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Carbon stock in grass cover of forests with different severity of stem pest-related stand weakening in the southern taiga zone of Western Siberia

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Abstract

The paper addresses the study of dark coniferous forests of the southern taiga, which were analyzed with regard to severity of stand weakening caused by stem pests, up to stand death. To assess the carbon stock of grass cover, the mass fraction of carbon in grass species and the aboveground mass of grass were measured. The carbon stock of grass cover was shown to vary during the change in its main microgroups caused by stand weakening. The carbon content in grass species abundant in different grass microgroups exhibits a narrow range of variation of 33.4–44.7 %, with an average of 41.1±0.9 %. The amount of carbon stored in the grass cover of dark coniferous forests in uplands ranges from 16.2 to 32.9 gC/m^2. It was revealed that in weakened stands, the grass cover stores 2–5 fold more carbon due to an increase in grass biomass. Considering that most of the grass carbon released to the atmosphere within a year, the efficiency of carbon sink in forest areas with dead stands becomes lower, despite an increase in grass mass, compared to forest areas where the stands are not damaged by stem pests.

Keywords

Grass, carbon content, southern taiga subzone, dark coniferous forests, carbon stock in grass biomass

Introduction

At present, considerable attention is being directed towards the assessment of carbon sequestration potential of ecosystems (Steenberg et al. 2023; Trentin et al. 2023; Hasegawa et al. 2024). In Russia, the main carbon storages are wetlands and forests (Alekseev, Birdsey 1994). Forest carbon stocks have been estimated for the country as a whole and for individual regions (Bazilevich 1993; Alekseev, Birdsey 1994; Zamolodchikov et al. 2018), and for localities (Koshurnikova and Verkhovets 2011; Osipov et al. 2019). The estimation includes not only primary forests, but also forests at different stages of post-fire and post-logging regeneration, since the capacity of ecosystems to long-term sequester carbon depends on successional dynamics of ecosystems (Vedrova 2011; Lukina 2018). In some cases, carbon sequestration may increase over time. In other cases, on the contrary, it may decrease. Some forests may reach an equilibrium where sequestration equals emission. In addition, the ratio of the carbon pool of the forest ecosystem components changes at different stages of successional dynamics (Vedrova et al. 2018b; Likhanova and Bobkova 2019; Lukina et al. 2023).

Grass cover is not among the forest components associated with the main carbon fluxes in forest ecosystems (live and dead wood, litter, soil). Unlike wood and soil, which store significantly larger amounts of carbon, grass cover is not always taken into account when assessing the carbon storages of ecosystems (Zamolodchikov et al. 2018). However, in communities with damaged stands (different types of clearcuts), the role of the grass cover in carbon storage in aboveground biomass increases (Koshurnikova and Verkhovets 2011; Osipov et al. 2019). In addition to logging and fires, the southern taiga zone of Western Siberia has also seen mass drying of forest stands in the last 10–15 years due to stem pest outbreaks (Krivets et al. 2015). This process is underway and affecting new regions (Krivets et al. 2024). The analysis of transformation of dark coniferous forests in the outbreak foci of *Polygraphus proximus* Blandford revealed significant variations in the natural carbon cycle, which affect the main carbon pools (wood and soil) (Kerchev et al. 2024).

The aim of this study was to assess the carbon stock of grass cover in forests with different degrees of damage caused by dendrophages.

Materials and methods

The study area is located in the southern part of Western Siberia, in close proximity to the southern border of the Tomsk Region. The geographical coordinates are as follows: 56°12´43´´N, 85°02´20´´E. The terrain is gently sloping and dissected by ravines and gullies. It is composed of loess-like carbonate loams on the surface. The climate is cold and moderately continental. The mean monthly temperature is -18 °C in January and 18 °C in July. The radiation balance is positive and amounts to 20–25 kcal/cm^2 per year. The duration of the frost-free period is almost three months (115 days). The sum of temperatures above 10 °C is 1750–1780°. The annual precipitation is 600–650 mm. The precipitation level exceeds the evaporation rate by about 100 mm (Kremenetski et al. 2003).

This region represents the southern extent of the forest zone, where hemiboreal forests are widespread, both birch-aspen and dark coniferous. Uplands are occupied by dark coniferous forests with a predominance of fir (Gorozhankina and Konstantinov 1978), which belong to the order Carici macrourae–Abietetalia sibiricae Lashchinskiy et Korolyuk 2016 of the class Asaro europaei–Abietetea sibiricae Ermakov, Mucina et Zhitlukhina 2016 (Lashchinsky and Korolyuk 2016), that unites plain dark coniferous hemiboreal forests. Under the canopy of dark coniferous tree species the shrub layer is not dense, the grass cover is well developed, multi-species, with the dominance of *Carex macroura*, the moss cover is poorly developed.

About 10–15 years ago, an outbreak of *Polygraphus proximus*, the stem pest of fir, was observed in dark coniferous forests in the southern part of Western Siberia (Krivets et al. 2015). The state (vitality) of a fir tree after attacks by a dendropage, expressed in changes in various tree parameters, including canopy density, is assessed on a scale containing six categories from I – a healthy tree, to VI – a dead tree (Krivets et al. 2015; Kerchev et al. 2024). A change in the stand state results in a corresponding change in the understory, including the grass cover. A botanical description of forest areas at different stages of stand weakening has been carried out. At each stage of stand weakening (insignificant weakened, severely weakened, dead) a certain microgroup of the grass cover is formed, its main parameters are given in the table (Table 1).

The microgroup dominated by *Carex macroura* (CX) is restricted to insignificantly weakened stands with medium canopy density, and a short grass microgroup (OX) is confined to stands with high canopy density, including dense biogroups of fir undergrowth. A mixed microgroup dominated by *Aegopodium podagraria* (AEG) is formed in severely weakened stands with lower canopy density. In dead stands with minimal canopy density, a tall grass microgroup dominated by *Aegopodium podagraria* (H-AEG) or *Urtica dioica* (H-URT) is formed. The nomenclature of vascular plant species is presented in accordance with the species list (Summary of Siberian Flora 2005). In general, the deterioration of the vitality of firs in the stand is accompanied by an improvement in the degree of development of the grass cover: an increase in abundance (projective cover), and height, and biomass (Table 1).

In the areas of different microgroups of grass cover, 100*100 cm plots were selected to estimate the biomass. The aboveground shoots from each plot were harvested, sorted by species, dried, and weighed under standard laboratory conditions. In total, 14 plots were taken in OX microgroup, 21 plots – in CX microgroup, 17 plots – in AEG microgroup, 6 plots – in H-AEG microgroup, and 10 plots – in H-URT microgroup.

The grass cover of the studied forests is species-rich. There are 25–39 grass species on an area of botanical description, which is 400 m^2 (Lashchinsky and Korolyuk 2015). We have encountered 117 grass species on mass assessment plots, from 3–5 to 25–30 species on a 1 m^2 plot. A total of 12 grass species, the most abundant in terms of cover and biomass across different microgroups, were subjected to chemical analysis. The total cover of the selected species in grass microgroups represents 60–70% of the total grass cover, and their total biomass accounts for 65–80% of the total aboveground biomass. Samples were taken from the mass of aboveground shoots (3–7 for each of the 12 selected grass species) to assess the mass fraction of carbon. In addition, mixed samples were prepared for each of the grass microgroups, with aboveground shoots of different species mixed in proportion to the species biomass in the total biomass of the microgroup (3 samples for each microgroup).

Carbon in the plant samples was determined using the EMA502 elemental analyzer CHNS (VELP, Italy).

Table 1. The main grass microgroups under the variously weakened stands in dark coniferous forests of the southern taiga zone of Western Siberia

Characteristics of forest stands (vitality and canopy density*)	Characteristics of grass cover				
	Microgroup	Coverage, %	Height, cm	Most abundant grass species	Mass, g/m^2
Insignificantly weakened stand: groups of healthy and almost healthy dark coniferous trees (I–II; 0.8–0.9); biogroups of fir undergrowth (0.8–1.0)	Short grasses OX	15–25 to 80	5–7 (10)	*Oxalis acetosella*, with occurrence of *Dryopteris expansa*, forbs (*Aegopodium podagraria*, *Equisetum pratense*, etc.), short grasses	25–60
Insignificantly weakened stand: groups of healthy and almost healthy dark coniferous trees (I–II; 0.5–0.7)	Sedge grasses CX	50–75	15–30	*Carex macroura*, with occurrence of forbs (*Aegopodium podagraria*, *Rubus saxatilis*, *Equisetum pratense*, etc.) and short grasses (*Oxalis acetosella*, *Cruciata krylovii*, etc.)	40–110
Severely weakened stand: groups of healthy and drying dark coniferous trees (II–IV; 0.4–0.6); small gaps	Forbs AEG	70–95	40–70	*Aegopodium podagraria*, *Equisetum pratense*, *E. sylvaticum*, *Rubus saxatilis* with occurrence of tall grasses (*Aconitum septentrionale*, *Urtica dioica*, etc.)	80–150
Dead stands: groups of dry trees and large gaps (V–VI; 0.1 and below)	Tall grasses (H-AEG), Nettle (H-URT)	95–100	120–130 (150)	*Urtica dioica*, *Aconitum septentrionale*, *Aegopodium podagraria*, with occurrence of tall grasses and forbs	130–400

Note. * – vitality categories are shown in Roman numerals; canopy density is expressed in Arabic numerals as fraction of one.

The amount of carbon for each of 12 species with assessed carbon content was calculated by multiplying the mass fraction of carbon by species mass. For the remaining grass species, the average value of the mass fraction of carbon in the 12 estimated species was used. The total amount of carbon for each plot was calculated as the sum of the amounts of carbon of its constituent species. Basic statistical parameters (mean, mean error) were calculated using EXCEL MS and PAST (Hammer et al. 2001).

Results

Table 2 summarizes data on the carbon content in grass species of dark coniferous forests in the southern taiga of Western Siberia.

Table 2. Carbon content in the most abundant grass species of dark coniferous southern taiga forests

Species	Mass fraction of carbon on average, %	Proportion of the species in grass microgroups				
		OX	CX	AEG	H-AEG	H-URT
Oxalis acetosella	**43.1±0.3**	+++	++	++	+	+
Cruciata krylovii	**41.5±0.9**	+	++	++	++	++
Stellaria bungeana	**39.1±0.8**	+	+	++	+	+
Carex macroura	**43.3±1.3**	+	+++	++	+	+
Rubus saxatilis	**43.6±0.3**	+	++	++	++	+
Dryopteris expansa	**44.7±1.3**	++	+	++	++	+
Aegopodium podagraria	**41.4±0.4**	+	++	+++	+++	++
Equisetum pratense	**33.4±0.4**	+	++	+	++	+
Equisetum sylvaticum	**38.6±0.9**	+	+	++	+	+
Milium effusum	**42.4±0.8**	+	+	+	++	++
Aconitum septentrionale	**42.0±0.3**	+	+	+	++	++
Urtica dioica	**40.5±0.8**	+	+	++	++	+++
	Mass fraction of carbon on average, %	**42.9±0.1**	**42.2±0.1**	**42.1±0.2**	**40.7±0.1**	**41.7±0.2**

Note. Proportion of the species in different grass microgroups: + indicates up to 5%, ++ indicates 5–15%, and +++ indicates more than 15% of the projective cover.

All the selected grass species are found in stands with different damage severity, but their abundance varies. The values of mass fraction of carbon obtained for the 12 grass species vary within a narrow range of 33.4–44.7 %, despite the different structure of the aboveground shoots. The carbon content is 41.1±0.9 on average (mean ± error of mean). The carbon content values for mixed samples from each grass microgroup are close to the mean value for individual grass species. With regard to similar carbon content values observed in the abundant grass species and the grass microgroups, we consider it acceptable to use the mean carbon content of the 12 abundant species studied or the mean carbon content of the corresponding microgroup when calculating the carbon content of the remaining less abundant species.

Due to the relatively narrow range of variation in the mass fraction of carbon in grass species, the amount of carbon stored by the grass cover is proportional to its accumulated biomass (Fig. 1).

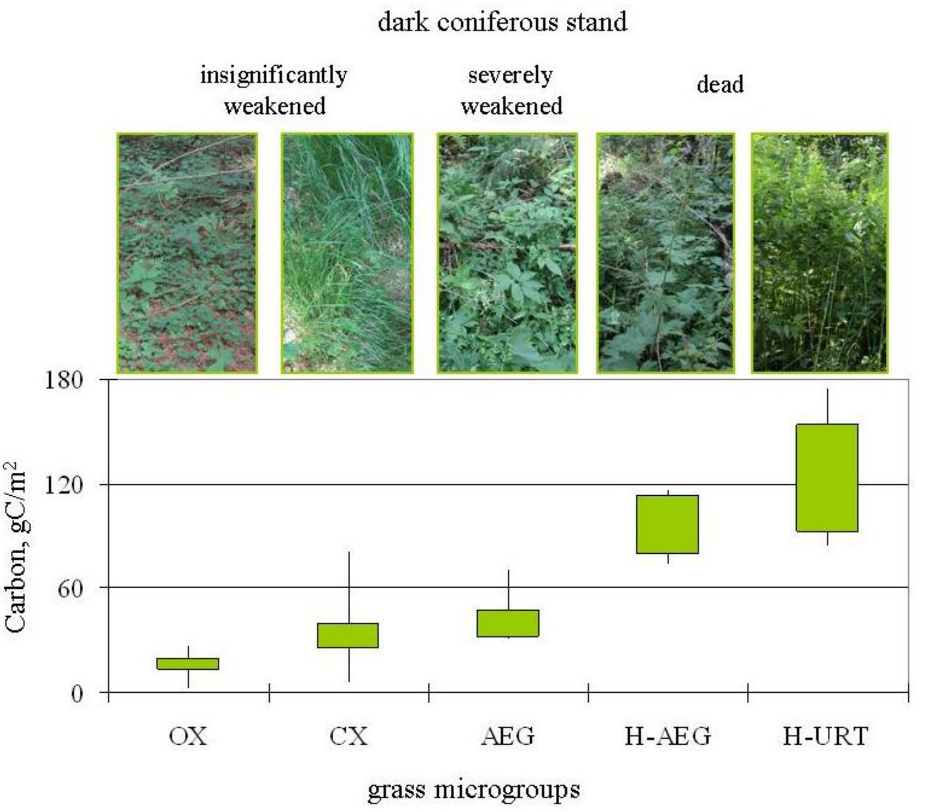

Figure 1. Carbon accumulated by the grass cover in dark coniferous forests with different severity of stem pest damage. The abbreviations for the grass microgroups are the same as in the text and in Table 1.

At an early stage or at the stage of insignificant forest damage, when the predominant microgroups are CX and OX, the grass cover stores a minimal amount of carbon: 16.2±1.7 gC/m^2 – in OX microgroup, and 32.9±3.3 gC/m^2 – in CX microgroup. As forest damage severity increases, the amount of carbon accumulated by grass species increases along with the total grass biomass. In severely weakened stands (AEG), the grass biomass and the amount of carbon stored by the grass cover are 1.3–2.5 fold higher. The maximum values are recorded in dead stands (98.3±7.0 gC/m^2 in H-AEG microgroup, 121.8±10.5 gC/m^2 in H-URT microgroup), where the grass biomass and the amount of stored carbon are 3–5 fold higher compared to those recorded in insignificantly weakened stands.

Discussion

The carbon content in grass species from the studied southern taiga forests (41.1±0.9) is close to similar estimates from other regions (42.0±0.8 for grasses of middle taiga pine and spruce forests of Komi (Bobkova and Tuzhilkina 2001); 43.5±0.6 for grasses of middle taiga deciduous forests of Komi (Pristova 2022); 41.7±1.5 for grasses of northern taiga spruce and birch forests of Komi (Pristova et al. 2018)), although other species were also analyzed. The range of values of the carbon content obtained for individual species is generally the same (39–46 %) (Pristova et al. 2018; Pristova 2022). Similar values of the carbon content are found for bog species (41–45(48) % (Kozlovskaya et al. 1978; Golovatskaya and Nikonova 2013)). Among the ground cover plants, except for grasses, the carbon content values of both forest and bog bryophyte species vary within the same range (39–46 %) (Kozlovskaya et al. 1978; Bobkova and Tuzhilkina 2001; Golovatskaya and Nikonova 2013; Pristova et al. 2018; Pristova 2022).

In contrast to grasses, dwarf shrubs (Kozlovskaya et al. 1978; Bobkova and Tuzhilkina 2001; Golovatskaya and Nikonova 2013; Pristova et al. 2018; Pristova 2022) and woody plants (Bobkova and Tuzhilkina 2001; Kerchev et al. 2024) exhibit a higher carbon content (47–53 % and 47–51 %, respectively), which is due to chemical composition restructuring during lignification (Kobak 1988). However, this is not the case for herbaceous(grass) species.

In addition to a narrow range of variation in the carbon content of individual plant species, the total grass biomass and the amount of accumulated carbon differ in forests formed under different bioclimatic conditions. As reported in (Alekseev, Birdsey 1994), the ground cover biomass is observed to decrease from the northern taiga subzone to the southern taiga. This is probably due to the fact that in the northern part, the ground cover consists of dwarf shrubs and mosses who have perennial aboveground shoots and accumulate its biomass over several years. Conversely, in the southern part, it consists mainly of grasses with aboveground shoots that die off at the end of the growing season and then grow again. The proportion of the grass biomass is different compared to other forest components, which exhibit no consistent response to different bioclimatic conditions. For example, as the ground cover biomass decreases from north to south, the tree layer biomass increases (Bazilevich 1993). Therefore, the proportion of grass cover compared to tree cover, and the proportion of carbon stored in grass cover respectively, is lowest in the southern taiga forests.

Changes in the grass cover under the canopy of the forest stand weakened by dendrophages exhibit common features with the pattern of such changes in gap dynamics (Dyukarev et al. 2022) and post-logging and post-fire regeneration (Khramov and Valutskiy 1977; Osipov et al. 2019). However, these changes occur in a reversed sequence due to gradual weakening of the tree layer (over several years), and not rapid (several days) as in the case of felling, fire.

The grass cover in the weakened stand is similar to that under the canopy of deciduous trees (birch, aspen) in the secondary stand. In both cases, the grass biomass (and stored carbon) increases 1.5–2.5 fold due to increased abundance of forbs and tall grasses (Aegopodium podagraria, Aconitum septentrionale, etc.) (from 48.8 g/m^2 in grass and dwarf shrub cover under dark coniferous canopy to 119.6 g/m^2 in grass and dwarf shrub cover under deciduous canopy (Khramov and Valutskiy 1977); from 136 gC/m^2 in grass and dwarf shrub cover under dark coniferous canopy to 178 gC/m^2 in grass and dwarf shrub cover under deciduous canopy (Koshurnikova and Verkhovets 2011); from 10–80 g/m^2 in grass cover under dark coniferous canopy to 130–210 g/m^2 in grass cover under deciduous canopy (Dyukarev et al. 2022)). The maximum values of the grass biomass are recorded in dead stands (310 g/m^2 in grass cover in sites with fallen trees (Dyukarev et al. 2022)).

All in all, the reduction in the carbon accumulating capacity of the dark coniferous forest stand caused by its damage and subsequent death is accompanied by increased carbon accumulating capacity of the grass cover. However, unlike trees, which sequester carbon for a long time, the aboveground shoots of grasses die off annually. The grass carbon can be stored in soil for a certain period of time, but the efficiency of soil carbon accumulation is low, since litter decomposition releases a large amount of carbon (90–94 % (Kobak 1988); 94–96 % (Vedrova et al. 2018a)) which is returned to the atmosphere. Thus, after the death of stand, forest ecosystems retain the previously stored carbon in slowly decomposing dead wood, as well as in the soil (Kerchev et al. 2024), but their carbon sink efficiency decreases, because the majority of living aboveground shoots is represented by herbaceous (grass) species.

Conclusion

The mass fraction of carbon in different grass species of dark coniferous forests in the southern taiga zone of Western Siberia varies within a narrow range of 33.4–44.7 %, with an average of 41.1±0.9 %. Moreover, the mass fraction of carbon in grass species, abundant at different stages of weakening of the forest stand by stem pest, has similar values, therefore the amount of carbon stored by grasses changes proportionally to the total mass of the grass cover as the stand is weakened. The carbon stocks of the grass cover under insignificantly weakened stand range from 16.2±1.7 gC/m^2 to 32.9±3.3 gC/m^2. As the dark coniferous stand further weakened by dendrophages, the amount of carbon stored by grasses increases – 1.3–2.5 fold in the severely weakened stand and 3–5 fold in the dead stand, reaching maximum values of 121.8±10.5 gC/m^2. Due to the peculiarities of the life form of grasses – most of the carbon they store is released in the same year, returning to the atmosphere – the efficiency of carbon sink in forest areas with dead forest stands is less than in areas with living forest stands.

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