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## PRODUCTION OF PHYTOMASS CARBON IN THE DARK CONIFEROUS FOREST OF THE WESTERN SIBERIA

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### ABSTRACT

The results of the studies have shown that the total C reserves of the dark coniferous forest phytomass of the southern taiga in the south-eastern part of the Western Siberia vary from 75.8 to 129.0 t/ha in secondary birch forest and from 48.9 to 110.5 t/ha in fir forests.

The analysis of the production process in dark coniferous forests of the southern taiga done using such parameters as absolute value of the C biomass growth, specific annual production of wood and efficiency of assimilation apparatus work, has determined a few differences in the intensity of the NPP phytocenoses which differ from each other by the type of the main plant formation (with or without change of species).

The typical feature of the secondary birch forests is the high efficiency of the assimilation apparatus work (2-4 times) than in fir forests. The data analysis only for pure birch forests has determined the connection between the intensity of C organic matter production and C mass in leaves. The total specific production of the growing crop decreases with age: in birch forests from 5.4 down to 3.1%, in fir forests from 8.2 to 5.5%, making 2.7 % at age of 170 years.

**Keywords:** phytomass, carbon, NPP, dark coniferous, Western Siberia

### INTRODUCTION

The Siberian boreal forests are of the great importance comprise about 20% of the global forested area and their contribution into the global primary production is estimated to be 20%. Siberian ecosystems have the important role in the maintenance of structural balance between carbon organic substances. They have considerable ability to self regulation and to reach the steady state under current environmental conditions. The necessity of thorough investigation of Siberian forest ecosystems is connected both with considerable uncertainty in amount of these natural sinks of atmospheric carbon and contribution of processes responsible for the accomplishment of given function.

Atmosphere carbon accumulated by wood is stored there during long time compared to other ecosystem compounds and it plays an important role in estimating of carbon balance between atmosphere and ecosystems. In the result of realized studies the carbon stocks and NPP accumulated in compounds of phytomass were obtained for prevailing forest types typical of the given site growing conditions.

The study of the net primary production of the phytocenosis on separate tiers allows a deeper understanding of the interaction between stand and understory, undergrowth, herb-shrub and moss layers.

The main indicator of the efficiency of the autotrophic part of the phytocenosis is the primary production of organic matter (NPP). The study of phytomass production by different plant communities is of considerable interest as a basis for the assessment of complex energy links in ecosystems. This indicator characterizes the actual increment of phytomass (increase) for a certain period of time per unit area [1, 2].

## MATERIALS AND METHODOLOGY

The sub-zone of southern taiga is mainly represented by Siberian fir (*Abies sibirica*) as the dominant species in the primary forests. Apart from Siberian fir, the stands also include Siberian pine (*Pinus sibirica*), Siberian spruce (*Picea obovata*) and Siberian larch (*Larix sibirica*). As primary forests are greatly influenced by anthropogenic and natural disturbances (lightning fires, insect outbreaks), derivative birch and aspen woods are increasingly widespread in the researched area.

The data has been collected on the territory of Bolshemurtinskiy forestry district of the Krasnoyarsk region (Ket-Chyulymskiy forest site area) (N57°, E93°). The total forested square meterage of the district comprises of about 447 000 ha with almost half of that size covered by dark coniferous plant formations. The relative proportion of primary and derivative fir forests including stands formed by species succession is approximately marked by 60% of total forest land occupied by dark coniferous species. The dark coniferous stands are differentiated by the age classes as follows: young growth – 23 %, middle-aged – 18 %, ripening – 15 %, old-growth – 30 % and overmature – 14% of the area covered [3].

Located at the Chyulymskiy denudation plateau, the study area belongs to southern part of West Siberian Plain in accordance with recent terrain analysis. Climate is characterized by gradually harsh winter (average annual air temperature in January fluctuates between –18 –23°C) and relatively warm summer (July temperature varies between 14 and 17°C). Respectively, the average annual air temperature is ranging from –1,8 to 1,9°C. Number of days with temperature comprising > 10°C is 85–110 as well as accumulated air temperature for the whole period is 1200–1300°C. Frostless season lasts 65–85 days. Annual precipitation is 400–500 mm with May-August period distinguished by 200–240 mm [4].

Sample plots selected for studies specify two recovery lines for primary dark coniferous forests affected by anthropogenic activities. First line shows secondary succession without changes in species composition typical after final felling with measures taken to preserve coniferous undergrowth (50 and 90-year-old). At the same time, second line includes succession of primary vegetation with changes in species composition by means of derivative birch forests (60, 65 and 100 -year-old). Both succession lines are

accomplished with formation of primary dark coniferous stands normally represented in Southern taiga by multiple-aged pine-fir-spruce forest of herb-sedge meadow type used as a control unit (170-year-old). Basic inventory data obtained from researched stands is depicted in Table 1 [5, 6].

The superterranean phytomass in the canopy was calculated via regression equations evolved through 59 sample trees (spruce – 20 units, fir – 30 units and birch – 9 units). The content of total carbon in vegetation and soil samples for the further calculation of its stock was determined using the measuring complex PSCO/ISI IBM-PC 4250 which works based on diffusive reflection in the near IR- spectral region.

Table 1. Main characteristics of the sample plots

Stand age, years	Composition of stands, age (years)	Floor	Mean diameter, cm	Mean height, m	Basal area, m <sup>2</sup>	Stem volume, m <sup>3</sup>
Birch forests						
60	Betula (60 years)	I	18	24	16.9	184
	Picea, Abies, Pinus sibirica (25 years)	II	5	5	2.7	16
65	Betula (65 years)	I	20	25	20.7	243
	Picea, Abies, Pinus sibirica (35 years)	II	7	10	6.6	51
100	Betula and Pinus sibirica (100 years)	I	24	24	15.3	175
	Picea, Abies, Pinus sibirica, Betula (91 years)	II	17	17	15.7	170
Dark coniferous forests						
50	Abies and Picea (50 years)	I	8	9	18.0	107
90	Picea, Abies, Betula (91 years)	I	11	12	22.5	164
The indigenous forest type (control)						
170	Picea, Abies, Pinus sibirica, Betula (170 years)	I	44	33	18.2	275
	Picea, Abies (100 years)	II	16	16	7.0	62

Table 2. Carbon content in phytomass compounds, C %

Fractions	Forest stand			
	Fir	Spruce	Birch	
Wood	49.7	50.9	47.5	
Bark	54.1	54.9	54.0	
Twigs	51.9	52.2	50.0	
Dried twigs	50.8	52.3	-	
Annual needle	53.9	53.2	-	
Needles	53.5	53.2	51.01	
Annual growth	54.3	52.9	54.8	
Fractions	Understory			
	Fir	Birch	Aspen	Cedar
Twigs	53.6	49.5	53.4	48.5
Leaves	-	51.1	52.8	52.3
Annual growth	-	52.9	52.9	-
Stem wood	-	-	-	53.5
Bark	-	52.2	53.6	-
Roots	52.1	50.0	49.9	-

The mass carbon content in different ecosystems of Siberia has a small range of varying the values separately in the components of ecosystems. In southern taiga ecosystems the carbon content in the phytomass components of tree canopy varies within 48–55 %. The raised carbon content have bark and annual increment of branches: 53–55 %. Stem wood differs from other phytomass components in its lowest content - 48-51%. Carbon concentration in needle is 51-54%, in roots of a tree layer – 50-54%, in shrubs (leaves and stems) and grasses – 48-51%, in underground runners – 41-49%, green mosses – 41-43%. Carbon content in dead birch wood as far as it is decomposed varies slightly (47-48%), that one of dead conifer wood it is from 50 to 58%. Mean indices of carbon concentration in litters of birch stands makes from 43 to 45 %, in litters of fir forests it is from 44 to 49 % (Table 2).

## RESULTS AND DISCUSSIONS

The total carbon stock of phytomass in dark coniferous stands of the southern taiga of the South-Eastern part of Western Siberia varies from 75.8 to 129.0 t ha<sup>-1</sup> in derivatives of birch forests and from 48.9 to 110.5 t ha<sup>-1</sup> in fir forests (Table 3). The main part of the stock (94-97 %) forms a tree stand. In derivatives of birch forests, phytomass carbon is 37-57 % higher than in 50 - and 90-year-old fir forests, and 14% higher than in 170-year-old (control).

Table 3. Stock (tC/ha) и NPP (tC/ha per year) in derivative forest stand of Central Siberia

Type of formation of native vegetation/ stand age, years	Aboveground part						Underground part		
	stand	under-story	under-growth	moss-lichen	herb-shrub	Total	coarse roots	roots d< 1cm	Total
Birch forests									
60 Stock	72.6	1.9	0.3	0.1	0.9	75.8	11.6	5.3	17.7
NPP	4.0	0.1	0.1	0.1	0.6	4.8	0.9	0.1	1.3
65 Stock	106.1	1.8	0.1	0.0	1.8	109.7	16.9	7.1	25.8
NPP	5.2	0.1	0.0	0.0	1.0	6.3	1.1	0.2	2.0
100 Stock	125.4	2.6	0.1	0.2	0.8	129.0	18.3	6.2	25.3
NPP	3.9	0.1	0.0	0.1	0.6	4.7	0.7	0.2	1.1
Dark coniferous forests									
50 Stock	45.9	1.9	0.3	0.3	0.5	48.9	6.1	3.3	10.3
NPP	3.8	0.1	0.1	0.1	0.3	4.4	0.5	0.7	1.4
90 Stock	67.2	2.0	0.2	0.2	0.8	70.3	9.3	3.5	13.7
NPP	3.7	0.1	0.0	0.1	0.5	4.4	0.6	0.7	1.7
The indigenous forest type (control)									
170 Stock	107.5	0.9	0.1	0.6	1.4	110.5	13.3	11.1	25.6
NPP	2.9	0.0	0.0	0.2	0.9	4.1	0.5	0.5	1.5

Carbon accumulation in organic matter NPP is virtually independent of the type of formation of plants, their composition and age. In derivatives of birch forests it varies from 4.8–6.1 tC/ha per year in 60–65 years of age to 4.7 tC/ha per year in 100 years, in the fir forests is 4.1–4.4 tC/ha per year. Thus, the net production is 3 and 8 % of the total carbon stock of the phytocenosis, respectively, in the derivatives of birch forests and fir plantations.

The wood tier in the derivatives of birch trees forms annually from 3.9 to 5.2 tC/ha carbon of organic matter. This figure reaches a maximum value in the 65-year-old plant with the emerging second tier of spruce and fir (table. 3).

Birch participation in carbon storage to create NPP decreases with age from 92 % in 60-year - old stands to 52%-in 100-year-old (Fig. 1). Carbon in the total annual production is formed mainly by needles (leaves) – 38-41% and stem wood – 24-28 %.

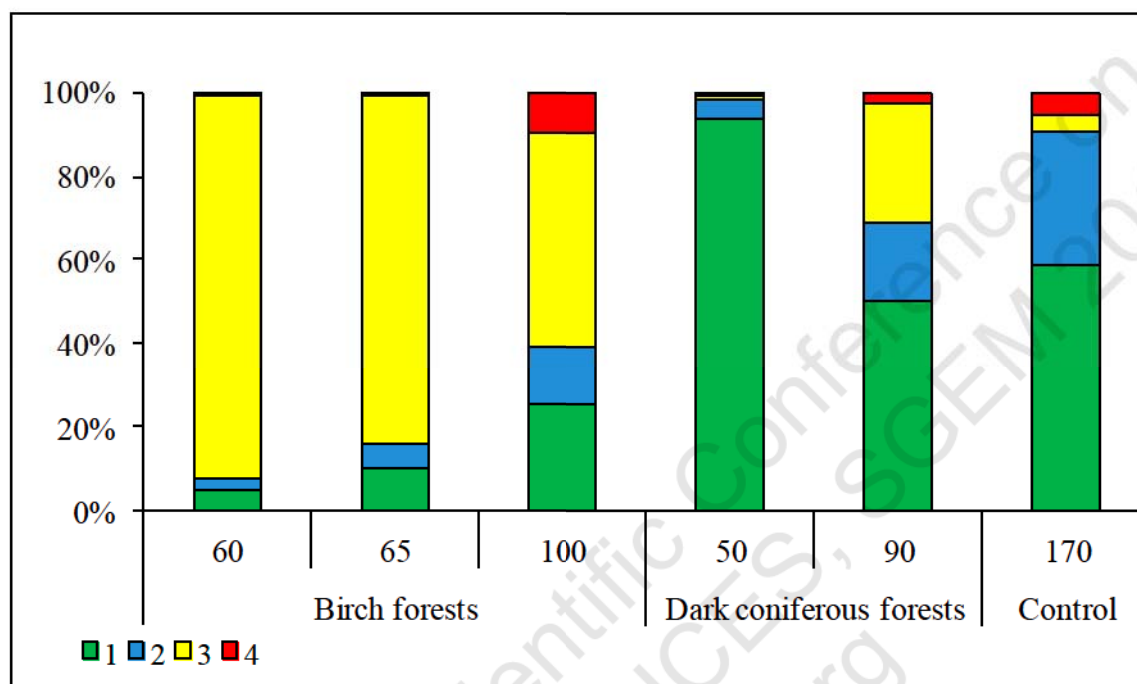


Figure 1. Distribution of annual carbon production of phytomass of stands by species. 1 – *Abies sibirica*, 2 – *Picea obovata*, 3 – *Betula pendula*, 4 – *Pinus sibirica*. Horizontal – stand age, years; vertical axis – percentage, %

Annual production of carbon from 50-and 90-year-old stands of fir-trees was 3.7-3.8 t/ha per year. The share of the main forest – forming species-firs in the NPP composition of the stand decreases from 93 to 51 % with age (Fig. 1). In General, the growth of organic mass equally involved needles (leaves) and wood trunks. The peculiarity of 170-year-old d, compared with high - 50-and 90-year-old fir-trees, is the predominance of the share of stem wood in annual production (36 %) compared with needles (29 %).

As the formation of the second layer of the coniferous species under the canopy of birch increases their contribution to the value of NPP c 8% in 60-year-old to 39% in 100 years of age (Fig. 1). In the indigenous fir-tree the second tier of 100-year-old fir almost in equal shares with the 170-year-old first tier is involved in the formation of net primary production.

In general, by the amount of carbon deposited annually by the wood tier, birch bark derivatives are 1.3–1.7 times higher than the fir trees, which are restored without changing the breed composition. These differences in the intensity of organic matter accumulation in annual growth can be explained by the biological characteristics of the predominant species (birch) in the composition of the plant, as well as the formation of a complex vertical and age structure of the forest stand.

Birch forests are characterized by higher efficiency of the assimilation part (2-4 times), despite the fact that the share of photosynthetic mass in the total carbon stock of



phytomass in them is much lower compared to 50 - and 90 - year – old fir-trees-4-7 and 12-17 %, respectively. The analysis of the data in table 4 shows that in most types there is no relationship between the intensity of organic matter production with the total reserves of phytomass, or with the reserves of above-ground phytomass; nor, most importantly, with the mass of assimilating bodies (for C). The exception is pure birch forests, where the proportion of birch leaves in the photosynthetic mass is 50-60 %. The reduction of the share of leaves to 12 % in a 100-year-old birch forest with a formed layer of coniferous trees breaks this connection. The calculation of the conditional indicator of " work " of the assimilation apparatus showed that in 60 - and 65-year-old birch forests 1 tonne of leaves (needles) produces carbon 1.48 and 1.27 tC/ha per year respectively, and in 100 – year-0.52 tC/ha per year.

Evaluation of effectiveness of formation of products of organic matter of the forest are most obvious when comparing the magnitude of the gain per unit stock biomass (specific annual production) (Table 4). Specific annual production of wood in 50-and 90-year fir plantations is 2 times (2.4–4.9 %) higher than in derivatives of birch (1.5-2.3 %).

Table 4. Carbon stock of phytomass (tC/ha) and NPP (tC/ha per year)

Characteristic	Type of formation of native vegetation					
	birch forests			dark coniferous forests		control
	60	65	100	50	90	170
Total phytomass	75.8	109.7	129.0	48.9	70.3	110.5
Overground phytomass	58.0	83.9	103.8	38.7	56.6	84.9
Mass of assimilators	3.2	5.0	9.0	7.7	8.1	6.8
NPP	4.8	6.3	4.7	4.4	4.4	4.1
$C_{NPP} / C_{\text{mass of assimilators}}$	1.5	1.3	0.5	0.6	0.5	0.6

In turn, the birch stands significantly exceed the specific productivity of the mass of assimilators of the fir, which is largely due to the biological characteristics of the species- edificators. Thus, as the share of dark coniferous plants in the composition of derived stands increases, the specific productivity of the mass of assimilators significantly decreases from 68 % in the 60-year-old to 19 % in the 100-year-old birch forest with the second tier of dark coniferous forests. Secondary fir plantations are characterized by higher specific productivity of branches and root systems, compared with birch forests. In general, the specific productivity of stands is independent of the type of formation of indigenous vegetation (with change and without change of species) with the age of planting decreases: in birch forests from 5.4 to 3.1, in fir forests from 8.2 to 5.5, reaching to 170-year age 2.7 %.

Total NPP in the study forest stands varies slightly, the average for the derivatives of the birch is 5.24 tC/ha per year and fir – 4.26 tC/ha per year. This suggests that in natural

conditions the ecosystem tends to a certain, stable value of the phytomass stock, which is achieved by a kind of compensation of total NPP due to different tiers of vegetation

## CONCLUSION

Estimation of NPP in the dark coniferous forest of Western Siberia has shown that despite the essential difference in the total carbon stock of phytomass (in the derivatives of secondary birch groves at 37-57 % higher than in 50 - and 90-year-old fir forest, and 14% higher than 170-year-old native spruce-fir forest), the total intensity of production of organic matter on average for birch (5.24 tC/ha per year) and fir (4.26 tC/ha per year) varies slightly.

In derivatives and indigenous plantings during the year in the process of photosynthesis accumulates, respectively, from 3 to 8 % of the total carbon stock of phytomass.

The analysis of the production process in the dark coniferous plantations of the southern taiga, carried out using such indicators as the absolute value of the increase in phytomass, specific annual production of wood and the efficiency of the assimilation apparatus, revealed a number of differences in the intensity of formation of NPP phytocenoses, differing in the type of formation of indigenous vegetation (with and without change of species). A characteristic feature of birch derivatives is a higher efficiency of the assimilation apparatus (2-4 times) than in the fir. The analysis of data for pure birch forests only found a connection between the intensity of carbon production of organic matter and the leaf mass. The total specific productivity of the stand with the age of planting is reduced: in birch forests from 5.4 to 3.1%, in fir forests - from 8.2 to 5.5, amounting to 170 years of age-2.7 %.

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