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Dendroclimatic studies of aspen growth in Moscow

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Abstract. This article presents the results of studying aspen (*Populus tremula* L.) growth in urbanized environment of Moscow metropolis with the help of dendrochronology method. Four significant correlation coefficients for data of two aspen chronologies and the group of forty-eight meteoparameters of current calendar year and the calendar year which was previous to the year of tree ring formation were established by the dendroclimatic method. According to the results of correlation calculation it was established that correlations sustainable for both considered chronologies as well as biologically interpretable ones between radial growth fluctuations and climatic data fluctuations are absent. It is due to the fact that the aspen trees on considered plots are in the conditions near the optimum zone and the factors, which are limiting radial growth size, change from year to year. One year one factor has strong deviation from optimal for species parameters, and another year it will be another factor. In this case the correlation analysis gives results about the lack of correlation, but it does not mean that climatic factors have no impact on tree ring formation. The absence of correlation, for instance, to the temperatures observed in May of the current year is important as this is a period of great cambium activity and assimilation biomass forming. So, the increase in temperature of this month, probably predicted with global warming, will not have a negative effect on aspen growth in the conditions of the studied stands.

1 Introduction

We believe that urban environment is evolutionally new for all woody plant species, and here lies the key challenge for city trees. In this respect, Moscow urban forests are truly unique. Over years, wild woodlands have been changing little by little to become urban forest parks. These processes involved trees regenerating mainly in a natural way. It took centuries for the environment and tree species to go through various transformations and evolutionary micro changes. Even with the emergence of urban environment, most urban forest trees continue to regenerate naturally. Consequently, we are likely to find here aspen types adapted to the urban environment.

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Dendrochronological method is good for integral tree assessments and therefore might be useful to identify such trees. Traditional methods do not always allow to assess a long-term overall tree response to human impacts. E.G. Mozolevskaya (2001), a renowned urban tree expert and a member of the Pamfilov's Public Utilities Management Academy argues that "the dendrochronological method widely-used in forest studies is also a promising technique to assess both current and future condition of trees and forest stands".

D.L. Kats (2000), the head of the Vologda Research and Development Center, regrets that the tree ring analysis has never been a method of choice for urban environment studies despite its significant practical potential. He further explains that while having an extensive impact on tree growth, urban environment parameters are changing rapidly, and therefore they are difficult to analyze. However, D.L. Kats believes that the dendrochronological assessment can be reasonably used to study the effects of deicing agents, construction works and air and soil pollution on the urban environment.

Experts often employ various dendrochronological methods to assess urban tree health [6], but using dendrochronological data for assessing ecosystem services offered by trees is a relatively new area of scientific research. Nevertheless, there are some earlier publications that laid the groundwork for it.

Dendrochronological data (radial growth variability over time and depending on a growing site) can be successfully used to assess ecosystem services provided by urban green spaces such as carbon sequestration, oxygen production and climate regulation (through transpiration).

A major challenge here is to measure biological productivity and carbon sequestration that forest stands provide over their ontogenesis. This issue is addressed in the publication by V.I. Tarankov, E.E. Melnikov, V.V. Akulov and S.M. Matveev (2008). These authors give clear reasons for dendrochronological analysis to be successfully used to give a quantitative evaluation of age-related carbon sequestration dynamics in forest stands.

The amount of carbon that urban trees can sequester is highly correlated to their ability to produce oxygen. To evaluate the capacity of urban trees to produce oxygen and sequester carbon dioxide, we refer to the research results described in the publication *Forest Landscape Management* by V.G. Atrokhin and V.Y. Kuramshin (1991). The authors point out that the higher the actual tree growth rate is in a certain forest stand, the more oxygen it releases into the atmosphere. In this respect, it seems reasonable to consider an actual stem growth rate as an overall "factor for evaluating recreational benefits that forest biogeocoenosis offers to humans" since "this type of growth is directly associated with the ability to provide recreational opportunities".

V.I. Tarankov (2006) believes that the tree growth rate should be the only factor to consider while evaluating the amount of oxygen produced by a forest. Leaves, conifer needles and grass cover can be disregarded because their biomass does not have any significant effect on the oxygen balance (carbon dioxide released when leaves and needles grow is subsequently absorbed when they decompose after the leaf fall).

Aspen has a not clear seen tree rings and that is why not a popular object of dendrochronological investigations. But there are some publications in this sphere which base on *Populus tremuloides* materials. This American species is systematically close to Eurasian *Populus tremula*.

Studies of trembling aspen (*Populus tremuloides* Michx.) in western Canada have shown a correlation between past insect defoliation events and the formation of narrow, abnormally pale-coloured ("white") tree rings. The objectives of this study were to test the hypothesis that defoliation causes the formation of white rings and to examine how defoliation affects ring width and density. Authors experimentally defoliated 7- to 18-year-old aspen in June, July, or August 1997 and subsequently found that white rings were formed the same year in all aspen that were severely defoliated in early June. These white rings were much narrower than in adjacent trees left as controls, and mean xylem density of the white rings was significantly reduced relative to normal rings. In the year following defoliation, the tree rings remained narrow, but their appearance and density had returned to normal. Aspen defoliated later in the season formed relatively normal rings in 1997, but ring widths were reduced in 1998. The results confirm that white rings in aspen can be a useful retrospective indicator of the severe, early season defoliation that is typical during major outbreaks of forest tent caterpillar (*Malacosoma disstria* Hbn.) and other insects.

For Alaskan aspen forests impacts of climate and insect herbivory on radial growth was investigated [4]. Authors think that as climate warms, trembling aspen (*Populus tremuloides*) is expected to become more successful in northern boreal forests because of its current presence in drier areas of North America. However, large-scale productivity decline of aspen has recently been documented throughout the United States and Canada as a result of drought and insect outbreaks. Authors used tree ring measurements (basal area increment (BAI) and stable carbon isotopes (δ13C)) and remote sensing indices of vegetation productivity (NDVI) to study the impact of climate and damage by the aspen epidermal leaf miner (*Phyllocnistis populiella*) on aspen productivity and physiology in interior Alaska. We found that productivity decreased with greater leaf mining and was not sensitive to growing season (GS) moisture availability. Although productivity decreased during high leaf mining years, it recovered to pre-outbreak levels during years of low insect damage, suggesting a degree of resilience to P. populiella mining. Climate and leaf mining interacted to influence tree ring δ13C, with greater leaf mining resulting in decreased δ13C when GS moisture availability was low. We also found that NDVI was negatively associated with leaf mining, and positively correlated with BAI and the δ13C decrease corresponding to mining. This suggests that NDVI is capturing not only variations in productivity, but also changes in physiology associated with P. populiella. Overall, these findings indicate that the indirect effects of P. populiella mining have alarger impact on aspen productivity and physiology than climate under current conditions, and isessential to consider when assessing growth, physiology and NDVI trends in interior Alaska.

Dendroclimatic analysis of aspen hybrids growth was investigated by authors from Latvia (Senhota et al., 2015). Fast-growing hybrids of *Populus* L. have an increasing importance as a source of renewable energy and as industrial wood. Nevertheless, the long-term sensitivity of Populus hybrids to weather conditions and hence to possible climatic hazards in Northern Europe have been insufficiently studied, likely due to the limited age of the trees (short rotation). In this study, the climatic sensitivity of ca. 65-year-old hybrid poplars (*Populus balsamifera* L. × *P. laurifolia* Ledeb.), growing at two sites in the western part of Latvia, and ca. 55-year-old hybrid aspens (*Populus tremuloides* Michx. × *P. tremula* L.), growing in the eastern part of Latvia, have been studied using classical dendrochronological techniques. The high-frequency variation of tree-ring width (TRW) of hybrid poplar from both sites was similar, but it differed from hybrid aspen due to the diverse parental species and geographic location of the stands. Nevertheless, some common tendencies in TRW were observed for both hybrids. Climatic factors influencing TRW were generally similar for both hybrids, but their composition differed. The strength of climate-TRW relationships was similar, but the hybrid poplar was affected by a higher number of climatic factors. Hybrid poplar was sensitive to factors related to water deficit in late summer in the previous and current years. Hybrid aspen was sensitive to conditions in the year of formation of tree-ring. Both hybrids also displayed a reaction to temperature during the dormant period. The observed climate-growth relationships suggest that increasing temperatures might burden the radial growth of the studied hybrids of Populus.

A comprehensive assessment of the tree growth/climate relationship was undertaken to better understand the potential impacts of climate change on the growth dynamics of four widespread and common boreal tree species, namely jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), eastern larch (*Larix laricina*), and trembling aspen (*Populus tremuloides*), located at the southern limits of the Canadian boreal forest (Mailett et. al. 2022). Over intra-annual time scales, results show that precipitation is likely the main driver of stem radius change (ΔR), with jack pine radius exhibiting the most consistent positive relationship. Precipitation had a stronger relationship with stem radius variation in black spruce and eastern larch during periods when volumetric water content (VWC) in the root zone was below average, pointing to the likelihood that certain species rely more heavily on available moisture in the uppermost layers of the soil column to replenish stem water, especially during extended dry periods. Warm air temperatures had an immediate negative impact on stem water content due to transpiration. This was most marked during periods of reduced moisture availability in the root zone, when trees are more susceptible to net water volume loss. During periods when moisture was not limiting, a positive relationship between lagged air temperature and ΔR was detected. Warm air temperatures may therefore play an important role in stimulating radial growth when moisture requirements are met. At annual temporal resolution, the growth/climate relationship changed over the lifetime of our study species. Over the last several decades, the relationship between precipitation and annual radial tree growth has weakened, while positive relationships between spring and summer air temperature and annual radial tree growth have emerged, likely signaling a decrease in moisture limitations, and a positive response to spring warming. Authors findings reveal that boreal forest tree species may benefit from spring and summer warming over the near term, providing there is sufficient moisture to support growth. Over the long term, rates of evapotranspiration are expected to overshadow gains in moisture related to an increase in precipitation. Under these circumstances, authors are likely to see reduced growth rates and an increasingly negative response of boreal tree species growth to warm air temperatures.

The data of the literature review indicate the importance of dendroclimatic studies of the growth of tree species in an urbanized environment for the purpose of monitoring their condition and forecasting changes in productivity, which in turn is associated with changes in the effectiveness of ecosystem services performed by tree species. It should also be concluded that fluctuations in the width of the aspen annual ring from year to year are climatically determined, but may also be associated with the influence of phyllophagous insects. The nature of the climatic relations of growth and climate is different for different geographical objects, which should be taken into account when predicting the response of aspen forests to global climate warming.

Now aspen trees are rarely used in urban land improvement plantings. However, today people expect much better ecosystem services from urban green spaces than they used to in the mid-20th century, and therefore this species seems to be quite promising. Tree failures can be avoided if appropriate maintenance felling is initiated in due time, that is before crowns grow too large to bear wind load and before there are too many dry branches which is a source of stems fungi infestation. The goal of our investigation was to established how climatic factors influence on tree rig width changes from year to year and on this base indicate the health of trees in urban conditions and predict the reaction of aspen stands in Moscow to global warming. Dendroclimatic studies of aspen growth in Moscow were performed for the first time.

2 Materials and methods

Sample plots were established within the aspen stands in Izmailovo forest park (IZM) and Terletsky forest park (TERL). Both forest parks are in the eastern districts of Moscow. The sample plot established in Terletsky forest park comprised the following tree species (estimated by wood volume): *Quercus robur* =50%, *Populus tremula* =30%, *Fraxinus* *pensilvannica* =10% and *Acer platanoides* <10%. The understory included *Cornus alba*, *Padus racemosa*, *Sorbus aucuparia*, *Salix capreae*, *Viburnum opulus* and *Lonicera xylosteum*. The new growth included *Acer negundo*, *Acer platanoides*, *Populus tremula*, *Quercus robur* and *Ulmus scabra*. The ground vegetation comprised *Urtica dioica*, *Solanum dulcamara*, *Carex pilosa*, *Athirium filix-femina*, *Impatiens parviflora*, *Galeobdolon luteum*, *Ajuga reptans* and some unidentifiable *Gramineae* species in vegetation.

The sample plot established in Izmailovo forest park comprised the following tree species (estimated by wood volume): *Pinus sylvestris* =50%, *Tilia cordata* =40%, *Salix alba* =10%, while *Crataegus species*, *Alnus incana*, *Alnus glutinosa*, *Ulmus scabra*, *Quercus robur*, and *Acer negundo* made up together less than 10%. The understory included *Acer platanoides*, *Acer negundo*, *Tilia cordata*, *Populus tremula* and *Quercus robur*. The ground vegetation comprised *Geum urbanum*, *Arctium lappa*, *Impatiens parviflora*, *Ranunculus repens*, *Urtica dioica*, *Taraxacum officinale*, *Galeobdolon luteum* and some unidentifiable *Gramineae* species in vegetation. Table 1 contains inventory data for the sample plots.

Table 1. Inventory data for the sample plots.

Sample plot	Height, m	Dia-meter at 1.3 m height, cm	Mean health status	Basal area, m^2	Coordinates
TERL	24	26	2	260	37.816869° 55.763730°
IZM	24	27	2	270	55.762165° 37.752956°

The sampling was made by coring. One core was taken from each model tree at 1.3m height of stem. Each plot was presented by 12 model trees. The tree rings were measured by using Lintab-5 with accuracy 0.01 mm and after that cross dated by using computer program TSAP Win [10].

3 Results and Discussion

Numerous ecological factors contribute to radial tree growth variability while climate change has a direct impact on radial tree growth dynamics [3, 15]. With weather changing from one vegetation season to another, tree ring widths also vary from year to year. Radial growth time series have a clear age-related trend which can be transformed using dozens of various methods to calculate a response to climate patterns. We divided the current year tree ring width by the mean tree ring width observed over the last five years to calculate growth indices. Then, based on individual tree ring chronologies, we calculated indexed tree ring chronologies which subsequently served as a basis for calculating mean generalized chronologies for each sample plot. Next, a correlation analysis was done to measure relationship strength between climate fluctuations and radial growth variations.

Data for 1991–2014 were used in calculations. With 23 observations, 21 degrees of freedom and the confidence level of 0.05, the correlation coefficients of 0.41 and higher are reliable. Correlation coefficients were calculated both for weather patterns of the year when a tree ring was formed and for weather patterns of the year preceding the vegetation season when tree ring formed. The results are shown in table 2.

We obtained 4 reliable correlation coefficients. For some chronologies they are observed for the precipitations in May of the preceding year, for the temperatures in February of the preceding year and for the temperatures in September of the current year for both chronologies. They all are difficult to interpret in any definitive way.

Table 2. Correlation coefficients between radial growth indices and weather patterns.

Month	**Preceding year precipitations**		**Current year precipitations**		**Preceding year temperatures**		**Preceding year temperatures**	
	TERL	**IZM**	**TERL**	**IZM**	**TERL**	**IZM**	**TERL**	**IZM**
January	0.04	-0.03	-0.27	-0.39	0.04	-0.17	-0.13	-0.33
February	0.04	-0.09	-0.08	0.09	0.49*	0.09	-0.23	-0.06
March	-0.25	0.02	0.21	0.35	0.33	-0.01	-0.25	-0.23
April	-0.15	0.30	-0.07	0.00	-0.07	0.01	-0.33	-0.08
May	-0.48*	-0.23	0.36	0.38	-0.07	0.25	0.03	0.27
June	-0.05	-0.12	0.37	0.13	0.07	0.35	-0.24	0.05
July	-0.06	-0.07	0.14	0.08	-0.38	-0.21	-0.18	-0.03
August	-0.23	-0.11	0.21	0.07	-0.20	0.14	-0.23	0.10
September	0.03	0.02	0.17	0.33	-0.27	-0.02	-0.50*	-0.44*
October	0.17	0.05	0.13	-0.09	0.00	-0.26	-0.15	-0.08
November	-0.04	0.14	-0.07	-0.09	0.00	0.25	-0.04	0.08
December	-0.32	-0.02	-0.02	0.21	-0.06	0.20	-0.08	0.05

* reliable correlation coefficients

However, the absence of correlation, for instance, to the temperatures observed in May of the current year is important as this is a period of great cambium activity and assimilation biomass forming. So, the increase in temperature of this month, probably predicted with global warming, will not have a negative effect on the growth of aspen in the conditions of the studied stands.

In our opinion this fact highlights the notion that while being indirectly subject to environmental impacts, aspen radial growth (as well as that of the other tree species) is a complicated physiological process significantly influenced by internal factors. We should note that correlation coefficients are differently distributed in the chronologies from Terletsky forest park and Izmailovo forest park. It might result from their environments being different. The sample plot within Izmailovo forest park is under great recreational load. The new growth and understory are sparse here and soil is compacted. The trees growing within the sample plot in Terletsky forest park are infected with *Ectoedemia argyropeza* which impairs the photosynthesis efficiency. Specific correlations recorded here might result from the pest population density being influenced by climate patterns. For the both forest parks, we observed a reliable correlation to September temperatures. Actually, a tree ring is almost completely formed by that time. In this case, we seem to observe local climate being influenced by local vegetation through transpiration, the intensity of which is associated with the photosynthetic rate and the width of water transporting xylem tissues formed over the last year. M.G. Romanovskii and R.V. Schekalev describe such mechanism in their publications [7]. This is true both for the mentioned aspen stands and for all urban woody plants in general because more or less the same conditions will be favorable for photosynthesis (if we consider it as a physical and chemical process) in all tree species. In our case, aspen tree ring dynamics only shows that such relationship exists.

Collective study is discussed the reasons why the correlation analysis is sometimes inefficient for assessing the impact of climate factors on the radial growth (Dendrochronological information …2007). The absence of clear correlation between growth variations and weather fluctuations does not necessarily mean that climate factors have no effect on aspen stem growth. Traditionally, dendroclimatic studies focus on forest stands under significant stress. If trees grow under normal environmental conditions, it will be rather difficult to calculate correlation coefficients since growth limiting factors change here from year to year. If this year productivity is limited by shortage of factor A, then next year, growth will be limited by shortage of factor B while factor A stays the same. There are also cases where the impact of factor A is offset by factor B. Therefore, based on the classical environmental concepts, the results we obtained can be interpreted as follows. Moscow lies in the area of the aspen range where climate factors combine in such a way as to ensure optimum growth situation for this very species. So, sampled forest stands grow under favorable conditions. Any upward or downward drastic deviations from mean exposure rates to the external factors affect aspen productivity in a negative way. The similar response both to upward and downward drastic deviations from the mean exposure rate combined with year-to-year changes in limiting factors makes the correlation analysis less useful for establishing relationship between productivity and climate factors.

4 Conclusion

In general, the correlation analysis has not provided any unambiguous information about the impact the climate factors might have on tree ring width. We could not identify factors having either positive or negative effect on stem growth. This is a typical result for forest stands growing under favorable conditions, and our findings support the conclusions we made in our previous research. Such results might not be promising for climate reconstruction studies, but they are of great importance for forestry and forest management where ecophysiological mechanisms are among key growth parameters. Therefore, we can say that the forest stands under study show good health in the urban environment and can be used as a source material for clonal propagation and micro propagation in urban land improvement plantings.

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