

Climate Trends and Average Increase in Aspen Forests Carbon Stock in Siberia According to Forest Inventory Data [†]

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Abstract: Aspen trees (*Populus tremula* L., 1753) are native to the boreal region of Siberia. These species' fast growth and ability to regrow from root suckers mean it is promising to create carbon farms using aspen trees for an efficient atmospheric carbon sequestration. This paper presents the findings in research focusing on studying the dynamics of aspen forests growth and condition in changing climate according to forest inventory conducted in 1972, 1982, 2002 and partially 2021. The research was carried out in aspen stands growing in the Central Siberian subtaiga forest-steppe ecoregion. From 1982 to 2002, there was a steady trend towards increasing growing season temperature sum. At the same time, the amount of precipitation in the same season and period did not exceed the median value. With an increase in temperature sum in 1982–2002 from 1800°C to 2100°C, the average forest carbon stock increased from 0.56 to 1.48 tonnes of carbon per hectare per year. The statement is true for pure aspen forests aged 10 to 30 years. A drastic decrease in the carbon sequestration potential was observed in aspen stands from the age of 40. After 55 years, the average increase in aspen forests carbon stock leveled off, and the differences became insignificant. Along with age-related increasing biomass growth rates in aspen forests, natural and pathological dieback led to reduction in resilience and wood loss. Aspen is characterized by rapid early growth rates, which allows using aspen forests sequestration potential to achieve effective carbon conservation.

Keywords: climate trends, carbon stock, Aspen trees, boreal region of Siberia

1. Introduction

Nowadays, there are climate changes that have a global impact on forest ecosystems [1]. Global warming changes carbon sequestration dynamics in forest ecosystems [2–6]. Climate change-induced consequences occurring in the forest sector pose certain economic and social threats [7] and reveal the need to develop a set of adaptation measures for the forest sector [8].

2. Materials and Methods

The study was conducted in reference aspen stands growing in the Karaul'noe forest management unit of the Educational and Experimental Forestry of the Reshetnev University located in the suburbs of Krasnoyarsk (Figure 1).

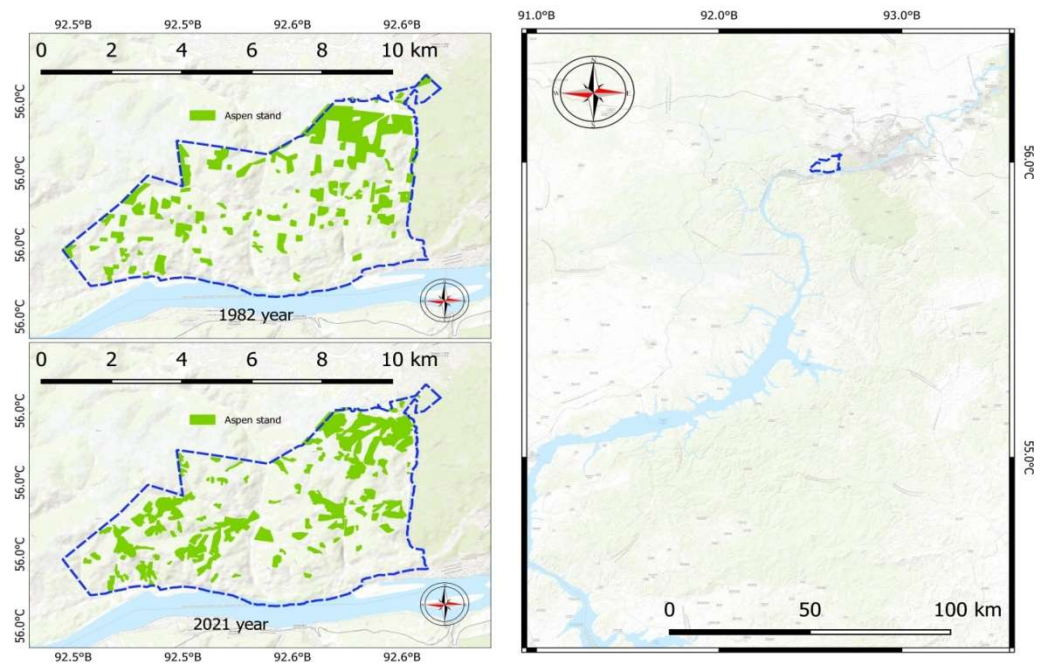


Figure 1. Map showing the location and outline of the study area (right side of the map) and dynamics of the aspen forests area according to 1982 to 2021 data.

Aspen forests are characterized by rapid increment during early growth, which allows implementing forest carbon sequestration to the maximum extent.

The research was based on the mass forest inventory data of 1972, 1977, 2002 and partially 2021. We selected the forest inventory data on aspen-dominated stands (pure and mixed). There were 84 forest stands. All of them, regardless of the inventory period, were characterized by a standard set of inventory indicators, including age, average height, average diameter, forest type, growing stock, etc.

Field study was carried out in the form of forest pathological inspection according to generally accepted methods [9,10]: forest reconnaissance survey and detailed survey. During the reconnaissance survey, a visual assessment of the aspen forests condition was made within forest compartments of at least 1.5 ha. A detailed survey was carried out on four research plots (RP) placed in typical tall-herbs aspen forests (Table 1). Trees (130-180 trees on each research plot) were divided into classes according to their condition: 1 - with no signs of weakening; 2 - weakened; 3 - severely weakened; 4 - dying; 5 - dead (lost viability): current-year and old deadwood, windthrow, windsnap. Tree condition was determined mainly by the tree crown assessment and other diagnostic features. Determining a set of specific and indirect signs, we also identified insects and diseases affecting trees. So-called balance approach was used as a methodological basis for calculating the forest carbon budget. Aspen forests were reference, their density varied from 0.4 to 0.8, rarely 0.9; bonitet class II-III; aspen share in the stand composition was from 4 to 10 units. High variety of aspen stands characteristics led to a high variability of the average growth rate values. Such growth differentiation is important when assessing the response of forest stands to temporal climatic trends.

Table 1. Natural and pathogens-induced loss of biomass and carbon in aspen stands.

Age, years	M, m ³ (total)	Natural loss				Pathogenic loss			
		%	stock, m ³ *ha ⁻¹	phytomass, tm ³ *ha ⁻¹	carbon, tC*ha ⁻¹	%	stock, m ³ *ha ⁻¹	phytomass, tm ³ *ha ⁻¹	carbon, tC*ha ⁻¹
50	179	3	5.4	3.59	1.20	5	9.0	5.99	2.01
55	192	3	5.8	4.20	1.41	5	9.6	7.01	2.35
60	204	5	10.2	7.45	2.49	10	20.4	14.89	4.99
65	216	5	10.8	7.88	2.64	10	21.6	15.77	5.28
70	227	10	22.7	16.57	5.55	15	34.1	24.86	8.33
75	237	10	23.7	17.30	5.80	15	35.6	25.95	8.69
80	247	15	37.1	27.05	9.06	20	49.4	36.06	12.08

The initial data was sorted by the share of aspen in a stand composition, then the average increase in growing stock was calculated depending on the coefficient of aspen share in a stand composition.

When studying climate trends, we used indicators reflecting the following growing season characteristics: the sum of temperatures above five degrees ($t > +50$) and the amount of precipitation for the studied period (1982-2020). The analysis was based on indicators obtained from the NASA POWER portal (<https://power.larc.nasa.gov>). The following data were added to the graphs to display the trend (Figure 2): median lines, the indicator for the entire observation period (red horizontal line), and a loess-type smoothing line with a confidence interval (blue line).

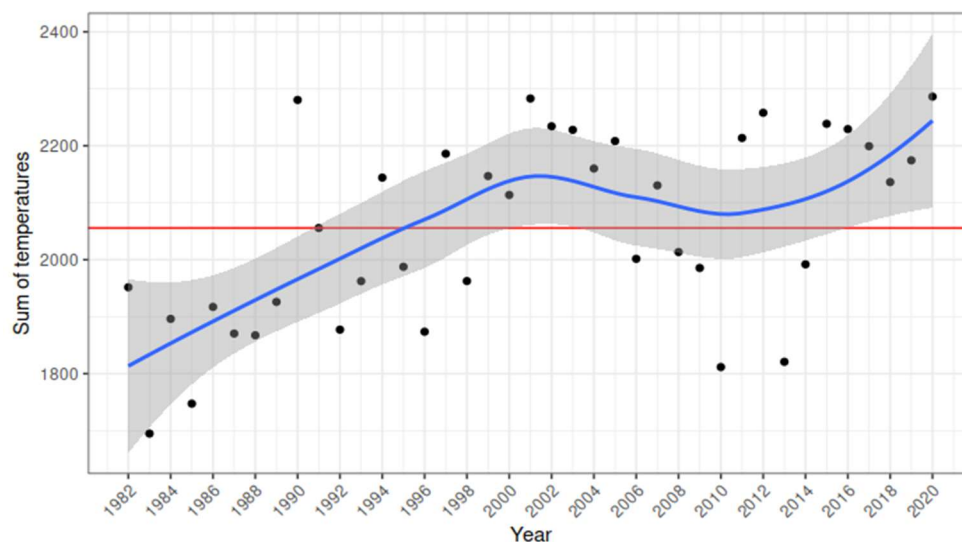


Figure 2. Correlation between the growing season temperature sum ($t > +50$) and that of the observation year.

At the next stage, the value of carbon capture was determined in the average increment over the stock. For this, we used the formula recommended by the IPCC [9]:

$$Gw = Iv * D * BEF (1 + R) * CF, \tag{1}$$

where Gw – average annual carbon increase in living biomass, tC/ha per year; Iv – average stock increase in stem wood, m³/ha per year; D – basic wood density, tons of dry matter/m³ of merchantable volume (for different species from 0.3 to 0.6 tons of dry matter per m³ of stem volume), 0.510; BEF – biomass expansion factor for conversion of merchantable volume to aboveground tree biomass; R – root-to-shoot ratio (for different species from 0.2 to 0.3); CF – carbon fraction of dry matter (default = 0.5), tC/t dry matter.

In order to identify trends and relationships, the data was presented in the form of a diagram (Figure 3).

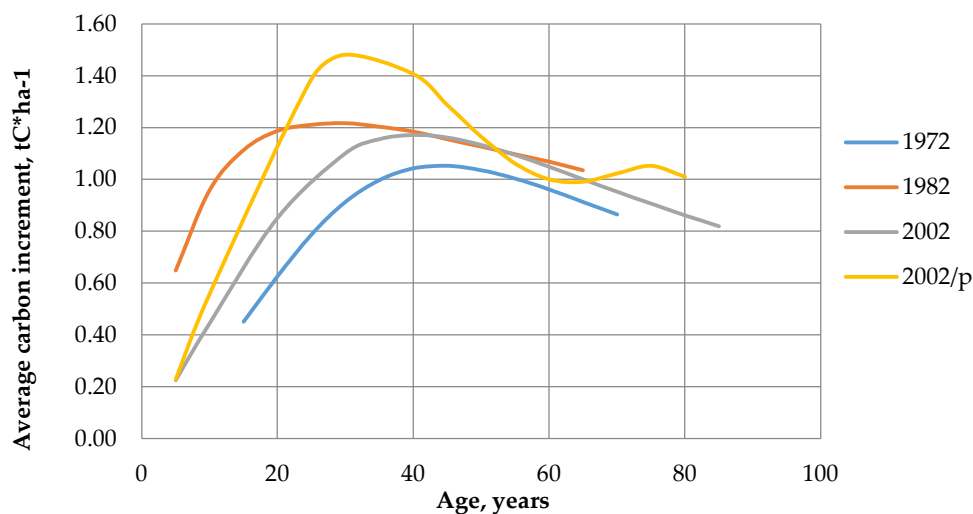


Figure 3. Trendlines for changes in the average annual carbon increment in the wood stock with age and inventory periods (year - mixed aspen forests, year/p - pure aspen forests).

Along with an increase in biomass growth in aspen forests, the reducing resilience and wood loss due to natural and pathogenic mortality began with age (Table 1).

3. Results

The graphs showed higher overall average growth rates in 2002 than in 1972. However, there were differences between relatively pure stands (share of aspen – 90–100 %) growth rates and mixed stands ones.

Based on the average points for age periods, paired regression lines were obtained with their subsequent Rational Function approximation. Differences in growth rates were significant at a young age; by the age of 50, the values of the average growth in aspen forests did not differ.

In the main period from 1982 to 2002, there was a steady trend of increasing the sum of temperatures during the growing season. At the same time, the amount of precipitation in the same period did not exceed the median value. There was some indirect influence of climate trends observed. The sum of effective temperatures over the growing season affected the average growth rate of young pure aspen stands. Therewith, the role of composition (pure or mixed forests) exceeded the role of climate change in the average growth rate dynamics

From the age of 40, a sharp decrease in the average carbon increment occurred in aspen stands. After 55 years, the value of the average increase in aspen forests leveled off, and the differences became insignificant.

Maximum trend line for the growth of pure aspen forests in 2002 let us conclude that with an increase in the sum of temperatures in 1982-2002 from 18000 to 21000, the average carbon increment in the stands increased from 0.56 tC * ha-1 per year to 1.48 tC *ha-1 per year. This statement is true for pure aspen forests aged 10 to 30 years.

From 50 to 80 years of age, the natural wood loss values varied from 3 to 15%. Pathogens-induced wood loss for the same age period varied from 5 to 20%. At the age of 90 years, the mortality reached 30% and the process of forest stand dieback began. Carbon emission was 1-12 tC*ha-1 regardless of mortality cause.

The conducted monitoring research make it possible to study the mechanisms of aspen forests adaptation to climate change and develop a scientific basis for organizing carbon farms in aspen stands in Central Siberia.

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References

1. Kashkarov, E.P.; Pomortsev, O.A. Global warming: the rhythmic basis for forecasting and its practical value in the northern hemisphere forests protection. *Conifers of the boreal area* **2007**, *24*(2-3), 207-216.
2. Sergienko, V.G. The expected impact of climate change on carbon balance and ecosystem productivity in the forest sector of the Russian Federation. *Proceedings of the Saint Petersburg Forestry Research Institute* **2018**, *1*, 74-90.
3. Kurganova, I.N.; Lopes de Gerenyu, V.O.; Myakshina, T.N.; Sapronov, D.V.; Shorohova, E.V.; Savin, I.Y. Carbon balance in forest ecosystems of southern part of Moscow region under a rising aridity of climate. *Contemporary Problems of Ecology* **2017**, *10*(7), 748-760.
4. Kolomyts, E.G.; Surova, N.A. Methods for determining carbon deposited in forest ecosystems under global climate change. *Luka: problems of regional and global ecology* **2019**, *28*(2), 189-218.
5. Fedorov B.G. *Russian carbon balance*; Scientific consultant: Moscow, Russia, 2017, 82.
6. Filipchuk, A.N.; Malysheva, N.V.; Zolina, T.A.; Yugov, A.N. The Boreal Forest of Russia: Opportunities for the Effects of Climate Change Mitigation. *Forestry Information: electronic online journal* **2020**, *1*, 92–113.
7. Koroleva, T.S.; Konstantinov, A.V.; Shunkina, E.A. Threats and socio-economic impacts of climate change for the forest sector *Proceedings of the St. Petersburg Research Institute* **2015**, *3*, 55-77.
8. IPCC Guidelines for National Greenhouse Gas Inventories, Hayama, Japan, 2006. Available online: <https://www.ipcc-nggip.iges.or.jp/public/2006gl/russian/index.html> (accessed 29.06.2022).
9. Mozolevskaya, E.G.; Kataev, O.A.; Sokolova, E.S. *Methods of Forest Pathological Inspection Focused on Stem Pests and Tree Diseases*; Lesnaya Promyshlennost: Moscow, Russia, 1984; p. 152.
10. *Guidelines for Planning, Organizing and Conducting Forest Pathological Examinations*; Appendix 3 to the Order of Federal Forestry Agency Dated December 29; Federal Forestry Agency: Moscow, Russia, 2007; Volume 523, p. 74.