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Aboveground Biomass and Productivity of *Larix gmelinii* Forests in Northeast China

SHI Fuchen[1,2]*, QU Laiye[3], WANG Wenjie[4], MATSUURA Yojiro[5], KOIKE Takayoshi[1] and SASA Kaichiro[1]

[1] Hokkaido University Forests, FSC, Sapporo 060-0809, Japan
[2] Institute of Geographical Sciences and Natural Resources Research,CAS, Beijing 100101, China.
[3] Boreal Forest Conservation Studies, Graduate School of Agriculture, Hokkaido University, Sapporo 060-8589, Japan
[4] Northeast Forestry University, Harbin 150040, China
[5] Forestry and Forest Products Research Institute, Tsukuba 305-8687, Japan

Abstract

Biomass and primary productivity of larch (*Larix gmelinii*) forests were investigated in the field and reviewed in the literature. Larch forests, an important and typical component of the ecosystem in the Daxingan Mountain region of northeast China, are regarded as important carbon sinks for moderating the global carbon balance. We tentatively summarized our own data and the published data to estimate their absorption and storage capacity of carbon dioxide. The aboveground biomass and primary productivity of these forests decrease with an increase in latitude, along the different climatic zones. Namely, in the same age group, aboveground biomass and primary productivity were generally higher in the southern climatic zone (85.37 ton·ha^{-1} for young forests), than those in the northern climatic zone (41.81 ton·ha^{-1} for young forests and 55.6 ton·ha^{-1} for middle age forests). Within the same vegetation type, higher density and primary productivity were observed in young and middle age forests (less than 50 to 100 years old), while relative lower values were observed in mature forests. A comparison of aboveground biomass and primary productivity between natural larch forests in the Daxingan Mountain region and larch plantations in other parts of northeast China was carried out in this study. To understand the potential growth traits of natural larch stands, based on the field studies and literature, attention was given to the belowground biomass and primary productivity in relation to climatic zones and larch species.

Key words: northeast China, Daxingan Mountains, larch (*Larix gmelinii*), biomass, primary productivity

Introduction

Natural larch forests, mainly composed of Dahurian larch (*Larix gmelinii* Rupr.,) are broadly distributed throughout the Daxingan Mountains in northeast China. These larch forests are regarded as a southeastern extension of the Siberian Taiga forests (Fukuda 1996, Kasischke and Stocks 2000). "Bright coniferous forest" is a special term usually used for larch forests in order to distinguish them from evergreen forests composed of *Picea* sp. and *Abies* sp., which have rather shaded forest floors (Shi 1999, Shi *et al.* 2000). Larch forests in this region usually have large biomass and high primary productivity, which may be related to the high adaptability of larch species to the extreme low winter temperatures, as well as, to the efficient utilization of water from the melting zone of permafrost soil during the hot and dry summer season (Zhou 1991, Xu 1998, Abaimov *et al.* 2000). Annual primary productivity in cold temperature regions is estimated to be about 8ton·ha^{-1}yr^{-1} (Whittaker and Likens 1975). However, natural larch forests in the Daxingan Mountains show higher primary productivity compared with the larch stands of other regions (Kullervo 1990).

Recently, several studies have focused on the estimation of absorption, accumulation and storage capacity of forested ecosystems to determine their suitability as a carbon sink (Roy *et al.* 2001). However, the data from Far East Russia and China are still insufficient. Larch forest ecosystems could be large carbon sinks, which could play an important role in moderating the increase of atmospheric CO_2. The sink capacity of young larch forests is usually larger than mature forests (Shi and Matsuura 2001). To estimate the biomass productivity of this region, it was necessary to investigate the stock of larch species and their potential growth capacity.

During the past decade, several studies have been done in the Daxingan Mountains to assess the biomass and primary productivity of local larch forests (Liu *et al.* 1994, Han 1994, Hong *et al.* 1994, Wang and Feng 1994, Xu 1998, Zhao *et al.* 1996) The capacity for regeneration after several intense forest fires was also studied (Uemura *et al.* 1990, Shi *et al.* 2000). Most of the research, however, focused on a tiny part of this region.

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* Corresponding author: fcshi@cern.ac.cn

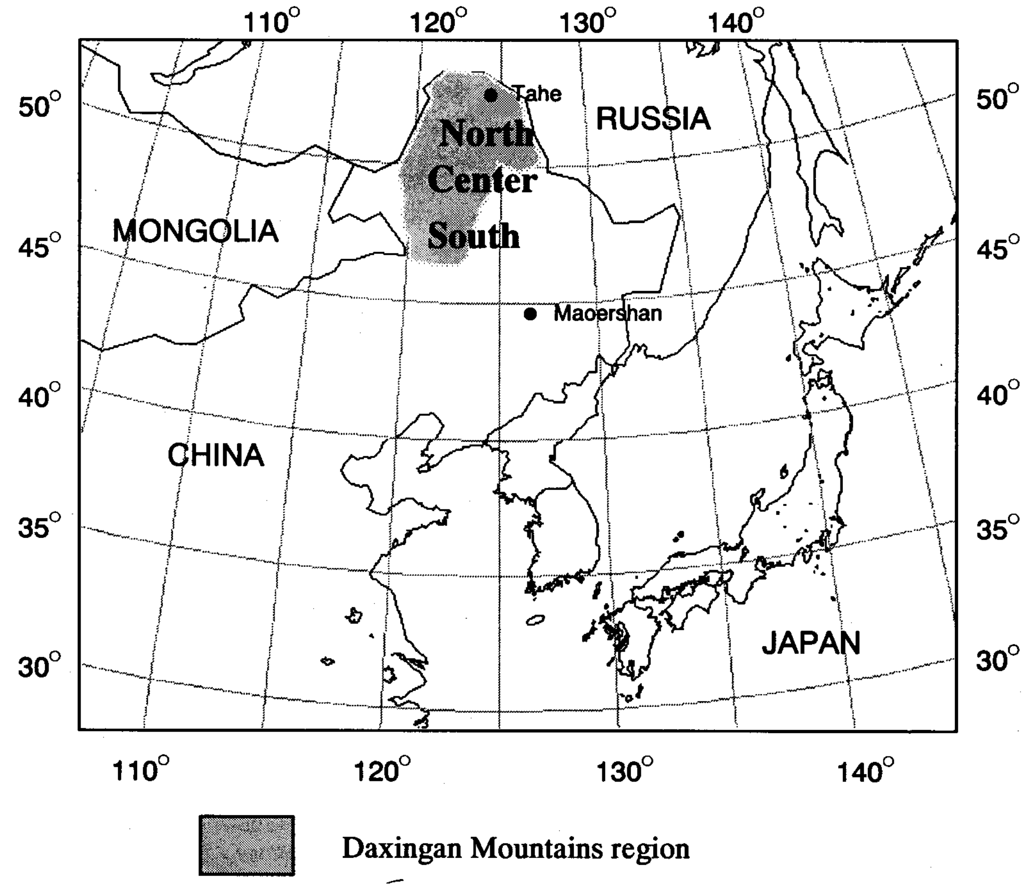

Figure 1. Three climatic zones in the Daxingan Mountains region, northeast China. The south climatic zone includes Aershan, Chuoer, Chuoyuan, Jiwen and Alihe Forestry Bureaus, the central climatic zone includes Wuerqihan, Kuduer, Tulihe, Yitulihe, Keyihe, Genhe and Ganhe Forestry Bureaus, the north climatic zone includes Jinhe, Alongshan, Mangui Forestry Bureaus

It is also difficult to evaluate the total carbon budget where frequent forest fires have occurred.

To clarify the progress pattern of primary productivity of larch stands and evaluate the carbon accumulation capacity in this region, we studied the biomass productivity of larch forests and reviewed the published literature. Furthermore, we compared the natural larch forests in the Daxingan Mountains and plantations in other parts of northeast China to evaluate the potential productivity of the forest ecosystems.

Study site

The Daxingan Mountain region is located in an extremely cold climatic region of China. The coordinates are 46°26′N to 53°34′N latitude and 119°30′E to 127° E longitude (Figure 1). Monthly mean temperatures are less than 10℃ for at least 9 months a year. While the months with mean temperatures over 10 ℃ are concentrated in a short period from May to August (ca.70-100 days). The annual mean temperature is between -2 ℃ to -4 ℃. Maximum and minimum temperatures are 39℃ and -52.3℃, respectively. Mean annual precipitation is about 350-500mm, with much of the precipitation coming in July and August. This is similar to the Siberian region (Abaimov *et al.* 2000).

Temperature and precipitation regimes in the Daxingan Mountains vary because the southwest-northeast orientation of the Mountains affects the movement of air from the seaside to the inner continental region. The contrast in climatic conditions of this region can be summarized as follows; the higher temperature and precipitation regimes are generally recorded in the southern region, while lower temperatures and less precipitation are usually found in the northern portion. Mean annual temperatures and precipitation are ca. -0.5 ℃, 492.8 mm in the south and ca. -2.1℃, 232.1 mm in the northern part, respectively. As the climatic conditions are severe in this region, forest ecosystems have a simple structure and few species. However, there are still some differences between the southern and northern parts because of the climatic adaptation capacity of flora as described in the micro-topographical difference in North American mountains (Chabot and Mooney 1985). In the Daxingan Mountains, *L. gmelinii* (larch), *Pinus sylvestris* var. *mongolica* (pine), *Betula platyphylla* (birch), etc. grow well, however, only *L. gmelinii* is a dominant species and can be seen as a pure stand or occasionally mixed with *B. platyphylla*. This region is the southern limit of the Siberian Taiga (Shi *et al.* 2000).

The Daxingan Mountains make up the southern limit of East Asian permafrost (Xu, 1998). In this region, organic matter, such as litter-fall and coarse woody debris decompose slowly because of low temperatures throughout most of the year. As a result of these conditions, large amounts of litter-fall accumulate on the forest floor. Furthermore, a thick peat layer, up to 2m, has formed in some valleys and high mountainous areas. Litter and peat are important components of carbon storage in this region. Therefore, the Daxingan Mountains function as a massive carbon reservoir, which contributes to the regulation of the carbon balance between land and atmosphere. The climatic zones of the Daxingan Mountains are classified, in accordance with thermal regimes (Guan 1988), southern climatic zone, central climatic zone and northern climatic zone (Figure 1). The southern climatic zone includes the Aershan, Chuoer, Chuoyuan, Jiwen and Alihe Forestry Bureaus. The central climatic zone includes the Wuerqihan, Kuduer, Tulihe, Yitulihe, Keyihe, Genhe and Ganhe Forestry Bureaus. The northern climatic zone includes the Jinhe, Alongshan, and Mangui Forestry Bureaus.

Materials and methods

Forest stands were divided according to age: young (<50yrs), middle age (50-100 yrs) and mature (>100 yrs). The biomass and primary productivity data were obtained from 355 standard plots and 1051-sampled trees (Liu *et al* 1994).

Larch forests were divided into the following four types based on the dominant species in the stand: *L. gmelinii*-herbage, *L. gmelinii-Rhododendron dauricum*, *L. gmelinii-Ledum palustre* and *L. gmelinii*-moss. In each forest type, aboveground biomass and primary

Table 1. Allocation in aboveground biomass of young and middle age forests in different climatic zones of the Daxingan Mountains

Age group	Climate zone	Mean age	Biomass ($ton \cdot ha^{-1}$)				
			Bole wood	Bark	Branch	Leaf	Total aboveground
<50 yr	North	34	29.14	5.94	4.38	2.35	41.81
	Central	29	39.81	7.94	6.39	2.60	56.74
	Southeast	29	63.63	9.00	8.95	3.79	85.37
	Mean		44.19	7.63	6.57	2.91	61.31
50~100 yr	North	55	38.82	7.80	5.91	3.09	55.62
	Central	54	52.17	9.42	7.85	2.90	72.34
	Mean		45.50	8.61	6.88	3.00	63.98

Table 2. Aboveground productivity of young and middle age forests in different climatic zones of the Daxingan Mountains

Age group	Climate zone	Mean age	Productivity ($ton \cdot ha^{-1} yr^{-1}$)				
			Bole Wood	Bark	Branch	Leaf	Total aboveground
<50 yr	North	34	2.26	0.38	0.30	2.35	5.29
	Central	29	3.57	0.61	0.51	2.60	7.29
	Southeast	29	4.86	0.58	0.63	3.79	9.86
	Mean		3.56	0.52	0.48	2.91	7.48
50~100 yr	North	55	1.48	0.25	0.20	3.09	5.02
	Central	54	2.59	0.40	0.37	2.90	6.26
	Mean		2.04	0.33	0.29	3.00	5.66

Table 3. Allocation in aboveground biomass and productivity among different forest types in Tahe Forest Bureau of the Daxingan Mountains

Forest type	Age* group	Mean Age (yr)	Aboveground biomass ($ton \cdot ha^{-1}$)					Productivity ($ton \cdot ha^{-1} yr^{-1}$)
			Bole wood	Bark	Branch	Leaf	Total	
Larix gmelinii — herbage forests	Young	28	53.35	6.22	3.00	1.83	64.40	4.17
	Middle	58	117.7	14.16	11.50	3.76	147.12	6.43
	Mature	136	127.05	11.54	12.52	2.90	154.01	4.10
	Mean		99.37	10.64	9.01	2.83	121.84	4.90
Larix gmelinii — *Rhododendron dauricum* forests	Young	32	53.9	5.97	2.66	1.78	64.31	3.81
	Middle	63	102.3	12.49	8.85	3.40	127.04	5.51
	Mature	142	125.4	15.26	16.52	3.84	161.02	5.06
	Mean		93.87	11.24	9.34	3.01	117.46	4.79
Larix gmelinii — *Ledum palustre* forests	Young	34	62.7	7.29	3.27	2.17	75.43	4.42
	Middle	60	71.5	7.97	4.71	2.25	86.43	3.73
	Mature	152	119.35	9.79	9.04	2.54	140.72	3.51
	Mean		84.52	8.35	5.67	2.32	100.86	3.89
Larix gmelinii — moss forests	Young	34	45.1	3.93	2.62	1.08	52.73	2.68
	Middle	60	101.75	12.08	8.51	3.30	125.64	5.48
	Mature	171	92.4	10.88	9.29	2.86	115.43	3.58
	Mean		79.75	8.96	6.81	2.41	97.93	3.91

productivity were measured in young, middle and mature forests (Zhao *et al.* 1996). The comparative study on the estimation of forest biomass and net productivity in different forest types was carried out in the Tahe Forestry Bureau (52°09-53°23'N, 123°20'-125°07'E), located in northeastern part of the Daxingan Mountains.

The biomass and primary productivity of larch plantation were investigated in Maoershan Experimental Forest Station (45°21'-45°25'N, 127°31'-127°34'E), in the Zhangguangcai Mountains of northeast China (Ding *et al.* 1990).

Biomass was estimated using a wellknown allometry (e.g., Shidei and Kira 1977, Han 1994), as follow:

$$W=a(D^2H)^b,$$

where *W, D* and *H* are biomass of a tree bole or each organ, stem diameter at breast height, and tree height, respectively, and *a* and *b* are best-fit coefficients.

Results

Biomass and net primary productivity in different climatic zones

Aboveground biomass, for the same age group of larch forests, increased from north to south, and this tendency coincided with the change of climate from north to south (Table 1). In the young forests, aboveground biomass was 85.37 $ton \cdot ha^{-1}$ in the southern climatic zone, which was 2 times larger than that in the northern climatic zone. Similar results were observed in the middle age forests, i.e. 72.34 $ton \cdot ha^{-1}$ in the central climatic zone, which was higher than that in the northern climatic zone (16.72 $ton \cdot ha^{-1}$).

Net primary productivity (NPP) of aboveground parts increased along the climatic gradient from north to south (Table 2). The young forests show the highest primary productivity (9.86 $ton \cdot ha^{-1} yr^{-1}$) in the southern climatic zone. In the middle age forests, NPP was about 6.26 $ton \cdot ha^{-1} yr^{-1}$ in the central climatic zone, which was higher than the yield in the northern climatic zone (1.27 $ton \cdot ha^{-1} yr^{-1}$).

Biomass and net primary productivity in different forest types

The *L. gmelinii*-herbage type had the largest values of both biomass and NPP of the four vegetation types (Table 3). The *L. gmelinii-Rhododendron dauricum* type was second, and the *L. gmelinii-Ledum palustre* and *L. gmelinii*-moss types were the smallest. However, mature forests of the same forest type usually had higher biomass and lower NPP. For example, the biomass was 140.72 ton·ha^{-1} in *L. gmelinii-Ledum palustre*; however, its NPP was 3.51 ton·ha^{-1}yr^{-1}; the lowest.

The relationship between tree density, biomass, primary productivity and forest age

In young and middle age forests, higher tree density was usually maintained and its peak value was ca. 2, 300 trees · ha^{-1} (Figure 2). However, density decreased drastically in mature 100-year-old forests, and only reached ca. 1000 trees·ha^{-1} in some cases. In young and middle age forests, there was an increase in biomass from 50-150 ton·ha^{-1}. In mature forests, the biomass reached the asymptotic value of 100-130 ton·ha^{-1}.

For aboveground productivity, higher values (mean value 5.0 ton·ha^{-1}yr^{-1}) were observed in young and

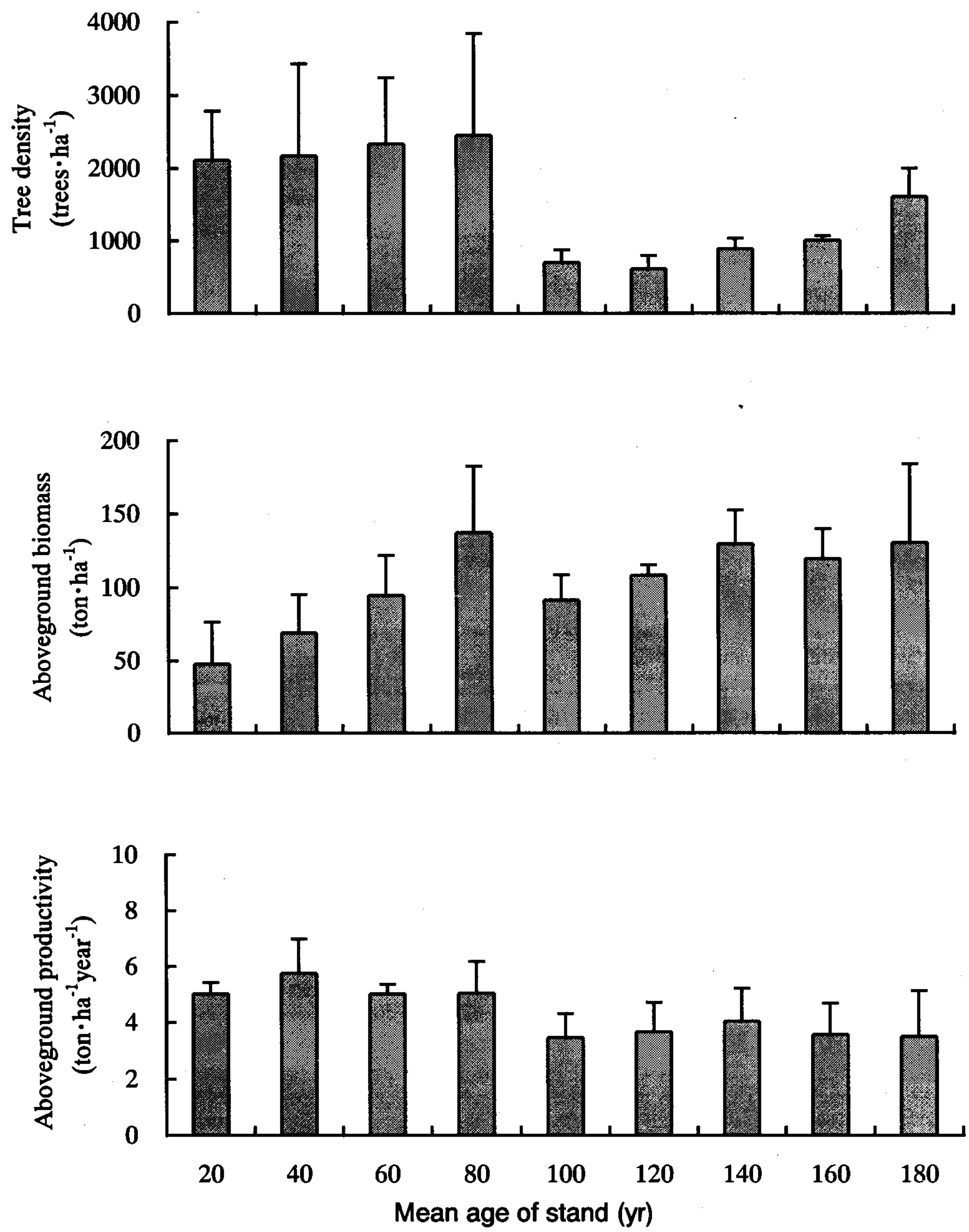

Figure 2. Mean and SD of tree density, aboveground biomass and productivity in different age classes of larch forests in the Daxingan Mountains region

Table 4. Allocation in aboveground biomass and productivity of a larch plantation stand in Maoershan of the Zhangguangcai Mountains

Mean Age (yr)	Aboveground Biomass ($ton \cdot ha^{-1}$)					Productivity ($ton \cdot ha^{-1}yr^{-1}$)
	Bole wood	Bark	Branch	Leaf	Total	
33	93.84	8.36	8.66	2.76	113.62	7.25

Table 5. Estimated values of the variables in the regression analyses between the biomass of each organ of individual tree and D^2H
Regression equation: $W=a\,(D^2H)^b$

Variable of regression analysis		Estimated value of regression variables				
		W_{wood}	W_{bark}	W_{branch}	W_{leaf}	W_{root}
Parameters	a	0.01258	0.02307	0.00136	0.01009	0.03615
	b	0.99331	0.70655	1.02797	0.64543	0.75995
Correlation coefficient	r^2	0.98	0.98	0.98	0.97	0.98

Table 6. Average biomass of boreal forests*

Areas	Aboveground biomass ($ton \cdot ha^{-1}$)	Belowground biomass ($ton \cdot ha^{-1}$)	Source
Daxingan Mountains	62.5	22.5	This study
Central Japan	116.3	31.09	Four-University research group (1964)
Siberia	56.0	20.2	Jarvis *et al.* (2001)
European Russia	91.0	32.8	"
Western Europe	101.0	36.4	"
North America	46.0	16.6	"

*Belowground biomass is assumed to be 0.36 of the aboveground biomass (Jarvis *et al.* 2001).

middle age forests. Whereas, a slight decrease in aboveground productivity (mean value was less than 4.0 $ton \cdot ha^{-1}yr^{-1}$) was observed after forest maturation.

Biomass and net primary productivity of larch plantation stands

L. gmelinii is the major species used for afforestation in northeast China and the plantations occupy up to two thirds of the total afforested area. Investigations carried out in the Maoershan Experimental Forest Station, Zhanguangcai Mountains (Ding *et al.* 1990), showed that the aboveground biomass of a 33-year-old larch plantation was ca. 113.62 $ton \cdot ha^{-1}$ and the NPP was estimated to be around 7.25 $ton \cdot ha^{-1}yr^{-1}$ (Table 4). This growth rate was almost the same as natural larch forests in the central climatic zone, while it was lower than those in the southern climatic zone (Table 1, 2).

There was a clear relationship between W and D^2H (Table 5). From this equation, the belowground biomass of the larch plantation could be calculated to be 31.52 $ton \cdot ha^{-1}$. It was about 27.7% of the aboveground biomass and 22% of the total biomass. Figure 3 shows the ratio of biomass in each organ of larch forests measured in different regions.

Discussion

The average of aboveground biomass of the Daxingan Mountains was 62.64 $ton \cdot ha^{-1}$ (Young and middle age forests were 61.31 $ton \cdot ha^{-1}$ and 63.98 $ton \cdot ha^{-1}$, respectively) (Table 1). It was slightly lower than that of global pine forests (73 $ton \cdot ha^{-1}$), but higher than all of Siberia (56 $ton \cdot ha^{-1}$) (Jarvis *et al.* 2001). Comparisons of aboveground biomass and belowground biomass of other forest species are illustrated in Figure 4.

Belowground biomass and NPP would account for a large percentage of the total biomass. Kajimoto *et al.*

(1999) reported that the belowground biomass (109 ton·ha^{-1}) of a 169-year-old mature *L. gmelinii* forest in north central Siberia with a deep permafrost layer was estimated to be 47% of the total stand biomass (232 ton·ha^{-1}). The tree density was very sparse because of competition among roots due to the infertile soil conditions and thin active layer of soil overlaying the permafrost. Precise estimates of belowground biomass are more difficult to make than for those aboveground. Actually, literature on belowground biomass and NPP in the Daxingan Mountains is quite limited. Han (1994) reported that the belowground biomass and NPP of a larch-birch (*L. gmelinii- Betula phlatyphylla*) forest was about 5.74 ton·ha^{-1} (19.86% of the total biomass) and 0.38 ton·ha^{-1}yr^{-1} (14.78% of the total NPP), respectively. The amount of belowground biomass varies drastically in boreal forests ecosystems. Jarvis *et al.* (2001) reported that the average root biomass is 36% (ranging from 12-50%) of the aboveground biomass. Ding *et al.* (1990) reported that belowground biomass and NPP of a *L. gmelinii* plantation in the Maoershan Experimental Station were about 28.70 ton·ha^{-1} (21.42% of total biomass) and 1.20 ton·ha^{-1}yr^{-1} (14.6% of the total NPP), respectively. We estimated belowground biomass to be about 22.5 ton·ha^{-1} throughout the Daxingan Mountain region (Table 6). Within the larch forests, well developed even under cold climatic conditions, root biomass of the larch forests in the Daxingan Mountains were slightly larger than those in Siberia and North America, but smaller than central Japan, European Russia and Western Europe (Schulze *et al.* 1995). Biomass allocation of *L. gmelinii* and *L. kaempferi* to the roots, displays site and species specific patterns (Figure 3). The percentage of roots of *L. gmelinii* in central Siberia reached 43%~47% (Kajimoto *et al.* 1999, Kanazawa *et al.* 1994). Allocation to branches is quite similar across the species. Biomass allocation in *L. gmelinii* was ca. 5% smaller than that of *L. kaempferi*, which was genetically analyzed (Takahashi *et al.* 1968, Koike *et al.* 2001).

The Daxingan Mountains, within an 8-degree range in latitude and 2-degree range in longitude, encompasses various climatic conditions and hydrological characteristics. In the southern climatic zone, the NPP of the larch forests was 9.86 ton·ha^{-1}yr^{-1}, which coincides with near subarctic conifer forests in northern Europe (9.01 ton·ha^{-1}yr^{-1}). These totals are less than subalpine conifer forests in Japan (11.15 ton·ha^{-1}yr^{-1}) (Shidei and Kira 1977). However, NPP was only 2.68 ton·ha^{-1}yr^{-1} in the northern climatic zone. Kajimoto *et al.* (1999) reported that the NPP of larch forests established on permafrost near central Siberia was 1.81 ton·ha^{-1}yr^{-1}. Table 7 shows the NPP values of boreal forests in the Daxingan Mountains and in Siberia. Among the larch forests of the same age (30 yrs), biomass clearly increases latitudinally from central Siberia (Kajimoto *et al.* 1999) to the southern part of the Daxingan Mountains (Shibuya *et al.* 2001a, b, Shi and Matsuura 2001) (Figure 4). This implies that climatic factors, such as precipitation and temperature, are the main limiting factors for the growth of larch forests in the Daxingan

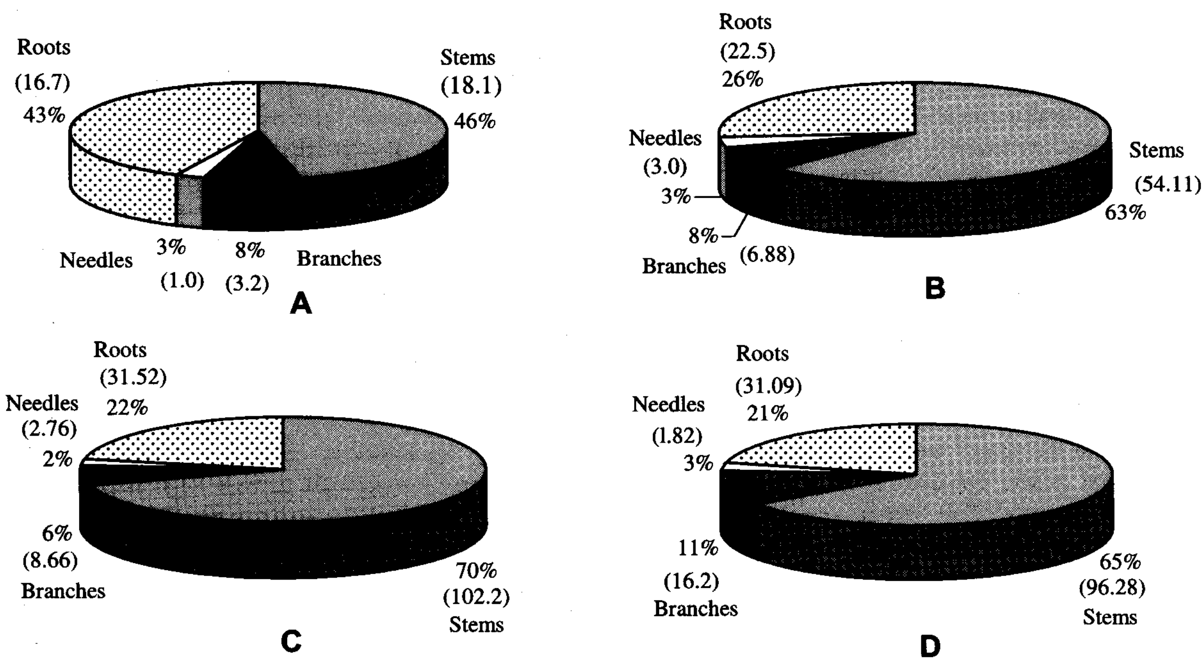

Figure 3. Aboveground biomass and belowground biomass rates in Larch forests*
A: Siberian *Larix gmelinii* forests (Kajimoto *et al.* 1999, for mature age forests)
B: Daxingan Mountains *Larix gmelinii* forests, northeast China; (for middle age forests)
C: A plantation of *Larix gmelinii* in Maoershan, northeast China (for young age forests)
D: *Larix leptolepis* (=*L. kaempferi*) forests of central Japan (Four-University Research Group 1964, for middle age forests)
*The biomass unit is ton·ha^{-1} for the figures in parenthesis.

Table 7. Average figures for net primary productivity in boreal forests

Parameters	NPP of Siberian boreal Forests[a] ($ton \cdot ha^{-1}yr^{-1}$)	NPP of *Larix gmelinii* Forests in central Siberia[b] ($ton \cdot ha^{-1}yr^{-1}$)	NPP of *Larix gmelinii* Forests in Daxingan Mountains[c] ($ton \cdot ha^{-1}yr^{-1}$)
Wood net annual increment	0.81	0.32	2.66
Needles	0.88	1.01	3.00
Aboveground productivity	**1.69**	**1.33**	**5.66**
Coarse roots	0.32	0.18	-
Fine roots	1.13-2.44	0.30	-
Belowground Productivity	**1.45-2.76**	**0.48**	-
Total net productivity	**3.14-4.45**	**1.81**	-

[a]From Jarvis *et al.* (2001); [b]From Kajimoto *et al.* (1999); [c]middle age forests.

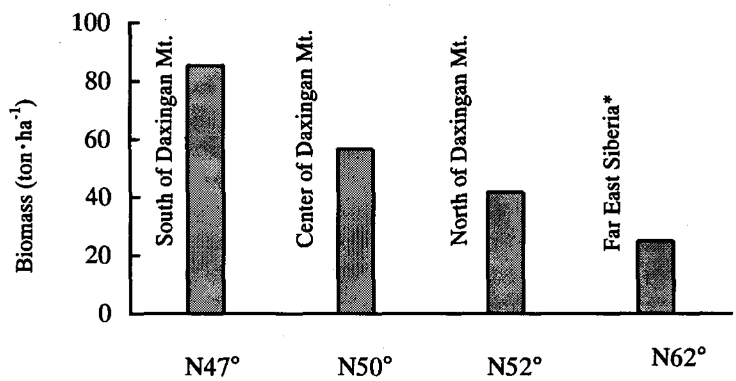

Figure 4. Biomass of larch forests (30 yr) in different latitude
*Data from Shibuya *et al.* (2001a, b)

Mountains, because the amount of precipitation and temperature in growing season increases from north to south in a similar longitudinal range. If the NPP of larch forests was a function combining precipitation and cumulative temperature, photosynthetic production, when the amount of solar radiation is the same, could be estimated from these two climatic elements. Therefore, it is possible that larch forests have the potential to increase NPP in a global warming scenario, if there is an adequate water supply in this region. The potential improvement in the primary productivity of the larch forests could regulate the amount of CO_2 in the atmosphere. In the northern thermosphere, there has been about a 2℃ increase in the annual mean temperature of the last 30 years and it will continue to increase in the future, especially around the Siberia region including the Daxingan Mountains (Kasisichke and Stocks 2000). Therefore, the growth rate of larch forests in this region should be carefully studied based on both biomass estimation and climatic factors including the dynamic of permafrost. In fact, with the existence of well developed permafrost layers in the north central Siberia region (i.e. Tura in Russia), we may be able to predict future changes in vegetation from the mixed spruce-larch forests at present to larch dominated forests as can be seen on the north and south-facing slopes in central Siberia (Yanagihara *et al.* 2000).

The density of mature larch forests in the Daxingan Mountains declined, which may be related to natural self-thinning and frequent forest fires. However, we could not discover the reason for the sharp decline in forest density at over 100 yrs old. Moreover, we should pay attention to the fire history of the stands because soil fertility (i.e. nitrogen mineralization) is an indicator of the relationship between the frequency of fires and the rate of soil mineralization (Matsuura and Abaimov 2000, Reich and Bolstad 2001). In the Daxingan Mountains, the frequency and severity of forest fires have greatly changed the regeneration processes of larch forests (Shi *et al.* 2000). Therefore, we should know precisely the fire frequency and speed of vegetation recovery in these regions. Nevertheless, larch forests in the Daxingan Mountains are expected to be a huge carbon sink and their role in helping to moderate global warming.

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