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INFLUENCE OF GLOBAL WARMING ON VEGETATION IN NORTHEAST CHINA①

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ABSTRACT: The response of vegetation in northeast China to global warming would be the following: 1) the future alteration types of edificators could be divided into three types; 2) the plant populations would move northwards about 400 - 700 km and upwards 250 - 350 m; 3) the distribution border of cultivated crops would change; 4) the phenological development of most plants would advance one season; 5) the productivity of main forest ecosystems would increase 7.65% and that of main agroecosystems would increase 36.4%.
KEY WORDS: global warming, edificator, vegetation, northeast china

Global warming is one of the serious environment problems which attract attentions of scientists and governments of various countries. The global atmosphere components change because of human activities and the development of industry. The increase of greenhouse effect leads to global warming. Based on the prediction of general circulation model(GCM), by the middle of next century, the concentration of CO_2 will be doubled and the global temperature will increase by 2℃ (Han, 1993; Sherwood, 1983). We studied the law of vegetation alteration under this condition in northeast China in this paper.

I. INFLUENCE OF GLOBAL WARMING ON DISTRIBUTION OF EDIFICATORS

1. The Movement of Edificators

Based on the following Kira's warmness index (WI), coldness index (CI) and Xu's humidity index (HI) (Xu, 1982, 1985, 1986).

$$WI = \sum (t - 5)$$

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$$CI = \sum(5 - t)$$

$$HI = P/WI$$

where t is monthly mean temperature, P is annual precipitation.

We calculated the moisture-temperature indexes (Table 1) and the future population types of 34 main edificators (Table 2).

Table 1 The water-temperature indexes of main edificators in the zonal vegetation in northeast China

Species	Warmness index (℃ · month)						Humidity index (mm/℃ · month)	
	Whole range	Optimum range	Lower limit		Upper limit			
			sample number	Mean ± SD	sample number	Mean ± SD	sample number	Mean ± SD
Pinus koraiensis	33 - 78	45 - 66	37	58.5 ± 5.4	15	32.1 ± 5.9	37	11.2 ± 1.9
P. tabulaeformis	48 - 92	72 - 87	12	87.9 ± 4.7	11	67.8 ± 7.1	12	7.8 ± 2.6
P. pumila	11 - 45	16 - 31	14	31.0 ± 7.4	7	18.4 ± 4.5	14	10.8 ± 1.4
P. sylvestris var. *mongolica*	21 - 59	30 - 48	11	50.7 ± 6.1	12	32.2 ± 4.4	11	9.9 ± 2.0
P. densiflora	70 - 90	73 - 89	5	87.6 ± 2.1	3	71.3 ± 5.1	5	10.7 ± 3.1
Larix dahurica	18 - 63	28 - 53	17	54.5 ± 7.0	11	28.0 ± 5.8	17	10.3 ± 1.5
Picea jezoensis	19 - 71	34 - 60	14	60.7 ± 5.0	10	32.1 ± 7.3	14	11.1 ± 2.0
P. koyamai var. *koraiensis*	18 - 70	30 - 60	29	56.6 ± 5.2	19	31.2 ± 8.4	29	10.7 ± 1.5
P. meyeri	34 - 67	36 - 58	5	50.6 ± 10.4	4	36.3 ± 6.7	5	7.7 ± 1.8
Abies nephrolepis	20 - 70	30 - 59	13	61.8 ± 4.8	11	32.8 ± 7.4	13	11.5 ± 2.3
A. holophylla	37 - 83	46 - 69	15	60.0 ± 6.1	16	49.6 ± 6.2	15	12.7 ± 1.9
Taxus cuspidata	46 - 88	51 - 73	15	65.7 ± 6.3	14	54.6 ± 6.1	15	12.7 ± 1.9
Betula ermanii	15 - 38	20 - 32	6	31.0 ± 4.5	6	22.3 ± 2.3	6	192.2 ± 0.0
Carpinus cordata	40 - 90	48 - 74	19	65.9 ± 11.1	14	51.0 ± 6.1	19	11.3 ± 2.2
A. tagmentosum	28 - 73	37 - 60	23	62.4 ± 7.0	6	38.2 ± 3.8	23	11.0 ± 2.1
A. ukurunduense	22 - 73	30 - 60	23	62.4 ± 7.0	16	29.9 ± 5.9	23	11.0 ± 2.1
A. triflorum	40 - 84	46 - 70	16	65.5 ± 10.4	12	49.0 ± 6.5	15	11.3 ± 2.0
A. mandshuricum	40 - 81	45 - 69	15	64.8 ± 10.4	12	49.0 ± 6.6	16	11.3 ± 2.2
A. pseudo-sieboldianum	40 - 84	48 - 73	17	65.8 ± 10.4	13	52.3 ± 5.9	17	11.3 ± 2.2
Quercus mongolica	34 - 92	47 - 72	49	41.5 ± 2.2	15	88.6 ± 1.5	49	10.6 ± 2.0
Q. liaotungensis	49 - 93	61 - 86	20	78.2 ± 10.2	11	56.2 ± 5.9	20	11.0 ± 2.3
Q. varibilis	46 - 92	75 - 88	9	82.5 ± 3.8	9	76.0 ± 2.9	9	10.5 ± 2.3
Q. acutissima	61 - 89	69 - 85	14	81.7 ± 4.5	14	71.6 ± 4.8	14	9.5 ± 2.2
Q. dentata	52 - 90	61 - 85	28	77.8 ± 10.4	6	55.9 ± 2.8	28	11.6 ± 3.5
Q. dliena	70 - 91	75 - 89	17	82.6 ± 4.2	20	77.9 ± 5.2	17	10.8 ± 1.6
Tilia amurensis	30 - 91	46 - 63	28	78.8 ± 7.0	13	36.6 ± 6.6	28	10.8 ± 2.0
Phellodendron amurense	39 - 70	47 - 61	27	77.3 ± 6.1	10	45.4 ± 3.4	27	11.5 ± 2.0
Acer mono	31 - 83	45 - 62	34	69.9 ± 9.1	18	41.5 ± 5.6	34	11.2 ± 2.0
Betula davurica	35 - 89	46 - 71	19	39.5 ± 3.4	15	90.4 ± 2.7	19	10.2 ± 1.2
Magnolia parviflora	53 - 89	63 - 85	17	81.8 ± 5.8	10	57.1 ± 4.2	17	11.7 ± 2.0
Rhododendron chrysanthum	12 - 23	13 - 22	3	21.0 ± 2.0	2	11.4 ± 1.4	1	192.2 ± 0.0
Dryas tschonoskii	9 - 15	9 - 15	2	15.5 ± 0.7	2	9.5 ± 0.7	1	192.2 ± 0.0
Salix rotundifolia	7 - 10	7 - 10	2	9.5 ± 0.7	2	7.5 ± 0.7	1	192.2 ± 0.0
Phyllodoce caerulea	9 - 17	9 - 16	2	14.5 ± 0.7	2	9.5 ± 0.7	1	192.2 ± 0.0

Table 2 The future alteration types of distribution of edificators of zonal vegetation in northeast China

		Upper limit (warmness index in ℃ · month)								Total species
		15 – 24	25 – 34	35 – 44	45 – 54	55 – 64	65 – 74	75 – 84	85 – 94	
	14 – 5	31 32								
		33 34								4
	24 – 15		3 13							2
	34 – 25				4 6 10	7 8				5
Lower limit						9 16				
	44~35					17				3
(warmness						1 15	11 12			
index in	54 – 45						14 18			
℃ ·mouth)							19 20			12
						27 28	21 29			
									22 25	
	64 – 55								30	3
	74 – 65								5 24	2
	84 – 75								2 23 26	3
Total species		4	2		3	9	8		8	34

1 . 1 Extended population

The extended population prefers to warmth and was grouped into two groups according to its *WI* value as follows: (1) *WI* being 45 – 75(℃ · month). This group includes *Pinus koraiensis*, *Abies holophyla*, *Taxus cuspidata*, *Quercus mongolica*, *Phellodendron amurense*, *Acer triflorum*, *Acer mandshurica*, and so on; (2) *WI* being 55 – 95(℃ · month). It included *Pinus tabulaeformis*, *Pinus densiflora*, *Quercus liaotungensis*, *Quercus varibilis*, and some subtropical species, for example, *Rhus verniciflua*, *Rhus chinensis*, *Linderaa obtusiloba*, *Magnolia parviflora*. These populations need more warmth, so they would move northwards during the climate warming in the future.

1 . 2 Retreated population

The *WI* of retreated population was 25 – 65 (℃ · month). The group includes *Larix dahurica*, *Picea koyamai* var. *koraiensis*, *Picea jozoensis*, *Abies nephrolepis*, *Pinus sylvestris* var. *mongolica*, and so forth which were the immigrants after Quaternary Glaciation from Siberia. In the Da Hinggan Mountains, these species retreated because of climate warming and permanent frozen soil melting.

1 . 3 Extinct population .

The *WI* of extinct population was 5 – 35 (℃ · month). The group includes *Dryas tschonoskii*, *Phyllodoce caerulea*, *Artous japonica*, *Empertrum sibiricum*, *Polygonatum ajanense*, *Arctous alpinus*, which were Arctic alpine elements. Their distribution in northeast China resulted from alternate cold and warm effects during glaciation and interglaciation. With the climate changes in the future, the alpine vegetation in the Da Hinggan Mountains, Xiao

Hinggan Mountains and Changbai Mountains would be extinct.

2. The Influence of Global Warming on the Distribution Border of Edificators

In northeast China, there are 15° latitudinal differences and 2,600 m altitudinal differences. These differences result in complexity of plant population. From south to north, there appear in turn warm-temperate population, temperate population, and cold-temperate population. There exists a linear relationship between warmness index (WI) and latitude (X), longitude(Y) and altitude (H) as follows:

$$WI = 288.94 - 2.51X - 0.81Y - 0.038H \qquad (r = 0.9812)$$

This model reflected macroscopic distribution pattern of WI value in plant growth season in the mountains in northeast China (Table 3). Moving northwards 1° latitude, WI decreased 2.51(℃ · month); moving eastwards 1° longitude, WI decreased 0.81(℃ · month); and moving upwards 100 m, WI decreased 3.8(℃ · month). Based on the formula, it was calculated that the edificators would move northwards about 400 – 700 km when the global temperature increased 2℃. However, the moving distance would become shorter and shorter as the latitude increases. According to the results of calculation, the population would move upwards about 260 – 365 m if the temperature increased 2℃, but the moving distance would be nearer and nearer as the altitude increases. Therefore, the population of alpine tundra at the Da Hinggan Mountains and Changbai Mountains might disappear (Xu, 1983).

II. THE INFLUENCE OF GLOBAL WARMING ON DISTRIBUTION OF VEGETATION TYPES

1. The Horizontal Changes of Vegetation Zones

The horizontal vegetation zones include latitudinal zones and longitudinal zones. Vegetation reflects the latitudinal and longitudinal zonation (Xu, 1992a). Based on the above regulation, we carried on the analysis of principal components analysis on F_1(latitude), F_2(longitude), F_3(altitude), F_4(precipitation), F_5(WI), F_6(CI) and F_7(HI) of 210 climate stations in northeast China(Table 4).

The first 2 components (F_1, F_2) accounted for 77.6842% of variation (Fig. 1) (Liu 1985).

From Fig. 1, we found that the vegetation be could divided into seven groups (Table 5).

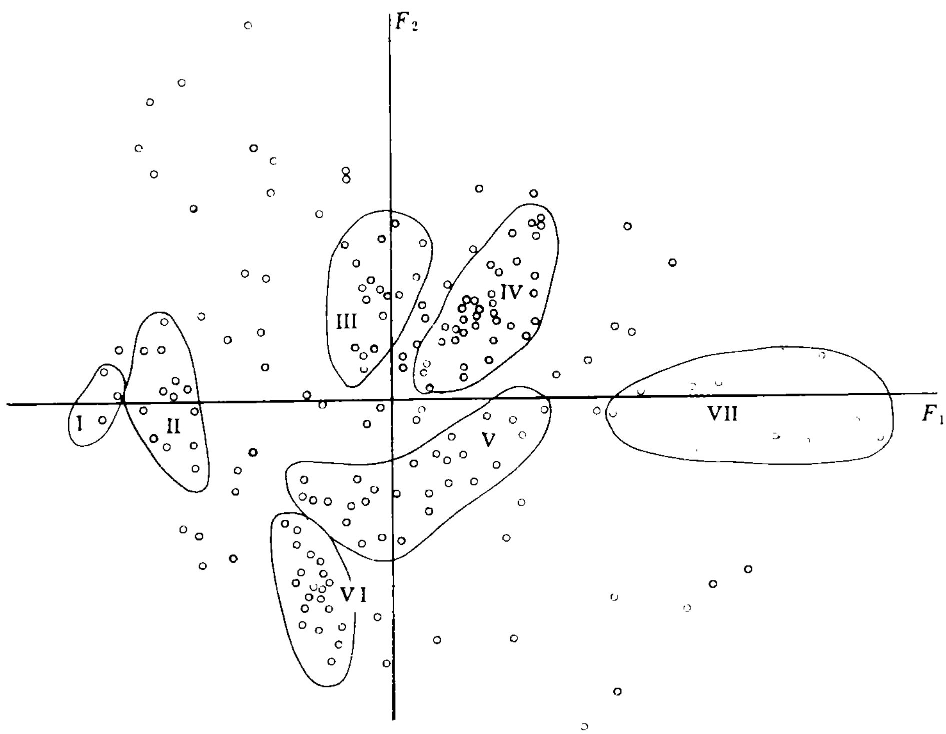
The data reflected the climate characters and certain ecogeographic patterns of different

Table 3 The future border of distribution of edificators of the zonal vegetation in northeast China

Species	Limit	Samples	WI (℃·month) Mean	WI SD	WI SD/7	CI (℃·month) Mean	CI SD	CI SD/5	T (℃) Mean	T SD	HI (mm/(℃·month)) Mean	HI SD	Moving distance (km)
Pinus	Upper	8	33.1	5.7	1.1	−120.2	13.8	1.9	−1.6	1.2	−	−	260
koraiensis	Northern	3	45.7	3.2	0.6	−125.9	5.6	0.8	−0.7	0.8	10.5	1.3	443
Tilia	Upper	3	31.6	3.5	0.7	−114.5	7.5	1.0	−1.7	1.2	−	−	260
amurensis	Northern	3	36.2	7.0	1.4	−128.6	9.0	1.2	−1.5	1.0	10.7	1.7	443
Acer	Upper	7	43.3	6.4	1.3	−199.1	10.9	1.6	0.1	1.0	−	−	260
mono	Northern	3	45.7	7.0	1.4	−129.1	8.8	1.3	0.7	0.8	10.1	1.0	443
A.	Upper	5	31.0	7.3	1.5	−11.5	8.6	1.2	−0.5	1.0	−	−	260
tagmentosum	Northern	3	47.7	7.8	2.6	−129.6	6.8	1.0	−1.2	0.2	10.5	1.3	443
A.	Upper	7	40.8	6.5	1.3	−102.3	8.9	1.3	0.5	0.6	−	−	260
ukurunduense	Northern	2	46.0	9.8	1.9	−132.0	7.4	1.1	−1.6	0.0	10.5	1.3	443
Abies	Upper	9	44.4	3.6	0.7	−97.7	8.9	1.3	0.7	0.9	−	−	260
holophylla	Northern	9	62.8	4.7	0.9	−83.5	6.9	0.9	3.2	0.8	12.0	2.0	620
Carpinus	Upper	10	51.4	5.9	1.2	−91.5	8.6	1.2	1.6	1.0	−	−	313
cordata	Northern	6	61.5	6.3	1.3	−85.2	10.3	1.5	2.9	1.2	9.8	1.3	620
A.	Upper	8	49.0	5.7	1.1	−92.1	7 4	1.1	4.3	0.7	9.8	1.3	260
triflorum	Northern	3	71.0	6.9	1.4	−77.3	7.4	1.1	4.3	0.7	9.8	1.3	620
A.	Upper	10	51.4	5.4	1.2	−91.2	8.2	1.2	2.0	0.7	−	−	313
mandshuricum	Northern	4	70.0	7.9	1.6	−80.0	7.3	1.0	3.6	1.1	9.8	1.3	620
Pinus	Upper	8	61.4	4.4	0.4	−78.7	7.2	1.0	3.4	0.8	−	−	365
tabulaeformis	Northern	12	79.3	4.2	0.6	−60.8	4.9	0.9	6.5	0.7	7.8	2.6	620
P.	Upper	3	73.1	4.9	0.7	−47.7	8.9	1.8	7.1	1.4	−	−	365
densiflora	Northern	5	88.1	3.3	0.5	−33.7	7.0	1.4	9.1	0.9	12.4	1.9	708
Picea	Upper	4	45.0	2.7	0.6	−98.0	2.4	0.3	0.9	0.6	−	−	260
meyeri	Northern	2	51.0	2.8	0.5	−88 0	2.8	0.4	1.8	0.6	7.6	1.1	620
Quercus	Upper	5	62.2	8.3	1.6	−80.6	4.9	0.7	3.6	0.9	−	−	365
liaotungensis	Northern	3	70.0	10.0	2.0	−70.0	6.1	0.9	5.2	1.0	11.8	0.9	620
Q.	Upper	4	71.5	6.6	0.9	−64.7	3.7	0.7	5.4	1.1	−	−	365
acutissima	Northern	4	80.0	7.1	1.0	−56.5	3.5	0.7	6.7	0.8	−	−	365
Q.	Upper	5	76.2	2.5	0.4	−51.0	7.9	1.5	7.1	0.8	−	−	365
variabilis	Northern	5	83.2	2.2	0.3	−43.6	7.3	1.4	8.4	0.7	9.9	2.8	620
Stipa	Western	4	64.6	4.7	0.6	−98.2	9.4	1.8	2.4	1.1	7.5	0.2	926
baicalensis	Northern	3	80.4	2.2	0.3	−66.0	7.2	2.4	6.1	0.8	5.2	0.2	−
S.	Western	3	73.0	1.4	0.2	−82.8	2.3	0.5	4.2	0.3	5.7	0.7	926
grandis	Northern	4	79.4	8.5	1.2	−66.3	5.8	1.1	5.9	0.8	4.8	0.4	−
S.	Upper	3	78.8	1.0	0.1	−68.1	1.4	0.3	5.8	0.2	5.0	0.7	926
krylovii	Western	4	68.4	10.4	1.4	−74.7	27.3	5.4	4.2	2.8	4.1	0.5	−
S.	Upper	3	86.9	5.0	0.7	−52.7	3.2	0.6	7.9	0.5	7.5	0.4	926
bungeana	Western	3	82.1	9.4	1.3	−54.1	8.0	1.6	7.3	1.4	5.8	1.1	−

Table 4 Eigenvalues and percentage of total variation

	Principal components						
	F_1	F_2	F_3	F_4	F_5	F_6	F_7
Eigenvalue	3.3306	2.1073	1.1059	0.3704	0.0419	0.0252	0.0186
Contribution rate	47.5798	30.1043	15.7991	5.2920	0.5984	0.3602	0.2663
Accumulated contribution rate(%)	47.5798	77.6842	93.4832	98.7752	99.3736	99.7337	100.0000



I. Warm-temperate *Pinus densiflora-Quercus* mixed forest

II. Warm-temperate mixed *Pinus tabulaeformis-Quercus* forest

III. Temperate mixed *Abies holophyla-Pinus koratensis* broad-leaved forest

IV. Temperate mixed *Pinus koraiensis* broad-leaved forest

V. Temperate meadow steppe

VI. Temperate typical steppe

VII. Cold-temperate coniferous forest.

Fig. 1. Ordination of zonal vegetation types on the first 2 principal components (F_1 and F_2)

vegetation types. Moreover, there was a linear relationship among WI, X, Y, and H in plateau vegetation as follows:

$$WI = 343.96 - 2.73X - 1.16Y - 0.027H$$

The model showed that, moving northwards 1° latitude, *WI* decreased 2.73 (℃ · month); moving eastwards 1° longitude, *WI* decreased 1.16(℃ · month); and moving upwards 100 m, *WI* decreased 2.7(℃ · month). Therefore the steppe vegetation would move eastwards 926 km with the climate warming.

Table 5 The moving state of zonal vegetation types in northeast China

Zonal climax vegetation types	Samples	Thermal indexes (℃ · month)			Moving distance (km)
		Optimum range	*WI*	*CI*	
Cold-temperate coniferous forest	11	33.0 − 50.2	41.6 ± 7.3	− 138.1 ± 116.8	443
Temperate mixed *Pinus Koraiensis* broadleaved forest	38	58.1 − 66.9	62.5 ± 3.7	− 91.6 ± 8.1	531
Temperate mixed *Abies holophyla-Pinus koraiensis* broadleaved forest	20	61.3 − 74.3	67.8 ± 5.5	− 74.6 ± 5.7	620
Warm-temperate mixed Pinus *tabulaeformis-Quercus* forest	16	86.3 − 90.5	88.4 ± 1.8	− 47.8 ± 3.6	708
Warm-temperate mixed *Pinus densiflora-Quercus* forest	7	85.9 − 92.5	89.2 ± 2.8	− 33.9 ± 5.1	708
Temperate meadow steppe	30	62.7 − 76.5	69.6 ± 5.8	− 84.9 ± 11.1	926
Temperate typical steppe	24	73.7 − 80.3	77.0 ± 2.8	− 67.4 ± 3.9	926

2. The Vertical Changes of Vegetation Zones

We divided northeast China into three natural zones according to the vegetation horizontal zone rule and geographic characters (Xu, 1986).

2.1 Temperate mixed coniferous broadleaved forest zone

The region includes the Xiao Hinggan Mountains, Wanda Mountain, Zhangguangcai Mountain, Changbai Mountains, and Liaodong Mountains. If the future temperature increases 2℃, the vertical changes of vegetation zones would occur. For example, in the Changbai Mountains (Xu, 1981), mixed *Abies holophylla-Pinus koraiensis* braodleaved forest (*WI* > 65 (℃ · month)) would move from 700 to 963 m; mixed *Pinus koraiensis* broadleaved forest (*WI* is 65 − 50(℃ . month)) would move from 700 − 1,100 m to 963 − 1363 m; *Picea-Abies* forest zone (*WI* is 50 − 23(℃ · month)) would move from 1,100 − 1,800 m to 1,363 − 2,063 m; *Betula ermanii* forest zone (*WI* is 23 − 15(℃ · month)) would move from 1,800 − 2,000 m to 2,063 − 2,158 m, and alpine tundra zone (*WI* < 15(℃ · month)) would move from 2,000 m to 2,158 m.

2.2 Cold-temperate coniferous forest zone

The region lies in mountains of northern Da Hinggan Mountains. With the global warming, the vertical distribution of vegetation zones would change. For example, in Baihali Mountain (its altitude is 1,410 m), *Quercus mongolica-Larix dahurica* forest (*WI* > 50(℃·month)) would move from 450 m to 686 m; *Larix dahurica* coniferous forest zone (*WI* is 50 – 25(℃·month)) would move from 450 – 1,100 m to 686 – 1,363 m; *Pinus pumila-Betula ermanii* forest zone (*WI* is 25 – 15(℃·month)) would move from 1,100 – 1,400 m to 1,363 – 1,410 m, and the alpine tundra would be disappears.

2.3 Temperate steppe zone

In this region, we choose Huanggangliang Mountain (its altitude is 2,029 m) to show the vertical vegetation distribution as follows: *Stipa baicalensis-Filifolium sibiriaum* meadow (*WI* is 45(℃·month)), *HI* is 7.5 mm/(℃·month) would move from 1,300 m to 1,563 m; mixed coniferous-broadleaved forest zone (*WI* is 45 – 30(℃·month)), *HI* is 9.5 – 18 mm/(℃·month) would move from 1,300 – 1,700 m to 1,563 – 1,963 m, and Coniferous forest zone and alpine meadow would disappear.

3. The Border of Cultivated Crops

Apple prefers to warmth, especially Fuji Apple demands ragid temperature condition. The major limiting factor to its north border of distribution is *CI* (Xu, 1992b), not *WI*. If the mean temperature in winter rises 2℃, the northern survival border of Fuji Apple might move northwards 110 – 160 km.

Cotton prefers to warmth too, and it can only be cultivated at west and south districts in Liaoning Province at present. If the temperature rises 2℃ in the future, the northern border of cotton would move northwards 220 km, that is Siping, Shuangliao districts in Jilin Province.

Ginseng prefers to coldness (Bi, 1991). It is mainly distributed in mixed *Pinus koraiensis* broad-leaved forest in the Changbai Mountains and Liaodong Mountains. The elevation for Ginseng cultivation will be increased from 500 m to 767 – 817 m according to:

$$H = H_0 + 100(21 - T_0)/r.a$$

where H_0 is base altitude, T_0 is mean temperature of July, r and a are parameters to be estimated.

III. THE INFLUENCE OF GLOBAL WARMING ON PLANT GROWTH AND DEVELOPMENT

(1) The Change of Plant Development Period. The frost-free period in northeast China is 92 – 202 days. Based on the function of frost-free period

$$F = 3.7945 + 7.4581T \qquad (r = 0.892)$$

where F is frost-free period, T is mean temperature of frost-free period. The growth period of plants would prolong for 15 days if the temperature rises 2℃.

(2) The Change of Tree Growth and Development. According to the observation on *Pinus sylvestriformis*, the species grows rapidly when mean temperature is above 10℃. Its phenological development would roughly advance one rhythm if the mean temperature increases 2℃. In the Changbai Mountains, the leaf of *Betula platphylla* may enlarge to 1.1 times and *Betula ermanii* 1.2 times. Stoma number on unit area increased 51.3% for *Betula platphylla* and 16.3% for *Betula ermanii* (Table 6).

Table 6 The comparison of *Betula* leaf shape and structure under different temperature conditions in the Changbai Mountains

Item		*Betula ermanii*		*Betula platphylla*	
		B. ermanii forest	Picea-Abies forest	*Picea-Abies* forest	Mixed *Pinus koraiensis* broad-leaved forest
Altitude (m)		1800 - 2000	1100 - 1800	1100 - 1800	500 - 1100
WI (℃·month)		23 - 15	50 - 23	50 - 23	>65
Leaf size (cm^2)		18.8	22.0	16.9	18.2
Stoma density (stomas/mm^2)		115	174	129	150
Stoma size (μm)	Long	35.1	33.0	31.7	31.5
	Short	24.1	22.3	22.7	22.1

IV. THE INFLUENCE OF GLOBAL WARMING ON VEGETATION PRODUCTIVITY IN NORTHEAST CHINA

1. The Influence of Climate Warming on Forest Productivity

There is a close relationship between the forest productivity and warmth distribution. Generally speaking, forest productivity decreases as the warmth lessens from low latitude to high latitude. In northeast China, the relationship was:

$$P_n = 0.0778WI + 5.3675 \qquad (r = 0.989)$$

where P_n is forest productivity.

The increase of CO_2 and temperature would promote the productivity. In northeast China, the productivity of main forest ecosystems would increases 7.65% (Table 7).

2. The Influence of Climate Warming on Crop Production

Northeast China is an important base of commercial grain. If the temperature rises 2℃,

Table 7 The future status of productivity of forest ecosystem in northeast China

Types	Mixed *Pinus koraiensis* broad-leaved forest	*Betula*-Poplar forest	*Picea-Abies* forest	*Larix* forest
Present productivity (t/ha·a)	20.14	14.19	13.35	9.50
Future productivity (t/ha·a)	21.23	15.30	14.54	10.59
Increase percentage(%)	5.41	7.82	8.10	11.47

accumulated temperature would increase 444℃ according to the formula:

$$\sum T \geqslant 10 = -1245.08 + 222.12T \qquad (r = 0.9571)$$

and the production of main agroecosystems would increase 36.4%, where the rate of growth will be 20% in Liaoning Province and that be more than 40% in Jilin and Heilongjiang provinces.

V. FUTURE STRATEGIES

(1) Facing the increase of sea level in the future, we should develop dynamic monitoring study on ecological environment in order to predict the global changes.

(2) Plant is sensitive to climate warming, so we should strengthen research on vegetation response to global warming in order to show the change of plant productivity and structure of vegetation components.

(3) Forest is very important for protecting ecological environment. It is a container and cleaner for the world, so we should increase the rate of forest coverage.

(4) If the future temperature increases, the alpine tundra zone will disappear in the Changbai Mountains. In order to save the vegetation, we should establish nature preserve for alpine tundra.

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