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Simulating sensitivities of Changbai Mountain forests to potential climate change*

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Abstract——Changbai Mt. forest in the northeastern China is both a very important timber resource of China and one of the most typical and less disturbed temperate mixed evergreen coniferous-deciduous forest in the world. In this paper, NEWCOP, a gap class model of forest growth and succession was proposed to simulate the sensitivity of the forest in Changbai Mountain to elevate CO_2, warmer temperature and precipitation change. NEWCOP was tested on long term simulation behaviors and short term fitting ability to field data. About the response of forests of Changbai Mountain to possible climate change, NEWCOP suggested that forest landscape go up within long term and forest biomass comes down within short term because of dieback of forest trees.

Keywords: gap model; climate change; forests; China.

1 Introduction

It is predicted that increasing greenhouse gases will lift global surface air temperature by 1.5℃ — 4.5℃ and mean precipitation by 7% — 11% in coming a couple of decades (Houghton, 1989; Schlesinger, 1987). Although the predictions may far away from perfect, the climate change and its effect on global ecosystem and human life have induced many scientists' concern as a major global environmental issue. And because it is estimated that the higher latitudes' area of the Northern Hemisphere may become greater warm than the lower latitudes' area (Neilson, 1989), present vegetation zone in the Northern Hemispheric higher latitudes area has been regarded to be going to change in large scale so that intensive investigations have been undertaking in boreal region (Smith, 1993; Bonan, 1990; Shugart, 1984).

Located in the northeast of China, covering 41°15′N—42°35′N and 127°15′E—129°00′E region with a total 19000 km^2 area, forest ecosystem in Changbai Mountain is unique in China and even in the world because of its undisturbed (Jeffers, 1986), typicality as temperate broadleaved-coniferous mixed forest, its good biodiversity and importance as one of main timber source in China. So it has an important scientific interest and practical value to study the response of forest ecosystem here to climate change.

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In this paper, a "gap" model, called NEWCOP has been built to simulate the forests in Changbai Mt. so as to use it to assess the sensitivity of the forest to potential climate change. As to climate change, even the prediction to the mean monthly temperature and precipitation change has not reached the agreement between different research group. So assumed climate change scenario is used.

2 Forests in Changbai Mountain

Changbai Mountain was a holy place of many nations, especially Manzu and Chaoxian. It is for so that its natural status could basically sustain up to present time. But disaster may be coming because of cutting, industrializing and cultivating. Without careful reservation, most of the natural'forest which has been thought only one existing temperate zone typical natural forest will disappear very soon, the many particular animals, plants and landscapes will also extinct because of suitable habitats' loss and degradation.

It is found that there grow more than 80 native tree species such as Korean pine, Changbai pine, Changbai larch, Korean spruce and ash and other very valuable trees which are widely used for fibre, oil, dye, medicine and other industrial field as raw materials resources. More than 50 species of beasts, 200 of birds, 1000 of insects, 87 of ferns and 1250 of seed plants including 800 medical herbs live here. Summing up, Changbai Mountain has the best biodiversity and the richest gene resources in the temperate region.

2.1 Vegetation types

The attitudinal zonation of vegetation on each slopes but eastern slop are very clear and similar. On the eastern slop, Changbai larch forest occupies most area above 1000m.

Lower region (<500m) now is dominated by secondary deciduous forest. The natural forest disappeared many years ago. Because of intensive human activities' repeatedly disturbance, the deciduous forest is mainly comprised of Mongolia oak that it is called oak forest. In the forest, there are some other deciduous tree species such as low valuable black birch, aspen, paper birch and by chance lime, ash, elm walnut and phellodendron. In fact, forests are very young. If human disturbance is not too serious after cutting, lower region (<500m) natural secondary forest is costly hardwood deciduous forest which is comprised of linden, ash, maple, oak, birch and so on. Good management and reservation can give it great chance to go to much better broadleaved-Korean pine forest, which is the zonation climax forest here. The forest biomass is about 200 ton/hm^2, leaf area index is about 4.33, net primary production is about 7.57 ton/(hm^2.a) (Xu, 1985).

The most valuable forest is broadleaved-Korean pine forest, which occupies most region within 500m—1200m elevation zone. Most of the timber production in this region is from this range, meanwhile this region therefore becomes one of the most important timber production area. Korean pine is the dominant climax tree species, but the hardwood tree species also play an important role in the ecosystem as partners and successional tree species. About this ecosystem, by now the problem on succession have not solved, though the explanations are gradually going to accordance. In general, the more the Korean pine, the more the forest biomass so that biomass of the almost pure Korean pine forest on the very steep slope can reach 400 ton/hm^2 with more than 800 cubic meters timber and a leaf area index of 10 in which even shrub can hardly live owing to its thick canopy (Xu, 1985). It was reported that the net primary production can even reach 20. 19 ton/(hm^2. a) (Li, 1981). The upper of this zone deciduous tree species' status is mostly replaced by evergreen conifer trees-fir and spruce as to form conifer forest in which generally darker and moist so that there are less grass but more bryothyte (Wang, 1980).

The ermans birch forest occupying the zone between 1700m and 2000m is very ugly: the trees are short (average 12m) and creep; the biomass is very low (130 ton/hm^2); and the wood quality is very poor and wood is nearly useless (Liu, 1955). But it is treeline forest and transition vegetation between forest and alpine tundra so that it is very sensitive to climatic change and human disturbance and can become early warning vegetation. It is a very good research location for global change.

In theory, if we do not limit the study in forest vegetation, the Changbai Mountain alpine tundra will be the best research place, which occupies the belt from elevation of 2000m to that of 1800m with very thin soil and cold temperature, and annual growth of plant must finish within less than 74 days (Chi, 1981). The complexity of the problem is in poor soil and the slow growth rate of the tundra plant. It is measured that main wooden plants here only grow less than 0. 08 cm in stem diameter per year. In fact, the biomass is only about 2. 2 ton/hm^2, 90% of which is underground biomass; net primary production is 0. 3 ton/(hm^2. a) but only 20% of which for the underground (Li, 1981).

The variety of the vegetation tell us: Changbai Mountain's vegetation biomass, net primary production and species composition mainly depend on the temperature, soil fertilizer and water balance. Of course, natural disturbance such as wind and volcano eruption should be important factors.

2. 2 Natural and human disturbances

In Changbai Mountain, a very important and mysterious disturbance is volcano eruption (including the fire caused). Recent three great eruption is 1579, 1668 and 1702 A. D. , and even in 1900 A. D. a slight eruption occurred (Chen, 1985). It was volcano eruption that destroy the originate vegetation (broadleaved korean pine forest, fir and spruce forest) to form the present larch forest on the eastern slope (Zhao, 1981).

Wind is another important disturbance. It can cause a great scale death of trees, but it is thought of as necessary action for forest natural regeneration. Common winds keep on killing old and weak trees and procure "Gap" for renew seedling growth. Sometimes winds may be extremely powerful as to destroying large area forest for secondary succession starting. The recent violent wind destroyed about 10000 hm^2 climax conifer and deciduous mixed forest.

Forest fire (excluding the fire caused by volcano eruption) also is an important disturbance. Fire often lead fire tolerate and drought tolerant species survive or regeneration. Natural fire seems to be limited in small scale in Changbai Mountain and helpful to forest development.

Anyway, human disturbance looks like only harmful thing. Timber harvesting is reducing natural vegetation with some species extinction and leading to forming of non-zonal vegetation; scenery view travellers are irrecoverable destroying weak and sensitive alpine tundra.

The model must be built based on the mentioned above.

3 Model

3.1 Model NEWCOP

Gap models simulate forest dynamics by computing the seedling establishment, DBH growth and mortality of each tree on a small·plot (sized gap formed by a dominant tree's death). First gap model JABOWA was introduced to simulate the deciduous forest in the east of USA (Botkin, 1972). But the most important contribution has been paid by Shugart (Shugart, 1980; 1984) because of his model FORET. By now, most gap models has a direct source FORET. Because gap model needs some simple demographic parameter of forest tree species and is driven by climate variables and other environmental variables, it has been applied to wide study object: forest management, climate vegetation interrelation, forest succession and so on. In fact, the gap model has been proved to be useful to wide types of forest and wide geological range.

The ZELIG model has been developed for convenient use of gap model, which is directly from the FORET, JABOWA and LINKAGE model (Smith, 1988). We feel that ZELIG includes the general nature of gap model and easy to modification and implementation. On the other hand, there was a gap class model KOPIDE (Shao, 1991) to simulate dynamics of broadleaved-korean pine mixed forest in the Changbai Mt. , but it can not be applied to other forest type and other place. Hence, a model, NEWCOP (Northeastern Woods Competition Occupation Processor) is developed for it in this paper. The model is suitable to simulate the changeable forest types on different location.

The basic structure of the model NEWCOP is similar to that of ZELIG. The basic equation is shown in Table 1. Some implements are done which involve regeneration process, life history like the followings:

(a) Deciduous trees are shaded within 100% growing season by evergreen trees and deciduous trees, but evergreen trees are shaded within 100% growing season by evergreen trees and within about 80% growing season by deciduous trees (Yan, 1995).

(b) Driver of regeneration are classified into 3 types, general seed disperse, after fire disturbance and after other disturbance under which different tree species are of themselves renewing ability.

(c) Biomass and LAI (leaf area index) equations needs species-specific parameters to fit the real forest stands.

Table 1 Basic equations of NEWCOP for specific tree species

Optimal breast height diameter (DBH or D) growth equation：

$$\left[\frac{d}{dt}D\right]_{\mathrm{opt}} = \frac{gD(1 - DH/D_{\max}H_{\max})}{260 + 3b_2D - 4b_3D^2}$$

(Botkin，1972)

Height(H)-DBH relation：

$$H = 130 + b_2D - B_3D^2$$

(Botkin，1972)

Actual annual DBH increment：

$$\delta D = \left[\frac{d}{dt}D\right]_{\mathrm{opt}} f_L(AL) \cdot f_T(DEGD) \cdot \mathrm{MIN}(f_D(DRY), f_N(NUT))$$

The effect of current year's >5℃ effective cumulative degree days (*DEGD*)：

$$f_T(DEGD) = \frac{4(DEGD - DD_{min}) \cdot (DD_{max} - DEGD)}{(DD_{max} - DD_{min})^2}$$

(Shugart，1984)

The effect of current year's drought day percentage in growing season (*DRY*)：

$$f_D(DRY) = \sqrt{\frac{d - 10 \cdot DRY}{10 \cdot DRY}}$$

(Pastor，1986)

note，if $DRY=0$ then $f_D=1$； $DRY>$d then $f_d=0$

The effect of current year's available light AL (proportion of full sunlight)：

$$f_L(AL) = c_1 \cdot (1 - e^{-c_2 \cdot (AL - C_3)}$$

(Botkin，1972)

AL at height $x=f$ (cumulative leaf area index above height x，$LA(x)$)：

$$AL = e^{k \cdot LA(x)}$$

(Beer-Lambert Law)

The effect of current year's soil fertility supply to requirement ratio (*NUT*)：

$$f_N(NUT) = n_1 + n_2NUT - n_3NUT^2$$

(Pastor，1986)

Specific tree species' biomass estimated by *DBH* (*D*)：

$$\mathrm{BIOMASS}(D) = d_1 \cdot D^{d_2}$$

(Xu，1985)

Specific tree species' leaf area index (*LAI*) estimated by *DBH*(*D*)：

$$LAI(D) = 1_1 \cdot D^{1_2}$$

(Cheng，1990)

If $\delta D < 0.1^{*} (D_{\max}/A_{\max})$，then current year's tree's mortality probability：

$$P_1 = 0.369$$

(Smith，1988)

For each year，tree's natural mortality probability：

$$P_2 = 4.605/A_{\max}$$

(Shugart，1984)

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*：The meaning of the symbols in the Table 1 and 2： $A_{\max}$： the recorded maximum age，a

$D_{\max}$： the recorded maximum diameter at breast height，cm $H_{\max}$： the recorded maximum height，m

g： growth parameter in the growth equation

$DD_{\min}$： minimum >5℃ effective growing degree days (℃ day) within distribution

$DD_{\max}$： Maximum >5℃ effective growing degree days (℃ day) within distribution

k： light extinction constant through tree canopy (set to 0.4) *l*： shade tolerance 1： tolerance — 5： intolerance

d： drought tolerance 1： tolerance — 9： intolerance *n*： poor nitrogen tolerance 3： tolerance — 1： intolerance

w： regeneration ability after no fire disturbance *r*： self sustainability *c*： ability of diffusion regeneration

c_1, c_2, c_3： parameters related to tolerant classes of specific tree species

n_1, n_2, n_3： parameters related to tolerant classes of specific tree species

b_2, b_3： regression parameters of tree height to *DBH* (estimated from $D_{\max}$ & $H_{\max}$)

f： fire tolerance *m*： life history parameter. 9 for evergreen tree； <9 for deciduous tree

d_1, d_2： parameters (estimated from field measurements) for biomass$=d_1 \times DBH^{d_2}$

l_1, l_2： parameters (estimated from field measurements) for leafarea$=l_1 \times DBH^{l_2}$

The involved site characteristics and related calculation is just similar to ZELIG model. However, in this case, we do not use solar angle to estimate the plot size but set the plot size 600—800 square meters because of the topological complexity of the mountain.

3.2 Parameters of species for NEWCOP

NEWCOP model has almost the same parameter requirements as the other gap model. The parameters for 19 main species (total 34) are listed in Table 2 and the key of symbols is listed in Table 3. The parameters of "Gap" class model have been thought easy to get, however to estimate parameters of this study still has a special difficulty because of very different description of dimensions and physiological characteristics of the involved species here from different literatures. The methodology of getting the parameters will be reported in another essay.

Table 2 Species-specific parameters used in NEWCOP model*

Name	A_{max}	D_{max}	H_{max}	g	DD_{min}	DD_{min}	l	d	n	w	r	c	f	m	d_1	d_2	l_1	l_2
PNKO	400	130	38	110	700	2400	3	9	1	1	2	1	4	9	0.077	2.51	0.50	1.69
LXOG	300	100	35	140	400	1600	5	2	3	4	2	1	1	8	0.026	2.83	0.40	1.69
ABHO	400	150	40	100	1000	2700	3	9	1	1	2	1	5	9	0.073	2.51	0.50	1.69
ABNE	200	60	30	100	450	1600	1	9	2	2	2	2	1	9	0.073	2.51	0.50	1.69
PCJE	300	100	35	90	400	1600	1	9	1	2	2	2	3	9	0.073	2.51	0.50	1.69
FRMA	300	110	35	160	800	2700	3	6	1	4	2	2	2	7	0.109	2.38	0.43	1.66
BEPL	150	60	30	215	500	2900	5	2	3	64	7	2	2	7	0.230	2.27	0.43	1.66
BECO	200	90	33	160	600	1800	3	8	2	2	2	2	3	7	0.230	2.27	0.43	1.66
BEDA	80	50	28	215	600	3100	5	1	3	2	2	2	5	7	0.230	2.27	0.43	1.66
BEER	200	60	25	70	300	1200	5	9	3	4	2	2	2	7	0.230	2.27	0.43	1.66
POKO	200	120	38	200	750	2400	4	9	1	1	2	1	3	7	0.470	2.01	0.43	1.66
PODA	150	60	25	215	600	2700	5	4	1	16	8	2	3	7	0.700	1.92	0.43	1.66
ACMO	200	60	25	80	800	2700	1	7	2	2	2	2	3	7	0.190	2.32	0.43	1.66
ACUK	80	25	15	80	450	1800	1	9	2	2	2	2	3	7	0.190	2.32	0.43	1.66
TIAM	300	80	32	130	700	2500	2	9	1	4	2	2	3	7	0.220	2.12	0.43	1.66
QUMO	350	100	30	140	700	2800	4	1	3	2	2	2	5	7	0.130	2.35	0.43	1.66
JANG	250	80	30	170	800	3100	5	6	1	4	2	2	3	7	0.109	2.38	0.43	1.66
PHIL	250	90	32	180	800	3200	4	8	1	4	2	2	2	7	0.109	2.38	0.43	1.66
ULAM	250	100	32	160	750	2500	3	9	2	4	2	2	1	7	0.070	2.42	0.43	1.66

* Main reference for parameters in Table 2.

A_{max}, D_{max}, H_{max}, g, l, d, n, w, r, c, f: Liu (1955), Zhou (1987), Zheng (1980), Huang (1964)

DD_{max}, DD_{min}: Xu (1981), Chi (1981), Shao (1991), Zhen (1990)

d_1, d_2, l_1, l_2: Li (1981), Xu(1985), Chen (1990).

Table 3 Scientific and common names of the 20 tree species used in the model, NEWCOP

Abbrev.	Scientific name	Common name
PNKO	*Pinus koraiensis Sieb. et Zucc*	Korean pine
LXOG	*Larix olgensis A Henry.*	Changai larch
ABHO	*Abies holophylla Maxim.*	Manchurian fir
ABNE	*Abies nephrolepis Maxim.*	East siberian fir
PCJE	*Picea jezoensis Carr.*	Hondo spruce
PCKO	*Picea koraiensis Nakai.*	Korean spruce
FRMA	*Franxinus mandshurica Rupr.*	Manchurian ash
BEPL	*Betula plytaphyla Suk.*	Szechuan birch
BECO	*Betula costata Trautv.*	——
BEDA	*Betula dahurica Pall.*	Black birch
BEER	*Betula emanii Cham.*	Erman's birch
POKO	*Populus koreana Rehder*	Korean poplar
PODA	*Populus davidiana Dode*	Aspen
ACMO	*Acer mono Maxim.*	Maple
ACUK	*Acer ukuranduense Trautv et Mey.*	——
TIAM	*Tilia amurensis*	Amur lime
QUMO	*Quercus mongolica Fisch.*	Mongolia oak
JANG	*Juglans mandshurica Maxim.*	Manchurian walnut
PHIL	*Phellodendron amurense Rupr.*	Amur cork tree
ULAM	*Ulmus propinqua Koidz.*	Spring elm

A special issue on estimation of the parameters of "Gap" model is about the "g" parameter (Table 1) of the growth equation which frankly affects the real growth of the species' dimension. This parameter has been estimated by several methods which includes: (1) fitting the man-made forests; (2) theoretically the relationship between "g" and maximum *DBH* increment; (3) fitting the production processing table; (4) this research adopts a reliable way——fitting both the maximum age and maximum *DBH* because the two controls are most important as soon as equation of the *DBH*-Height relationship is defined.

4 Validation of NEWCOP

First of all, this class model has been applied worldwide forests with basic match to observation. Therefore, there is no doubt that the idea of "Gap" class model's simulating composition dynamics of small forest stand is correct. But we still have to prove that the "Gap" class model NEWCOP do work in Changbai Mountain.

In order to test NEWCOP, a large number of simulations have been done in Changbai Mountain. The model has been run every 200m interval along the elevation from clear-cutting floor; the model has also been run from initialization of measured field. In all simulations including simulating the sensitivity of Changbai Mt. forests to potential climatic change, the following site parameters are used:

Field moisture capacity (FC):	28 cm
Permanent wilt point (PWP):	15 cm
Fertility:	8000 kg/(hm^2·a)
Frequency of wind disturbance:	1/400 (annual)

The climate data is calculated from the nearest meteorological stations, which includes monthly mean temperatures and their STDs (standard deviation) and monthly mean precipitations and their STDs.

4.1 Validation of long term dynamics of forest stands

There are 2 aspects which can be used to test the long term integrating ability and behaviors. The first one is forest distribution and tree distribution. On the north slope of Changbai Mt., from elevation 600 to elevation 1600, four types of forest have been well known (Wang, 1980), called broadleaved-Manchurian-fir-Korean-pine forest, broadleaved-korean-pine forest, mixed Korean-pine-fir-spruce forest, and mixed fir-spruce forest. From Fig. 1(a)-1(d), all the types of forests are clearly identified. In fact, NEWCOP can simulate even forest types dividing line along elevation. For example, the 100m-interval simulations have reproduced the observation: the elevation 1200m is the upper limit of mixed Korean-pine-fir-spruce forest, 700m that of broadleaved-Manchurian-fir-Korean-pine forest, 1000m that of roadleaved-koran-pine forest. That is true, all the observation that break this limit can be explained by considering the effect of the hot spring at the elevation 2000m of the north slope.

Second aspect is available forest ecological theory about growth and succession. From Fig. 1(a) and 1(b), it is shown that birch and aspen always first establish in a bare floor (resulted from clear-cutting in the early stage, wind or any other non-fire disturbance) followed by the some hardwoods such as ash, maple, oak and so on. and lastly the Korean pine and Amur lime dominate the forest stands. The simulations just tell us the same as the text book. The reason is that dominant tree species can survive and renew all by themselves but not by disturbances which often are the necessary conditions of the renewing of the species like the birch, aspen, larch.

In addition, NEWCOP shows that Mongolia oak appears at the all forest at all the stage (Fig. 1(b)) though it is shade intolerant, of slow growth, and no special advantage during nitrogen and water competition because of no lack of nitrogen and good soil water condition. Considering that its long life span much over birch, aspen, we seem to agree that the life span is one of the most important factors to control the succession, agreeing with observation.

Long term validation proves that the model NEWCOP' long term behavior is very sensitive to the climate condition.

4.2 Validation of mediate term dynamics of forest stands

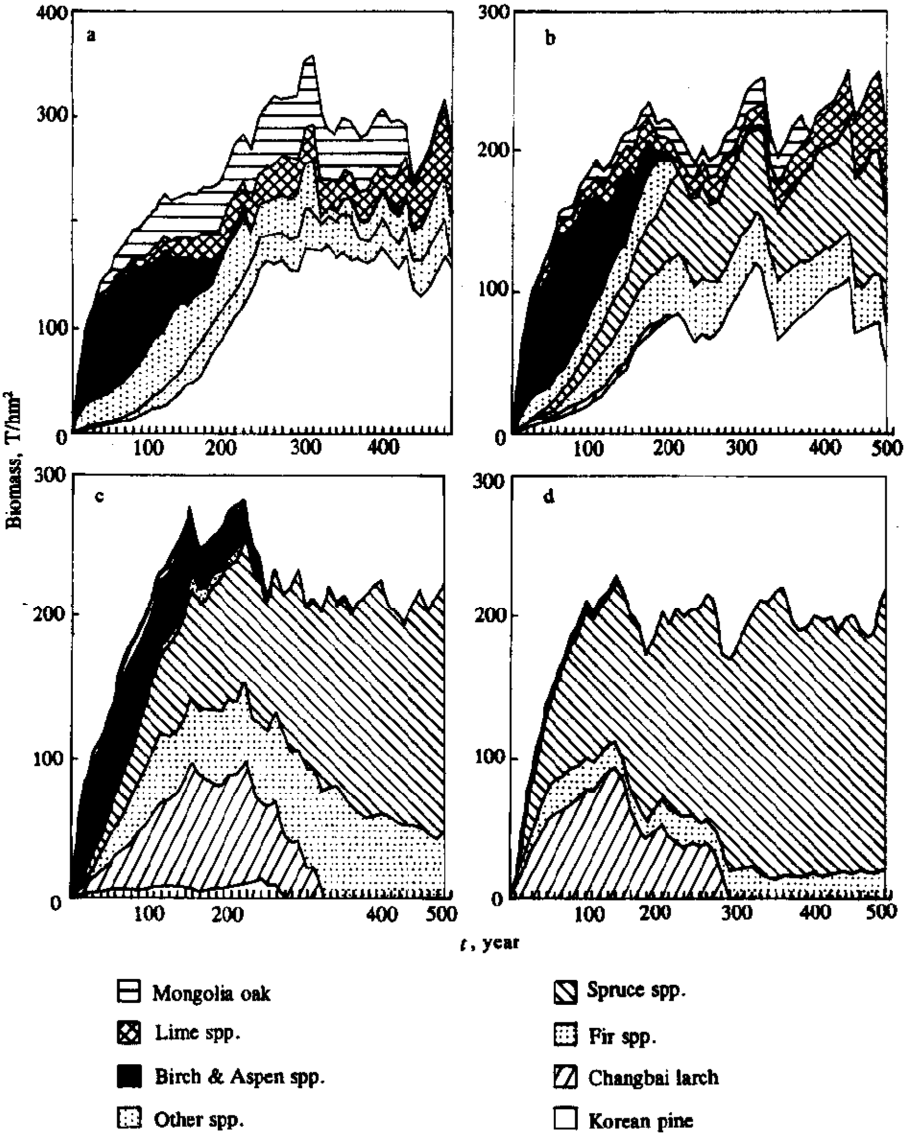

Fig. 1 Species composition (by biomass) of forest at Changbai Mt. from bare floor under without climate change

(a): 600m (b): 1000m (c): 1200m (d): 1600m

The objective of the mediate term testing is to wonder whether the model can "smoothly follow" the actual forest stands on the field. Simulations show that NEWCOP can do that patty well. The Fig. 2 is an example of good following an actual forest stands. At this case, 2 ha forest fixed plot with over 10 years record of observation at elevation 740m of Changbai Mt. is divided into 25 small plots with an area of 800 m^2 as the initial forest states for 200 years simulation. The forest was cut selectively by Japanese invaders in 1940s so that Fig. 2 just shows the continuous growth of Korean pine (because the big Korean pine was preferred at that time). We have also tested other 5 plots ranged from elevation 630m—1370m, which have showed similar "smoothly follow" and with good explanations.

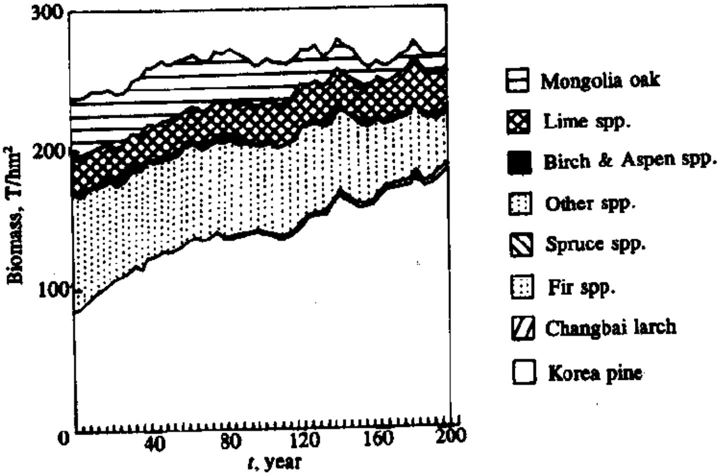

Fig. 2 Species composition (by biomass) of standing forest at the elevation 740m of Changbai Mt. without climate change from the year 1979

Mediate term validation shows that the model NEWCOP's simulation of tree's growth is reasonable.

4.3 Short term behavior of the model NEWCOP

The short term behavior is relatively easy to see. First of all, we ran the NEWCOP on man-made pure forest several years based on the initial number of actual planted trees. The result is that simulation underestimate the growth of the almost all the species involved the running. The explanation of the cases is that the human management (thinning for example) actually has improve the light condition and reduced the competition of species so that the objective tree species can grow faster than natural trees without management.

The strong verification of NEWCOP involves using the model to develop histograms of frequency of trees per *DBH* class to compare the simulated data against the remeasured data which are separately obtained from simulation and actual measurement by the same initial condition (Daaleen, 1989). Fig. 3 shows the result of comparison for Korean pine on same plots at the elevation 740m of Changbai Mountain. In general the simulation overestimates the frequency of trees within low *DBH* class and underestimates it within high *DBH* class. However, the simulation presents close match to actual *DBH* class distribution. To other tree species, simulations show the similar match.

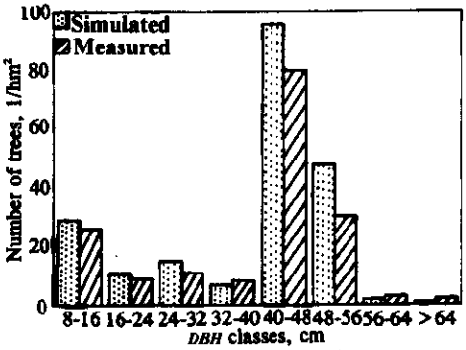

Fig. 3 Comparison of the simulated and the measured *DBH* distribution of Korean pine in a standing forest at the elevation 740m of Changbai Mt. in 1989

The simulation is initialized from the same stand in 1979

5 Application of modelling sensitivity of forest to climate change

The NEWCOP has been proved to be reasonable to simulate forests of Changbai Mt. at every time scale. So we have applied it to test the sensitivity of forests to climate change in this paper.

5.1 Response of forests distribution to climate change

A total of 6 simulations is performed using the elevation 600m, 800m, 1000m, 1200m, 1400m and 1600m of Changbai Mountain. GFDL transient $2\times CO_2$ climate change scenario with a linear change over 100 years (from year 300-year 400 in this section and year 1-year 100 in next section) then another 100 years equilibrium climate (year 400—500 in this section and year 100—200 in next section). CO_2 fertilizer is assumed as zero. All the simulations are run under without climate change and with climate change condition from bare floor, then comparisons are done.

The simulations of running NEWCOP with GFDL transient climate change scenario suggested a big change of forest composition and some tree species disappeared at different elevation. Taking elevation 600m (very important broadleaved-Korean-pine forest is main forest type here) for instance, Fig. 4 shows a fast disappearance of Korean pine, lime and Mongolia oak and breakdown of forest biomass. The dieback occurs at a short period of the transient stage (year 300 to year 370), ash and some other deciduous tree species replace them. A natural explanation is that current climate at the elevation is near the climate low edge of distribution of those tree species so that warmer climate may lessen the growth and lead to dieback.

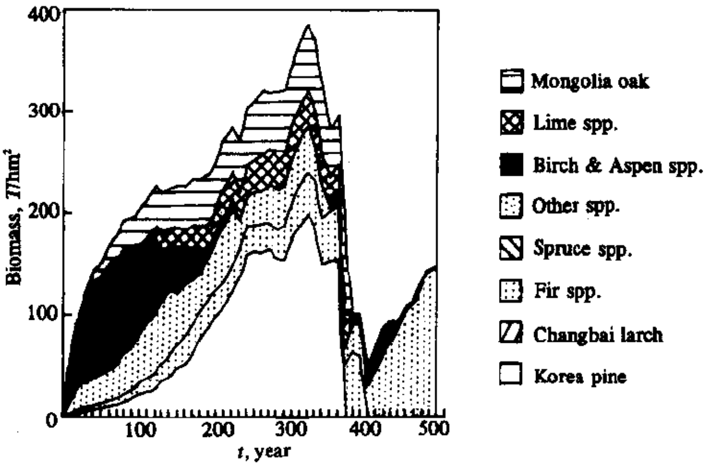

Fig. 4 Species composition (by biomass) of forest at the elevation 600m of Changbai Mt. from bare floor with the GFDL $2\times CO_2$ climate change scenario from 300 year (the years 300—400 for linear climate change, 400—500 for equilibrium climate)

For similar reason, at elevation 800m, same thing occurs but Mongolia oak. However dieback occurs a bit later (year 340 to year 400 in the simulation); at elevation 1000m, Korean pine, fir and spruce disappear, but Korean pine dieback occur after 150 years since beginning of the climate change and fir and spruce dieback occur at just beginning stage of climate change; at elevation 1200m and 1400m, fir and spruce will be replaced by Korean pine and deciduous trees.

The conclusion is that deciduous trees may be much more than the current proportion in forest composition and the coniferous trees may be reduced. The economic lost may be very big because of the fast dieback.

5.2 Response of present standing forests to climate change

The previous mentioned GFDL climate change scenario is set to begin just now on. We test the response of the actual standing forest at elevation 740m. The simulation is set to begin against field measured data with the climate change and keep running for 200 years. Fig. 5 shows that Korean pine and lime will disappear, Dieback occurs about 90 year from now. Abies holophylla will appear. Within only ten years, the biomass lost may reach 150 ton/hm^2. A primary explanation is that all standing korean pine and lime are near mature, however weaken growth capability and unsuitable climate for regeneration of seedlings lead to biomass storage lost. That is a warning for the leaders and management.

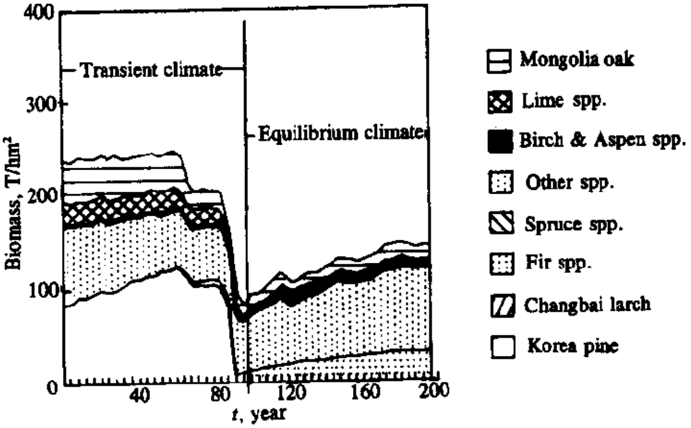

Fig. 5 Species composition (by biomass) of standing forest at the elevation 740m of Changbai Mt. with the GFDL $2\times CO_2$ climate change scenario from the year 1979 (1979—2079 for linear transient climate, 2079—3079 for equilibrium climate)

6 Conclusion

This paper presents the results of computer simulations by using the model NEWCOP. The proposed model show good behaviors for reproducing actual forests' distribution, processes and the species composition. The following points should be paid a close attention.

Forest landscape zones may rise, and for valuable conifer forest and conifer deciduous forest, area suitable for forest growth will decrease and biomass (t/hm^2) will increase.

If more landuse information is collected, we can use NEWCOP to assess potential lose or benefit of Changbai Mountain forests under climate change condition in the future.

Major uncertainty is from lack of the reliable prediction about the climate change in Changbai Mt. region.

In theory, the studying result on response of Changbai Mountain forest to future climatic change can beneficially be implicated to plantation tree species selection, cutting planning and forest management. For it, the reliable climatic prediction is called for.

Changbai Mountain natural reserve is one of the most important national reserves. Its management should pay attention to the results of global change.

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