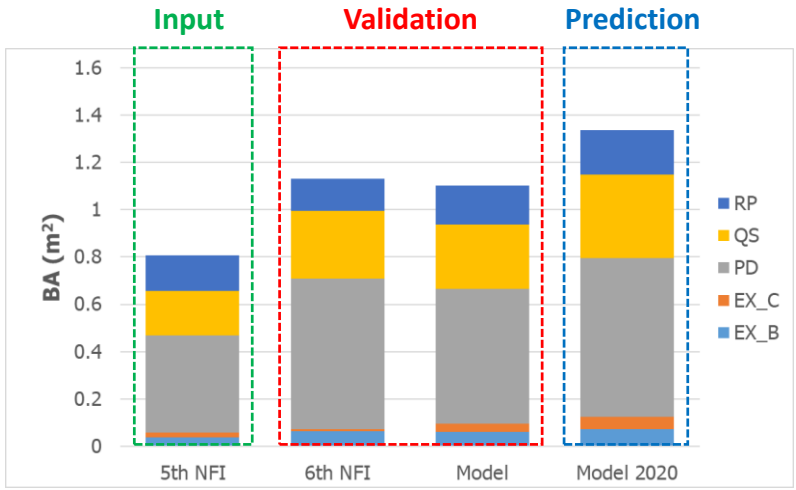
Case 1: AF - CO



< Distribution of dbh >

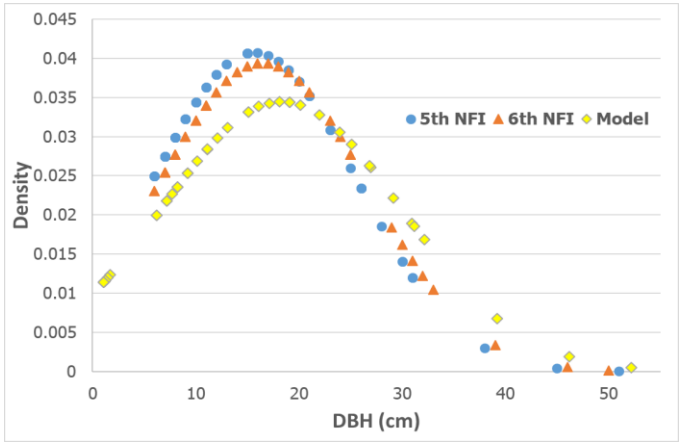


< The relation between dbh and height >

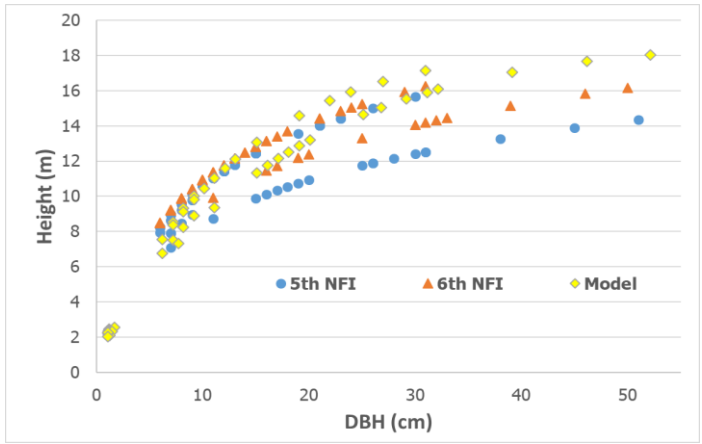


< The BA of each tree species >

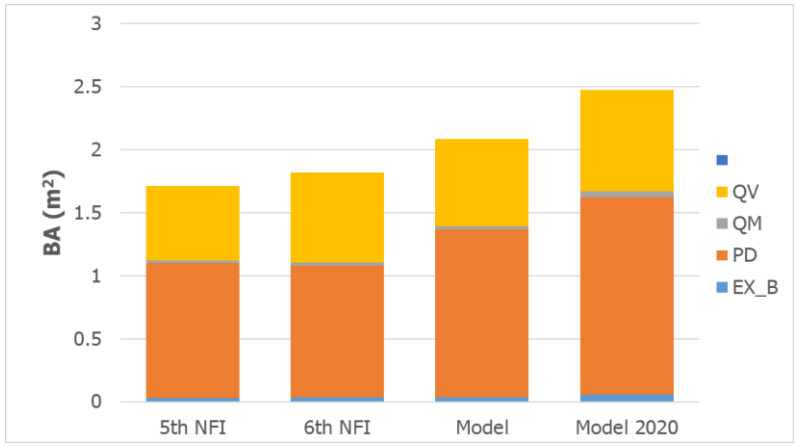
Case 2: NF - CO



< Distribution of dbh >



< The relation between dbh and height >

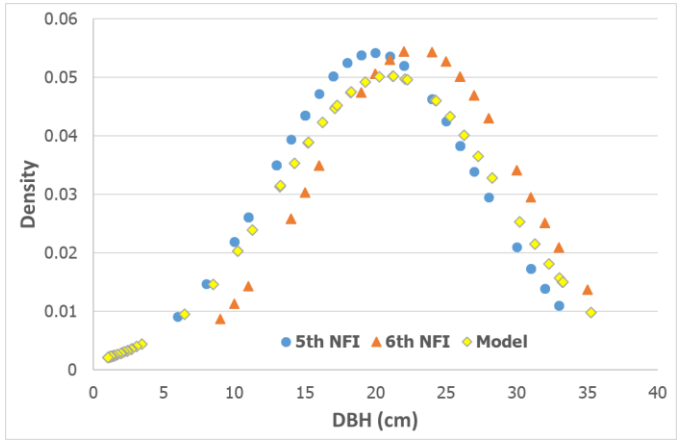


< The BA of each tree species >

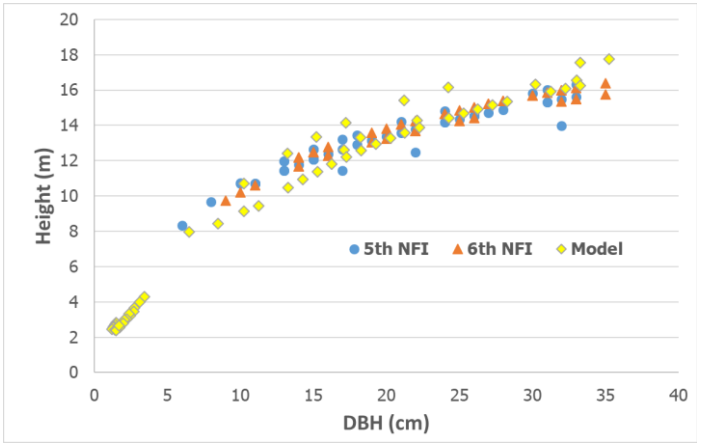
Results – 3) Assessment and prediction of forest dynamics

- Change in patterns of annual growth are found different depending on tree species and altitude.

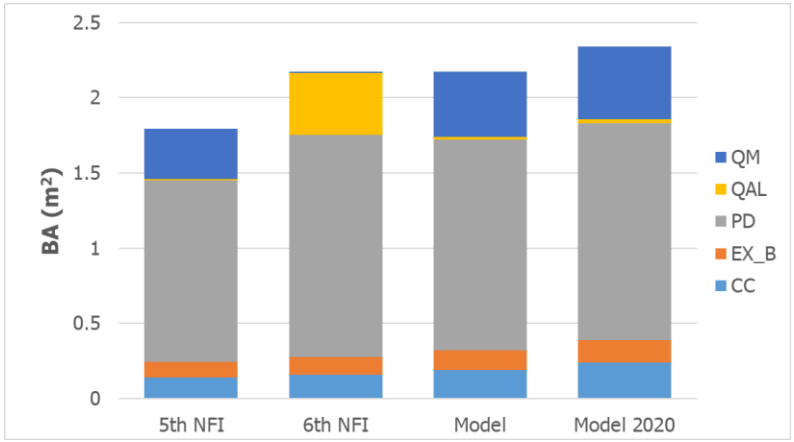
Case 3: AF - BL



< Distribution of dbh >

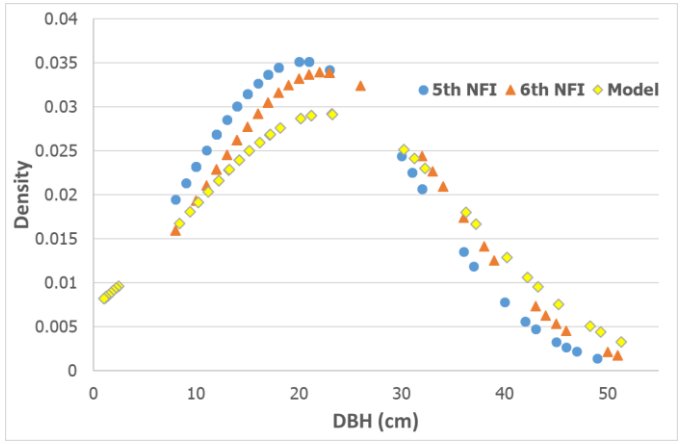


< The relation between dbh and height >

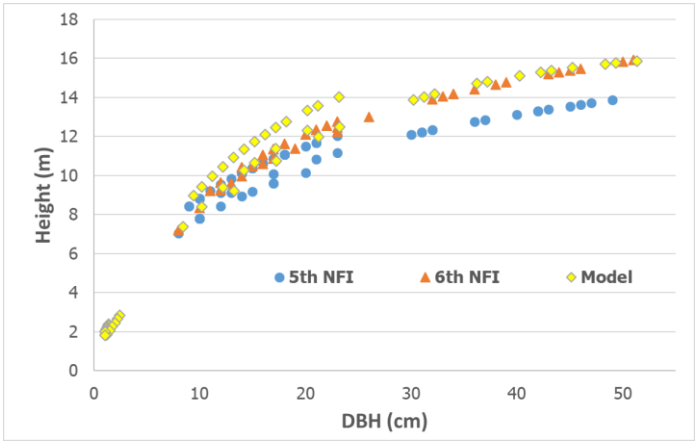


< The BA of each tree species >

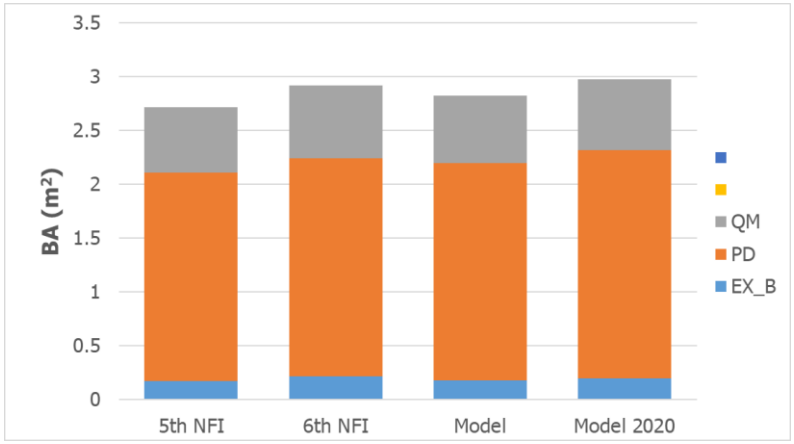
Case 2: NF - BL



< Distribution of dbh >



< The relation between dbh and height >



< The BA of each tree species >

Conclusion and Summary

- R1
  - In current climate condition, diameter growth of coniferous forest in South Korea (*P. densiflor, P. koraiensis, and L. kaempferi*) has a **negative** correlation with **temperature**. Conversely, broadleaf forest trees (*Q. variabilis* and *Q. mongolica*) had a **positive** correlation with **temperature**.
  - It differences in tendency of forest productivity change depend on tree species and location of forest areas such as LLF and HMF.
- R2
  - According to our findings, the coniferous forest area in South Korea will be shrunken. These areas would be likely replaced by broadleaf forests naturally. This situation will be accelerated by climate change.
- R3
  - PPA-SiBGC is helpful to estimate of forest dynamics from the plots-scale to the national-scale. This model will be useful to build the spatio-temporal forest management strategies specified by tree species and altitudinal zoning for sustainable development and to cope with climate change in South Korea.

EGU General Assembly 2020 **BG3.23: Mountain forests under climate change**

I would like to give special thanks to Adam Erickson who is the main developer of the PPA-SiBGC model. He gave us technical supports despite his busy schedule.

Thank you very much for your attention!

Moonil Kim[1*], Nick Strigul[2], Elena Rovenskaya[1], Florian Kraxner[1], and Woo-Kyun Lee[3]

(kimml@iiasa.ac.at)

[1]Ecosystems Services and Management Program (ESM), International Institute for Applied Systems Analysis, A-2361 Laxenburg, Austria
[2]Department of Mathematics and Statistics, Washington State University, 14204 Salmon Creek Avenue, Vancouver, WA, 98686, USA
[3]Department of Environmental Science and Ecological Engineering, Korea University, Seoul, 136-701, Republic of Korea

International Institute for Applied Systems Analysis IIASA

National Research Foundation of Korea NRF

KOREA UNIVERSITY 고려대학교 KOREA UNIVERSITY

This work was also supported under the framework of international cooperation program managed by the National Research Foundation of Korea (Project No. 2019K2A9A1A02094860).