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## The influence of atmospheric emissions from Arkhangelsk pulp and paper mill on radial growth of spruce

To cite this article: O S Barzut and M V Surso 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **263** 012021

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# The influence of atmospheric emissions from Arkhangelsk pulp and paper mill on radial growth of spruce

O S Barzut<sup>1</sup> and M V Surso<sup>2</sup>

<sup>1</sup> Northern (Arctic) Federal University named after M.V. Lomonosov

<sup>2</sup> Federal research center for integrated Arctic researches of the Russian Academy of Sciences

E-mail: o.barzut@narfu.ru

**Abstract.** Spruce is sensitive to atmospheric pollution and can serve as a bioindicator of environmental quality. Dendrochronological studies revealed no significant changes in the radial growth of spruce in the zone of influence of the Arkhangelsk PPM. Correlation coefficients between the total annual emissions of the Arkhangelsk PPM into the atmosphere and the values of the radial annual growth of individual trees during the period from 2001 to 2016 did not prove the connection between them, both when comparing these parameters in the year of the event and with the delay for the year.

## 1. Introduction

The main environmental impacts of the Arkhangelsk pulp and paper mill are wastewater discharge into the Northern Dvina River, emissions of pollutants into the atmosphere, and waste management activities. The dynamics of emissions of pollutants into the air during the activities of the mill can be traced from 2001 to 2016 according to the data presented in the reports on environmental activities [1-5]. For this period, 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 main contribution to atmospheric pollution (more than 80%) is made by emissions from the thermal power plant. Thus, the Arkhangelsk PPM, located 14 km South-East of the city limits of Arkhangelsk, can be attributed to the enterprises of environmental pollutants [6]. The greatest impact on forest vegetation, which occupies a large area around the Arkhangelsk industrial agglomeration, has emissions of pollutants into the air. Special sensitivity to them differ evergreen coniferous species: pine and, especially, spruce [7-10]. In this sense, sulphur dioxide emissions are particularly unfavorable [11]. There are data indicating the influence of atmospheric pollution on the width of the annual ring [9]. In this regard, spruce can be considered as a bio indicator for the study of air pollution of industrial zones.

## 2. Dynamics of radial growth of spruce in the zone of influence of Arkhangelsk PPM

These studies combined data of dendrochronological analysis of spruce trees in 6 plots located at different distances from the Arkhangelsk PPM (figure 1). The most remote, taken as a control, is plot number 1, located near the Kennitsy village.





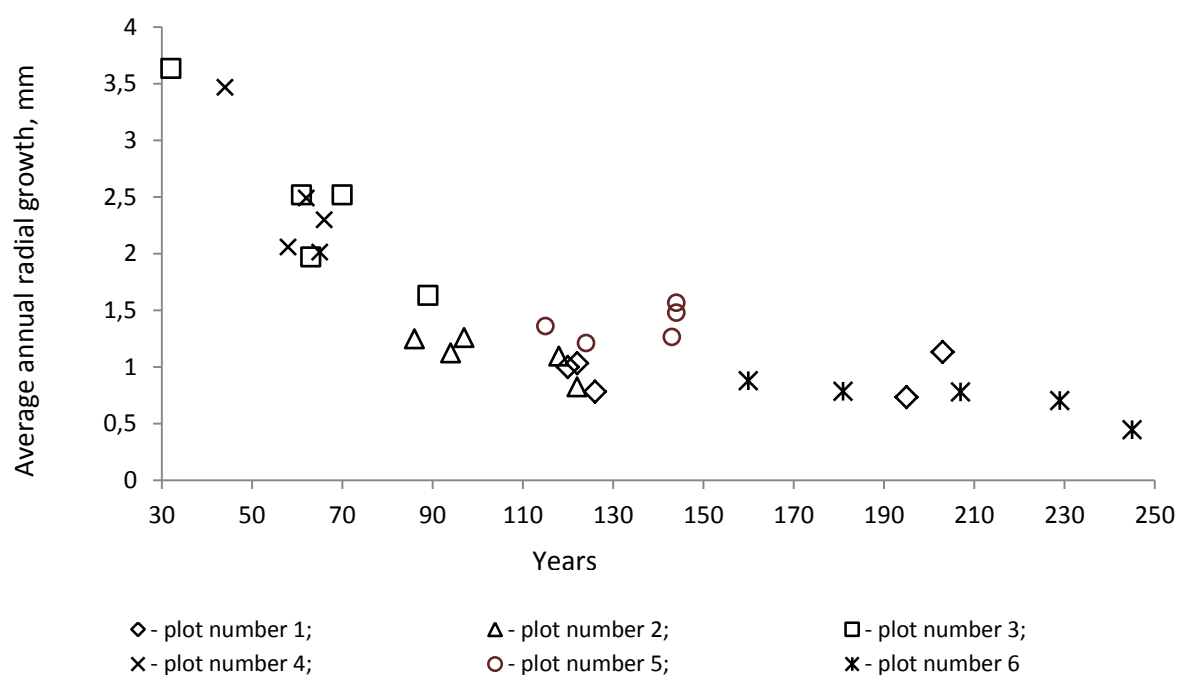
**Figure 1.** Location of plots.

The age of spruce ranged from 32 to 245 years. At plots numbers 3 and 4, the mean annual radial growth of individual plants was highest, ranging from  $1.632 \pm 0.081$  to  $3.634 \pm 0.207$  mm, due to the small age of the trees (32-89 years). In plants whose age exceeded 100 years, the average annual radial growth decreased. Thus, the oldest tree (245 years) has the average annual ring width of the smallest –  $0.446 \pm 0.012$  mm.

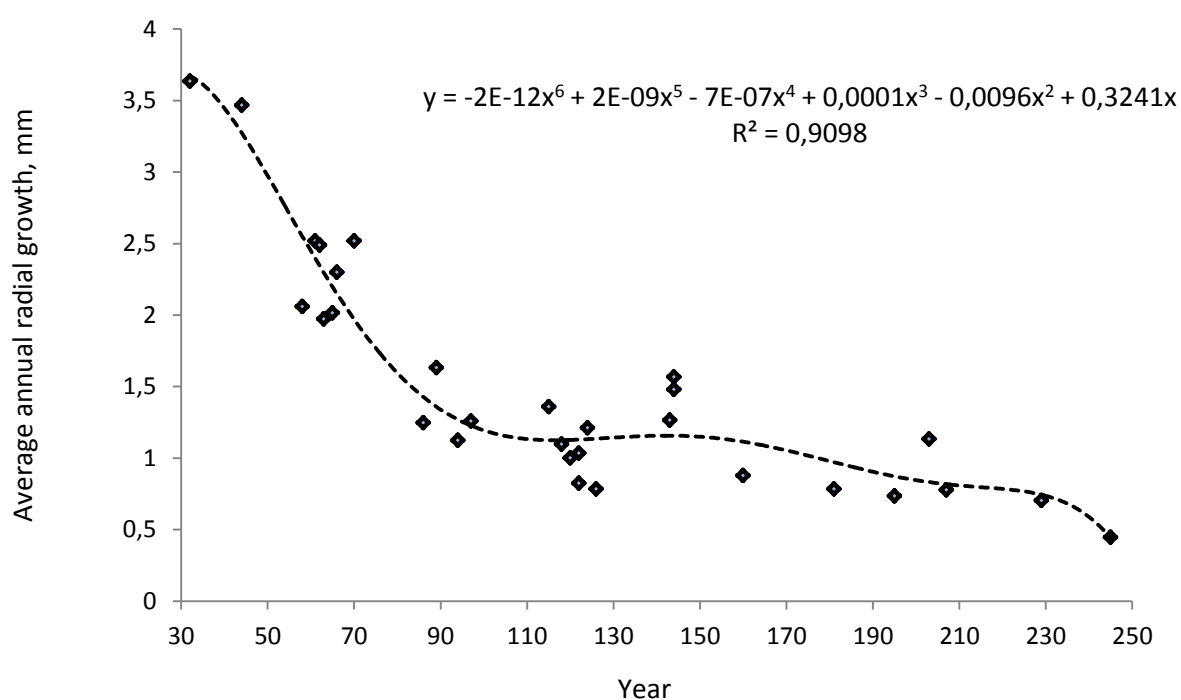
The graphical representation of the dependence of the average value of the annual ring width on the age of the plant (figure 2, a) demonstrates well the "age curve" of spruce. The change in the mean value of the annual radial increase of spruce depending on the age is approximated by the polynomial equation of the sixth order (figure 2, b), the tightness of the relationship is very high (the coefficient of determination –  $R^2 = 0.91$ ). The variability of annual radial increment in spruce varies greatly, and most trees have a very high level of variability –  $CV > 50\%$  [12].

The interrelation between the dynamics of absolute values of annual radial growth of individual spruce plants growing at different distances from the emission sources and the dynamics of total annual gross emissions of the Arkhangelsk PPM has been studied. Comparison of the dynamics of the values of the annual ring width and the value of the gross emission of the Arkhangelsk PPM in the year of formation of the annual layer did not show a clear synchronicity or asynchrony (in the case of negative impact) of these two indicators for any of the experimental plots.

Visual comparison of absolute values of radial increment did not reveal of general regularities in dynamics of annual increments in spruce. There is no commonality in the occurrence of reference years characterized by the maximum or minimum values of the indicator. The calculated correlation coefficients between the total annual emissions of the Arkhangelsk PPM into the atmosphere and the values of the radial annual growth of individual trees did not prove the connection between them, both when comparing these parameters in the year of the event and with the delay for the year.



a



b

**Figure 2.** Dynamics of the average annual radial growth of individual spruce plants depending on the age: a - for individual trees of different plots; b - the curve of the age trend according to all plots.

### 3. Conclusions

In cases of negative influence of emissions on the width of the annual ring, the correlation coefficients have negative values, and the degree of influence is determined by the value of the correlation coefficients. The results showed a weak ( $r < 0.3$ ) relationship in the majority (76.6 %) of plants, moderate ( $r=0.31-0.50$ ) – in 23.3% of plants, and significant ( $r=0.51-0.7$ ) – in less than 1% of plants. Thus, during the period from 2001 to 2016, no significant direct or delayed negative impact of the Arkhangelsk PPM emissions into the atmosphere on the studied areas of spruce forests was revealed.

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