*environmental sciences proceedings*

MDPI

*Proceeding Paper*

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

**Andrey A. Vais, Valentina V. Popova, Alina A. Andronova, Olga A. Gerasimova, Viktor N. Nemich and Pavel V. Mikhaylov ***

Scientific Laboratory of Forest Ecosystems, Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarskii Rabochii Prospekt, 660037 Krasnoyarsk, Russia

* Correspondence: mihaylov.p.v@mail.ru

† Presented at the 3rd International Electronic Conference on Forests—Exploring New Discoveries and New Directions in Forests, 15–31 October 2022; Available online: https://iecf2022.sciforum.net/.

**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 carbon farms can be created using aspen trees for efficient atmospheric carbon sequestration. This paper presents the findings of research focusing on the dynamics of aspen forests' growth and conditions in a changing climate according to forest inventories 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 the 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. This 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 reductions in resilience and wood loss. Aspen is characterized by rapid early growth rates, which allows aspen forests' sequestration potential to be used to achieve effective carbon conservation.

**Keywords:** climate trends; carbon stock; aspen trees; boreal region of Siberia

check for updates

**Citation:** Vais, A.A.; Popova, V.V.; Andronova, A.A.; Gerasimova, O.A.; Nemich, V.N.; Mikhaylov, P.V. Climate Trends and Average Increase in Aspen Forests' Carbon Stock in Siberia According to Forest Inventory Data. *Environ. Sci. Proc.* **2022**, *22*, 8. https://doi.org/10.3390/IECF2022-13079

Academic Editor: Rodolfo Picchio

Published: 21 October 2022

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

**Copyright:** © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

## 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).

Aspen forests are characterized by rapid early growth, which allows forest carbon sequestration to be implemented 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.

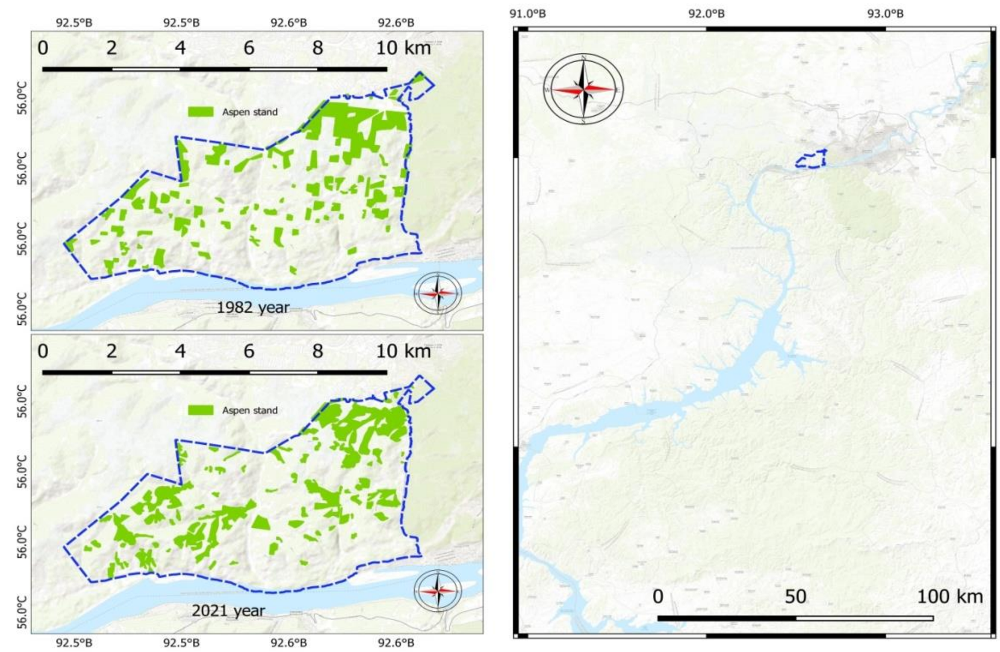


**Figure 1.** Map showing the location and outline of the study area (right side of the map) and dynamics of the aspen forests area according to data from 1982 to 2021.

A field study was carried out in the form of forest pathological inspection according to generally accepted methods [9,10]: a 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 (RPs) placed in typical tall-herb aspen forests (Table 1). Trees (130–180 trees on each research plot) were divided into classes according to their condition: 1—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. The so-called balance approach was used as a methodological basis for calculating the forest carbon budget. Aspen forests were the reference; their density varied from 0.4 to 0.8, rarely reaching 0.9, with a bonitet class of II-III, and the aspen share in the stand composition ranged from 4 to 10 units. The high variety of aspen stand 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 pathogen-induced loss of biomass and carbon in aspen stands.

| Age, Years | M, $m^3$ (Total) | Natural Loss | | | | Pathogenic Loss | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | % | Stock, $m^3 \times ha^{-1}$ | Phytomass, $tm^3 \times ha^{-1}$ | Carbon, $tC \times ha^{-1}$ | % | Stock, $m^3 \times ha^{-1}$ | Phytomass, $tm^3 \times ha^{-1}$ | Carbon, $tC \times ha^{-1}$ |
| 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 were sorted by the share of aspen in a stand composition, and then the average increase in growing stock was calculated depending on the coefficient of the aspen share in a stand composition.

As we were 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 (accessed on 29 June 2022)). 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).

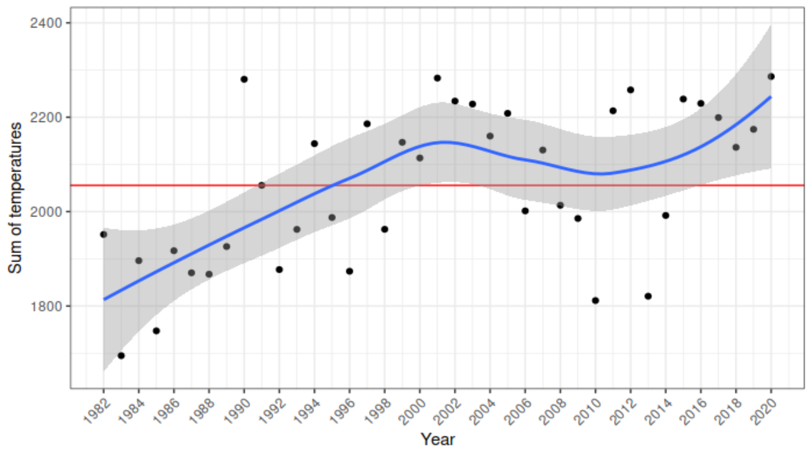


**Figure 2.** Correlation between the growing season temperature sum (t > +50) and that of the observation year.

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]:

$$Gw = Iv \times D \times BEF\,(1 + R) \times CF, \quad (1)$$

where Gw is the average annual carbon increase in living biomass, tC/ha per year; Iv is the average stock increase in stem wood, $m^3$/ha per year; D is basic wood density, tons of dry matter/$m^3$ of merchantable volume (for different species, ranging from 0.3 to 0.6 tons of dry matter per $m^3$ of stem volume), 0.510; BEF is the biomass expansion factor for conversion of merchantable volume to aboveground tree biomass; R is the root-to-shoot ratio (for different species, ranging from 0.2 to 0.3); CF is the carbon fraction of dry matter (default = 0.5), tC/t dry matter.

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

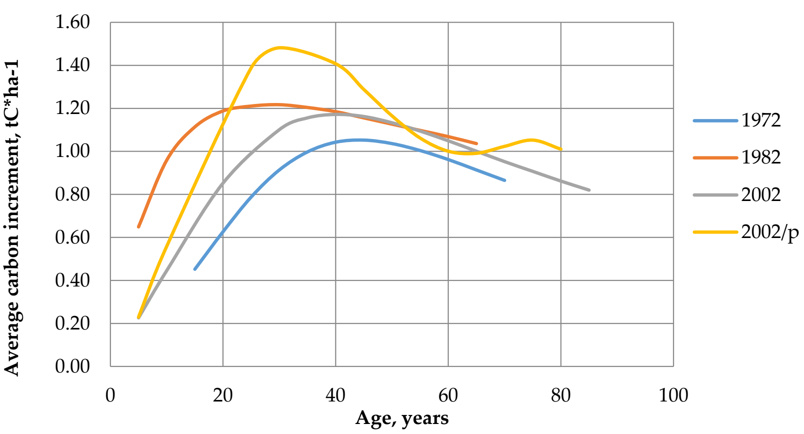


**Figure 3.** Trendlines for changes in the average annual carbon increment in the wood stock with age and inventory periods (year—mixed aspen forests, year/p—pure aspen forests).

Along with an increase in biomass growth in aspen forests, the declining resilience and wood loss due to natural and pathogenic mortality increased 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 increase in 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. Therefore, 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.

The 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 18,000 to 21,000, the average carbon increment in the stands increased from 0.56 tC/ha per year to 1.48 tC/ha 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%. Pathogen-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 emissions reached 1–12 tC/ha regardless of mortality cause.

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

**Author Contributions:** Conceptualization, A.A.V. and V.N.N.; methodology, A.A.V., V.V.P. and A.A.A.; formal analysis, A.A.V., O.A.G. and V.N.N.; investigation, A.A.V., O.A.G. and V.N.N.; writing—original draft preparation, A.A.V.; writing—review and editing, A.A.V. and P.V.M.; visualization, V.N.N.; project administration, P.V.M.; funding acquisition, P.V.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** The research was carried out within the framework of the state assignment, set out by the Ministry of Education and Science of the Russian Federation, for the implementation by the Scientific Laboratory of Forest Ecosystems of the project «Assessment of forest ecosystems resilience under climate change as a basis of carbon budget monitoring» (FEFE–2021–0018).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

## 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 Boreal Area* **2007**, *24*, 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. *Proc. St. Petersburg For. Res. Inst.* **2018**, *1*, 74–90. [CrossRef]
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. *Contemp. Probl. Ecol.* **2017**, *10*, 748–760. [CrossRef]
4. Kolomyts, E.G.; Surova, N.A. Methods for determining carbon deposited in forest ecosystems under global climate change. *Luka Probl. Reg. Glob. Ecol.* **2019**, *28*, 189–218.
5. Fedorov, B.G. *Russian Carbon Balance*; Scientific Consultant: Moscow, Russia, 2017; p. 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. *For. Inf.: Electron. Online J.* **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 *Proc. St. Petersburg Res. Inst.* **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 on 29 June 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. Federal Forestry Agency. *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.