The influence of atmospheric emissions from the pulp and paper industry on the radial growth of the Scots pine in Arctic zone

O S Barzut¹, M V Surso² and U V Porshneva¹

¹Northern (Arctic) Federal University named after M.V. Lomonosov, Arkhangelsk, Russia
² Federal Center for Integrated Arctic Research of the Russian Academy of Sciences, Arkhangelsk, Russian Federation

o.barzut@narfu.ru

Abstract. The peculiarities of the radial growth of pine in the conditions of air pollution in the Arctic zone are considered. The results of measurements of the width of annual rings of pine growing at different distances from the emission source are presented. The variability of annual radial growth of pine trees varies in a wide range: from moderate to very high. Age changes in the width of annual rings of pine are corresponding to the regularities of the curve of the "large growth". The average annual radial growth begins to decrease in plants older than 70 years. The dependence of the average annual radial growth of pine on age is approximated by an exponential equation. The accuracy of the approximation (coefficient of determination) is very high. Comparative analysis of the width of the annual rings and the value of gross emissions of the APPM in the year of formation of the annual layer did not show a clear synchronicity or asynchrony in the dynamics of these indicators for all plots. In most cases, the relationship between the total annual emissions of the APPM into the atmosphere and the width of the annual rings of pine was insignificant. The analysis of dendrochronology did not reveal a significant influence of atmospheric emissions of the Arkhangelsk pulp and paper mill on the growth of pine. The correlation coefficients between total annual atmospheric emissions and radial annual increments did not show a relationship between them, both when comparing these parameters year-on-year and with a delay of one year. For the period from 2001 to 2018 significant direct or delayed negative effect of emissions from Arkhangelsk pulp and paper mill in the atmosphere in the investigated areas of pine forests have not been identified.

1. Introduction

The main types of impact of the pulp and paper industry on the environment are the discharge of wastewater into water bodies, emissions of pollutants into the atmosphere, as well as activities for the management of production waste. For woody forest vegetation, the greatest danger is atmospheric pollution, which occurs as a result of the transfer of air masses and which depends on the prevailing wind directions and speeds.

In this work, we studied the effect of atmospheric emissions from the Arkhangelsk Pulp and Paper Mill (APPM) on the radial growth of pine. Around the APPM there is a sanitary protection zone, which is: in the North-East - 500 m, in the East - 600 m, in the South - 450-760 m, in the North-West - 350 m, in the South-West - 100 m from the border of the industrial site. At the borders of this zone,
according to the results of environmental monitoring [10], in recent years there are no maximum permissible concentrations of pollutants for the atmospheric air of populated areas. Also, there is no maximum permissible level of physical effects on the air. However, the potential for atmospheric pollution due to wind dispersion remains and requires further study.

The APPM is located in Novodvinsk city, at a distance of 14 km in a south-easterly direction from the city limits of Arkhangelsk; therefore, we cannot exclude a negative effect of the APPM on air quality in Arkhangelsk [5, 6]. The main part of atmospheric emissions of APPM (more than 80% of all atmospheric emissions) is emissions from the thermal power plant. The dynamics of emissions of pollutants into the air during the activities of APPM can be traced from 2001 to 2017 according to the data presented in the reports on environmental activities [9-13]. For recent years, there was a decrease in total emissions of pollutants into the atmosphere. The greatest decrease was achieved in sulfur dioxide due to the improvement of coal quality (reduction of sulfur content) and reduction of its use. In addition, air filters have been upgraded, which has also led to a reduction in atmospheric emissions. The lowest total emission of pollutants into the atmosphere was observed in 2007 against the background of the overall reduction of emissions during this period.

The studies were aimed at identifying the effect of atmospheric pollution, the supposed source of which is APPM, on the radial annual growth of Scots pine trees growing at different distances from the APPM. Scots pine is highly sensitive to atmospheric pollution due to accumulation of harmful compounds in needles [1, 2]. External signs of damage to pine plants by toxic gases are necrosis and chlorosis of needles, dying and premature fall of needles, curvature and death of young shoots. High concentrations of sulphur dioxide in the air entering the atmosphere as a result of APPM emissions are particularly unfavorable to plants [14]. Sulfur dioxide is oxidized in the atmosphere, turning into sulfurous anhydride (SO$_3$), and then into sulfuric acid. Sulfuric acid destroys the tissue of the leaves, on the surface of which light and brown spots are formed. Trees are a violation of metabolism, destroys chlorophyll, reduced photosynthesis, the cells of bark, phloem, and cambium are damaged. The productivity of trees is reduced. Weakened trees are exposed to diseases and pests [8]. Scots pine (Pinus sylvestris L.) is a bio indicator that is often used to the monitoring of the influence of atmospheric pollutions on the environment [7].

2. Results and Discussion
We performed a dendrochronological analysis of pine trees on 6 experimental plots located at different distances from the APPM (Fig 1).
The most remote is plot number 1, which is located about 120 km North-East of APPM. This plot is taken as a control. At each plot, three pine trees were selected; close in size to the average height and diameter. These trees on the south side of the trunk at chest height were taken samples for dendrochronological analysis. Measuring the width of the annual rings was done on a binocular microscope MBS-10. Individual dynamics of radial growth is studied for each tree. By means of statistical analysis and standard Excel packages Microsoft-2007 the average values of the width of the annual rings of individual pine trees were obtained and the graphs of the dynamics of radial increments were plotted.

For plots located in the area of expected atmospheric pollution (plots No. 2-6), the age of pine trees varies from 46 to 112 years. The age of the trees growing on the 4th and 5th plots was the lowest (46-90 years). On these plots the average values of annual radial growth of individual trees have the greatest value: from 1.984± 0.0497 to 3.195±0.1003 mm. This is due to the peculiarity of coniferous species at a younger age to form wider annual rings. The average annual radial growth begins to decrease in plants older than 70 years.

The control plot No. 1 is characterized by a higher age of pine trees – 155-218 years. The average width of the annual rings of individual trees here varies from 0.6397±0.0176 to 1.0962±0.0271 mm, and the level of variability is high (for 62.5% of samples) or very high (for 37.5% of samples). In other plots, the variability of annual radial growth of pine trees varies in a wide range: from medium to very high, but most trees (40% of the samples) have a very high level of variability – CV>50% [4].

Graphic representation of the dependence of the average width of the annual ring on the age of pine (Fig 2) is approximated by the "age curve".

![Graph](image-url)
Figure 2. Dynamics of the average annual radial growth of individual pine trees depending on the age: a - for individual trees of different plots; b - the curve of the age trend according to all plots.

The decrease in the width of annual rings in trees older than 70 years is shown in Fig 2a. The change in the mean annual radial growth of pine depending on the age factor is best approximated by the exponential equation (Fig 2b). The accuracy of the approximation (coefficient of determination) is very high – $R^2=0.804$ [3].

Comparative analysis of the width of the annual rings and the value of the gross emission of APPM in the year of formation of the annual layer did not show a clear synchronicity or asynchrony in the dynamics of these indicators for all plots. Visual comparison of indicators of absolute radial growth of the studied plants among themselves did not reveal general regularities in the dynamics of annual layers. It was not possible to establish commonalities in the onset of reference years characterized by maximum or minimum values of growth.

The correlation coefficients between total annual atmospheric emissions and radial annual increments did not show a relationship between them, both when comparing these parameters year-on-year and with a delay of one year, i.e., when estimating the radial increment response in the year following the emission. In cases where emissions had a negative effect on the annual ring width, the correlation coefficients would be negative.

The degree of influence of the factor is determined by the value of the correlation coefficients ($r$). In most cases (72.2%), the relationship between the total annual atmospheric emissions of APPM and the width of annual rings in pine was weak ($r < 0.3$). Moderate ($r=0.31-50$) relationship was observed in 16.7% of cases. A significant relationship ($r=0.51-0.7$) was observed in 11.1% of cases.

Thus, for the period from 2001 to 2018 significant direct or delayed negative effect of emissions from Arkhangelsk pulp and paper mill in the atmosphere in the investigated areas of pine forests has not been identified.

References
[1] Alexandrova E 2015 Bioindicative assessment of the quality of the urban environment. Problems of development of the territory 5 (79) 170-178 (in Russian)
[2] Atkina L et al 2008 Characterization of Siberian spruce trees in street plantings of Ekaterinburg. Forest Bulletin 3 (60) 27-31 (in Russian)
[3] Dvoretsky L 1971 Handbook of variational statistics (Moscow: Forest industry) p 104 (in Russian)
Russian)

[4] Mamaev S 1970 A levels of variability of anatomical and morphological features of pine. *Botanical research in the Urals*, Notes of the Sverdlovsk branch of the Soviet Union Botanical society 5 58 – 67 (in Russian)

[5] Gutman S S and Teslya A B 2018 Environmental safety as an element of single-industry towns' sustainable development in the Arctic region Conference Series: Earth and Environmental Science, 180 (1) 012010 Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85051926483&doi=10.1088%2f1755-1315%2f180%2f1%2f012010&partnerID=40 [Accessed 27th February 2019]

[6] Popova L 2014 Chemical pollution of the Archangelsk urban ecosystem. p 231 (in Russian)

[7] Runova E et al 2014 Some features of the use of dendrochronological assessment of the growth of Pinus sylvestris L. in the bioindicative research in the urban environment of the Northern territories. *Forest Bulletin* 5 146-150 (in Russian)

[8] Turovtsev V and Krasnov V 2004 Bioindication: Textbook. p 260 (in Russian)

[9] Arkhangelsk pulp and paper mill [Electronic resource] Available from: http://www.appm.ru/ [Accessed 17th January 2019] (in Russian)

[10] Environmental reports / Arkhangelsk pulp and paper mill [Electronic resource] Available from: http://www.appm.ru/documents/ecology/ [Accessed 17th January 2019] (in Russian)

[11] Report on environmental activities of "Arkhangelsk PPM" for 2014 (for the press) Available from: http://www.appm.ru/documents/ecology/report_ecology_2014.pdf [Accessed 17th January 2019] (in Russian)

[12] Report on environmental activities of "Arkhangelsk PPM" for 2015 Available from: http://www.appm.ru/documents/ecology/report_ecology_2015.pdf [Accessed 17th January 2019] (in Russian)

[13] Report on environmental activities of "Arkhangelsk PPM" for 2016 Available from: http://www.appm.ru/documents/ecology/report_ecology_2016.pdf [Accessed 17th January 2019] (in Russian)

[14] Resistance of wood species to atmospheric pollution. Gas cleaning ability of plantings Available from: http://ifreestore.net/5633/19/ [Accessed 17th January 2019] (in Russian)