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Structure of the organic matter pool in *Pinus sibirica* dominated forests of Central Siberia

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Abstract

Organic matter pool and its distribution between growing stock, dead wood and windfall in upland and lowland *Pinus sibirica* dominated forests of Central Siberia (along the Yenisei River) is evaluated. The average growing stock is changing with advancing age from 163.9 ± 20.4 to 295.4 m^3 ha^{-1} thus reaching its maximum in the mature forests (337.0 ± 19.6 m^3 ha^{-1}). According to the data collected, stock variation coefficient numbers display acceptable (growing stock: 14–28%) and high variability (windfall and dead wood: 63–85%). Windfall prevails in the structure of coarse woody debris (CWD) from 130.8 ± 18.5 to 171.7 ± 20.1 m^3 ha^{-1}, with the stocks greatly exceeding the amount of growing wood stock in middle-aged and declining stands in 1.4 and 2.1 times, respectively. The observations comply with common trend of deterioration of dark coniferous forests in Siberia.

Key words

Siberian pine, stock, organic matter, growing stock, windfall, dead wood, coarse woody debris, dynamics, Siberian territories adjacent to Yenisei River, ZOTTO observatory

Introduction

Ecosystems of Central Siberia play critical part in keeping up carbon stock and flows on the planet. They are capable of managing autoregulation and achieving sustainable state in the present environment parameters (Vaganov et al. 2005) and climate change. Specification and high accuracy of estimation of the biological forest ecosystems potential in terms of organic matter accumulation and mineralisation require on-site field research. Windfall and dead wood have a great impact for several decades on (Storozhenko 2012) intensity and volume of the mineralisation fluxes from forest ecosystems to the atmosphere (Safonov et al. 2012). The studies are considered to be the state of the art because of the fact that the stock is tended to accumulate in the soil surface, thus stimulating fire hazards and fire intensity (Shvidenko et al. 2009). The main issues that caused the uncertainties in assessment and required further research are connected with the lack of knowledge in

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decomposition process, organic matter accumulation and estimation of relation between growing wood and coarse woody debris (CWD) structure and stock. CWD stock and dimensional structure depend on the growing stock composition, its age structure and the stock preceding the history of the woodland.

At the present moment, the data applicable to the territories of Russia on carbon cycle in the ecosystems of pine, larch and birch forests is obtained. The absence of carbon cycle parameters for dark coniferous forests with *Pinus sibirica* dominating has become a key factor of choosing the topic of studies. The research results related to phytomass (growing stock) and CWD stocks can be applied as a base values in monitoring process of natural and disturbed Siberian ecosystems and evaluating the ecosystems role in absorbing atmospheric carbon. The CWD in northern ecosystems appears to be the important source of carbon and nutrient release to the soil solution.

Siberian pine forests mostly act as main moisture storage with significant biosphere functions. Their age structure of pine stands is determined to be one of the key factors of forest sustainability to the disturbance influence (Kovalev 2002).

The research is aimed at defining structure and dynamics of the organic matter stock distribution between growing stock, dead wood and windfall in the undisturbed dark coniferous forest with Siberian pine prevailed. The research is committed to classify numerically the total balance of the organic matter stock establishing in the forest biocenosis in accordance with destructive process. The work represented describes the tendency of the accumulation of the wood complex destructive part in the primary forests of Central Siberia.

Material and methods

The study of organic matter pool in the *P. sibirica* stands was conducted within a radius of 100 km of the international observatory ZOTTO (Zotino Tall Tower Observatory http://research.sfu-kras.ru/labs/zotto/publications) located near Zotino village (Krasnoyarsk territory, 60° N, 89° E). The tall tower covers the measurement territory of deciduous, light and dark coniferous ecosystems in different landscapes. The taxation results are keyed in the Zotto Forest database (http://forest.sfu-kras.ru).

According to the Forestry Management Regulations (Forestry Management Regulations 2012), when the forest taxation is held in the natural habitat of the Siberian pine in all the age groups, pine forests are reported to be woodlands with prevailing pines share in the growing stock composition in amounts of three and more units. *P. sibirica* forests also include *Picea obovata, Abies sibirica*, *Populus tremula, Betula pendula* and *Larix gmelinii* with differentiating share in the stand composition according to the succession stage.

The analysis of satellite data (Klimchenko et al. 2011) identified 11 classes of aggregated land surface on the tall tower footprint. The analysis results showed that the forest area was about 84%. Dark coniferous communities were determined to occupy the largest area amongst other forest stand classes with *P. obovata* and *A. sibirica* dominating 46% and *P. sibirica* forests of about 2%, respectively.

The materials were collected via the method developed by Schulze E.-D. (2010), which had been acknowledged worldwide by scientific community and applied not only by foreign scientists (Gustafson et. al. 2011) but also by the Russian Forest Management System (State Forest Inventory of Russia, 2012). The circle sites (radius of 15 m) were used for taxation with forest inventory arranged on a selective basis. The sample plot was divided into three concentric circles with radius 3.5, 7.5 and 15.0 m. The growing stock inventory in the first circle was full, whereas the inventory in the second and third ones was selective. The minimal length in the tree girth of the first circle acceptable for inventory comprised 10 cm, the second circle was characterised by 30 cm tree girth and the third one ended up with 60 cm tree girth. The inventory process was directed to the North with identification of plant species, course, distance from the centre of sample plot to the certain tree, circle length at the 1.3 m height, height itself and disturbances observed. The full inventory of windfall and stubs broken down by species was organised on each sample plot in 7.5 m radius. Windfall was measured in terms of length and diameters of opposite ends as well as stubs were determined by height and two diameters: saw cut (or crack) and root crown altitude. CWD was divided into three decay classes based on the visual and physical properties (Mukhortova 2012; Klimchenko 2012). Dead wood was examined by altitude and diameter at 1.3 m height. The research work reflects CWD as the ground and terrestrial woody debris with diameter d greater than 1 cm in the thin end (Shvidenko 2009).

Owing to the Siberia forestry zoning pattern, Vorogovka river basin (right stream of the Yenisei river) relates to Bakhninsko-Velminsky district of the Central Siberian Plateau. *P. sibirica, A. sibirica* and *P. obovata* prevail in the vegetation cover but they are frequently replaced by *P. tremula* and *Betula pendula* after the fires (Pleshikov et al. 2002). The typologic base is represented by green-moss *P. sibirica* forests occupying drained watershed divide with favourable soil watering regime and bryophyte ones growing on the inside parts of the watersheds. Dark coniferous forest in the research area is distinguished by mixed type of growing stock.

Mountain and plain *P. sibirica* woodlands of Central Siberia are characterised by the hydro-moss type of the main burning conductors; therefore, these stands are distinguished by the greatest fire resistance. Wildfires occur in *P. sibirica* after 90–130 years as well as in *A. sibirica* after 70 years. The regular disturbances of the canopy cover caused by the wildfires affect the age structure of growing stock. The dark coniferous autochthonous communities recover after the wildfire through the long-term derivative change of main species that is why there are few young and middle-aged forests available. The stands observed are mainly represented by the final stages of the post-fire regeneration with advancing growing stock age of more than 130 years in *A. sibirica* and more than 160 years in *P. sibirica* (Klimchenko 2011).

Plots were classified by age groups as far as the *P. sibirica* age class was equal to 40 years. Age group distribution appeared to be 40–80 years for young forest, 81–120 years for middle-aged forest, 121–160 years for ripening forest, 161–200 years for mature timber, more than 200 years for old-growth forest.

The research work is committed to show the stock structure in the volume values (m^3 ha) as the transition into the weight values (t ha^{-1}, t C ha^{-1}) causes the additional error figure derived from the design ratio of wood density to the carbon stock concentration in the organic matter.

Results and discussions

Analysis of the taxation data showed that mature timber and declining stands dominate in the forest area (Tab. 1). Such an age structure is reported to be typical for dark coniferous forests of Central Siberia with forest recovery occurred under hardwood canopy.

Table 1. *Pínus sibírica* forests characteristics of the research of plots

Characteristic	Age group forests			
	middle-aged	ripening	exploitable	old-growth
Average age, years min max	103 97 110	140 131 157	179 161 197	218
Tree density (trees ha^{-1}) min max	2526 1609 3046	1260 396 1895	1459 452 2662	410
Total basal area (cm^2m^{-1}) min max	25.1 20.6 32.8	29.6 25.1 34.1	38.2 27.7 53.3	24.4
Mean diameter $D_{1.3}$(cm) min max	21.7 18.8 28.9	34.45 26.9 42.5	31.9 26.9 44.4	47.0
Mean height H (m) min max	15.5 14.6 16.9	20.5 19.6 21.91	20.9 17.2 26.9	28.0
Number of plots	5	3	10	1

The organic matter stocks accumulated in stems of growing stock and CWD in *P. sibirica* forests comprise 397–920 m^3 ha^{-1} (Tab. 2) with 35–68% exposed by CWD. CWD-located wood stock in the researched area varied from 173 to 625 m^3 ha^{-1}, that is, 55–212% of growing stock volume. Such differences are likely to be explained by growing stages of the stands.

As shown in Table 2, the organic matter stocks accumulated in stems of growing stock increased two times with aging from 163 m^3 ha^{-1} at the 102-year old (middle-aged forest) to 337 m^3 ha^{-1} at the 184-year old (mature forest). However, further ontological development reveals that growing stock has a tendency to decrease (13%), whereas CWD stock is greatly increasing. As soon as phytocoenosis is weakened by endogenic cause, certain part of trees is decayed with further transition to dead wood and windfall. This process is considered to enhance active phytomass organic matter transfer to wood debris.

Table 2. Distribution of organic matter stock in terms of the age group forests

Age group (number of plots)	Average age, years	Stock, m^3 ha^{-1}			Windfall/dead-wood % of growing-stock
		growing-stock	windfall	dead-wood	
Middle-aged (n = 5)	103	163.9 ± 20.4	171.7 ± 20.1	63.8 ± 21.8	105/39
min		102.2	130.5	8	
max		229.3	247.5	121.4	
V, %		28	26	76	
Ripening (n = 3)	150	319.5 ± 39.6	123.4 ± 36.4	50.6 ± 9.9	39/16
min		213.2	113.5	17.0	
max		300.5	250.6	77.6	
V, %		14	56	63	
Mature (n = 10)	184	337.0 ± 19.6	130.8 ± 18.5	61.4 ± 16.6	39/18
min		217.8	30.3	11.1	
max		451.2	274.8	177.2	
V, %		18	45	85	
Old-growth (n = 1)	218	295.4	590.8	35.4	200/12

± standard error.

During the increase in age, it is appeared that the total stock (CWD + growing stock) is rising 2.3 times, reaching its maximum level in old-growth forest. But the role of CWD and growing stock in establishing total organic matter stock in ecosystems is changing rapidly in accordance with dynamic biogeocoenosis indicators. Ripening and mature forests in successional stage hold the CWD stock that is 1.8 times lower than growing stock value. This illustrates that the processes of accumulation, decay and decomposition of organic matter are balanced. It should be noted that CWD stock in middle-aged and old-growth forests exceeds growing stock in 1.4 and 2.1 times, respectively, thus showing available degradation processes related to consolidation of competitive relations between certain trees of different age groups. There is also a tendency of certain old-growth trees degradation by means of insect pests' hazard. Trees disturbance comprises 50–80% within the framework of age generations.

Trees depreciation and dead wood formation in *P. sibirica* forests occur with similar characteristics. Its stock does not change greatly from 50 to 63 m^3 ha^{-1} up to 184-year-old stands, whereas its stock is dropped abruptly up to 35 m^3 ha^{-1} in 218-year-old stands.

Windfall debris is evolved from current litter and accidentally overaged wood (storm and snow damage, etc.) from other category of growing stock. But we should not deny the fact that CWD pool at the first stages of successional development may be partially inherited from initial growing stock burnt down by forest fires. Depending on the species and typological terms, such CWD is tended to preserve on the soil surface in upper canopy layer for up to 70 years (Storozhenko 2012). As represented in Table 2, the research objects are characterised by remarkable windfall stock ranging from 123 to 590 m^3 ha^{-1} with its value exceeding growing stock at different age stages.

The current research was not supposed to identify the reasons for phytodetritus heavy stock but its results fully comply with the already published data on phytomass and phytodetritus stock in the dark coniferous forests of Central Siberia (Vedrova and Koshurnikova 2007; Vedrova 2011) and support the concept of the dark coniferous forest degradation worldwide (Pavlov et al. 2008). Overall, significant values of CWD stock may be partially explained by the fact that *P. sibirica* forests types mainly occupy drained watershed divides with favourable soil watering regime where dead wood is greatly scattered because of the lack of severe fires.

Dynamics of CWD stock distribution is showcased via U-curved line in the literature data. In Figure 1, CWD stock distribution in pine forests of Central (along the Yenisei river) Siberia has fragmental features with advancing age, as there are no plots with young forests represented.

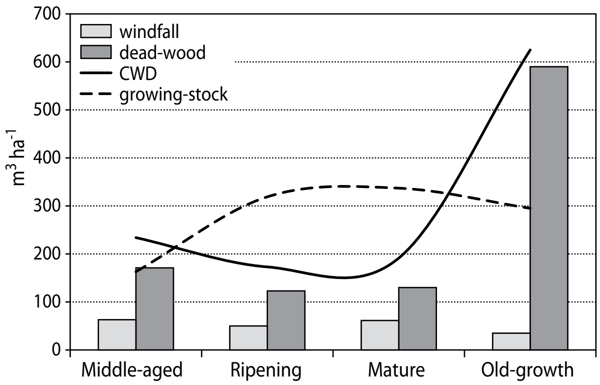

Figure 1. Structure of the organic matter stock in the age-group forests

By comparing the results obtained with literature data, it is obvious that growing stock and windfall values in ripening and mature timber are included in the range of absolute and relative numbers calculated for dark coniferous forests of taiga zone of the Russian Plain (Storozhenko 2012). Although the dead wood stock is a little bit higher, it correlates with the range of values elaborated by Safonov et al. (2012) for southern taiga spruce (31.8–208.1 m^3 ha^{-1}).

The statistical analysis of the collected data showed the allowable variation of growing stock (14–28%) and great variability of dead wood (63–85%). If the comparison is made with already published data, the coefficient of variation for CWD and growing wood stock is 25% and 45%, respectively, in Kamchatka spruce forests. The coefficient of variation for windfall stock constitutes 31% in the dark coniferous forests along the Yenisei river basin divide (Klimchenko and Verkhovets 2012). Shvidenko et al. (2009), Kapitsa et al. (2012) and Tetyukhin et al. (2012) repeatedly reported about the significant variability of CWD stock within the relatively homogeneous formations, thus obstructing the distribution of estimations obtained for certain geobiocoenosis at the landscape and regional level and showing the necessity for further research. For example, 110-year-old spruce forest in the Novgorod region (Safonov et al. 2012) demonstrated the great dynamics in changing the organic matter stock structure in the long term. Three years of observations revealed that the growing wood stock had been decreased for 38% (from 571.6 to 352.2 m^3 ha^{-1}) as well as CWD stock had been increased 2.9 times (from 101.7 to 292.5 m^3 ha^{-1}).

Conclusions

The total stock of organic matter accumulated in stemmed part of growing trees, dead wood and windfall tends to vary from 397 to 920 m^3 ha^{-1} in accordance with successional stage of stands development where 35–68% share is occupied by CWD. Middle-aged and old-growth forests are characterised by large CWD stock that exceeds growing stock 1.4 and 2.1 times, respectively. It enables us to detect the available degradation related to competition enhancement between certain trees of different age groups. Taking into consideration successional process of growing stock and organic matter development prior to its decay (old growth), it is found that plant competition has a great impact on CWD pool establishment at the first stages. The older is growing stock, the more crucial influence is exerted by wood – destroying fungus in this process.

The evaluation of biological role of forest ecosystems pertaining to atmospheric CO_2 is considered to be scientifically significant and still actual worldwide. By extending the research area in organic matter stock and structure, it is possible to obtain statistically correct data in terms of its species and age structure. The results collected are reported to contribute to database consolidation and calculation of carbon fluxes and stock dynamics in different types of ecosystems at regional and global scales in conditions of current climate changes.

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