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Simulation of Forest Succession in Kwangnung Experimental Forest with Gap Model

You, Young Han, Seung Tai Park[1], Chang Seok Lee[2] and Joon-Ho Kim[3]

Institute of Natural Science, Seoul Women's University, Department of Biology Education, Chonbuk National University[1], Department of Biology, Seoul Women's University[2], Department of Biology, Seoul National University[3]

Gap모델을 이용한 광릉삼림군락의 천이에 대한 모의 실험

유영한 · 박승태[1] · 이창석[2] · 김준호[3]

서울여자대학교 자연과학연구소, 전북대학교 생물교육과[1],
서울여자대학교 생물학과[2], 서울대학교 생물학과[3]

ABSTRACT

Forest stand development in Kwangnung Experimental Forest, Korea, was simulated with a forest succession gap model of the JABOWA/FORET type, in order to predict climax species and characterize the trend of community structure along the succession. The model runs for a period of 1,000 yr and is based on the averaged successional characteristics of 50 forest plots with an individual size of 1/12 ha gap consisted of the 15 major tree species. The total biomass and leaf area index have arrived at a steady state since about 200 yr and these values are smaller than that of field survey. *Carpinus cordata, C. laxiflora, Quercus mongolica* and *Q. serrata* were expected to be climax species that represent about 86% of total biomass in later stage and these results coincided with the previous succession studies from field survey in this area.

Key words: Computer simulation, Forest succession, Gap model, Kwangnung

INTRODUCTION

Forest ecosystems are complex entities which exhibit the dynamic responses of tree populations to changes of environmental conditions. The mechanisms and theories involved in the forest growth are still an issue in ecology (Finegan 1984, McIntosh 1981). Because of the long life history of the tree involved, no direct complete forest succession study has been possible to prove any of the theories. So, past and current successional theories still rely on the descriptions of plant communities with different known ages. The

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sites for these succession study must have similar environmental factors such as substrate, external disturbance or microclimate. However, these assumptions are often rejected.

Many plant ecologists made mathematical models and used them for research of forest succession (Botkin *et al.* 1972, Dale *et al.* 1985, Leemans and Prentice 1987, Shugart and Noble 1981, Solomon and Webb 1985), due to the accumulation of information and data on plant community succession. The forest simulation model described in this paper (FOREK; FOREsts of Kwangnung) belongs to the groups of gap model, according to the criteria proposed by Dale *et al.* (1985).

In this paper, we simulated forest succession in Kwangnung Experimental Forest by using a succession gap model, in order to predict the climax species and characterize the trend of community structure, and then compare the model results with field survey's.

Description of the model

The model presented in this paper is based on JABOWA model of Botkin *et al.* (1972) and FORET model of Shugart and West (1977). A detailed explanation of the model is given in their papers. The simulation program runs on a basis of 1/12 ha plots, which is larger than the mean gap size in Kwnagnung forest ($90m^2$, Cho 1992). Stand development on each forest plot is simulated by calculating establishment, growth, and death of individual trees as probabilistic process. To obtain forest development on a large area, the successional patterns of all plots of one run are averaged. The averaged data can be interpreted as the assembled successional growth of a multitude of small forest stands with the same site conditions.

Forest succession is driven by external and internal variables of the species or the stand. Extrinsic variables to stand are growing degree-day and light. Intrinsic variables to the species are maximum potential growth rate and mortality, while shading and crowding are intrinsic factors to the stand. This model starts with a randomly selected cohort of seedlings in a gap to simulate tree establishment. Unfavorable environmental factors and site conditions control the exclusion of species from seed pool. Growth of each individual tree is simulated by decreasing the maximum potential growth rate at optimum. To do so, growth multipliers for each limiting factor are calculated. The growth curve for optimum diameter growth of each species was obtained by fitting a theoretical growth equation (Botin *et al.* 1972).

Death of individual trees is determined with a mortality function, that allows only 0.1% of all trees to reach the maximum physiological age. Also trees are killed if they are growing slower than specified by the user. The individual species data for light, maximum age etc. were derived from silvicultural sources and field observations in Kwannung (Cho 1989, Ministry of Forestry 1984). The conventional data base to run a JABOWA-FORET type model was not always readily available for Korean tree species, thus sprouting tendency and ktimes are omitted or modified.

The major trees used in this model are 15 species which dominate or codominate the Kwangnung Experimental Forest (Table 1), which have been widely studied than any other area in Korea (You *et al.* 1995).

Model parameter

In determining the model parameters, we used Botkin *et al.* (1972) and Shugart and West (1977) methods. DEGDmax and DEGDmin are used to scale the species growth curve for thermal effects with the assumption that the species ecological amplitude is reflected in the species range. This assumption is reinforced by the observation that isopleths of physiological degree-days tend to correspond closely to the northern and southern range boundaries of tree species ranges. DEGDmax is the physiological degree-day value with an isopleth correlated with species's southern range boundary; DEGDmin is the analogous isopleth associated with the northern boundary. Data of species distribution boundary in the world were taken from Chung (1974). Physiological degree-days were calculated from temperature isopleth of world temperature (Yoshino 1978).

The b2 and b3 parameters were calculated from the heights and diameters of recording

Table 1. Basic parameters used in this model. DEGDmax and DEGDmin are maximum and minimum degree-days; b3 and b2 are constant in the equation relating height to diameter; AGEmax is maximum age (years); G is growth constant.

Species	DEGDmax	DEGDmin	b3	b2	Tc[1]	AGEmax	G	Reproduction[2] 1234
Zelkova serrata	8123	2241	.020	16.42	1	200	18.8	TTTF
Pinus densiflora	8378	1366	.104	17.92	3	150	176.6	FTTF
Carpinus laxiflora	8378	1366	.278	38.94	1	150	138.0	TFFF
Carpinus cordata	8378	1366	.379	45.43	1	200	136.5	TFFF
Fraxinus rhynchophylla	8123	1404	.212	34.83	1	150	83.0	TFFF
Quercus acutissima	8378	1879	.473	22.26	3	150	220.7	FTTT
Quercus aliena	12205	1366	.473	22.26	2	150	203.1	FTTT
Quercus dentata	12205	1587	.380	53.23	3	150	130.0	FTTT
Quercus variabilis	8123	1366	.473	22.26	3	200	210.4	FTTT
Quercus serrata	8123	1404	.216	43.26	2	200	132.5	FTTT
Quercus mongolica	8123	2241	.286	57.26	1	200	118.8	FTFT
Cornus controversa	8378	1366	.102	20.84	3	200	115.2	TTTF
Prunus sargentii	6362	1536	.230	41.40	3	150	179.2	FTTT
Acer mono	6142	1366	.393	52.63	2	150	113.0	TFFF
Acer pseudo-sieboldianum	8123	5385	.299	41.80	1	235	107.2	TFFF

[1]Tc is the shade tolerance class; class 1 and 2 are considered shade tolerance, class 3 shade intolerance.
[2]Reproduction switches are used in the BIRTH subroutine and take values of T (true) or F (false). Switch 1 is T if the species requires leaf litter for successional recruitment. Switch 2 is T if the species requires mineral soil for successional recruitment. Switch 3 is T if the species is shade intolerant. Switch 4 is T if the species has seedling rate reduction by herbivore.

trees compiled by Cho (1989) and our field survey in Kwangnung (unpublished data). The tolerance class of each tree (Tc) was taken from Cho (1989) and You (unpublished data). AGEmax, the maximum age for each species was taken in field survey in Kwangnung. The G parameter, which scales the growth rate of each species under optimal conditions was calculated by assuming that a tree under optimal conditions should grow to two-thirds of its maximum height at one-half of its maximum age (AGEmax).

RESULTS

General indicator of forest succession

The computer simulation was run for period of 1,000 yr and for 50 replicates (plots). Species-, and tree specific data are provided through time in intervals of 10 yr. Two general indicators of general forest dynamics in this model are the above-ground total biomass and the stand leaf area (Fig. 1). The above-ground total biomass increased rapidly until 50 yr with a value 179 ton/ha and then decreased markedly to 130 ton/ha at 150 yr. This decrease may be caused by stand thinning associated with forest canopy competition. After

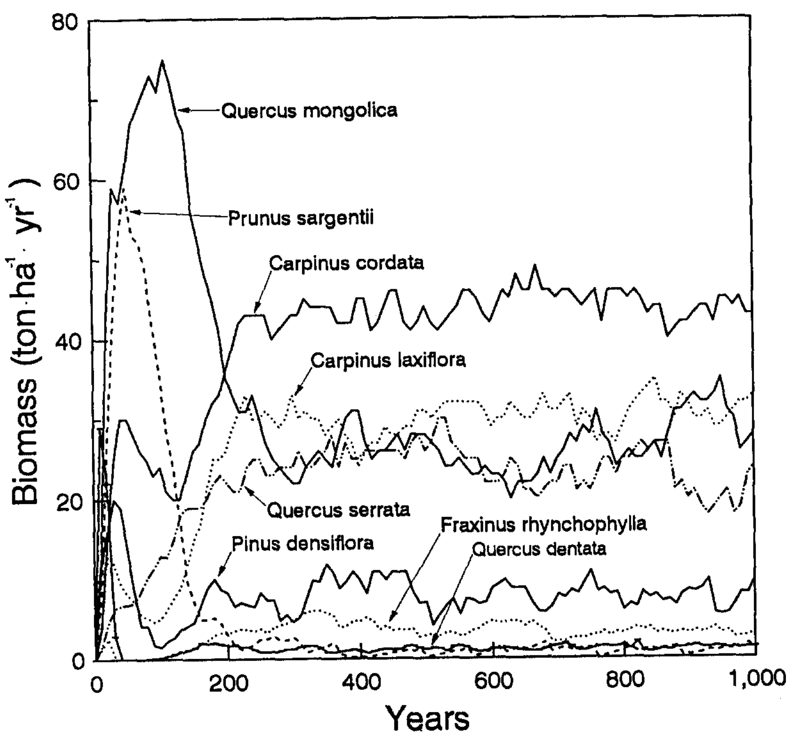

Fig. 1. Overall forest dynamics during 1,000 year of simulated stand development in Kwangnung Experimental Forest. (a) Biomass (metric tons/ha), (b) leaf area (m^2 of leaves/m^2 of land area). Data shown above are mean values for 50 simulated 1/12 ha plots for each of the 1,000 year.

this time, the total biomass changed with a little increase to 150 ton/ha at 180 yr and remained relatively stable at a range of 140~150 ton/ha during all the following years.

Leaf area rose rapidly during the first 30 years of stand development, reaching a value of $10.4 m^2/m^2$ and then declined to a minimum of $7.0\ m^2/m^2$ at 140 year. At this time, the typical forest would be an even-aged forest with a dense canopy but a relatively sparse understory. With the death of some canopy trees and the subsequent appearance of subcanopy trees, the leaf area index increased to a value of 7.8 at 180 yr. Leaf area index, similar to the change pattern of total biomass, varied slightly after about 180 yr.

Biomass dynamic of 15 major species

Absolute biomass estimations for 15 major species in Kwangnung over each of the 1,000 simulation yr for 50 stands are shown in Fig. 2. It is important to note that there is a large variation in forming these average value. According to the overall pattern of biomass change, the simulation can be divided into three main periods, i.e. 0 - 50 yr, 50 - 250 yr and 250 - 1,000 yr.

The first period (0 - 50 yr) is characterized by a peak increase of newly established trees on the bare plot and then all the shade intolerant species except for *Pinus densiflora* are reduced into nearly zero. *Quercus mongolica, Prunus sargentii, Carpinus cordata* and *Pinus densiflora* are codominant species at pionner stage. *Quercus acutissima* reaches its peak very early at 10 simulation yr and subsequently loses its importance.

The second period (50 - 250 yr) is the transition stage from an early successional forest to a steady state forest. During this period *Quercus mongolica, Prunus sargentii, Pinus densiflora* are diminished, but *Carpinus cordata, Carpinus laxiflora* and *Quercus serrata* dominate. *Quercus mongolica* dominate until 200 yr. Pioneer species may be replaced by climax species at this stage. *Quercus mongolica* and *Prunus sargentii* are the species with the biggest change. At a stage age of 100 yr, the canopy of average forest plot is almost entirely dominated by *Quercus mongolica* with an understory *Prunus sargentii, Carpinus cordata, Quercus serrata, Carpinus laxiflora* and *Pinus densiflora*. However, at a stand age of about 150 yr, *Quercus mongolica* breaks up and a reduction in biomass happens. The latter condition favors shade tolerant species like *Carpinus cordata* and *Carpinus laxiflora* that are able to grow in the understory in spite of the shade of the large tree of *Quercus mongolica*. At this period, *Prunus sargentii* reach a maximum at about 50 yr, diminishes its importance rapidly, and disappears mostly around 250 yr. Thus, the final forest composition is almost free of *Prunus sargentii*. The biomass increase in shade tolerant species or decrease in shade intolerant species means that a successional replacement occurs at this time.

In the third period (250 - 1,000 yr), the biomass of species is relatively stable. *Carpinus cordata* and *Carpinus laxiflora*, as slow growing, shade tolerant trees, have competitive advantages over *Prunus sargentii* and *Quercus mongolica*. Species can be further divided into three groups on the basis of the magnitude of biomass. Group one is species with high biomass, i.e. the biomass of *Carpinus cordata* represents about 30% of the total biomass.

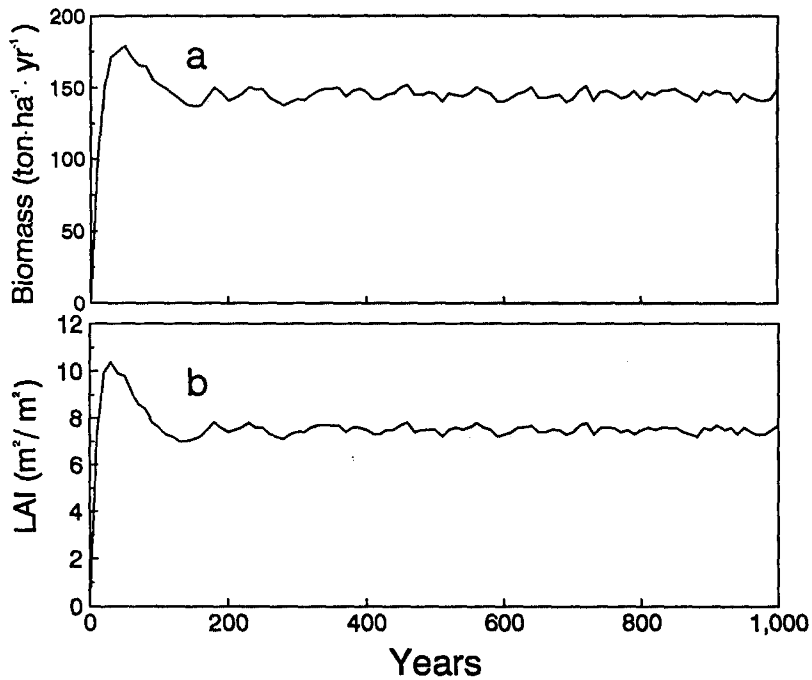

Fig. 2. Simulated development of absolute biomass (ton/ha) for 15 major species in Kwangnung Experimental Forest. All simulations are based on an average of 50 plots. Biomass data were calculated per yr and recorded in one yr intervals. For plotting reasons a ten-point moving average is calculated for the data.

Group two is species with moderate biomass, i.e. *Carpinus laxiflora* (23%), *Quercus mongolica* (17%) and *Quercus serrata* (16%). The third group consists of the rest 11 species representing about 14% of total biomass. Thus these trees included in group one or two are dominant and codominant species in later successional stages in Kwangnung Experimental Forest.

DISCUSSION

The simulation model FOREK was applied to Kwangnung Experimental Forest. Kwangnung Experimetal Forest has been preserved over 530 yr (Forestry Station 1959). This period is enough time for forest community to reach a climax stage in temperate region (Whittaker 1975). The current structure and composition of forest community are considered as a climax stage (You *et al.* 1995), and gaps occur frequently (Cho 1991). So it may be an appropriate area to which gap model can be applied.

The total biomass (ca. 150 ton/ha) of simulation study at later stages is smaller than that of the field study (214 ton/ha; You 1994). The mean value (ca 7.5 m^2/m^2) of leaf area index at later successional stages is larger than that of a deciduous climax forest in temperate zone (6.2 m^2/m^2; Whittaker 1975).

When compared with the total biomass (ca 120 ton/ha) and leaf area index (ca 5.8 m^2/m^2) in Mt. Naejangsan forest using by gap model (You 1990), both values in Kwangnung are larger. But the change patterns between the two simulation studies are nearly similar.

The high percentage (86% of total biomass) of *Carpinus cordata* (30%), *Carpinus laxiflora* (23%), *Quercus mongolica* (17%) and *Quercus serrata* (16%) at steady state stage is consistent with that of the prediction of climax species in this area (Kang and Oh 1982, Kim 1977, You *et al.* 1995). Also the dominance of *Quercus mongolica* and *Q. serrata* was predicted as climax species in Mt. Naejangsan with simulation study (You 1990).

The great importance of *Prunus sargentii* from pioneer to transition stage and the appearance of *Pinus densiflora* at steady state stage during all the simulation yrs are either ecologically questionable, or partially inconsistent with actual forest structure and composition in Kwangnung (Kang and Oh 1982, You *et al.* 1995). The causes of such difference of estimation between by simulation and by field study may be explained by as follows. The species included in this model are not all representative major species, when ranked by importance value. According to the field survey report in Kwangnung (You *et al.* 1995), *Pinus koraiensis* and *Sorbus alnifolia* are codominant species, but these species are excluded in this model, because adequate parameters for these species were not available.

FOREK is a stochastic simulator such as JABOWA/FORET that attempts to reproduce the random and probabilistic characteristics of a forest. We assumed that temperature and light variables are driving forces for forest succession in our model. But other environmental factors that may determine species competition, including soil water and soil nutrient status, are also important. Thus, for a better simulation of forest succession, all the major species and other environmental factors should be considered in the forest succession model.

적 요

광릉삼림군락의 천이를 주요 15종의 목본으로 구성된 Gap model (1/12 ha)로 1,000년 동안 예측하고, 이를 전의 야외 조사결과와 비교하였다. 총생물량과 엽면적지수는 약 200년 후 안정화 되었다. 이 모의실험값은 전의 야외조사의 것보다 약간 작았다. 까치박달나무, 서어나무, 신갈나무, 졸참나무 등은 천이후기단계에서 계속하여 전체 생물량의 86%를 차지함으로써 이들 수종은 극상수종으로 예측되었는데, 이러한 결과는 광릉에서 선행된 천이연구 결과와 일치하는 것이다.

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