Predicting the vegetation distribution and terrestrial carbon-fluxes using MC1 model

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Abstract

The objective of this study was to predict the distribution of vegetation and terrestrial carbon fluxes in Korean ecosystem using certain simulations of the MAPSS-CENTURY (MC1) model. For the overall simulations, two categories of climatic and ancillary input data were required. ECHO-G model provided future climate data under A1B scenario. In addition, both World Soil Map from FAO and DEM of Korea were revised by IDSW (Inverse Distance Squared Weighting) method in ArcGIS. From the results of the past simulations (1978 ~ 2007), the potential vegetation of Korea was evaluated as cool temperate mixed forest. Also, total soil carbon of Korea was estimated to be between 2,010 and 8,410 gC/m^2. On the other simulations of the future (2071 ~ 2100), there were certain changes in vegetation distribution and carbon dynamics in Korean ecosystem. However, Korea-specific dynamic vegetation model needs to be developed because some parameters and algorithms of MC1 are not applicable for Korean ecosystem.

Key words: MC1, vegetation distribution, terrestrial carbon fluxes, GIS

1. Introduction

According to Intergovernmental Panel on Climate Change, the average of annual global temperature has been inclined by 0.6 ± 0.2℃ over the past 100 years. It may be related to about 31% increase of carbon dioxide concentration in the atmosphere, compared to pre-industrial era (IPCC, 2001). Due to the complexity of the global ecosystem and the impossibility of controlled experiments, it is required to develop qualitative, computer-based models. Previously, many dynamic vegetation models have been prepared by several countries; CEVSA (Cao and Woodward, 1998), MINoSGI (Watanabe *et al*., 2004), Medrush Vegetation (Osborne *et al*., 2000), and MC1 (Lenihan *et al*., 2008), etc.

Despite the importance of assessing the climate change impacts, there has been no climate change model developed specifically for regional characteristics of Korea. However, it can be coped by analyzing the applicability of previous models to Korea ecosystem. Kim *et al*. (2009) cited that some researchers have already tried to apply those global-scale models to assess the impact of climate change on Korean ecosystem. In this study, we analyzed MC1 model and simulated the vegetation distribution and terrestrial carbon-fluxes in Korea using MC1 model.

2. Material and Methods

2.1 The model, MC1

MC1 model is a dynamic global vegetation model (DGVM) including three modules of biogeographic module (MAPSS), biogeochemistry module (modified CENTURY), and fire module (MCFIRE). This model can routinely generate simulations of tens to hundreds of years period on spatial data grids with cell sizes ranging from $900m^2$ to about $2,500km^2$ (Bachelet *et al*., 2004). As shown on Fig. 1, it simulates 1) plant life-form and vegetation classes, 2) the movement of carbon, nitrogen, and water fluxes for ecosystem, and 3) fire disturbance, respectively (Bachelet *et al*., 2001).

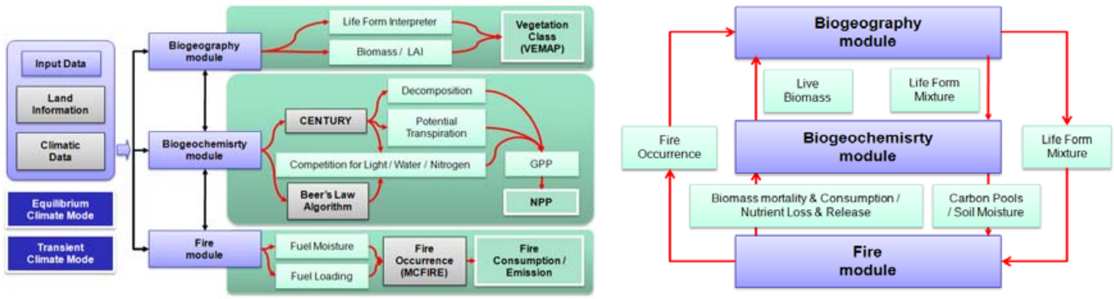


Figure 1 The structure of MC1 model (source from Bachelet *et al*., 2001)

2.2 Study area and data preparation

The study area for this study is located in South Korea, 124°54′ ~ 131°6′ at longitude and 33°9′ ~ 38°45′at latitude (Fig. 2). It is presented as a raster data in 0.05° of spatial resolution and 4,860 of pixels, excluding the part of the ocean. For the overall simulations, MC1 needed two categories – climatic and ancillary – of input data. In terms of climatic dataset, seven climatic factors are needed to be built; they are cumulative precipitation, monthly mean temperature, mean daily maximum and minimum temperature, vapor pressure, wind speed, and solar radiation. Ancillary dataset includes general geographical information, such as elevation, latitude, absolute area, and soil information – Soil bulk density, soil texture, mineral depth, and rock fragment.

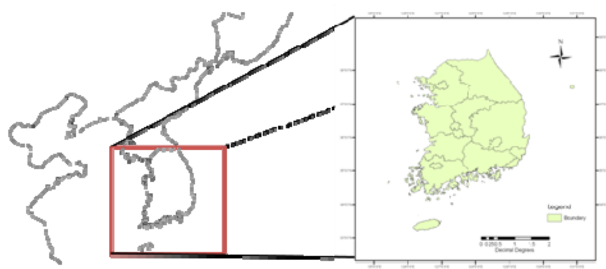


Figure 2 Location of study area

Korea Meteorological Administration (KMA: http://www.kma.go.kr/sfc/sfc_03_02.jsp) provided observed climatic data obtained by 75 weather stations across South Korea for the past years between 1978 and 2007. For the simulation, this data was interpolated with Inverse Distance Squared Weighting (IDSW), one of the spatial statistic methods (Equation 1). In addition, the future climatic data set was predicted by ECHO-G model with A1B scenario by National Institute of Meteorological Research (NIMR: http://www.nimr.go.kr/metri_home/) in 0.2432° of grid size. To construct ancillary data set, elevation, latitude, and absolute area data were achieved from the digital map of National Geographic Information Institute (NGII: http://www.ngi.go.kr/). Also, soil information – Soil bulk density, soil texture, mineral depth, and rock fragment – were provided by Food and Agriculture Organization (FAO) and International Soil Reference and Information Centre (ISRIC). These datasets were rescaled by ArcGIS 9.2 to fit on 0.05° spatial resolution in WGS-84 coordination system (Fig. 3).

$$W = \frac{\sum \frac{W_i}{d_i^2}}{\sum \frac{1}{d_i^2}} \qquad \text{(Equation 1)}$$

Where W stands for estimated climatic value in unobserved point, W_i is the observed climatic value in point i and d(km) is the distance between certain observed point and point i. This IDSW method was applied for interpolation of precipitation, wind speed, vapor pressure, and radiation (Eq. 1).

$$|\Gamma| = 0.00688 + 0.0015\cos\{0.0172(i - 60)\} \qquad \text{(Equation 2)}$$

$$T = \frac{\sum \frac{T_i}{d_i^2}}{\sum \frac{1}{d_i^2}} + \left[z - \frac{\sum \frac{z_i}{d_i^2}}{\sum \frac{1}{d_i^2}} \right] \Gamma \qquad \text{(Equation 3)}$$

On the other hands, for interpolating the temperature data, it considers observed time and elevation as well as distance between two points by Equation 2. Where $|\Gamma|$ is the absolute temperature lapse rate by day number, i stands for day numbers in year. This absolute temperature lapse rate is applied on Equation 3,where T stands for estimated temperature at the object point, T_i is the observed temperature at the observatory I, d_i is the distance from the object point to the observatory, z is the elevation at the object point, and z_i is the elevation at the observatory i.

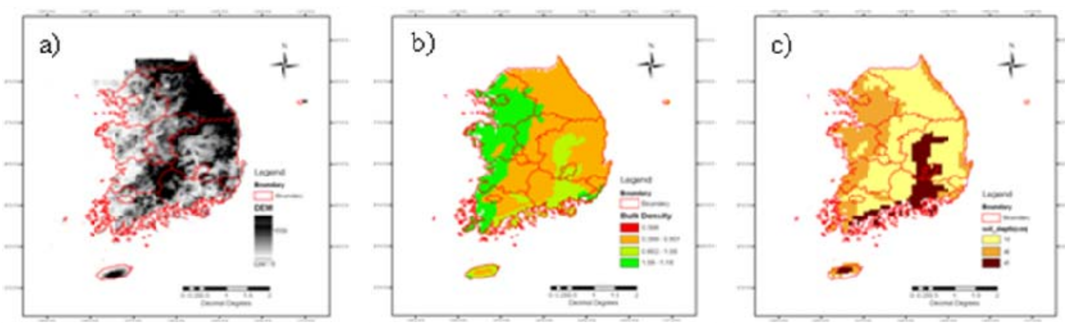


Figure 3 a) DEM from NGII, b) Soil bulk density and c) Soil depth from FAO

2.3 Vegetation Classification

As shown on Fig. 4, the biogeography module in MC1 model simulates the vegetation classes by life-form interpreter and vegetation class rule based process. By climatic gradient, the life-form interpreter – temperature and precipitation- determine the leaf phenology into evergreen and decsiduous and leaf shape into needleleaf and broadleaf for trees and C3 and C4 for grasses.

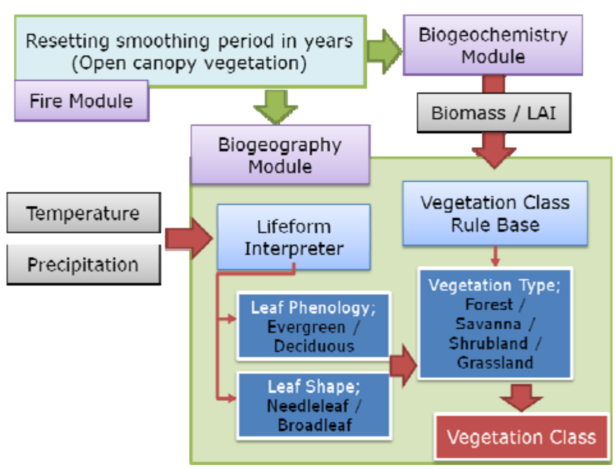


Figure 4 Vegetation Classification Process (source from Bachelet *et al*., 2001)

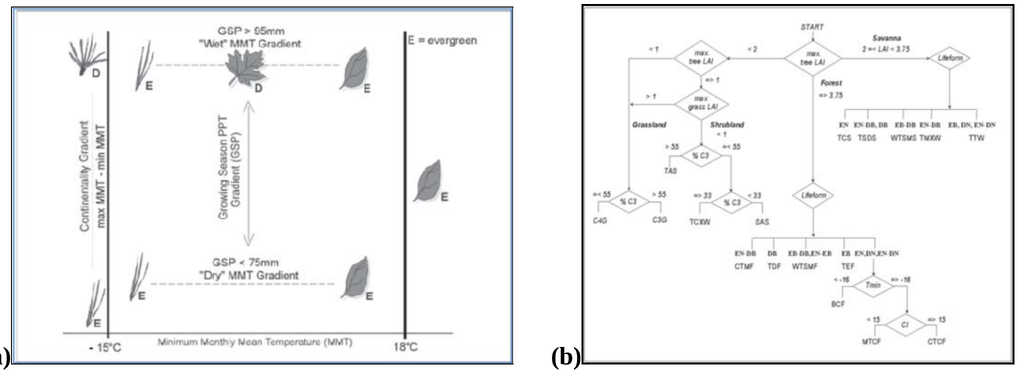
(a) (b)


Figure 5 (a) Lifeform interpreter and **(b)** vegetation classification rule based process (source from Bachelet *et al.*, 2001)

The biogeochemistry module calculates the leaf carbon in ecosystem and converts it to the leaf area index (LAI). By the vegetation class rule based process using a certain threshold – LAI, this model classifies vegetation into forest, savanna, shrubland, and grassland. Prentice *et al*. (1992) and Neilson (1995) applied the minimum monthly mean temperature (MMT) and the growing season precipitation (GSP) as thresholds for determining the leaf longevity and leaf shape (Fig. 5 (a)). Once the vegetation has been assigned a LAI-based class, detailed classes are determined by the lifeform interpreter; 21 classes (Fig. 5 (b) and Tab. 1). This is defined by Vegetation/Ecosystem Modeling and Analysis Project (VEMAP members, 1995).

Table 1 VEMAP vegetation classes in MC1 (source from Bachelet *et al*., 2001)

No	Class	No	Class
1	Tundra	13	Temperate subtropical deciduous savanna
2	Boreal coniferous forest	14	Warm temperate subtropical mixed savanna
3	Maritime temperate coniferous forest	15	Temperate conifer savanna
4	continental temperate coniferous forest	16	Tropical deciduous savanna
5	Cool temperate mixed forest	17	C3 grassland
6	Warm tempeate mixed forest	18	C4 grassland
7	Temperate deciduous forest	19	Mediterranean shrubland
8	Tropical deciduous forest	20	Temperate arid shrubland
9	Tropical evergreen forest	21	Subtropical arid shrubland
10	Temperate mixed xeromorphic woodland	22	Taiga
11	Temperate conifer xeromorphic woodland	23	Boreal larch forest
12	Tropical thorn woodland		

During the simulation of biogeography and biogeochemistry module, MC1 model assumes that fire events reset the smoothing period to zero, which assigns the biogeography module to simulate an open canopy vegetation type. The smoothing period is required to reduce inter-annual variability and to reflect the delayed vegetation responses to climate change (Bachelet *et al*., 2001).

2.3 Carbon Dynamics

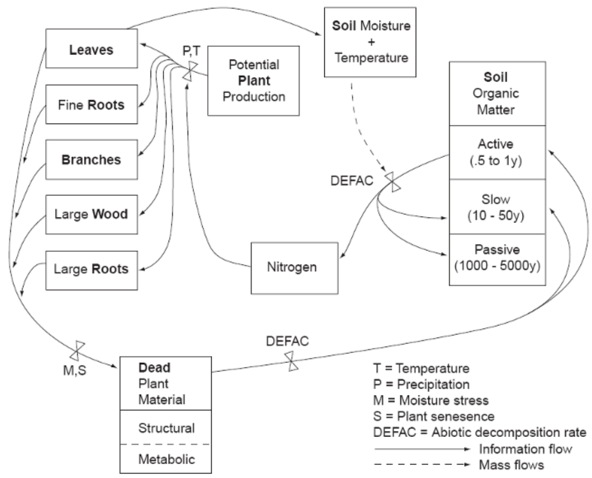


Figure 6 Schematic of biogeochemistry module (source from Bachelet *et al.*, 2001)

Fig. 6 depicts the biogeochemistry module in MC1 model. Monthly carbon and nutrient dynamics for the ecosystem can be achieved from its simulation, including live shoots, roots, and standing dead material. In the biogeochemistry module, it applied an algorithm of Parton *et al.*(1994) to predict potential biomass production for each life-form by temperature, soil moisture, and availability of nitrogen. During the simulation, it assumes that aboveground and belowground vegetations are exposed to the senescence due to stress from age, drought, and cold weather. Moreover, it includes decomposition effects on the active and passive soil carbon. This can estimate the results of Beer's Law tree and grass shading algorithm, which would change the tree and grass vertical root distribution.

3. Results and Discussion

3.1 Vegetation Distribution

Using the MC1 model simulations, the Equilibrium mode, and the 30 years' mean values for climatic information, this study estimated the potential vegetation distribution maps based on both past (1978 ~2007) and future (2071 ~ 2100) climatic information. Fig. 7 (a) indicates that most areas in South Korea were occupied by coniferous forests; including continental temperate conifer (91%), maritime temperate conifer (4%), and warm temperate conifer (3%). On the other hand, as shown on Fig. 7 (b), the MC1 simulation by ECHO-G A1B scenario indicated certain changes in potential vegetation distribution in the future.

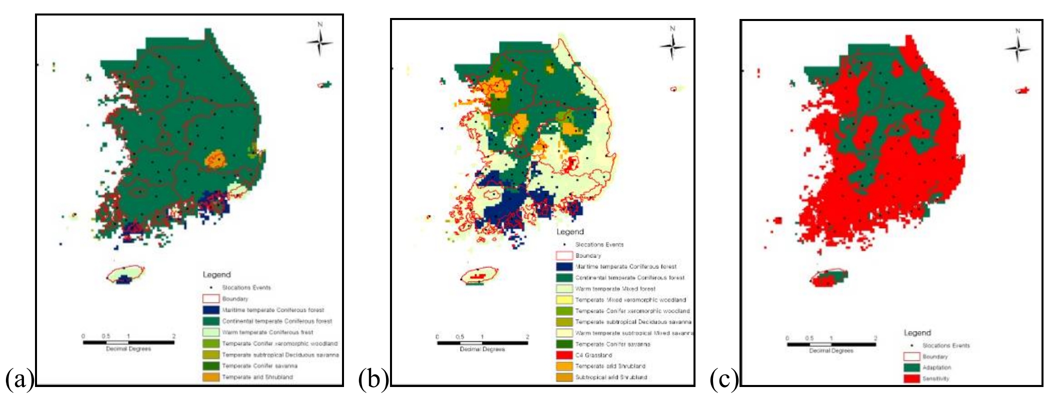
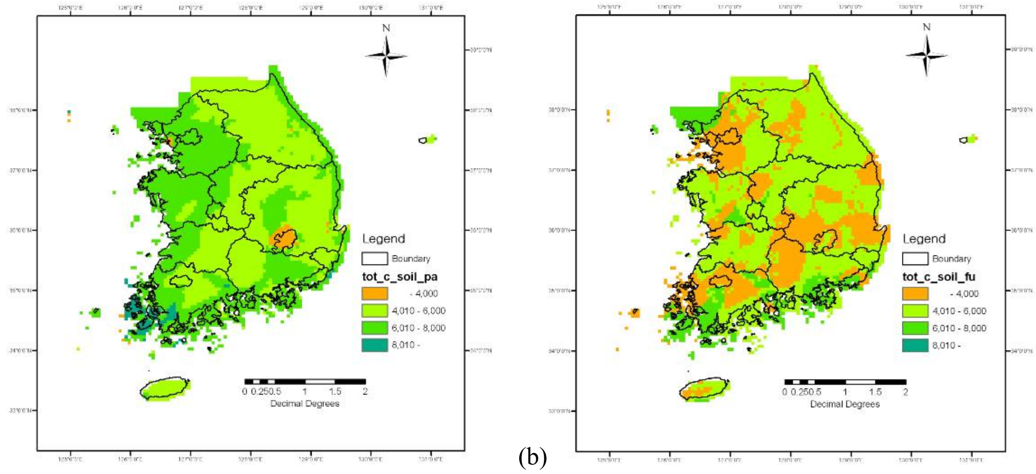


Figure 7 Vegetation distribution for (a) past (1978 ~ 2007), (b) future (2071 ~ 2100) ecosystem, and Sensitvity on vegetation distribution (c)

Compared to the past distribution, coniferous forest area was decreased down to 34% and 11% respectively in continental temperate conifer and maritime temperate conifer,. Moreover, 6% of the shrubland area were located in near metropolitan cities – especially, Seoul metropolis. Lastly, the sensitivity of vegetation distribution was assessed by calculating the vegetation class changes in each grid. As shown Fig. 7 (c), red areas depict that vegetation class in each grid were diverted during the simulation, while green areas indicate no changes in vegetation distribution.

3.2 Estimating Carbon Fluxes

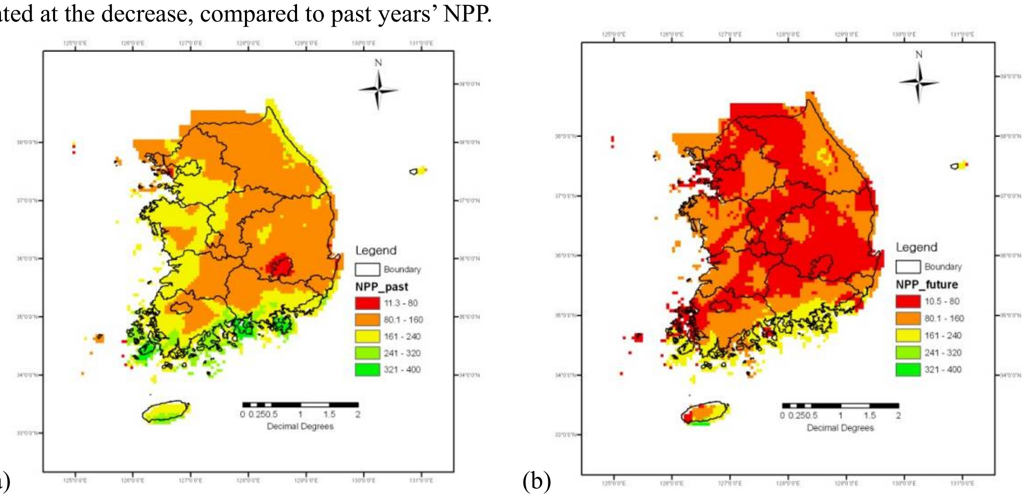
Fig. 8 shows spatial distributions of mean total soil carbon (TSC) of past years (1978 ~ 2007) and future years (2071 ~ 2100), estimated by MC1. The value of past TSC was ranged from 2,010gC/m^2 to 8,410gC/m^2; while the TSC was ranged from 1,810gC/m^2 to 6,900gC/m^2 in the future. The simulation on past TSC could be supported by previous researches; Jeon et al. (2007) reported that TSC (Soil depth: 50cm) of pine forest in Korea is 8,450 gC/m^2 and Kim (2006) presented that TSC (Soil depth: 30cm) of Korea is 10,260 gC/m^2. Compared between future TSC and past TSC, the area of TSC (range 2,010 ~ 4,000gC/m^2) would be extended from the Southern East area to overall Southern part of Korea and central part of Korea including Seoul Metropolis and Kyoung-gi province (Fig. 8). Overall, TSC of future years was estimated as decreased, compared to past years' TSC.



(a) (b)

Figure 8 Mean total soil carbon (TSC) of (a) past (1978 ~ 2007) and (b) future (2071 ~ 2100) ecosystem

As shown in Fig. 9, mean annual net primary production (NPP) of past was covered, ranging between 11.3gC/m^2/yr and 360gC/m^2/yr. The value of NPP in Middle and Southern East province - 56.8% of total study area - was ranged from 81gC/m^2/yr to 160gC/m^2/yr. As results of future carbon flux simulation, 47% of total study area would produce no more than 80gC/m^2/yr of NPP. This area excludes Eastern, Western and Southern coast and middle part of study area (Fig. 9). As well as TSC in the future, on the whole, NPP of future years was estimated at the decrease, compared to past years' NPP.

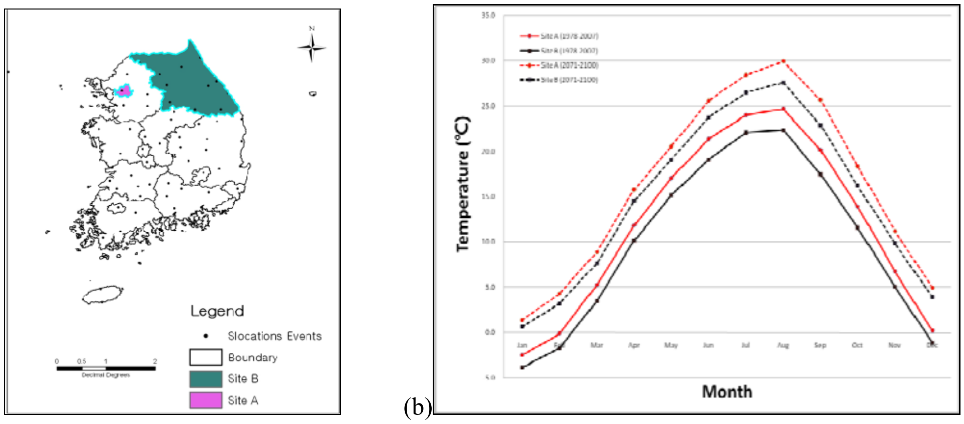


(a) (b)

Figure 9 Mean annual net primary production (NPP) of (a) past (1978 ~ 2007) and (b) future (2071 ~ 2100) ecosystem

3.3 Site Comparison by temperature

Despite the similarity of increase in mean temperature, monthly mean temperature of site A is higher than one of site B in both past and future (Fig. 10). Because the MC1 life-form interpreter classified the vegetation class by temperature and precipitation, site A had more changes in vegetation classes compared to site B.



(a) (b)

Figure 10 The location of site A and B (a), and the monthly mean temperature trends of site A and B in 1978 ~ 2007 and 2071 ~ 2100, respectively

Simulations of vegetation classes and carbon dynamics of MC1 model are based on the US ecosystem. Therefore, some parameters and variables are not suitable to apply this model for predicting Korean vegetation distribution and carbon fluxes. For example, the actual vegetation distribution is not matched to simulated potential vegetation distribution. As Bachelet et al. (2001) asserted, the rule of life-form interpreter of MC1 model was derived from observed data for US territory. Therefore, adjusting parameters and variables should be followed to apply this model to Korean ecosystem. Consequently, for more effective assessment on Korean ecosystem, further analysis of MC1 model and other climate change models for integrated model is needed. Also, it is essential to develop and construct Korea-specific model to comprehend the structure and function of Korean ecosystem.

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