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Plant Biomass and Productivity of *Larix gmelinii* Forest Ecosystems in Northeast China: Intra- and Inter- species Comparison

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Abstract

Databases of plant biomass and productivity of forests were prepared to make inter- and intra- species comparison in this report. Within the species of *L. gmelinii*, a substantial variation in plant biomass and productivity were observed in this region. The allometric relations ($Y=a(D^2H)^b$) of *L. gmelinii* tree were essentially affected by sites and forest composition. Moreover, net primary production (NPP) of young forest increased more rapidly with biomass than the middle-aged and mature forests. This relationship was also influenced by forest management. Natural *L. gmelinii* forests in Mts. Daxinganling decreased their NPP when the biomass was higher than 100-110 ton ha⁻¹, while NPP still increased when the biomass reached to 168 ton ha⁻¹ in plantation. In a scale of small region, biomass and productivity were mainly regulated by tree age and site condition. The accompany species may indicate the productivity. However, in a large scale, they were mainly determined by latitude – dependent climatic condition. The productivity from shrub layer and grass layers were positively correlated with NPP. Moreover, NPP (including these two layers) decreased more moderately with latitude than only tree productivity did. This finding indicates that shrub and grass layers may contribute more to NPP in the larch forests in high latitude region. Furthermore, root/shoot ratio in biomass exponentially increased with latitude, indicating that biomass allocated more to underground in less productive environment in high latitude region in Siberia. Finally, inter-species comparisons indicate that larch forests in Northeast China are expected to be a carbon sink by their higher NPP.

Key words: Allometric relations, Mts. Daxinganling, NPP, Latitude dependence, Root/shoot ratio

1. Introduction

Larch is a deciduous coniferous species and its carbon gain capacity is similar to evergreen species (Gower and Richards, 1990). The high photosynthetic capacities of larch species suggest that larch forest ecosystem may function as an important CO₂ sink (Koike *et al.* 2000). Recently, estimation of carbon sequestration capacities of larch forest has been conducted by different ways, such as micrometeorological, ecophysiological and biomass summation methods, in Northeast China (Wang *et al.* 2002). Synthesis of such previous data on biomass and productivity of the larch forests in this region may be important for full understanding their roles in carbon sequestration in response to global warming.

Papers were limited based on direct analysis of forest productivity and carbon budget by net search on China National Knowledge Infrastructure (CNKI) (1994-2002) (Liu 1994; Wu 1995). Nevertheless, before 1994, some works related directly to this kind of field works were made on this species (Ding *et al.* 1982; Feng and Yang 1985; Ding *et al.* 1990; Liu *et al.* 1990&1991; Han 1994), which is unavailable by web search. Through

these works and data done in Siberia, Russia, intra-species comparison of biomass and productivity of larch forest in this region can be done. Furthermore, many larch species, such as *Larix sibirica*, *L. olgensis*, *L. principis-rupprechtii*, *L. kaempferi*, *L. occidentalis*, *L. decidua*, *L. laricina* and *L. gmelinii*, and boreal species belonging to other genus are distributed in northern hemisphere (Gower and Richards 1990; Zhou 1991). For understanding the ecological characteristics of *L. gmelinii* in Northeast China, it is useful to make inter-species comparison with such different larch species and other forest types, both of which are found in China and other temperate or boreal forest regions. Therefore, intra- and inter-species comparison on the primary production and related items were discussed in this paper.

The objectives of this paper are following: 1) to confirm the hypothesis that the allometric differences are significant not only in the inter-species comparison (among different larch species) but also intra-species comparison (within *L. gmelinii*); 2) To examine the regulation mechanism of biomass and productivity in a local scale and a large scale, i.e. biomass and

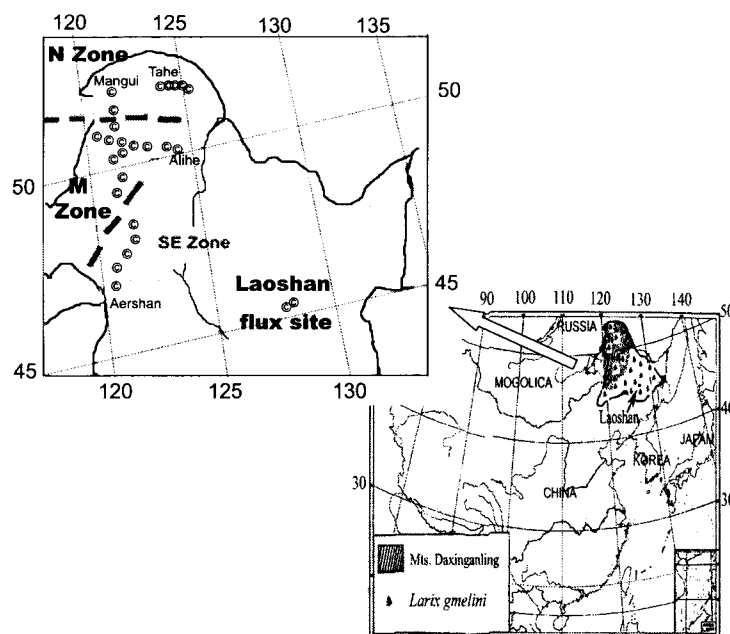


Fig. 1. The research sites (Mts. Daxinganling and Laoshan flux site) for data collection in Northeast China used in present paper.

productivity of *L. gmelinii* forests are regulated (or indicated) by species associations, tree age, forest management in a local scale, while by latitudinal changes in climate in a large scale; and 3) to examine the forest productivity of *L. gmelinii* in Northeast China with respect to other larch forests, other kinds of forests both in China and in boreal and temperate forest regions around world.

2. Data acquisition and analysis

2.1 Data acquisition

All data on the biomass and productivity of *L. gmelinii* were collected from the reports for the two sites in Mts. Daxinganling (N46°26'-53°34', E 119°30'-127°) and Laoshan flux site (N45°20', 127°34'), Northeast China (Fig. 1), and in some locations in Siberia of Russia. Two study sites in northeast China are typically cold temperate, continental climate, characterized by small precipitation and short growing period. Annual precipitation occurs mostly 350-723mm. Mean annual temperature is about -6°C -3°C and frost-free period is about 76-140 days. The mean altitude is 300-1700 m a. s. l. The soil is characterized by typical dark brown soil, brown coniferous forest soil, meadow soil and bog soil.

Data of other seven larch species (*L. sibirica*, *L. olgensis*, *L. principis-rupprechtii*, *L. kaempferi*, *L. occidentalis*, *L. decidua*, *L. laricina*) were cited from reports in China, Japan, USA and Canada. In total, 118 allometric relationships (38 for *L. gmelinii*, 5 for *L. olgensis*, 18 for *L. principis-rupprechtii*, 20 for *L. kaempferi*, 5 for *L. sibirica*, 9 for *L. occidentalis*, 5 for *L. decidua* and 18 for *L. laricina*) were collected, and were employed for comparison to detect inter- and intra-species differences (Details see Appendix 1 Table A). At stand level biomass and productivity, 39 data were collected (18 for *L. gmelinii* forests, 3 for *L.*

olgensis forests, 1 for *L. principis-rupprechtii* forests, 7 for *L. kaempferi* forests, 5 for *L. sibirica* forests, 5 for *L. decidua* forests) were collected (Table 2). At ecosystem level, 43 data on biomass and net primary productivity (NPP) were available (30 for *L. gmelinii* forests, 9 for *L. olgensis* forests, 1 for *L. principis-rupprechtii* forests, 2 for *L. kaempferi* forests, 1 for *L. sibirica* forests) (Table 3). Then totally 29 data sets for 22 forest types in China and data of Europe Russian forests, Siberian forests, BOREAS sites, and temperate and boreal forests, were selected to make comparison with *L. gmelinii* forests in northeast China (Table 7, Appendix 1 Table B.).

2.2 Biomass and productivity calculations

In most of the cases, biomass increments of tree, shrub and grass were measured for productivity estimation. For biomass measurements of these different layers, almost all the authors used the allometry method, except Ding *et al.* (1982 & 1990); they used the standard tree method in an even-age and similar-tree-size larch plantation. All the authors used similar method to estimate understorey and grass biomass, but there were some differences in the size and numbers of plots (Feng *et al.* 1985; Liu *et al.* 1990; Ding *et al.* 1982 & 1990). For litterfall estimation, some authors used the standard method (Liu *et al.* 1990 & 1991; Gower *et al.* 1993), namely litter-trap method or litter screen method, but others used so-called "direct collection method", i.e., collection of all the litterfall that fell within a year in a plot with size of 1m×1m (Feng *et al.* 1985; Ding *et al.* 1982 & 1990). The loss of biomass due to grazing by herbivores was neglected in almost all the studies reviewed in this paper. Since insect frass mass is generally small and does not differ noticeably among species, such biomass loss by herbivory may not greatly affect productivity estimation (Gower *et*

al.1993).

Belowground biomass is also essential for productivity estimation. And the method used in the root biomass estimation is important for ensuring the precision of productivity. Feng *et al.* (1999) proposed the method of soil block sampling, which was originally applied by Karizumi (Karizumi 1977). The essence of this method was a procedure of sampling roots in part of ground soil (soil cores) instead of total soil for saving time. In the study of *L. gmelinii*, Feng *et al.* (1985) had used similar method to estimate the root biomass of mature natural larch forest. The roots in one fourth of total ground area were dug out, and then estimated total root biomass of standard tree. Similar method was also used by Han *et al.* (1997) on *L. principis-rupprechtii*. However, other researchers (Ding *et al.* 1982&1990; Liu *et al.* 1990&1991; Han and Liang 1997; Kajimoto *et al.* 1999 & 2003) dug out total root of a standard tree instead of part of root. Also, some authors just estimated its biomass based on results of root/shoot ratio from other references (Liu *et al.* 1994). Therefore, total root-dug-out method, soil blocking method and indirect root/shoot ratio method were generally used in underground root biomass estimation of larch species in all referenced papers.

2.3 Data analysis

Since the deficiency in data of shrub and grass layer in biomass and productivity estimation in boreal larch in Eurasia continent (Gower *et al.* 2003), analysis in this report were set two levels to underlying the importance of these two layers. One level only considered the tree layer of larch trees including their biomass and productivity distributed to the organs of stem, root, leaf and so on, which was called as **stand level**. The other level considered the tree layer, shrub layer and grass layer of larch forest ecosystem including their biomass and productivity distributed to different layers, which we called it as **ecosystem level**. In this paper, the productivity of such ecosystem and stand level was called separately net primary productivity (NPP) and stand productivity.

When we discuss the age-effect on plant biomass and productivity, we divided the forest into 4 stages according to definition by Zhao *et al.* (1996); Young (<50-yr-old), middle-aged (50~100-yr-old), mature

(100~200-yr-old), and over-mature(>200-yr-old). When we discuss the relationship between forest composition and productivity, Seven associations were considered; *Rhododendron dauricum* and *L. gmelinii* (RL), *Ledum palustre* and *L. gmelinii* (LL), *Sphagnum spp.* *Ledum palustre* and *L. gmelinii* (SLL), *Pleurozium schroberi* and *L. gmelinii* (PL), herbs and *L. gmelinii* (HL), and *Betula platyphylla* and *L. gmelinii* (BL) (Zhou 1991; Han 1994) (Table 1).

The latitude dependence of NPP, stand productivity and root:shoot (Root biomass: aboveground biomass) ratio were simulated by one component exponential model ($y=a \exp(bx)$). The coefficient value of b indicates the changing rate of NPP, stand productivity and root:shoot ratio along latitude.

The similarity test of two regression lines (intercept and slope value) (in Fig. 5) was based the method proposed by Chen *et al.* (1988) (Appendix 2). ANOVA was used to make comparison of two factors, such as NPP inter-species comparison in Table 7. The significance of linear regression, such as Fig. 3 and Fig. 8, was tested by F-test of regression analysis, which has included in Excel 2003.

All statistical analysis and best-fitting were done by SPSS 11.0 (SPSS Inc., USA), and Origin 7.0 (OriginLab, USA) and Excel 2003.

3. Results and discussion

3.1 Intro-and inter-species difference in allometric relations

The allometric coefficient values (a and b) best fitting by D^2H for *L. gmelinii*, *L. olgensis*, *L. sibirica*, *L. principis-rupprechtii* and *L. kaempferi* or D for *L. kaempferi*, *L. occidentalis*, *L. decidua* and *L. laricina* (D : Diameter at breast height; H : tree height) as independent parameters were listed in Appendix 1 Table A. In the case of *L. gmelinii* forests, we found the coefficient values were different by forest types. Since this large difference, almost no statistical differences were observed in the besting coefficient values of a and b when consider all forest types (Appendix 1, Table A).

For comparing the biomass contribution to leaf and root with growth of tree among larch species (Fig. 2), the tree height-DBH relationship (Reanalyzed from Takahashi, 1960) ($H = -0.013DBH^2 + 1.1784DBH - 1.7945$; $R^2 = 0.88$, $p < 0.001$, DBH:6-46cm; H: 5-30m)

Table 1. Main *L. gmelinii* forest types in Mts. Daxinganling in Northeast China.

Abbr.	Forest types	Abbr.	Forest types
RL	Association <i>Rhododendron dauricum</i> , <i>L. gmelinii</i>	CL	Ass. <i>Carex schmidtii</i> , <i>L. gmelinii</i>
VL	Ass. <i>Vaccinium vitis-idaea</i> , <i>L. gmelinii</i>	QL	Ass. <i>Quercus mogolica</i> , <i>L. gmelinii</i>
LL	Ass. <i>Ledum palustre</i> , <i>L. gmelinii</i>	HL	Ass. grass, <i>L. gmelinii</i>
VLL	Ass. <i>Vaccinium vitis-idaea</i> , <i>Ledum palustre</i> , <i>L. gmelinii</i>	PPL	Ass. <i>Pinus pumila</i> , <i>L. gmelinii</i>
SLL	Ass. <i>Sphagnum spp.</i> <i>Ledum palustre</i> , <i>L. gmelinii</i>	BL	Ass. <i>Betula phlatyphylla</i> , <i>L. gmelinii</i>
PL	Ass. <i>Pleurozium schroberi</i> , <i>L. gmelinii</i>	HAL	Ass. <i>Hylocomium proliferum</i> , <i>Alnus mandshurica</i> , <i>L. gmelinii</i>

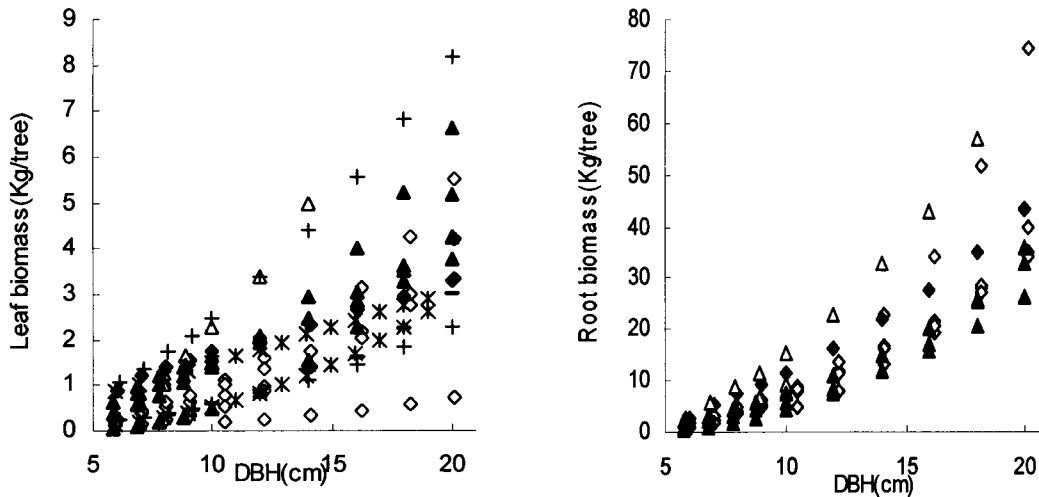


Fig. 2. Biomass distribution to leaf (left) and root (right) with the DBH increase in different larch species. In the allometric relationship with D^2H as independent factor, the DBH and H relationship re-analyzed from Takahashi (1960)(Appendix 3, Table C) and together with the range of DBH and H in Appendix 1 Table A were used for calculation of leaf biomass and root biomass. The data is shown in Appendix 3 Table D to H.
 ◇: *L. gmelinii*; ◆: *L. olgensis*; △: *L. principis-rupprechtii*; ▲: *L. kaempferi*; *: *L. occidentalis*;
 +: *L. laricina*; -: *L. decidua*

together with the effective range of DBH and H in Appendix 1 Table A were used to calculation of root and leaf biomass (Appendix 1 Table C). All allometric relationships of young and middle age forests were selected to make comparison (Fig. 2). The result showed that all larch species had a wide range of leaf biomass, but a relative conservative value of root biomass (Fig. 2). For example, at DBH=20cm, H=20m, leaf biomass of *L. gmelinii* ranged from 0.70 kg tree⁻¹ to 5.50 kg tree⁻¹, while *L. kaempferi* ranged from 3.80 kg tree⁻¹ to 6.60 kg tree⁻¹. However, root biomass of *L. gmelinii* ranged from 36.00 kg tree⁻¹ to 74.00 kg tree⁻¹ and *L. kaempferi* ranged from 26.00 kg tree⁻¹ to 36.00 kg tree⁻¹. This finding indicates leaf biomass is easier to be influenced by site environment relative to root. Root biomass of *L. gmelinii* is more flexible than other larch species (Fig. 2 right), which maybe related to its less productive environment (Gower et al.1990; Kajimoto et al.2003). In this chapter of discussion mentioned the relationship between latitude and root/shoot ratio. However, there were not obvious differences in biomass contributions to root in different larch species, and similar result was observed in leaf biomass (Fig. 2), indicating that the pattern of leaf and root contribution to total biomass is habitat-related instead of species-specific.

3.2 Tree age affects *L. gmelinii* forest biomass and productivity

Young forests (<50yrs) had a lower biomass accumulation (61.00 ton ha⁻¹) but a higher productivity (7.50 ton ha⁻¹yr⁻¹) than middle-aged and mature forests at stand level (Table 2). This tendency is the same as the results of Feng et al. (1999). It is also similar to the volume growth data at Tahe (Fig. 1) (Zhao et al.1996): young forests (3.20 m³ha⁻¹yr⁻¹) were 14% and 100% higher than that of middle-aged and mature forests. At

ecosystem level, biomass of young, middle-aged and mature larch forest ecosystems were 67.00 ton ha⁻¹, 91.00 ton ha⁻¹ and 161.00 ton ha⁻¹, respectively. However, the ecosystem productivity, NPP of young, middle-aged and mature larch ecosystems were 7.70 ton ha⁻¹yr⁻¹, 8.60 ton ha⁻¹yr⁻¹and 8.50 ton ha⁻¹yr⁻¹, respectively. This tendency was somewhat different from the results of stand level mentioned above, indicating that shrub layers and grass layers of *L. gmelinii* forests is essential important for productivity and biomass production estimation. The importance of ground layers in Eurasian larch forests was pointed out by Gower et al. (2001) in the review study of boreal forest productivity. Moreover, possible reason is the relative higher light penetrated from sparse canopy, which resulted in many species invasion even in pure plantations (Zhou 1991).

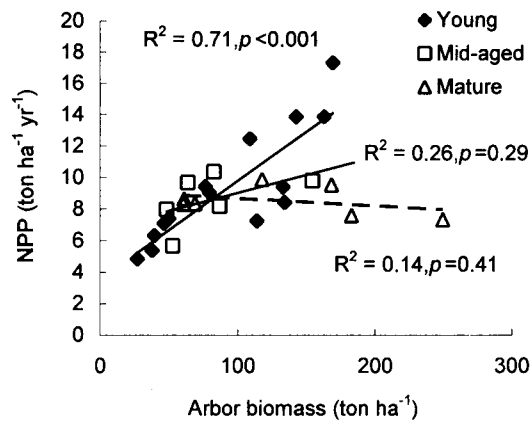


Fig. 3. Age effects on the relationship between stand biomass and NPP of *Larix gmelinii* forests. Data in Table 2 and 3 are used in these figures.

Table 2. Stand biomass and productivity of larch forest in Northeast China and its allocation in different organs.

Species	Location	Forest status	Distribution	Forest age	Biomass (ton ha ⁻¹)					Stand Productivity (ton ha ⁻¹ yr ⁻¹)								
					Timber	Bark	Branch	Leaves	Root	Total	timber	Bark	Branch	Leaves	Root	Total		
<i>L. gmelinii</i>	Mts. Daxinanling, Northeast China ¹	Young	SE zone	29	63.63	9.00	8.95	3.79	na	85.31	4.86	0.58	0.63	3.79	na	9.86		
			C zone	29	39.81	7.94	6.39	2.60	na	56.74	3.57	0.61	0.51	2.60	na	7.29		
			N zone	34	29.14	5.94	4.38	2.35	na	41.81	2.26	0.38	0.30	2.35	na	5.29		
		Middle	C zone	54	52.17	9.42	7.85	2.90	na	72.34	2.59	0.40	0.37	2.90	na	6.26		
			/natural	N zone	55	38.82	7.80	5.91	3.09	na	55.62	1.48	0.25	0.20	3.09	na	5.02	
		Mature	C Zone	186	143.95	33.39	10.87	1.96	58.96	249.21	2.04	0.47	0.15	1.96	0.84	5.46		
			/natural	C Zone	175	57.26	19.02	6.96	1.46	32.61	117.34	1.71	0.56	0.21	1.46	0.97	4.91	
	Laoshan, Northeast China ²	Young /plantation	Laoshan, Flux site	33	93.84	8.36	8.66	2.76	na	113.62	na	na	na	na	na	7.25		
				24	111.74 [#]		18.22	4.66	34.17	168.79	4.66 [#]		0.76	4.67	1.42	11.51		
				24	108.36 [#]		17.46	3.63	33.14	162.59	4.52 [#]		0.72	3.63	1.38	10.25		
				24	89.55 [#]		12.85	3.12	27.38	132.90	3.73 [#]		0.54	3.12	1.14	8.53		
				24	93.84 [#]		8.66	2.76	28.70	133.96	3.91 [#]		0.36	2.76	1.19	8.22		
				21	85.15	12.53	10.98	3.32	30.37	142.35	6.14	0.08	1.02	3.38	1.92	12.54		
				Krasnoyarsk, Ru ³	Mature/natural	155	51.20 [#]		3.06	1.23	20.00	75.49	1.47		0.09	1.23	0.58	3.37
						155	3.03 [#]		0.41	0.10	3.90	7.44	0.12		0.02	0.10	0.16	0.40
Yakutia, Ru ⁴	Mature/natural	169	114.90 [#]		6.43	1.68	108.60	231.61	0.67		0.16	1.68	0.23	2.74				
Evenkia, Ru ⁵	Overmat./nat.	240-280	18.10 [#]		3.20	1.00	16.70	39.00	0.26 [#]		0.06	1.01	0.48	1.81				
<i>L. olgensis</i>	Liaoning, Cn ⁶	Young/artificial	32	197.48 [#]		28.28	4.78	53.07	290.41	12.57 [#]		1.31	4.78	3.00	21.66			
	Jilin, China ⁷	Mature/natural	180	206.73 [#]		14.19	5.06	20.11	246.09	2.40 [#]		0.17	5.06	0.88	8.51			
		Mature/natural	120	na		na	na	na	202.38	na		na	na	na	8.21			
<i>L. principis-rupprechtii</i>	North China ⁸	Mature/Natural	116	na		na	na	na	214.31	na		na	na	na	11.44			
<i>L. kaempferi</i>	Sichuan, Cn ⁹	Middle/artificial	na	104.75	15.93	28.94	4.10	37.83	191.60	4.55	0.69	1.26	4.10	1.64	12.30			
	Hokkaido, Jp ¹⁰	Young/ artificial	21	69.20 [#]		12.20	4.90	na	86.30	6.70 [#]		3.00	4.90	na	14.60			
	Morioka, Jp ¹¹	Young/ artificial	39	145.40 [#]		15.50	3.60	34.80	199.88	5.80 [#]		3.26	3.59	1.96	14.61			
	Henan, China ¹²	Young/artificial	10	55.67 [#]		14.73	4.60	23.92	98.92	5.57 [#]		1.47	4.60	2.39	14.03			
			20	101.46 [#]		20.42	6.00	37.38	165.26	5.07 [#]		1.02	6.00	1.87	13.96			
			23	169.90 [#]		23.10	6.26	50.17	249.43	7.39 [#]		1.00	6.26	2.18	16.83			
33	159.76 [#]		19.57	5.17	44.29	228.79	4.84 [#]		0.59	5.17	1.34	11.97						

<i>L. sibirica</i>	Yaroslavl, Russia ¹³	Young/artificial	22	85.30	13.00	13.40	3.87	na	115.57	5.80	0.87	2.37	3.87	na	12.91		
		Young/artificial	29	112.20	17.10	12.16	3.31	na	144.77	4.41	0.74	2.20	3.31	na	10.66		
	Samara, Russia ¹⁴	Young/artificial	21	61.60	9.00	15.00	6.10	na	91.70	6.78	0.98	3.40	6.10	na	17.26		
	Krasnoyarsk, Ru ¹⁵	Young/artificial	25	na		na	na	na	na	2.84	0.70	0.91	2.15	2.17	8.77		
	Mts. Altai& Tian,Cn ¹⁶	Mature/natural	120	na		na	na	na	202.38	na		na	na	na	8.21		
<i>L. decidua</i>	Czechoslovakia,Ru ¹⁷	Young/Natural	36	42.81	5.89	4.80	0.96	8.93	63.39	1.35 [#]		0.08	0.96	0.25	2.63		
		Young/ artificial	28	165.60 [#]		21.80	3.70	na	191.00	Xeric:3.73 [#]		0.81	3.57	na	8.11		
	Tyrol, Australian ¹⁹	Young/artificial		27	64.89 [#]		47.80	22.54	26.95 ^{**}	162.20	na		1.71	3.59	na	10.41	
				27	30.22 [#]		20.74	9.78	23.35 ^{**}	84.10						na	12.50 [*]
				27	9.41 [#]		7.37	3.48	11.20 ^{**}	31.50							na

*: Mean value (total biomass exclude leaf/age plus leaf biomass), in the original reference (Li *et al.* 2003), they calculated the mean growth rate as total biomass/age. The values were 6.01, 3.11 and 1.16 ton ha⁻¹ yr⁻¹, respectively #: stem biomass and bark biomass; **: stump and root biomass; na, data were not available. All data were from Satoo 1977; Feng *et al.* 1985; Liu *et al.* 1991; Liu *et al.* 1994; Ding *et al.* 1982&1990; Wang 1992; Gower *et al.* 1993; Su 1995; Kajimoto *et al.* 1999; Zhao TS 1999; Feng *et al.* 1999; Usoltsev *et al.* 2002; Li *et al.* 2003. Information of sites: 1) 47° 3' N~53° 20' N, 119° 36' E~125° 19' E, T_{annual}-2~-6°C, 300~1700m a.s.l., precipitation 350~500mm. 2) 45° 16' N, 127° 34' E, T_{annual} 2.8°C, 300 m a.s.l., precipitation 723mm. 3) 70° N, 90° E, 70~290m a.s.l. 4) 63° N, 129° E, 220 m a.s.l. 5) 64° 19' N, 100° 13' E, 160m a.s.l. 6) 40° N~42° N, 122° E (Wang *et al.* 1992), T_{annual}7~11°C, precipitation 600~1100mm. 7) 41° 53' N~42° 04' N, 127° 57' E~128° 11' E, T_{annual}4.9~7.3°C, 740m a.s.l., precipitation 600~900mm. 8) 36° N~40° N, 111° E~115° E (Wang *et al.* 1992), T_{annual}10~20°C, precipitation 400~600mm. 9) 31° 50' N, 103° 50' E, T_{annual} 4.7°C, 2950 m a.s.l., precipitation 1193mm. 10) 43° 13' N, 142° 23' E, T_{annual} 6.7°C, 230m a.s.l., precipitation 1275mm. 11) 39° 45' N, 141° 08' E, 360m a.s.l. (Usoltsev *et al.* 2002). 12) 33° 40' N~33° 45' N, 110° 48' E~110° 50' E, T_{annual}12°C, 1400~1800m a.s.l., precipitation 700~1100mm. 13) 58° 6' N, 38° 42' E, 105 m a.s.l. 14) 53° 30' N, 50° 20' E. 15) 56° 13' N, 92° 19' E. 16) 37° N~46° N, 74° E~95° 30' E, (for Mts. Tianshan). 17) 49° 19' N, 16° 40' E. 18) 43° 52' N, 91° 51' W. 19) 47° 07' N, 11° 30' E. The mean annual temperature in Siberia including sites 3,4,5,13,14,15 was-18~-28°C (<http://www.meteo.ru/isklim/cl2000e.htm>).

Table 3. Biomass and productivity of larch forest ecosystem in Northeast China and its distribution in different layers.

Species	Location	Age/origin	Distribution	Forest type	Forest age	Biomass (ton ha ⁻¹)					Ecosystem Productivity, NPP (ton ha ⁻¹ yr ⁻¹)					
						Tree	Shrub	Grass	Litterfall	Total	Tree	Shrub	grass	litterfall	Total	
<i>L. gmelinii</i>	Mts. Daxinanling, NE China ¹	Young /natural	SE zone	LL	29	49.84	2.20	0.35	2.98	55.38	7.39	na	na	na	7.39	
				HL	29	108.60	6.05	0.11	1.98	116.74	12.31	na	0.14	na	12.45	
			C zone	LL	29	37.74	3.69	na	0.66	42.09	4.29	1.10	na	na	5.39	
				RL	29	46.31	5.65	na	0.94	52.90	5.01	1.84	0.16	na	7.11	
				HL	29	76.33	2.51	na	1.82	80.66	7.21	na	2.20	na	9.41	
			N zone	LL	34	27.08	1.76	4.72	1.00	34.56	3.69	0.53	0.64	na	4.86	
				RL	33	39.39	25.63	8.87	na	73.89	4.21	1.90	0.23	na	6.34	
				HL	32	79.04	0.00	0.19	na	79.23	8.88	na	0.14	na	9.02	
			Middle /natural	C zone	LL	55	52.73	1.02	2.04	2.22	58.01	4.92	0.10	0.21	0.44	5.67
					RL	55	86.71	24.29	8.40	na	119.40	5.99	1.62	0.56	na	8.17
		N zone		HL	56	154.09	0.00	0.18	na	154.27	9.63	na	0.14	na	9.77	
				LL	53	48.21	2.44	0.84	0.77	52.26	4.86	2.96	0.14	na	7.96	
		Mature /natural	C zone	RL	54	63.61	8.66	0.77	1.41	74.75	6.34	3.21	0.11	na	9.66	
				HL	50	82.61	0.00	2.06	1.44	86.11	7.59	na	2.44	na	10.33	
				LL	127	117.34	78.54	na	0.20	196.08	4.91	4.91	na	0.04	9.86	
			N zone	RL	109	249.21	35.94	na	0.12	285.27	5.46	1.85	na	0.03	7.34	
				HL	130	182.64	0.00	1.04	na	182.68	7.17	na	0.43	na	7.60	
				PL	107	60.43	20.05	na	34.21	115.14	1.56	1.46	na	5.30	8.32	
		Laoshan, NE China ²	Young/plantation	Laoshan, Flux site	LL	33	113.62	na	na	na	113.62	na	na	na	na	7.25
					RL	24	168.79	8.16	2.63	8.01	187.59	11.51	2.83	2.63	0.33	17.30
HL	24				162.59	6.42	1.18	5.41	175.60	10.25	2.20	1.18	0.23	13.86		
HL	24				132.90	0.85	0.40	3.52	137.67	8.53	0.29	0.40	0.15	9.37		
			LL	24	133.96	0.10	0.05	2.81	136.92	8.22	0.03	0.05	0.12	8.42		
			HL	21	142.36	2.69	0.57	na	145.62	12.54	0.87	0.45	na	13.86		

<i>L. olgensis</i>	Krasnoyarsk, Ru ³	Mature/natural	155	75.49	20.40*	na	95.89	3.37	2.74*	na	6.11				
			155	7.44	11.20*	na	18.64	0.40	0.95*	na	1.35				
	Yakutia, Ru ⁴	Mature/natural	169	231.61	13.70*	na	245.31	2.74	0.44*	na	3.18				
			32	290.41	3.02	0.50	10.89	304.80	21.66	1.37	0.50	na	23.53		
	Liaoning, China ⁶	Young/artificial	130	251.49	20.81	1.24	3.16	276.70	5.66	2.60	1.24	na	9.50		
			134	161.40	5.42	1.30	1.49	169.61	4.31	0.68	1.30	na	6.29		
			128	245.10	19.20	0.82	0.41	265.53	5.42	2.40	0.82	na	8.64		
			134	246.90	4.89	0.11	na	251.90	5.94	0.61	0.11	na	6.66		
			136	208.66	21.76	1.21	0.33	231.96	6.48	1.26	1.21	na	8.95		
			136	116.30	12.34	1.52	1.41	131.57	3.60	1.54	1.52	na	6.66		
			180	246.09	4.89	0.11	na	251.09	8.51	0.88	0.11	na	9.50		
			120	208.66	21.76	8.21	12.33	250.96	9.48	2.00	0.62	na	10.10		
<i>L. principis-rupprechtii</i>			North China ⁸	Mature/Natural	116	214.31	34.21	12.03	17.34	274.89	11.44	1.84	0.54	na	13.82
<i>L. kaempferi</i>			Sichuan, China ⁹	Middle/artificial	Na	191.56	0.17	0.23	16.27	208.23	12.25	0.04	0.06	0.71	13.05
	Hokkido, Japan ¹⁰	Young/artificial	39	203.32	1.70	2.35	6.70	214.07	13.52	0.60	1.70	na	15.82		
<i>L. sibirica</i>	Mts. Altai & Tian, Cn ¹⁶	Mature/natural	120	202.38	17.38	11.67	13.20	244.63	8.21	1.01	0.52	na	9.74		

Note: na: data were not available. *: shrub +grass. All data were from Satoo 1974; Feng et al. 1985; Liu et al. 1991; Liu et al. 1994; Wu & Feng 1995; Su YM 1995; Ding et al. 1982&1990; Feng et al. 1999; Usoltsev et al. 2002. Site description was in Table 2.

With the increase of biomass of tree layer, age gave an important effect on the relationship between NPP and tree biomass (Fig. 3). NPP value of young forests increased sharply with biomass ($R^2=0.71, p<0.01$), while that of mature forests and middle-aged forests decreased slightly with biomass ($R^2<0.26, p>0.05$). This is important for the management of larch forests with the aim of economic production (Wang 1992). For the management of short-rotation and fast-growing plantation in this region, young forest management will have the best economic yield. Increasing competition in root system due to limitation of soil nutrition and stomata conductance may be the reason why old forests decline their productivity, which had been reviewed by Gower *et al.* (1996) and Kajimoto *et al.* (1999).

3.3 Predications of *L. gmelinii* forests biomass and productivity by accompanying species

Table 3 shows the differences in biomass and ecosystem productivity of *L. gmelinii* trees between forest types. In each age group, biomass of HL forests was the highest, followed by RL forests and LL forests. With all the data for statistical analysis, we found the following significant differences ($p<0.05$); tree layer biomass of HL forests ($122.00 \text{ ton ha}^{-1}$)>RL forests

($92.00 \text{ ton ha}^{-1}$)>LL forests ($56.00 \text{ ton ha}^{-1}$) and productivity of HL forests ($8.90 \text{ ton ha}^{-1}\text{yr}^{-1}$)>RL forests ($5.60 \text{ ton ha}^{-1}\text{yr}^{-1}$)>LL forests ($5.20 \text{ ton ha}^{-1}\text{yr}^{-1}$). In each age group, this kind of tendency was more marked (Table 4). Similarly, at ecosystem level, NPP value of HL forest ecosystem ($9.7 \text{ ton ha}^{-1}\text{yr}^{-1}$)>RL forests ($7.8 \text{ ton ha}^{-1}\text{yr}^{-1}$)>LL forests ($7.1 \text{ ton ha}^{-1}\text{yr}^{-1}$) were observed (Table 3). Same tendency and similar result on volume growth rate have been reported by three authors (Feng & Yang 1985; Zhao *et al.* 1996, Feng *et al.* 1999). Therefore, the association species can be used as an indicator for forest productivity (Feng & Yang 1985), which is totally related to the fertility of sites (Zhou 1991).

3.4 Management affects the trait of *L. gmelinii* forests biomass accumulation and productivity

When the biomass accumulation was above 100-110 ton ha^{-1} , NPP decreases with biomass were observed in natural forests in Mts. Daxinganling (Fig. 4, left). However, NPP increases with biomass were observed in plantation when biomass was higher than 168 ton ha^{-1} . Forest management has essentially changed the trait of biomass accumulation.

Mean growth rate of tree layer biomass

Table 4. Productivity difference with *L. gmelinii* forest types at stand level and ecosystem.

Levels	Forest type	Young forest	Middle age forest	Mature forest
Stand	HL>RL (%)	44~110	19~61	31~35
	RL>LL (%)	17~44	22~30	9~11
Ecosystem	HL>RL (%)	32~42	7~20	4~14
	RL>LL (%)	30~32	21~44	-4~-26

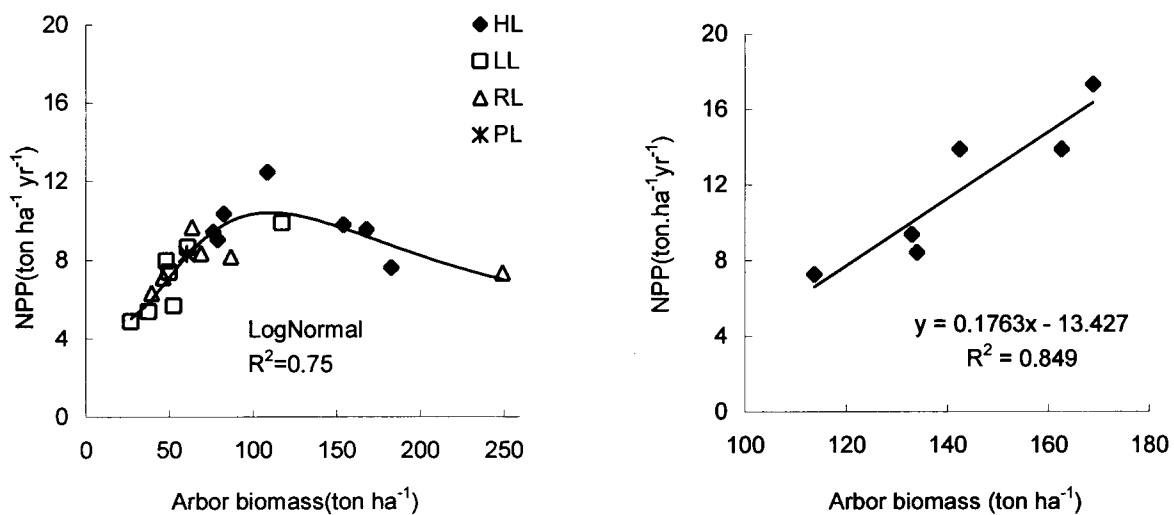


Fig. 4. Relationship between stand biomass and ecosystem production of natural (Left) and artificial (Right) *L. gmelinii* forests. Abbreviation in left figure can be found in Table 1. The right figure only includes young forests at Laoshan flux site (Table 3). Data in Table 2 and 3 are used in these figures.

(Biomass/Age; B/A) was positively correlated with tree productivity, while the relationship was different between plantation and natural forests (Fig. 5, left). Similar findings on natural larch forests in China have reported by Zhou *et al.* (2002). We found that plantation and natural forests are different in this relationship. Plantations usually had a higher growth rate (B/A value), while natural forests had a lower one. However, with the increase in B/A values, productivity of tree layer increased with a similar rate (combined slope=1.91) both natural forests and plantation since no statistical difference between the two slope values ($p>0.05$) (Fig. 5, left).

Stand productivity was positively correlated with NPP, while the relationship was different between plantations and natural forests (Fig. 5, right). With the increase in stand productivity, plantation (Slope=1.64) increased faster than that of natural forests (Slope=0.68). The two slope values differed

significantly ($p<0.05$). Therefore, productivity of tree layer in plantation contribution more to total ecosystem productivity is a result of forest management. For getting more economic production, forester usually manage plantation by mowing grass and shrub, which may affect the relationship between stand productivity and NPP as shown in our result (Fig. 5).

3.5 Latitude dependent productivity of Larch forests from China to Siberia

Climatic differences of habitats substantially affected the biomass and productivity of *L. gmelinii* forests (Liu *et al.* 1994). At stand level, in a given forest type and given age group, biomass and productivity of trees increased gradually from north to south (Table 2&3). The order was as follows: Siberia, Russia <N zone <C zone <SE zone <Laoshan flux site (Table 2 & 3). Similar results were observed at ecosystem level (Table 2 & 3). Therefore, *L. gmelinii* forest productivity in

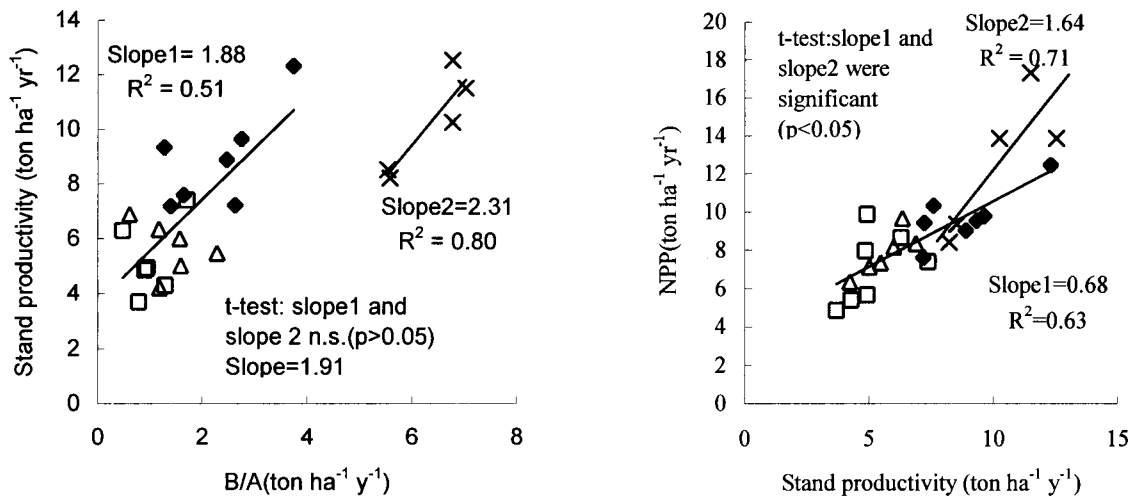


Fig. 5. The relationship between B/A (biomass divided by age) and tree productivity (Left), tree productivity and NPP (Right). Data in Table 2 and 3 are used in these figures.
□: Natural LL; ◆: natural HL; △: Natural RL; ×: plantation

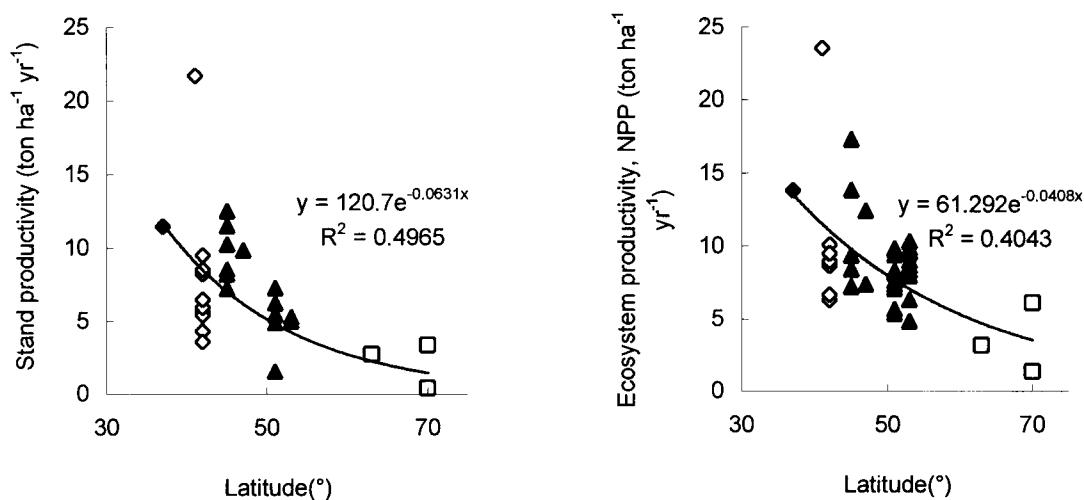


Fig. 6. Relationship between stand productivity (Left) and ecosystem productivity, NPP (Right) and latitude. Data in Table 2 and 3 are used in these figures.
◆: *L. principis-rupprechtii*; ◇: *L. olgensis*; ▲: *L. gmelinii* in NE China; □: *L. gmelinii* in Siberia.

northeast China is strongly dependent on climate and site-specific environment from south to north in Northeast China (Liu *et al.* 1994; Feng *et al.* 1999).

Fig. 6 shows the relationship between latitude and stand productivity and NPP (*L. olgensis* and *L. principis-rupprechtii* were included in this figure). A strongly dependent pattern on latitude was observed both at ecosystem and stand level (Fig. 6). Considering the temperature gradient with latitude (annual mean temperature in North China, 10~20°C, NE China, -6~11°C and Siberia -18~-28°C) (Note after Table 2), our result implies that temperature may be the limiting factor controlling this pattern. This latitude (temperature) dependent pattern is similar to the report of Reich and Bolstad (2001) on temperate forests through the world.

Furthermore, the decrease of stand productivity by increase of latitude (Fig. 6, left) was 54% steeper than that of NPP (Fig. 6, right). This finding indicates that productivity from shrub layer and grass layer in higher latitude (North) may contribute more to NPP than does in the lower latitude (South). From North China to Siberia, a lot of site-specific shrub and grass species accompany *L. gmelinii* forests (Wang 1992; Abaimov *et al.* 1998). These accompanying species, for example *Rhododendron dauricum*, *Ledum palustre*, *Sphagnum spp.* In Mts. Daxinganling, Northeast China, usually have a strong adaptability for acclimating the environment of larch forest floor, which may improve the percentage of their productivity to NPP.

3.6 Latitude dependent root/shoot ratio of *L. gmelinii* forests from China to Siberia

Root biomass is essentially important for the estimation of NPP in terrestrial ecosystem. However, in many cases, we can only estimate root biomass by way of root/shoot ratio because of the lack of available data (e.g. Gower *et al.* 2001). Root/shoot ratio of larch forests from North China to Siberia ranged from 0.2 to 1.2 (data in Table 2), and it exponentially correlated with latitude (Fig. 7). Similar tendency (extreme higher root biomass) was also reported by Kanzawa *et al.* (1994) in Yakutsk, Russia.

In Siberia permafrost, the water is just available in the active layer in summer season (Kajimoto *et al.* 1999&2003), while water supply was substantial increased in Northeast China since no continuous permafrost. Moreover, tree in less productive environment with low temperature usually need more root to reserve carbohydrate and to absorb soil nutrients (Kozłowski & Pallardy 1997). This large difference in water availability and temperature maybe responsible for the change of root/shoot ratio along latitudinal change.

3.7 Contribution of shrub and grass productivity to total NPP estimation of *L. gmelinii* forests

As mentioned in above 3.2, 3.3 and 3.5 paragraph of this report, shrub and grass layer productivity is important for larch forest productivity estimation. The percentage of contribution by biomass and productivity of shrub and grass in NE China were 0-40% and 0-50%,

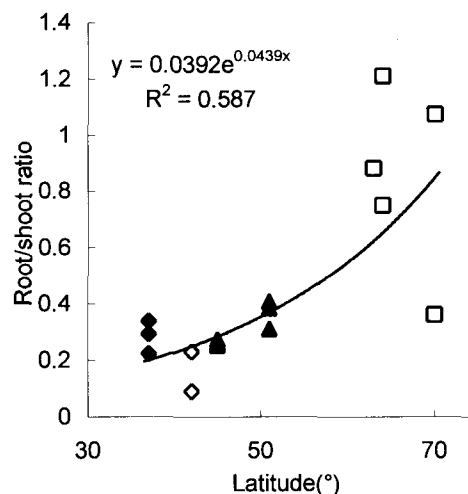


Fig. 7. Relationship between root/shoot ratio (Root biomass/ aboveground biomass) and latitude. Data in Table 2, Kajimoto *et al.* (2003), Han & Liang (1997) and Han *et al.* (1997) are used in these figures.

◆: *L. principis-rupprechtii*; ◇: *L. olgensis*; ▲: *L. gmelinii* in NE China; □: *L. gmelinii* in Siberia.

Table 5. Contribution of tree, shrub and grass on total biomass and NPP estimation.

	Tree (%)	Shrub (%)	Grass (%)
Biomass	52~100	0~40	0~14
NPP	19~100	0~50	0~24

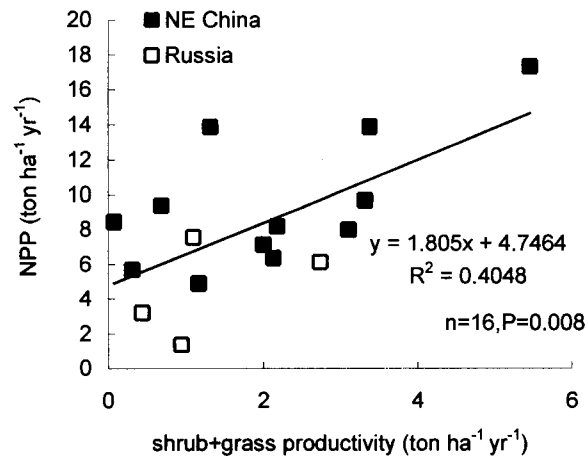


Fig. 8. The correlation between productivity of shrub and grass and NPP
Data in Table 3 are used in these figures.

Table 6. Productivity of different larch forests at stand level and ecosystem.

Levels	<i>L. gmelinii</i> in NE China	<i>L. gmelinii</i> in Russia	<i>L. olgensis</i>	<i>L. principis-rupprechtii</i>	<i>L. kaempferi</i>	<i>L. sibirica</i>	<i>L. decidua</i>
Stand	7.05 (n=15)	6.24 (n=18)	7.93 (n=10)	11.44 (n=1)	13.76 (n=2)	11.56 (n=5)	10.98 (n=6)
	1.56~12.54	0.40~12.54	3.60~21.66		12.00~16.80	8.21~17.26	2.60~27.70
Ecosystem	9.01 (n=27)	8.46 (n=30)	9.98 (n=9)	13.82 (n=1)	14.4 (n=2)	9.74 (n=1)	na
	4.90~17.30	1.35~17.30	6.29~23.53		13.05~15.82	na	na
Main Distribution Region	NE China	Siberia Russia NE China	NE China Korea Russia	North China	Japan, China	Russia, Mongolia	Europe

Note: in each level, the upper part is mean value with number of samples. The lower part is the range of sample.

Table 7. Comparison between *L. gmelinii* forest in Northeast China and other forests in boreal and temperate forest regions.

	<i>L. gmelinii</i> in NE China	<i>L. gmelinii</i> in Russia	Broadleaved forest in NE China [@]	Evergreen Needle forest in China [@]	Europe Russia [#]	North America ^{##}	Siberian forest [*]	South BOREAS Site ^e	Boreal evergreen [*]	Boreal Deciduous [*]	Temperate evergreen [†]	Temperate deciduous [†]
No.	27	4	8	21	45	19	na	3	15	7	14	11
NPP	9.01±2.80	4.55±2.80	11.4±2.2	8.6±4.1	8.30±4.70	12.90±7.50 ⁺⁺	3.14-4.45	4.10-7.80	4.90-6.90	9.60±1.70	8.70±3.80	10.30±6.40 ⁺⁺

&: re-analyzed data from Cannell 1982; * From Jarvis et al. 2001. # From Gower et al. 1997; Steel et al. 1997 and Jarvis et al. 2001. to convert from carbon to biomass, multiple by 2; ##, Lassoie et al. 1985; + Re-analyzed data from Whittaker and Marks(1975) and Reich and Bolstad(2001); ++ only above ground productivity; @: from data in Appendix 1 B, na: data not available.

respectively (Table 5). Moreover, the productivity of shrub and grass from NE China to Siberia was positively correlated with NPP ($p=0.008$) (Fig. 8). Therefore, exact estimation of these parts might explain the disparity of NPP estimation between the methods of biomass summation, ecophysiological and eddy-covariance by CO_2 flux tower.

3.8 Comparison of productivity of *L. gmelinii* forests with other larch species

The average value of larch forests were $7.05 \text{ ton ha}^{-1} \text{ yr}^{-1}$ at stand level and $9.01 \text{ ton ha}^{-1} \text{ yr}^{-1}$ at level of ecosystem (NPP), which were generally lower than other larch species (Table 6). However, a wide range of productivity in these species ($2.60 \text{ ton ha}^{-1} \text{ yr}^{-1}$ to $27.70 \text{ ton ha}^{-1} \text{ yr}^{-1}$) were observed (Table 6), indicating that no

clear evidence was derived from our study to say that one species is more productive than others.

3.9 Comparison of biomass and productivity between *L. gmelinii* forests and other kinds of forests

The productivity of broadleaved and mixed forests ranged from $8.01\text{--}14.45 \text{ ton ha}^{-1} \text{ yr}^{-1}$ with a mean value of $11.40 \text{ ton ha}^{-1} \text{ yr}^{-1}$ (Table 7, Appendix 1 Table B). The NPP of *L. gmelinii* forests in Northeast China ranged from $4.90 \text{ ton ha}^{-1} \text{ yr}^{-1}$ to $17.30 \text{ ton ha}^{-1} \text{ yr}^{-1}$, and its mean value was about $9.01 \text{ ton ha}^{-1} \text{ yr}^{-1}$ (Table 6), which was lower than that of broadleaved and mixed forests ($p=0.03$). The productivity of evergreen conifer forests ranged from $1.39 \text{ ton ha}^{-1} \text{ yr}^{-1}$ to $15.47 \text{ ton ha}^{-1} \text{ yr}^{-1}$ with a mean value of $8.60 \text{ ton ha}^{-1} \text{ yr}^{-1}$ (Table 7), which

was as low as that of *L. gmelinii* in ($p=0.71$) (Table 6). Therefore, our results showed that *L. gmelinii* had a similar range of NPP to evergreen conifer forests, but slight lower than broadleaved and mixed forests in the same region in China.

Comparison between *L. gmelinii* forests and forests in boreal and temperate forest regions (Table 7) indicated that The productivity of *L. gmelinii* in Northeast China were substantially higher than that of Siberian forests, boreal evergreen and south BOREAS sites, and similar to that of Europe Russia forests, boreal deciduous forests and temperate evergreen forests, and somewhat lower than temperate deciduous forests. No marked differences were found between *L. gmelinii* in Northeast China and Europe Russia forests ($p=0.45$), and between *L. gmelinii* in Northeast China and temperate evergreen forests ($p=0.78$). These findings suggest that *L. gmelinii* forests in Northeast China keep high ability to fix CO₂, especially when intensive management would be implemented (Zhao 1994).

4. Concluding remarks

By this intra- and inter-species comparison, we found that:

Considerable variation of allometric relations was found among different association of *L. gmelinii* forest and different larch species. This variation may be habitat dependent, but not species specific, i.e. one species may have big difference in its allometric relationship when grown in different site. Leaf biomass is easier to be influenced by site environment relative to root and no obvious differences in biomass contributions to root, leaf biomass in different larch species.

Both at the levels of stand and ecosystem, biomass accumulation and productivity were affected by tree age and management and habitat environment. Moreover, shrubs and grasses make a proportionally higher contribution to the productivity of ecosystem. In a regional scale, NPP of larch forests increase with latitude from North China to Siberia, Russia. Moreover, carbon allocation to root increases as latitude increases.

L. gmelinii forest productivity in Northeast China was similar or even higher than other larch forests, other kinds of forests both in China and in boreal and temperate forest regions around world.

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Appendix 1

Table A. Allometric relationships of *L. gmelinii* in Northeast China and some other *Larix* spp. around world.
(Unit: D, cm; H, m; W, kg tree⁻¹)

Species	location	Forest status	Allometric function	R ²	Status of tree	
<i>L. gmelinii</i>	Daxinganling, Northeast China	LL	$W_{s+bark}=0.0461 (D^2H)^{0.8722}$	0.90	DBH=4.74-8.7;	
		Middle age forests	$W_b=0.035 (D^2H)^{0.5624}$	0.88	H=5.9-9.6	
			$^{\#1}W_f=0.01397 (D^2H)^{0.5628}$	0.76	Natural forests	
				$\&1W_r=0.00753 (D^2H)^{0.9725}$	0.96	
		RL	$W_{s+bark}=0.01837 (D^2H)^{0.9559}$	0.98	DBH=10.3-20.4;	
		Middle age forests	$W_b=0.001695 (D^2H)^{1.0685}$	0.98	H=9.9-18.6	
			$^{\#2}W_f=0.00118 (D^2H)^{0.7122}$	0.92	Natural forests	
				$\&2W_r=0.03966 (D^2H)^{0.7537}$	0.90	
		HL	$W_s=0.01380 (D^2H)^{1.0110}$	0.98	DBH=10.2-22.4;	
		Middle age forests	$W_{bark}=0.02601 (D^2H)^{0.72045}$	0.98	H=11.2-21.3	
			$W_b=0.0007979 (D^2H)^{1.1271}$	0.96	Natural forests	
				$^{\#3}W_f=0.002291 (D^2H)^{0.8659}$	0.88	
			$\&3W_r=0.001699(D^2H)^{1.1179}$	0.96		
	BL	$W_s=0.01258 (D^2H)^{0.99331}$	0.98	MeanD=16.20;mean		
	Middle age forests	$W_b=0.00136 (D^2H)^{1.02797}$	0.98	H=17.20		
		$W_f=0.01009 (D^2H)^{0.64543}$	0.96	Natural forests		
			$W_r=0.03615 (D^2H)^{0.75995}$	0.98		
	LL	$W_{s+bark}=0.0818 (D^2H)^{0.8248}$	0.96	DBH=7.28-35.6;		
	Mature larch forests	$W_b=0.0003 (D^2H)^{1.2131}$	0.94	H=9.3-28.1 age=175		
		$^{\#4}W_f=0.0020 (D^2H)^{0.7979}$	0.69	Natural forest		
		$\&4W_r=0.0208 (D^2H)^{0.8881}$	0.98	density=811		
RL	$W_{s+bark}=0.3429 (D^2H)^{0.6829}$	0.96	DBH=8.34-32.5;			
Mature larch forests	$W_b=0.0037 (D^2H)^{0.8589}$	0.79	H=9.5-27.3 age=186			
	$W_f=0.0026 (D^2H)^{0.7199}$	0.71	Natural forest			
		$W_r=0.0426 (D^2H)^{0.7921}$	0.98			
SLL	$W_{s+bark}=0.0319 (D^2H)^{0.9683}$	0.98	DBH=7.44-36.2;			
Mature larch forests	$W_b=0.0635 (D^2H)^{0.4798}$	0.90	H=9.0-25.0 age=107			
	$W_f=0.0259 (D^2H)^{0.918}$	0.85	Natural forest			
		$W_r=0.0766 (D^2H)^{0.7228}$	0.96	density=2934		
Laoshan Experimental forest Northeast China	Young plantation	$W_s=0.0021369 (D^2H)^{1.2043}$	0.96	DBH=6-22; H=7-18		
		$W_{bark}=0.001038 (D^2H)^{1.14}$	0.90	age=20		
		$W_b=0.00324 (D^2H)^{1.0106}$	0.94	plantation		
		$^{\#5}W_f=0.00021 (D^2H)^{1.1687}$	0.96	density:=1450		
		$\&5W_r=0.00169 (D^2H)^{1.1881}$	0.98			
<i>Central Siberia Russia</i>	Over mature nature forest	$W_{s+bark}=0.00362 (D^2H)^{0.738}$	0.99	DBH=6.8-18.5;		
		$W_b=0.00203 (D^2H)^{0.635}$	0.99	H=5.5-11.2		
	Natural forest	$W_f=0.00103 (D^2H)^{0.593}$	0.99	age=240-280		
		$W_{r-coa}=0.00175 (D^2H)^{0.552}$	0.96	density=1910		
<i>L. olgensis</i>	Liaoning, Northeast China	Young plantation	$W_s=0.238 (D^2H)^{0.7193}$	0.94	DBH=1.5-26.5;	
			$W_{bark}=0.1392 (D^2H)^{0.5128}$	0.92	H=1.5-20.9	
			$W_b=0.2606 (D^2H)^{0.4928}$	0.92	age=7-52	
		$^{\#1}W_f=0.1760 (D^2H)^{0.3255}$	0.94			
		$\&1W_r=0.0916 (D^2H)^{0.6855}$	0.94			
	<i>L. principis- rupprechtii</i>	Heicha Mt. Shanxi, Central China	Young plantation	$W_{s+bark}=0.04951 (D^2H)^{0.8542}$	0.99	DBH=2-17;age=20
$W_b=0.01735 (D^2H)^{0.9316}$				0.96		
			$^{\#1}W_f=0.005913 (D^2H)^{0.8433}$	0.95		
			$W_{t-above}=0.0720 (D^2H)^{0.8783}$	0.98		
			$\&1W_r=0.05244 (D^2H)^{0.8059}$	0.96		
			$W_r=0.12426 (D^2H)^{0.8528}$	0.98		
Guancen Mt. Shanxi, Central China		Young plantation	$W_{s+bark}=0.02470$	0.98	DBH=3-10;age=18	
			$(D^2H)^{0.9589}$	0.97		
			$W_b=0.005252 (D^2H)^{1.0440}$	0.92		
			$^{\#2}W_f=0.002214(D^2H)^{0.9683}$	0.99		
			$W_{t-above}=0.0322 (D^2H)^{0.9776}$	0.97		
			$\&2W_r=0.009366$	0.99		
	$(D^2H)^{0.9775}$					
	$W_t=0.04159 (D^2H)^{0.9774}$					
Guandi Mt. Shanxi, Central China	Young plantation	$W_{s+bark}=0.04470(D^2H)^{0.855}$	0.99	DBH=3-10,age=14		
		0	0.86			
		$W_b=0.1015 (D^2H)^{0.6637}$	0.89			
		$^{\#3}W_f=0.002204 (D^2H)^{0.9669}$	0.97			
		$W_{t-above}=0.1299 (D^2H)^{0.7775}$	0.96			
	$\&3W_r=0.01742 (D^2H)^{0.8655}$	0.97				
	$W_t=0.1455 (D^2H)^{0.7929}$					

<i>L. kaempferi</i>	Liaoning, Northeast China	Young plantation	$W_s = 0.0381 (D^2H)^{0.9067}$	0.98	DBH=3.5-24.4; H=3.6-22.7 age=7-40 Plantation
			$W_{bark} = 0.01465 (D^2H)^{0.7672}$	0.98	
			$W_b = 0.0862 (D^2H)^{0.5805}$	0.96	
			$W_l = 0.0820 (D^2H)^{0.4262}$ $\&^1 W_r = 0.0217 (D^2H)^{0.7906}$	0.90 0.96	
	Sichuan, Southwest China	Young plantation	$W_s = 0.0127 (D^2H)^{0.9926}$	0.98	DBH=10.5-23.7; H=12.5-16.2 Age=23
			$W_{bark} = 0.0100 (D^2H)^{0.7991}$	0.94	
			$W_b = 0.0043 (D^2H)^{0.9592}$	0.96	
			$W_t = 0.0001 (D^2H)^{1.2073}$ $W_{t-above} = 0.0204 (D^2H)^{0.9719}$ $\&^2 W_r = 0.0019 (D^2H)^{1.0951}$	0.96 0.98 0.99	
	Henan, Central China	Young plantation	$W_{s+bark} = 0.04427D^{2.5831}$	0.93	DBH=9.7-24.4 H=9.5-25.5 Age=10-33
			$W_b = 0.06339D^{1.8467}$	0.73	
			$W_l = 0.04406D^{1.5261}$	0.57	
			$\&^3 W_r = 0.04853D^{2.1735}$ $W_t = 0.1583 D^{2.2947}$	0.83 0.93	
	Hokkaido Japan	Young plantation	$W_{s+bark} = 0.0195D^{2.377}$	na	DBH=12.3-20.9, H=13.9-17.1m, Age=21 plantation Age=120
			$W_b = 0.004797D^{2.778}$	na	
			$\&^4 W_l = 0.007798D^{2.252}$	na	
			$W_t = 0.0450D^{2.695}$	na	
<i>L. sibirica</i>	Altai and Tian Mts, Northwest China	Mature natural forest	$W_s = 0.03994 (D^2H)^{0.8718}$	0.88	
			$W_{bark} = 0.02438 (D^2H)^{0.7181}$	0.94	
			$W_b = 0.03389 (D^2H)^{0.5511}$	0.92	
			$W_l = 0.1388 (D^2H)^{0.8488}$ $W_r = 0.006984 (D^2H)^{0.9724}$	0.74 0.88	
<i>L. occidentalis</i>	Idaho Montana USA Cascade Mts, Washington USA	Middle age forest	$W_{s+bark} = 0.2942D^{1.5593}$	0.91	DBH=1-17, age was not available. DBH=6.0-20, Age=65-70
			$W_b = 0.1821D^{1.2885}$	0.90	
			$\&^2 W_l = 0.1307D^{1.0557}$	0.92	
			$W_s = 0.0695D^{2.460}$ $W_{bark} = 0.04764D^{2.020}$ $W_{b-live} = 0.003281D^{2.648}$ $W_{b-dead} = 0.000628 D^{2.333}$ $\#^1 W_l = 0.001663 D^{2.499}$	0.99 0.97 0.93 0.33 0.91	
<i>L. decidua</i>	Wisconsin USA	Young forest	$W_{s+new-twig} = 0.000176D^{2.166}$	0.73	
			$W_s = 0.248D^{2.111}$	0.97	
			$W_{b-live} = 0.000553D^{3.423}$	0.96	
			$W_{b-dead} = 0.00177D^{2.850}$ $\#^3 W_l = 0.000492D^{2.912}$	0.52 0.91	
<i>L. laricina</i>	Manitoba Canada	Forest after fire	$W_{s+bark} = 17.1D^{2.388}$	0.94	D _{basal} =0.7-4.1, age=4-130. Measurement was done after fire. D in function is basal diameter
			$W_b = 11.8D^{2.176}$	0.92	
			$W_l = 7.4D^{1.735}$	0.75	
			$W_r = 11.7D^{2.500}$ $W_t = 36.6D^{2.211}$	0.79 0.92	
	Minnesota USA			$W_{s+bark} = 0.0731D^{2.393}$	0.96
				$W_b = 0.0776D^{2.0550}$	0.80
				$W_l = 0.1359D^{2.2980}$	0.98
				$W_s = 0.0464 D^{2.5050}$ $W_{bark} = 0.0168D^{2.0868}$ $W_{s+bark} = 0.0609D^{2.4472}$ $\#^1 W_l = 0.0061D^{1.9790}$	0.98 0.99 0.98 0.77
	Nova scotia USA			$W_b = 0.0178D^{2.1727}$	0.80
				$W_t = 0.0946D^{2.3572}$	0.99
				$W_{s+bark} = 0.0762D^{2.3051}$	0.995
				$\#^2 W_l = 0.0466D^{1.7250}$	0.95
Maine USA			$W_b = 0.0436D^{1.9810}$	0.96	
			$W_t = 0.1265D^{2.2453}$	na	

Subscript: t: total biomass; s: stem biomass without bark; l: leaf biomass; r: root biomass; na, not available. All above equations were referenced from Satoo 1974; Feng & Yang 1985; Gower *et al.* 1987; Liu *et al.* 1991; Wang 1992; Wang & Feng 1994; Gower *et al.* 1993; Wu & Feng 1995; Su *et al.* 1995; Ter-Mikaelian *et al.* 1997; Han *et al.* 1997; Feng *et al.* 1999; Zhao *et al.* 1999; Bond-Lamberty *et al.* 2002, Chai *et al.* 2002. Superscript: different symbols and numbers at each equation are the frequent number used in Table D-H of Appendix 3.

Table B. Net primary productivity of other main forest types near Northeast China.

Forest type	Age (Yr)	Density (stem ha ⁻¹)	NPP (ton ha ⁻¹ yr ⁻¹)	Biomass (ton. ha ⁻¹)				
				tree	shrub	grass	Litter	Total
Broadleaved and mixed forests								
BKP*	220	620	8.01	352.2	11.70	na	na	363.90
MOF*	32	1960	14.18	192.47	17.70	2.26	10.55	222.98
AF*	31	1590	10.31	99.62	12.69	4.54	19.80	136.65
DMF*	37	1050	11.95	134.44	12.08	1.98	16.10	164.60
HF*	28	1170	12.04	91.73	2.65	3.36	11.04	108.78
BF*	38	1280	14.45	196.71	8.60	1.71	11.03	218.05
LIBE**	215	928	9.96	212.30	7.00	0.68	na	220.10
TSACBE**	117	117	10.07	549.20	17.10	1.65	na	568.00
Average	90	1089	11.40	228.60	11.20	2.30	13.70	250.40
Evergreen conifer forest								
CPF*	29-50	730-3150	12.69	77.27-248.20	na	na	na	77.27-248.17
CPF*	18-30	380-3640	5.85	27.23-72.58	na	na	na	27.23-72.58
CPF*	34	1035	13.67	117.06	1.14	0.46	na	118.67
PAF*	104	na	10.78	203.35	2.34	1.11	na	207.80
KPL*	27	3590	14.10	75.88	na	na	na	75.88
PINH†	28-37	1300-1700	8.39	81.28	na	1.45	11.16	93.89
PINT†	17-29	1070-7800	6.59	60.08	0.47	0.31	na	60.86
PINM†	20	1752	5.03	100.62	3.01	0.89	2.28	106.8
PINA*	17	na	2.66	31.36	19.88	6.46	10.50	68.19
PINE*	16	2200	11.63	138.75	10.39	7.81	19.40	176.58
CUNL*	18	2310	9.86	119.76	10.27	7.65	8.72	146.40
	25	2685	15.47	217.62	15.74	12.95	29.59	275.90
	53	1290	11.30	253.59	9.93	11.69	16.35	291.56
CUNL**	20	2750	8.40	127.90	0.84	3.90	2.00	134.60
	20	2750	10.34	150.90	1.46	2.60	1.40	156.30
	23	2750	4.84	100.30	0.34	0.60	2.30	103.60
ABIF†*	131	274	12.94	525.50	15.10	3.79	na	544.50
	114	345	4.69	194.40	87.40	0.64	na	282.60
ABIS†*	320	277	1.39	276.30	3.42	0.12	na	279.80
PICP*	40-50	640-950	3.26	155.30	2.28	13.13	11.01	161.64
PICB*	28	3460	7.56	56.36	21.23	14.23	15.98	107.82
Average	50	2035	8.60	148.30	12.10	5.00	10.90	178.60

BKF: Broadleaved Korean pine (*Pinus koraiensis*) forest; KPL: Korean pine plantation; MOF: Mogolian oak forest; AF: Aspen forest; DMF: Deciduous mixed forest; HF: Hardwood forest; BF: Birch forest; CPF: Chinese pine (*Pinus tabulaeformis*) forest; PAF: *Picea koiensis* and *Abies koraiensis* forests. PINH: *Pinus henryi*; PINT: *Pinus tabulaeformis*; PINM: *Pinus massoniana*; PINA: *Pinus armandii*; PINE: *Pinus elliottii*; CUNL: *Cunninghamia lanceolata*; LIBE: *Lithocarpus cleistocarpus*+*Betula insignis*; TSACBE: *Tsuga chinensis*+*Acer spp.*+*Betula spp.*; ABIF: *Abies fabrici*; ABIS: *Abies squamata*; PICP: *Picea purpurea*; PICB: *Picea balfouriana*; na: data were not available. Data with "*" were referenced from Zhao 1994; Zhai et al. 1994; Ma 1994; Zhou & Wang 1981; Yan et al. 1994; Chen 1994; Chen et al. 1994; Tian et al. 1994; a. Data with "#" were conducted in Siberia from Gower et al. 1996 and 2001. † in north china from Xiao 1990 & 1992. – in Southeast China from Jiang 1986. Data of ++ conducted in south china were from Feng et al. 1982 & 1984; +* is from Luo et al. (2000) in Southeast China (near Tibet).

Appendix 2

Statistical analysis on the similarity of two regression lines (Intercept and slope value) (Chen *et al.* 1988)

1. Data required

- 1). Size of the two samples; n_1, n_2
- 2). Coefficients for the two regression lines: a_1, b_1 and a_2, b_2 ; the equation for regression line is $y=a+bx$; where a is intercept and b is slope.
- 3). Standard deviation of the residual for each sample and their freedom: $S_{\sigma_1}, S_{\sigma_2}, f_1=n_1-2, f_2=n_2-2$
- 4). Sum of square for the independent variable of x_1 and x_2 , Lx_1x_1 and Lx_2x_2
- 5). Mean values for the independent and dependent variables for two regression line: $\bar{x}_1, \bar{x}_2, \bar{y}_1, \bar{y}_2$.

2. Procedure for analysis

- 1) Significance test on the difference between the residual of variance of $S_{\sigma_1}^2$ and $S_{\sigma_2}^2$ by F test.

Construction of F statistic: the numerator in the following equation of statistic is the large one between $S_{\sigma_1}^2$ and $S_{\sigma_2}^2$.

$$F = \frac{S_{\sigma_1}}{S_{\sigma_2}}; \quad 1)$$

When $F < F_{\alpha}(n_1-2, n_2-2)$, this means that no significance difference between two residual of variance, and two residual of variance can be combined as S_{σ}^2 , by following equation;

$$S_{\sigma}^2 = \frac{f_1 S_{\sigma_1}^2 + f_2 S_{\sigma_2}^2}{f_1 + f_2}; \quad 2)$$

- 2) Significance test on the differences between slope values (b_1 and b_2) by t-test.

Under the base of insignificant difference on $S_{\sigma_1}^2$ and $S_{\sigma_2}^2$, t statistic can be constructed by following equation;

$$t = \frac{b_1 - b_2}{S_{\sigma} \sqrt{\frac{1}{Lx_1x_1} + \frac{1}{Lx_2x_2}}}; \quad 3)$$

When $|t| < t_{\alpha}(n_1-2, n_2-2)$, this means that no significance difference between slope values, and they can be combined as slope value of b , by following equation;

$$b = \frac{b_1 Lx_1x_1 + b_2 Lx_2x_2}{Lx_1x_1 + Lx_2x_2}; \quad 4)$$

- 3) Significance test on the difference between intercept values (a_1 and a_2) by t-test.

Under the base of insignificant difference between b_1 and b_2 , t statistic can be constructed by following equation;

$$t = \frac{a_1 - a_2}{S_{\sigma} \sqrt{\frac{1}{n_1} + \frac{\bar{x}_1}{Lx_1x_1 + Lx_2x_2} + \frac{1}{n_2} + \frac{\bar{x}_2}{Lx_1x_1 + Lx_2x_2}}}; \quad 5)$$

When $|t| < t_{\alpha}(f_1+f_2) = t_{\alpha}(n_1+n_2-4)$, this means that no significance difference between slope values, and they can be combined as slope value of a , by following equation;

$$a = \frac{n_1 \bar{y}_1 + n_2 \bar{y}_2}{n_1 + n_2} - b \frac{n_1 \bar{x}_1 + n_2 \bar{x}_2}{n_1 + n_2}; \quad 6)$$

If all these three tests showed that no difference between two regression line, we can combine these two line by the new a and b value.

Appendix 3

Table C. Relationship between DBH and Height for Japanese larch (From Takahashi 1960).

DBH(cm)	Height(m)	DBH(cm)	Height(m)	DBH(cm)	Height(m)
8.6	6.3	14.45	14.2	19.2	16.1
8.24	7.15	14.86	14.3	20.5	19.84
8.15	5.8	15.85	11.5	20.52	15.25
8.27	7.17	15.95	15.52	20.7	18.2
8.2	7.3	16	13.5	21	18
10.35	7.7	16.1	13.2	21.85	18.55
6.6	5.9	16.1	13.3	23.5	15.1
12.05	8.5	16.4	14.35	23.6	18.1
13.7	10.1	16.8	16.8	23.7	15.95
13.8	9.5	17.3	17.2	24.2	17.6
15.85	11.5	17.6	11.25	29.7	18.5
15.95	15.52	17.8	14.8	34.4	28.1
12.7	10.9	17.92	14.02	35	23
17.6	11.25	18.1	15.8	37.4	29.6
17.8	14.8	18.4	14.2	37.7	23.3
11.27	10.3	18.5	15.92	40.3	21
13.63	12.3	18.6	17.8	42.7	26.25
16	13.5	18.7	16.9	46.8	23.5

From this data in Table C, we derived a equation between DBH and Height as following:

$y = -0.013x^2 + 1.1784x - 1.7945; R^2 = 0.8758$. Based on this equation, a tree height can be calculated when a given DBH is known. Together with the tree height and DBH as well as the allometric relations in Table A, the following tables could be calculated. These data were used in Figure 2.

Table D. Biomass contribution to leaf and root biomass for *L. gmelinii*.

D(cm)	H(m)	D ² H	Leaf (kg/tree)					Root (kg/tree)					
			#1	#2	#3	#4	#5	&1	&2	&3	&4	&5	
6	4.81	173.08	0.25			0.28		0.97				1.63	
7	5.82	285.05	0.34			0.39	0.16	2.33				3.22	1.86
8	6.80	435.24	0.43			0.51	0.25	3.81				4.74	3.40
9	7.76	628.41	0.52			0.65	0.39	5.16				6.00	4.92
11	9.15	1008.29	0.68	0.16	0.91	0.88	0.68	7.85	8.65	5.00		8.34	8.22
12	10.65	1584.71	0.88	0.22	1.35	1.17	1.15		11.90	8.02		11.50	13.58
14	12.24	2432.72		0.30	1.96	1.55	1.90		16.49	13.01		15.97	22.70
16	13.88	3643.68		0.41	2.78	2.01	3.05		21.34	19.08		20.72	34.08
18	15.35	5083.30		0.51	3.71	2.49	4.50		27.79	28.23		27.04	51.70
20	16.64	6722.41		0.63	4.72	2.98	6.24		34.94	39.66		34.07	74.18

DBH is a given data according to the range in Table A for allometric relations. Tree height is calculated according to best-fitting equation in Table C. Allometric relations for *L. gmelinii* is from Table A. #1 to #5, and &1 to &5 are the equation name labeled in Table A for leaf and root of *L. gmelinii*, respectively.

Table E. Biomass contribution to leaf and root biomass for *L. olgensis*.

D(cm)	H(m)	D ² H	Leaf	Root
			(kg/tree) #1	(kg/tree) &1
6	4.81	173.08	0.94	2.81
7	5.82	285.05	1.11	5.21
8	6.80	435.24	1.27	7.38
9	7.76	628.41	1.43	9.13
11	9.15	1008.29	1.67	11.48
12	10.65	1584.71	1.94	16.03
14	12.24	2432.72	2.23	21.85
16	13.88	3643.68	2.54	27.43
18	15.35	5083.30	2.83	34.94
20	16.64	6722.41	3.10	43.40

DBH is a given data according to the range in Table A for allometric relations. Tree height is calculated according to best-fitting equation in Table C. Allometric relations for *L. olgensis* is from Table A. #1 and &1 are the equation name labeled in Table A for leaf and root of *L. olgensis*, respectively.

Table F. Biomass contribution to leaf and root biomass for *L. principis-rupprechtii*.

D(cm)	H(m)	D ² H	Leaf (kg/tree)			Root (kg/tree)		
			#1	#2	#3	&1	&2	&3
6	4.81	173.08	0.46	0.33	0.32	2.63	1.08	1.17
7	5.82	285.05	0.70	0.53	0.52	5.75	2.79	2.70
8	6.80	435.24	0.99	0.79	0.78	8.84	4.70	4.29
9	7.76	628.41	1.35	1.13	1.12	11.51	6.48	5.69
11	9.15	1008.29				15.36	9.19	7.76
12	10.65	1584.71	2.95			22.74		
14	12.24	2432.72	4.24			32.72		
16	13.88	3643.68				42.74		
18	15.35	5083.30				56.82		

DBH is a given data according to the range in Table A for allometric relations. Tree height is calculated according to best-fitting equation in Table C. Allometric relations for *L. principis-rupprechtii* is from Table A. #1 and &1 are the equation name labeled in Table A for leaf and root of *L. principis-rupprechtii*, respectively. D(cm)

Table G. Biomass contribution to leaf and root biomass for *L. kaempferi*.

D(cm)	H(m)	D ² H	Leaf (kg/tree)				Root (kg/tree)		
			#1	#2	#3	#4	&1	&2	&3
6	4.81	173.08	0.74	0.05	0.68	0.44	0.90	0.33	2.21
7	5.82	285.05	0.91	0.09	0.86	0.62	2.06	1.04	3.13
8	6.80	435.24	1.09	0.15	1.05	0.84	3.21	1.92	4.22
9	7.76	628.41	1.28	0.24	1.26	1.10	4.21	2.81	5.48
11	9.15	1008.29	1.56	0.42	1.59	1.55	5.70	4.27	7.24
12	10.65	1584.71	1.90	0.73	2.00	2.18	8.39	7.28	10.76
14	12.24	2432.72	2.27	1.22	2.50	3.02	11.98	11.94	15.04
16	13.88	3643.68	2.70	1.99	3.09	4.13	15.57	17.17	20.10
18	15.35	5083.30	3.11	2.98	3.69	5.37	20.59	25.28	25.96
20	16.64	6722.41	3.51	4.18	4.29	6.71	26.44	35.73	32.64

DBH is a given data according to the range in Table A for allometric relations. Tree height is calculated according to best-fitting equation in Table C. Allometric relations for *L. kaempferi* is from Table A. #1 and &1 are the equation name labeled in Table A for leaf and root of *L. kaempferi*, respectively.

Table H. Biomass contribution to leaf biomass for *L. occidentalis*, *L. decidua* and *L. laricina*.

D (cm)	<i>L. occidentalis</i>		<i>L. decidua</i>	<i>L. laricina</i>	
	#1	#2	#1	#1	#2
6	0.14	0.86		0.22	1.05
7	0.21	1.01		0.30	1.37
8	0.30	1.17	0.36	0.38	1.72
9	0.40	1.32	0.42	0.48	2.10
10	0.52	1.48	0.60	0.58	2.47
12	0.82	1.79	0.86	0.83	3.39
14	1.21	2.11	1.31	1.13	4.42
16	1.68	2.43	1.58	1.47	5.57
18	2.26	2.76	2.22	1.86	6.82
20	2.95	3.08	3.02	2.29	8.18

DBH is a given data according to the range in Table A for allometric relations. Allometric relations for *L. kaempferi* is from Table A. # No. and & No. are the equation name labeled in Table A for leaf of *L. occidentalis*, *L. decidua* and *L. laricina*, respectively.