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## Time Trend in Aboveground Biomass, Net Primary Production, and Carbon Storage of Natural *Larix gmelinii* Stands in Eastern Siberia

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### Abstract

To evaluate the carbon storage and sink capacities of natural *Larix gmelinii* stands in eastern Siberia, aboveground biomass (AGB), aboveground net primary production (ANPP), and carbon storage in the biomass and soil organic layer were estimated in relation to stand age. The stands studied ranged from young to mature. The AGB and carbon storage in the biomass increased sigmoidally with stand age. The asymptotes of the biomass and carbon storage were 102 t·ha<sup>-1</sup> and 51 tC·ha<sup>-1</sup>, respectively. While the annual increment in the biomass was small, the carbon storage capacity of the AGB was considerable, due to the long period during which asymptotic carbon storage occurs. In addition, the carbon sink capacity of the biomass changed with stand age. The ANPP of the stands was smaller when compared with temperate and boreal stands. However, the results suggested that Siberian *Larix* stands functioned as carbon sinks. The deciduous leaf habit of larch species may contribute to the carbon sink capacity of the *Larix* stands. Carbon storage in the organic layer of soil was 80-100 % of that in the AGB, and constituted a significant carbon storage compartment.

*Key words:* aboveground biomass, carbon storage, *Larix gmelinii*, net primary production, organic layer

### Introduction

Among terrestrial ecosystems, carbon storage in forest ecosystems is relatively large (Post *et al.* 1982), and is estimated to be approximately 1150 GtC (IPCC 2000). Among forest biomes, total carbon storage is greatest in boreal forests. Siberian forests (5.96 × 10<sup>8</sup> ha; Rosencranz and Scott 1992) account for approximately 14 % of the world's forest area (IPCC 2000) and are therefore an important carbon sink. However, it is apprehensive that deforestation in these regions due to intensive logging (Rosencranz and Scott 1992) and frequent wildfires (Goldammer and Furyaev 1996) is contributing to global warming. Indeed, warming has been particularly marked at high latitudes in the Northern Hemisphere since 1970s (Chapman and Walsh 1993). Some terrestrial ecosystems at the high latitudes are expected to be affected by global warming and to cause positive feedback on the atmospheric carbon concentration (Oechel *et al.* 1993, Goulden *et al.* 1998). Therefore, the carbon storage and flux of Siberian forests must be evaluated quantitatively for understanding global-scale carbon dynamics.

When wildfires are the cause of forest disturbance, biomass recovery and the accumulation of the soil organic layer are important factors when evaluating the carbon dynamics between the forest ecosystem and atmosphere, because they are easily consumed during

wildfires (Gorbachev and Popova 1996, Conard and Ivanova 1997, Kasischke and Bruhwiler 2003). In cold regions, like Siberia, a large amount of carbon accumulates in the organic layer and mineral soil (Cebrián and Duarte 1995, IPCC 2000) because of the slow decomposition rate of detritus. Therefore, the accumulated carbon in the organic layer and mineral soil must also be measured along with biomass recovery of forest.

In this study, we estimated the aboveground biomass and net primary production, and carbon storage in the biomass and the soil organic layer of natural *Larix gmelinii* stands in eastern Siberia in relation to stand development, in order to evaluate the carbon storage capacity of the *Larix* stands. In general, many *Larix* stands in eastern Siberia are disturbed intensively by wildfire (Shvidenko and Nilsson 2000), and we studied stands in which the dominant trees had regenerated within a short period following fires.

Some parts of this study have already been reported in Shibuya *et al.* (2001a, b).

### Study sites and Methods

#### Sites

The study sites were located in the Kenkeme (62° 13' N, 129° 11' E) and Neleger (62° 18' N, 129° 30' E) districts, 30-40 km from Yakutsk in west to northwest

direction, in the Republic of Sakha, Russia. Both districts are located on the region of continuous permafrost soil and are subject to frequent wildfires. We set up eight plots (Plots I-VIII, Table 1), including repetitively measured plots, in natural *Larix gmelinii* stands in both districts. The investigations were conducted in each mid-summer of consecutive five years (1997-2001). Some dominant *Larix* trees (3-9 trees) were sampled near Plots I, II, and IV to determine stand age. In these plots, the ages of sample trees fell within relatively narrow ranges (less than 5 years), which indicated that each stand was approximately even-aged. The trees in Plots V and VI varied considerably in size, suggesting uneven-aged stands; ages of these stands estimated from 2 sample trees were 230 years old and more. The stand ages of Plots III, VII, and VIII were assessed using 1 to 3 dominant trees near each plot. In the older stands (Plots V-VIII), it was supposed that uneven-aged stand structure resulted from gap formation by death of canopy trees, due to some past surface fires (Gorbachev and Popova 1996, Matveev and Usoltzev 1996). In all, the study stands covered wide age-range from young (22 years old) to mature (>230 years old, Table 1).

Shrubs, such as *Vaccinium* and *Betula* species, moss, and lichen were the dominant forest floor vegetation in all the plots. All of the plots were located on almost flat slopes of sandy or silty soil. Depth of active layer of soils was approximately 1 m in each plot.

Meteorological long-term records at Yakutsk indicate that the annual mean temperature and precipitation are  $-10.0$  °C and 237 mm, respectively. The monthly mean temperature during the growing season exceeds 5 °C from May to September.

#### Methods

Plot size was determined depending on tree size (9-2500 m<sup>2</sup>). The stands with a high tree density for their stand age were chosen for our investigation. In each plot, all trees higher than 1.3 m were identified, and their diameters at breast height (D), heights (H), and heights of the live crown base (H<sub>b</sub>) were measured.

Aboveground biomass (AGB) was estimated using the mean tree method only for Plot II, and AGBs of the other plots were estimated using the allometric method. Twenty-two *Larix* trees (see Appendix 1), ranging from 0.2 to 28.8 cm in D, were sampled to determine the allometric equations. For the sample trees, D and H

Table 1. Stand description.

Plot	Stand age <sup>1)</sup> (years)	Density (trees·ha <sup>-1</sup> )	D <sup>2)</sup> (cm)	H <sup>2)</sup> (m)	BA (m <sup>2</sup> ·ha <sup>-1</sup> )	Canopy closure <sup>3)</sup> (%)
I *	22	10000	3.0 0.5-7.0	4.7 1.8-7.4	8.91	63
	23	10200	3.3 0.3-7.5	4.9 1.8-7.6	11.09	
II <sup>4)</sup>	50	76667	-	3.2 1.3-5.4	-	
III	54	30100	1.7 0.2-10.8	2.9 1.3-10.2	15.01	
IV*	120	5972	7.4 3.7-13.4	9.6 4.8-14.3	28.62	71
	121	5903	7.4 3.7-13.5	9.7 4.8-14.6	29.05	
V	>230	2235	9.3 0.1-34.5	9.0 1.3-17.5	24.90	
VI	>230	1833	12.8 0.9-25.5	11.9 2.3-21.8	27.40	68
VII	170 <sup>5)</sup>	1816	10.3 0.3-38.7	9.3 1.4-20.7	26.64	
VIII*	170 <sup>5)</sup>	2104	8.7 0.1-41.8	8.2 1.3-19.5	20.72	
	173 <sup>5)</sup>	2116	8.7 0.1-42.0	8.6 1.3-20.5	21.29	

\* They were measured twice for estimation of ANPP.

<sup>1)</sup> Stand age in the measurement.

<sup>2)</sup> Upper and lower indicate mean and range, respectively. D: DBH, H: height.

<sup>3)</sup> Canopy closure is determined on a crown projection diagram.

<sup>4)</sup> Only tree height was measured.

<sup>5)</sup> Estimated from a sampled dominant tree in the plot.

were measured, and fresh weights of stem and all of branches and leaves were measured in the field. The small samples of stem, branches, and leaves were taken from all sample trees and were dried at 80 °C to constant weight, and the fresh weight was converted to the dry weight. We derived three groups of allometric equations for stands at differing growth stages and depending on sampling sites (Table 2). Some trees (2-5 trees per plot) of Plots V, VII, and VIII were larger in D than sampled trees for the allometric equations. However, we considered that the extrapolation in the allometry for such larger trees did not result in large estimation error of AGB, because allometric relationship between stem mass and  $D^2H$  is known to be rather stable irrespective of tree size (Kira and Shidei 1967), and stem mass generally accounts for larger portion of AGB in mature stands.

In Plots I, IV, and VIII (young, middle-aged, and mature stands, respectively), tree census was made twice to estimate aboveground net primary production (ANPP). The intervals of the census were 1 year for the Plots I and IV, and 3 years for the Plot VIII. In these plots, we measured stem girth at breast height instead of D. ANPP was estimated by the summation method (Kira and Shidei 1967) using the following equation:

$$\text{ANPP} = \Delta y + \Delta L + \Delta G$$

$\Delta y$  was estimated as the annual increment of aboveground woody (stem and branch) biomass between tree measurements.  $\Delta L$  is the annual litter mass. We measured litter mass in one year using 4 litter traps (70×70 cm in area) set regularly in Plots I and VIII. Fine litter mass (i.e., branches less than 1 cm in diameter, fragments of barks, and larch cones, etc.),

other than leaves, was negligible (less than 0.1  $\text{t}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ ) in both plots, and we assumed that  $\Delta L$  equals the stand leaf biomass for all of the three plots.  $\Delta G$  is the mass grazed between measurements and was also assumed to be zero in our calculation of ANPP. For the Plot VIII,  $\Delta y$  and  $\Delta L$  were estimated as mean values in 3 years (on the biomass of each organ, see Appendix 2).

We sampled three *Larix* trees near Plots I, IV, and VIII, which were used to estimate ANPP, to determine the carbon content in aboveground tree organs. The carbon content was measured using an NC-analyzer (SUMIGRAPH NC-1000).

Carbon storage in the organic layer ( $A_0$  layer) was determined for Plots I, II, IV, and VIII. Accumulated fine organic materials in the  $A_0$  layer (i.e., branches less than 1 cm in diameter, leaves, and other materials such as barks) were sampled from 4 small squares (50×50 cm in area and 5-15 cm in thickness) set in each plot, and their dry weights were determined. Coarse woody detritus (branches and stems more than 1 cm in diameter) was sampled from the entire area of each plot, and the dry mass was determined. We took a small sample of each material and determined its carbon content using an NC-analyzer.

Further, Sawamoto *et al.* (unpublished data) estimated carbon storage in mineral soil down to a 1 m-depth in Plots I, IV, and VIII. They determined carbon content and bulk density of each layer of mineral soil down to a 1 m-depth by soil samplings in the plots, and then estimated the carbon storage in mineral soil (see method in detail: Sawamoto *et al.* 2000).

Table 2. Allometries for *Larix gmelinii* trees.

Plot	Allometry	$r^{2*}$	n
I·II	$W_s = 0.0534 (D^2H)^{0.77}$	0.982	9
	$W_b = 0.0098 (D^2H)^{0.79}$	0.944	9
	$W_l = 0.0085 (D^2H)^{0.71}$	0.964	9
VII·X·XI	$W_s = 0.0863 (D^2H)^{0.85}$	0.978	8
	$W_b = 0.0382 (D^2H)^{0.68}$	0.928	8
	$W_l = 0.0144 (D^2H)^{0.60}$	0.976	8
V·VI·VIII·IX	$W_s = 0.0502 (D^2H)^{0.88}$	0.987	22
	$W_b = 0.0096 (D^2H)^{0.80}$	0.938	22
	$W_l = 0.0111 (D^2H)^{0.82}$	0.955	22

Abbreviations; D: diameter at breast height, H: height,

$W_s$ : stem mass,  $W_b$ : branch mass,  $W_l$ : leaf mass.

Dimesions; D: cm, H and Hb: m, Mass: kg.

\* Coefficient of determination.

## Results

### Stand condition and AGB

Table 1 shows the stand condition of the plots investigated. Tree species such as *Pinus sylvestris*, *Betula platyphylla*, and *Salix bebbiana* grew in some plots, but the proportion of *L. gmelinii* in basal area was close to 100 % in all of the plots. Tree density was the highest in Plot II, and decreased to about 2000 ha<sup>-1</sup> in the four mature stands (Plots V-VIII). Canopy closure was 60-70 %, irrespective of stand age. The maximum height of *Larix* trees in our sites was 20-22 m. The basal area was the largest in Plot IV at 29 m<sup>2</sup>·ha<sup>-1</sup>. The basal areas in the four mature stands ranged from 20.7 to 27.4 m<sup>2</sup>·ha<sup>-1</sup>.

Figure 1 shows the AGB of the plots. The maximum AGB was 104 t·ha<sup>-1</sup>, which is slightly smaller than the published AGB (120 t·ha<sup>-1</sup>) for *Larix* stands in eastern Siberia, excluding extraordinary data (Osawa et al. 1993, Kanazawa et al. 1994, Schulze et al. 1995). The AGB increased with stand age and was saturated at around 120 years. The relationship between AGB and stand age was approximated closely by a logistic growth curve (Fig. 1). The AGB of the plots appears to remain close to the asymptote until 200-250 years.

In this study, stand leaf biomass ranged from 1.50 to 3.42 t·ha<sup>-1</sup> (Fig. 2). The relationship between leaf biomass and stand age differed from that between AGB and stand age, and did not follow a logistic curve. The ratio of leaf biomass to AGB decreased with stand age, from 9 % in young stands to 2 % in mature stands (see Appendix 2).

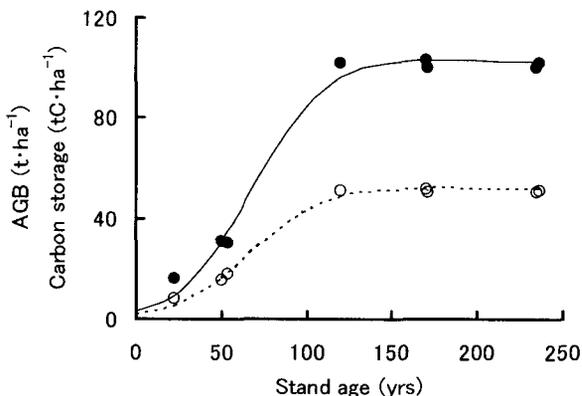


Fig. 1. Aboveground biomass (AGB) and carbon storage in the biomass in relation to stand age. The solid circles and curve are for AGB, and the open circles and dotted curve are for carbon storage. Data of the second census in Plots I, IV, and VIII are not included. Regressions: for AGB:  $y=102.36/(1+32.10\exp(-0.052x))$  ( $r^2=0.990$ ), for carbon storage:  $y=51.19/(1+27.61\exp(-0.051x))$  ( $r^2=0.993$ ).

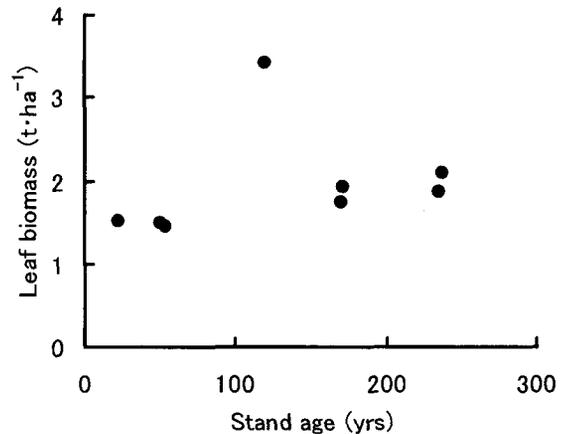


Fig. 2. Leaf biomass in relation to stand age.

### Carbon storage in the AGB and ANPP

The carbon content of aboveground tree organs (leaves, branches, bark, and stem wood) of *Larix* trees ranged from 47 to 54 % and did not differ among three sample trees. We applied the carbon content of the sample tree from Plot I to Plots II and III, and that from Plot VIII to Plots V-VII, according to stand age. The carbon storage in the AGB increased with stand age and followed a logistic curve closely (Fig. 1), reaching an asymptote of 51 tC·ha<sup>-1</sup> at around 120 years.

Table 3 shows estimates of ANPPs. The ANPPs were 5.10, 6.26, and 3.10 t·ha<sup>-1</sup>·yr<sup>-1</sup> in Plots I, IV, and VIII, respectively. The ANPP was large in young (Plot I) and middle-aged stands (Plot IV), and small in a mature stand (Plot VIII). In the mature stand, the annual production of leaves accounted for 2/3 of the ANPP.

### Carbon storage in the organic layer (A<sub>0</sub> layer) and mineral soil

Table 4 shows the carbon storage in the A<sub>0</sub> layer and mineral soil, up to a depth of 1 m, in Plots I, II, IV, and VIII. The total carbon storage in the A<sub>0</sub> layer and mineral soil ranged from 46.67 to 150.33 tC·ha<sup>-1</sup>. The storage in the A<sub>0</sub> layer was smallest in Plot I, a young stand. Carbon storage in the A<sub>0</sub> layer was roughly stable in Plots IV and VIII. The carbon storage in the A<sub>0</sub> layer increased with stand age, but appeared to be saturated after 120 years. In Plots IV and VIII, approximately 80 % of the carbon in the AGB was stored in the A<sub>0</sub> layer.

## Discussion

### AGB growth and carbon sink capacity

The plots investigated in this study were rather dense and well-stocked as for *Larix* stands around Yakutsk, and thus, the growth course of AGB (Fig. 1) may be a pattern for well-stocked *Larix* stands in eastern Siberia. According to the age census of dominant trees and stand inventory (Table 1), *Larix* stands in eastern Siberia generally regenerate at high density (10<sup>5</sup> ha<sup>-1</sup>) after a fire, and the dominant trees appear to be

Table 3. Net primary production by trees.

Plot	Stand age (years)	$\Delta y$ <sup>1)</sup> (t·ha <sup>-1</sup> ·yr <sup>-1</sup> )	$\Delta L$ <sup>1)</sup> (t·ha <sup>-1</sup> ·yr <sup>-1</sup> )	ANPP <sup>2)</sup> (t·ha <sup>-1</sup> ·yr <sup>-1</sup> )	TNPP <sup>3)</sup> (tC·ha <sup>-1</sup> ·yr <sup>-1</sup> )
I	23	3.28	1.82	5.10	2.54
IV	121	2.93	3.54	6.47	–
VIII	173	1.15	1.95	3.10	1.50

<sup>1)</sup>  $\Delta y$ : annual increment of aboveground woody biomass,  $\Delta L$ : leaf biomass.

<sup>2)</sup> Net primary production of aboveground organs.

<sup>3)</sup> Total net primary production including root production.

Table 4. Carbon storage in soil.

Plot	Stand age (yrs)	Layer	Mass (t·ha <sup>-1</sup> )	C storage (tC·ha <sup>-1</sup> )
I	23	A <sub>0</sub>	25.08	8.18
		Mineral soil**		38.49
		Total		46.67
II*	50	A <sub>0</sub>		17.00
IV	121	A <sub>0</sub>	97.38	41.35
		Mineral soil**		52.44
		Total		83.40
VIII	173	A <sub>0</sub>	99.75	38.11
		Mineral soil**		112.22
		Total		150.33

\* Only carbon storage in A<sub>0</sub> layer was measured.

\*\* Measured by Sawamoto *et al.* (unpublished data).

established in a short period. The mean annual increment in AGB was small, and was less than 1 t·ha<sup>-1</sup>·yr<sup>-1</sup> until 120 years (Fig. 1). The moderate leaf biomass of *L. gmelinii* stands in eastern Siberia seems to be 1-2 t·ha<sup>-1</sup> (Fig. 2; Osawa *et al.* 1993, Kanazawa *et al.* 1994, Schulze *et al.* 1995). Considering the loosely closed canopy (Table 1) with this range of leaf biomass, the leaf biomass of *Larix* stands in eastern Siberia is smaller when compared with those of *L. kaempferi* (3.0±1.0 t·ha<sup>-1</sup>) and other temperate deciduous broadleaved (3.1±1.5 t·ha<sup>-1</sup>) stands in Japan (Tadaki 1976). The small annual increment in the AGB in the *Larix* stands might primarily result from the cold and dry climate in eastern Siberia and the small leaf biomass. The typical leaf biomass of dense *L. gmelinii* stands in eastern Siberia is around 2 t·ha<sup>-1</sup> (Fig. 2; Osawa *et al.* 1993, Kanazawa *et al.* 1994, Schulze *et al.* 1995).

The increase in the AGB with stand age, as well as carbon storage in the AGB, followed a logistic curve (Fig. 1). Schulze *et al.* (1995) showed a similar time trend in AGB for the *L. gmelinii* stands near Yakutsk in eastern Siberia. Characteristically, the *Larix* stands

appear to maintain the asymptotic carbon storage until 200-250 years. Therefore, the carbon storage capacity of *Larix* stands in eastern Siberia throughout their life span is thought to be considerable.

The ANPP was the largest in Plot IV (Table 2). In general, the maximum ANPP of a forest stand is realized at the stage when leaf biomass reaches its maximum (Kira and Shidei 1967, Tadaki *et al.* 1977). The trend in the ANPP of Siberian *Larix* stands seemed to match this model (Fig. 2 and Table 3); however, the ANPP was rather smaller than values reported for Japanese *Larix* stands (e.g., 14.5 and 15.7 t·ha<sup>-1</sup>·yr<sup>-1</sup> in 21- and 39-year-old stands, respectively: Satoo 1970, 1974), temperate deciduous stands (mean NPP: 12 t·ha<sup>-1</sup>·yr<sup>-1</sup>, Whittaker 1975), and boreal stands (mean NPP: 8 t·ha<sup>-1</sup>·yr<sup>-1</sup>, Whittaker 1975).

Our estimates of ANPP only consisted of the annual increment in AGB ( $\Delta y$ ) and leaf biomass ( $\Delta L$ ), as explained in Methods. Kajimoto *et al.* (1999) reported that the net primary production rate of roots in a *Larix gmelinii* stand in central Siberia was approximately 1/3 of that of the aboveground parts. Therefore, we may estimate total NPP (TNPP) by adding 1/3 of the ANPP

as coarse root production (Table 3). TNPP ranged 1.50 to 4.08 tC·ha<sup>-1</sup>·yr<sup>-1</sup> in carbon base. Needle litter production (in carbon base) accounted for 35-63 % of the TNPP, and the ratio increased with stand age. Therefore, it is concluded that needle litter production considerably contributes to carbon sink capacity of natural *Larix* stands in eastern Siberia. The productivity of forest floor vegetation was omitted from the NPP; however, this is not a serious problem because the production of understory trees and shrubs is considerably small, e. g., about 7 % of the total net production of a mature *Larix* stand near Yakutsk (Kanazawa *et al.* 1994).

Sawamoto *et al.* (2003) estimated net ecosystem production (NEP) for Plots I and VIII. Even in the mature stand (Plot VIII), the NEP was positive (1.24 tC·ha<sup>-1</sup>·yr<sup>-1</sup>), indicating that the *Larix* stand in eastern Siberia functions as carbon sink at mature growth stage. Although some boreal forests and tundra are suggested to act as carbon source under global warming (Oechel *et al.* 1993, Goulden *et al.* 1998), mature *Larix* stands in eastern Siberia probably act as carbon sinks. This may be partly explained by the deciduous habit of *Larix* species, producing a large amount of litter every year. Schulze *et al.* (1999) also suggested that old larch (*Larix gmelinii*) and pine (*Pinus sylvestris*) stands of Siberia, such as 140 years old and over 200 years old, respectively, contributed to significant carbon sinks.

#### Carbon storage in soil

The carbon storage in the A<sub>0</sub> layer approximately equaled that in the AGB in Plots I and II, and was about 80 % of the AGB in Plots IV and VIII (Fig. 1 and Table 4). Although our data are insufficient (Table 4), the A<sub>0</sub> layer seems to have continued carbon accumulation over the 120 years since stand regeneration, as well as the case of AGB. This carbon storage is, however, very susceptible to wildfire. In Alaskan black spruce forests, more than 80 % of the ground-layer biomass is consumed by burning in the season when soil moisture is low (Kasischke *et al.* 2000). Kasischke and Bruhwiler (2003) also assumed that carbon emission from the A<sub>0</sub> layer during a fire ranged 1.0 to 12.0 tC·ha<sup>-1</sup> in boreal forest in the Russian Far East. Furthermore, indirect post-fire carbon emission from residual organic materials in soil is expected to be considerably larger than direct carbon emission during the fire (Dixon and Krankina 1993). Therefore, the A<sub>0</sub> layer is a key compartment of the carbon storage in *Larix* stands, and its dynamics might affect largely carbon dynamics of boreal forests worldwide. The carbon storage in soil of Plots IV and VIII was apparently larger than that in the AGB (Table 4), and was slightly less than the mean carbon storage in dry and moist boreal forests (110-130 tC·ha<sup>-1</sup>) as estimated by Post *et al.* (1982), but was very small compared with an estimate for boreal forests (344 tC·ha<sup>-1</sup>) by IPCC (2000). We need much more accurate data on carbon storage in the Siberian larch ecosystems in order to evaluate its potential capacity among the terrestrial ecosystems.

#### Conclusion

Our results suggested that in eastern Siberia mature *Larix* stands served as carbon sink. Lindroth *et al.* (1998) pointed out that boreal forests are generally a carbon sink for a long period, but may sometimes be a carbon source on an annual basis because of the sensitivity of the carbon dynamics to temperature. Siberian *Larix* stands may be a more stable carbon sink than other boreal forests because of their deciduous leaf habit. An other prominent characteristic of Siberian *Larix* stands is that the carbon storage in the A<sub>0</sub> layer is large. Consequently, carbon storage by *Larix* stands is defined as detritus-type rather than biomass-type, as compared with tropical and temperate forests. Stored carbon in the A<sub>0</sub> layer of *Larix* stands is significant in the global carbon budget because it is susceptible to global warming.

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## Appendix 1. Size and aboveground biomass of sample trees.

Species	D (cm)	H (m)	Ws (kg)	Wb (kg)	Wl (kg)	Wt (kg)	Tree age (years)	Plots*
<i>L. g.</i>	8.0	8.02	14.002	1.525	0.501	16.028	-	III, IV, V, VI, VII, VIII
<i>L. g.</i>	24.0	16.75	346.261	36.426	3.979	386.666	234	III, IV, V, VI, VII, VIII
<i>L. g.</i>	16.0	13.85	106.297	18.628	3.459	128.384	213	III, IV, V, VI, VII, VIII
<i>L. g.</i>	1.4	2.17	0.398	0.100	0.072	0.570	24	III, IV, V, VI, VII, VIII
<i>L. g.</i>	2.0	3.30	0.632	0.118	0.084	0.834	51	III, IV, V, VI, VII, VIII
<i>L. g.</i>	1.2	2.26	0.255	0.197	0.014	0.466	21	III, IV, V, VI, VII, VIII
<i>L. g.</i>	8.5	11.70	20.611	3.060	0.653	24.325	-	III, IV, V, VI, VII, VIII
<i>L. g.</i>	12.7	14.00	41.459	3.195	0.891	45.545	-	III, IV, V, VI, VII, VIII
<i>L. g.</i>	5.5	6.10	3.708	0.670	0.432	4.811	22	I, III, IV, VI, VII
<i>L. g.</i>	3.0	5.05	0.914	0.193	0.116	1.222	22	I, III, IV, VI, VII
<i>L. g.</i>	2.1	4.01	0.532	0.133	0.082	0.727	19	I, III, IV, VI, VII
<i>L. g.</i>	2.5	3.64	0.481	0.079	0.057	0.617	22	I, III, IV, VI, VII
<i>L. g.</i>	2.1	3.39	0.375	0.075	0.054	0.504	19	I, III, IV, VI, VII
<i>L. g.</i>	1.3	2.65	0.149	0.021	0.020	0.190	18	I, III, IV, VI, VII
<i>L. g.</i>	1.1	2.26	0.148	0.035	0.023	0.205	17	I, III, IV, VI, VII
<i>L. g.</i>	0.8	1.73	0.063	0.011	0.010	0.084	20	I, III, IV, VI, VII
<i>L. g.</i>	0.2	1.57	0.027	0.007	0.006	0.040	20	I, III, IV, VI, VII
<i>L. g.</i>	5.1	7.10	3.960	0.140	0.154	4.254	-	III, IV, VI, VII
<i>L. g.</i>	6.1	7.91	5.937	0.441	0.283	6.661	-	III, IV, VI, VII
<i>L. g.</i>	7.9	10.34	12.363	0.691	0.568	13.622	-	III, IV, VI, VII
<i>L. g.</i>	28.8	20.63	280.553	32.701	4.192	317.426	-	III, IV, VI, VII
<i>L. g.</i>	11.3	12.20	28.495	2.477	0.889	31.851	-	III, IV, VI, VII

\* Plots in which sample trees were used to determine estimation-equations of aboveground biomasses.

Abbreviations: *L. g.* : *Larix gmelinii*, D: diameter at breast height, H: height, Ws: stem weight, Wb: branch weight, Wl: leaf weight, Wt: aboveground weight, -: not measured. Weight is dry weight.

## Appendix 2. Biomass of each aboveground organ.

Plot	W <sub>s</sub> (t/ha)	W <sub>b</sub> (t/ha)	W <sub>l</sub> (t/ha)	W <sub>t</sub> (t/ha)	Remarks
I	12.26	2.41	1.51	16.18	1st census
	15.00	2.95	1.82	19.77	2nd census
II	26.90	2.32	1.50	30.71	
III	26.43	2.36	1.45	30.24	
IV	90.36	7.66	3.43	101.45	1st census
	92.94	8.01	3.54	104.49	2nd census
V	88.67	9.35	1.87	99.89	
VI	93.98	5.30	2.09	101.37	
VII	96.67	4.72	1.74	103.13	
VIII	88.44	9.46	1.92	99.82	1st census
	91.57	9.77	1.98	103.32	2nd census

Abbreviations; W<sub>s</sub>: stem biomass, W<sub>b</sub>: branch biomass, W<sub>l</sub>: leaf biomass, W<sub>t</sub>: aboveground biomass.