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INTEGRATED EFFECT OF CLIMATE AND AIR POLLUTANTS ON DIURNAL TREE RING FORMATION OF SCOTS PINE, NORWAY SPRUCE AND SILVER AND DOWNY BIRCH TREES STEM CIRCUMFERENCE

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The integrated effect of climatic and other abiotic stress factors including surface ozone on diurnal tree ring width formation of the prevailing in Lithuania tree species as the main response parameter of tree capacity to adapt to and mitigate the recent global changes was investigated. The obtained data revealed that Norway spruce is better adapted to recent climatic conditions in temperate forest than birch trees. Even during the drought episode spruce stem increment exceeded increment of the rest of considered tree species. Silver and Downy birch tree reactions revealed the lowest sensitivity of these tree species not only to unfavorable environmental factors but also to favorable factors which should stimulate tree growth intensity. This is why the growth intensity of this tree species recently has been gradually decreasing. The hypothesis that the coniferous species are more adaptive to recent climate changes was confirmed. The study is based on the results obtained conducting national project supported by Lithuanian Council of Research "FOREstRESS" (SIT- 3/2015).

Keywords: diurnal scale, tree ring, meteorology, ozone, integrated effect, adaptive capacity

INTRODUCTION

Climate change with increasing air temperature by intensity of 3 - 6 °C for 100 year period might have affected affect forest sustainability and adaptive capacity to unfavorable environmental conditions such as drought, frost and heat as well as air pollution such as acid deposition (Augustaitis et al., 2007a, 2010a, 2010b, 2011; Holmberg et al., 2013) and tropospheric ozone (Paoletti et al., 2007, Serengyl et al, 2011, Sicard et al., 2016; Vuorenmaa et al., 2017) or resistance to pest damage (Augustaitis, 2007). The lack of atmospheric humidity is predicted to reinforce negative effect of climate warming in southern and central parts of Europe, meanwhile in north eastern part of Europe a gradual increase in precipitation amount should mitigate this negative effect of climate changes (IPCC, 2014). Continuous monitoring of the tree ring formation throughout the year is crucial for the understanding of tree reactions to changes in environmental conditions, such as temperature, soil water content and rainfall. This investigation can be performed by using automatic dendrometers, which provide data on time series of diurnal rhythms of water storage depletion and replenishment which result in general tree ring formation (Zweifel and Hasler, 2001, Deslauriers at al., 2007).

In the presented study tree growth on the basis of diurnal growth intensity was investigated to the aim to detect the adaptive capacity of the prevailing in Lithuania forest trees to recent climate changes.

To meet the objectives of the study we attempted to detect:

- differences in inter-annual tree ring formation of prevailing in Lithuania tree species growing under different site conditions;
- effect of casual environmental factors on tree ring width formation on the basis of variation in stem circumference at diurnal scale;
- adaptive capacity of the considered tree species to recent changes in environmental condition.

MATERIALS AND METHODS

Intensive investigations at selected forest sites combining growth analysis at diurnal scale in tree stem circumference, stem sapflow intensity, meteorology and air pollution including surface ozone was performed.

Site description

Forest site 1 (FS-1): Oligotrophic mineral soil Forest Site. Soil type is *haplic arenosol*, water table is deeper than 2 m. Soil water potential at the depth of 40 cm is higher than that at the depth of 10 and 20 cm. Scots pine with silver birch and Norway spruce dominate in the first stand layer.

Forest site 2 (FS-2): Mesoeutrophic peatland soil forest site. Soil type is *terric histosol*, depth of water table is about 0.5 m. Scots pine, downy birch and Norway spruce dominate in the first stand layer as well.

The main dendrometric characteristics of the two typical for such a region mixed mature forest sites (FS) under very different growth conditions in Aukštaitija IMS are presented in table 1.

Table 1. Main dendrometric characteristics of the considered mixed stands

Site	Oligotrophic mineral soil forest site				Mesoeutrophic organic peatland forest site			
Parameter	DBH	Height	Basal area	Number	DBH	Height	Basal area	Number
Species	cm	m	m^2 ha^{-1}	unit ha^{-1}	cm	m	m^2 ha^{-1}	unit ha^{-1}
BIRCH	33.4	30.5	13.1	149	36.6	30.0	16.5	160
PINE	31.8	29.5	23.7	299	40.0	31.5	13.6	80
SPRUCE	29.8	29	3.5	50	43.5	32.0	11.5	241
TOTAL			**40.2**	**498**			**41.6**	**481**

Variation in meteorology, solar activity and surface ozone

Meteorological parameters: temperature, precipitation amount, humidity, atmospheric pressure, wind speed, solar radiation, UV A and B as well as data on surface ozone were obtained from Aukstaitija IMS. Over the 2016 vegetation period precipitation amount made about 253 mm, mean daily temperature 16.3°C, humidity – 79%, atmospheric pressure – 995 mbar, total solar radiation 211 $w \cdot m^{-2}$, UV A and UV B radiation 5.12 $w \cdot m^{-2}$ and 0.12 $w \cdot m^{-2}$, respectively, and ozone concentration 57 $\mu g \cdot m^{-3}$.

Drought effect was investigated between the 20th of June and the 2nd of July. During this period mean daily humidity decreased up to 65% and air temperature exceeded 25°C. This period was selected as the main for the evaluation of the adaptive capacity of prevailing in Lithuania tree species.

Data sampling methods

Data on 100 tree inter-annual sequences representing mean ring width formation of *Picea abies* (L.) Karst, *Pinus sylvestris* L, *Betula pendula,* and *Betula pubescens* growing under different nutritional and humidity conditions in north eastern part of Lithuania, Aukstaitija IMS, during the 2016 vegetation period were analysed. Six averaged data series of tree ring width formation on hourly scale were prepared to detect peculiarities of tree ring formation in relation to meteorology and air pollutants including ozone.

Data analyses

Pearson correlation analysis was used to analyze the relationship between stem ring formation and meteorological parameters on hourly scale and to detect key parameters most significantly related to changes in stem circumference during 2016 vegetation period. Linear multiple regression technique of the statistic software STATISTICAR 7.0 was employed to detect the integrated effect of the considered environmental factors. To develope the multiple regression models, the selected parameters were excluded from the regression model by a stepwise procedure based on their lowest level of significance (Draper & Smith 1998). Finally, variables with a high level of significance ($p < 0.05$) were used to run the models. These parameters were evaluated as key factors limiting diurnal fluctuation in stem circumferences of the considered tree species under different growth conditions.

RESULTS

Inter annual fluctuation in stem circumference of the prevailing tree species in Lithuania in 2016

Precise measurements of stem increment indicated close temporal linkages between temperature, solar radiation and patterns of stem ring width formation during diurnal cycles (McLaughlin et al., 2003). On the10th – 12th of May the first signs of increase in stem circumference of coniferous trees were detected and first of all at mineral soil forest site (FS-1) (Fig. 4). After a few days their growth started at peat land forest site (FS-2). Birch tree growth started a few days later at both considered forest sites. The end of tree ring width formation was detected approximately at the same time at both monitored sites, i.e. on the 15-18th of August. The obtained data revealed that in the middle of August tree ring width formation stopped. Therefore the 95 day period from tree ring width formation since the 12th of May up to its end the 18th of August were chosen for the detailed investigation of the causative effects of meteorology and surface ozone on changes in stem circumference on diurnal scale.

The obtained results revealed that spruce trees demonstrated the highest growth rate during this period at both considered forest sites. Differences were found comparing the growth rate of the pine and birch trees. On mineral

oligotropic soil pine trees demonstrated more intensive growth than birch trees, meanwhile on organic soil adverse effect was detected, i.e. birch tree growth rate exceeded that of pine trees.

Exceptionally different growth rates were established for the considered tree species during the drought period, which were most intensively expressed from the 22nd up to the 30th of June. During this period mean daily temperature exceeded 20 ˚C, humidity decreased up to 57%, UVA and UVB reached the highest value 6.68 $W \cdot m^{-2}$ and 0.15 $W \cdot m^{-2}$, respectively, and mean concentration of surface ozone reached 68 $\mu g/m^3$ (min – 31 $\mu g \cdot m^{-3}$, max – 93 $\mu g \cdot m^{-3}$). The obtained results were rather surprising. At mineral forest site with limited humidity regime pine trees due to water depletion demonstrated the greatest decrease in stem circumference, twofold lower reduction was recorded for spruce trees meanwhile increase in birch stem circumference was close to zero.

At organic soil forest site contrary to mineral soil FS downy birch trees suffered tree circumference reduction. Pine trees demonstrated the highest decrease in circumference, but no reduction was recorded for spruce trees. There increase in stem circumference was detected what shows that during drought episodes more humid site conditions were more favorable for spruce tree growth than those for pine and birch trees.

During the entire period of tree ring width formation, i.e. from the 12th of May up to 18th of August only precipitation amount had direct for 3 days positive effect on increase in stem circumference (Fig 1). At mineral soil forest site this effect was more significant than at peatland soil site. Based on the obtained results we can conclude that spruce trees were more tolerant to the lack of precipitation at both considered sites meanwhile pine trees demonstrated higher resiliencies to this meteorological parameter.

Different results were obtained investigating the effect of air humidity on stem ring formation. Both coniferous tree species demonstrated higher requirements for humidity for greater rate of tree stem growth than birch trees, and surprisingly at peatland soil forest site. Solar characteristics, i.e. photoperiods (sun angle), total radiation, PAR as well as UVA and UVB inhibited tree ring formation. The effect of these factors was reinforced by higher atmospheric pressure and surface ozone concentration.

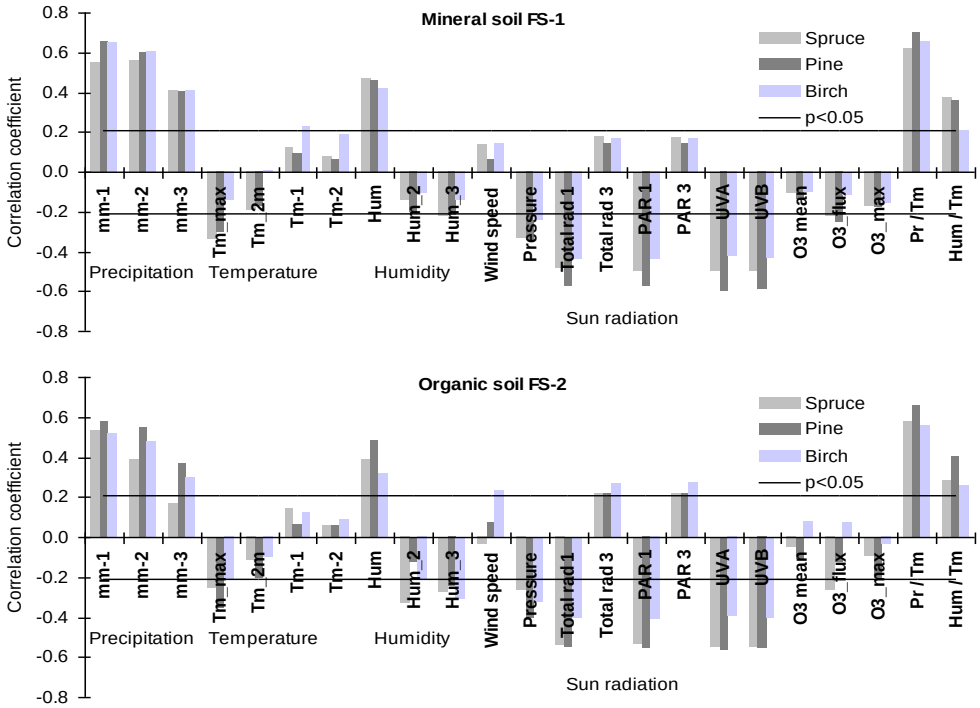

Figure 1. Relationship between diurnal data, meteorology and growth rates of the prevailing tree species under different growth conditions 12 05 – 18 08 2016

The obtained data confirmed the background knowledge in the field of short time tree ring width formation. Stem circumference is positively related to precipitation and relative humidity and negatively to temperature, sunshine hours and drought (Linares et al., 2009; Deslauriers et al., 2007; Zhang et al., 2016). However reactions of the considered tree species to these meteorological events under different growth conditions differed significantly due to their different strategies when surviving under different (favorable or unfavorable) environmental conditions (Lévesque et al., 2014; Zweifel et al., 2009) first of all heat and drought episodes and what quite well indicates their needles spectral reflectance (Masaitis et al., 2013).

The direct effect of precipitation, and a few day delayed effect of air humidity and temperature was found to be a main driver of growth rate of the considered tree species. This growth reaction shows that pine trees seem to be the most sensitive species to environmental changes. Meteorology and surface ozone explained more than 60% variation in BAI during vegetation period (Table 2). Key factors which were responsible for BA increment were mainly precipitation amount and humidity over the last 3 days. Effect of ozone concentration also remained statistically significant on BAI

formation on diurnal scale. This findings well agreed with results obtained on annual scale which indicated that meteorology and acidifying compounds explained variation in annual pine tree ring width variation most significantly (Augustaitis et al., 2007b, 2015; Juknys et al., 2014). However these obtained results contradict the findings obtained in Central or Southern Europe, where increment of Scots pine was least sensitive to environmental changes and differed least between different growth conditions (Seidling et al., 2012).

Considered meteorological parameters together with surface ozone also quite well explained variation in spruce tree stem BAI formation on diurnal scale. It proved that Norway spruce trees is quite well adapted to recent climatic conditions in temperate forest what contradicts the knowledge of the previous century, i.e. that warm and dry summers reduce radial growth in spruce stems and especially in the subsequent vegetation period (Spiecker, 1991; Eckstein et al., 1989). Gradual increase in amount of precipitation contrary to Central and Southern Europe is partly a response to these newest spruce growth phenomena.

In contrast to coniferous tree species, we faced a different problem when analyzing birch tree ring width formation. Key factors responsible for such birch tree growth peculiarities were precipitation amount and humidity. Least significant was the effect of temperature. These results well agreed with data obtained on annual scale, where air temperature of months had no significant effect on birch growth and only precipitation amount during June at mineral soil forest site stimulated birch tree ring width formation (Augustaitiene et al., 2018).

Table 2. Integrated effect of meteorology and surface ozone on tree ring formation of prevailing in Lithuania forest tree species on different site condition.

Mineral oligotrophic soil FS-1					Organic mesoeutrophic soil FS-2				
Dependent Variable FS-1 Spruce: R= 0.769 R²= 0.591 F(5,91)=26.336 p<0.0000 Std.Error of estimate: 0.0073					Dependent Variable FS-2 Spruce: R= 0.727 R²= 0.529 F(5,91)=20.477 p<0.0000 Std.Error of estimate: 0.0113				
	B	Std.Err.	t(91)	p<		B	Std.Err.	t(91)	p<
Intercept	-0.0319	0.0175	-1.8218	0.0718	Intercept	-0.0324	0.0273	-1.1864	0.2386
mm	0.0009	0.0002	4.1344	0.0001	mm	0.0013	0.0003	3.8632	0.0002
Hum	0.0008	0.0001	5.5939	0.0000	Hum	0.0010	0.0002	4.5396	0.0000
Hum_3	-0.0004	0.0001	-3.7397	0.0003	Hum_3	-0.0007	0.0002	-4.2604	0.0000
O3 flux	0.0002	0.0001	3.1824	0.0020	O3_max	0.0003	0.0001	2.5676	0.0119
Tm_max	-0.0007	0.0002	-3.0355	0.0031	Tm_max	-0.0007	0.0003	-1.9791	0.0508
Dependent Variable FS-1 Pine: R= 0.803 R²= 0.645 F(5,90)=32.810 p<0.0000 Std.Error of estimate: 0.1382					Dependent Variable FS-2 Pine: R= 0.794 R²= 0.630 F(5,90)=30.697 p<0.0000 Std.Error of estimate: 0.10603				
	B	Std.Err.	t(90)	p<		B	Std.Err.	t(90)	p<
Intercept	-0.4729	0.3371	-1.4029	0.1641	Intercept	-0.4104	0.2586	-1.5872	0.1160
mm	0.0278	0.0043	6.5391	0.0000	mm	0.0154	0.0033	4.7215	0.0000
Hum	0.0126	0.0027	4.6094	0.0000	Hum	0.0115	0.0021	5.4468	0.0000
Hum_3	-0.0076	0.0019	-3.9124	0.0002	Hum_3	-0.0067	0.0015	-4.5470	0.0000
O3_max	0.0039	0.0015	2.5889	0.0112	O3_max	0.0029	0.0011	2.5190	0.0135
Tm_max	-0.0117	0.0043	-2.7435	0.0073	Tm_max	-0.0097	0.0033	-2.9622	0.0039
Dependent Variable FS-1 Birch: R= 0.642 R²= 0.412 F(6,90)=18.341 p<0.0023 Std.Error of estimate: 0.0463					Dependent Variable FS-2 Birch: R= 0.581 R²= 0.337 F(6,90)=16.310 p<0.0165 Std.Error of estimate: 0.0704				
	B	Std.Err.	t(90)	p<		B	Std.Err.	t(90)	p<
Intercept	-0.0010	0.0114	-0.0852	0.9323	Intercept	-0.0055	0.0172	-0.3204	0.7494
mm	0.0009	0.0001	6.5029	0.0000	mm	0.0010	0.0002	4.7491	0.0000
Tm_2m	0.0010	0.0004	2.5528	0.1243	Tm_2m	0.0013	0.0006	2.2371	0.0778
Hum	0.0002	0.0001	1.8820	0.0631	Hum	0.0004	0.0001	2.6502	0.0095
Hum_3	-0.0002	0.0001	-2.5643	0.0120	Hum_3	-0.0004	0.0001	-3.6543	0.0004
O3_max	0.0001	0.0001	1.8320	0.0703	O3_max	0.0002	0.0001	2.8210	0.0059
Tm_max	-0.0010	0.0004	-2.4997	0.0642	Tm_max	-0.0016	0.0006	-2.6401	0.0498

Based on the obtained results we can conclude that coniferous tree species are more responsive to the changes to environmental factors than birch trees. Favorable environmental conditions resulted in significant increase in their stem circumference. The problem arises evaluating a rather stable growth of birch trees during the entire vegetation period. It is established that the long-term seasonal tree-growth biorhythm is partially synchronized with the photoperiod, not only because of its effects on basic physiological and growth processes (Heide, 1993) but also as a sign of local adaptations to a specific temperature photoperiod regime (Ježík et al., 2015). Obtained data on birch tree ring formation was controversial to this statement.

The capacity of birch trees to maintain high mid-day leaf water potential by reducing their crown-level stomatal conductance with the decrease in soil water availability (McDowell et al., 2008) could be evaluated as the highest adaptive capacity to extremely changing environmental conditions. Gradual reduction in leaf stomata density on a single birch tree as result of acclimation to extreme changes in environmental conditions (Wagner et al., 1996) also supported this statement. It explains why no regular pattern was obtained investigating the effect of meteorology and surface ozone on fluctuation in stem circumference on diurnal scale. However, the fact that favorable meteorological conditions did not result in higher rate of tree ring width formation could be attributed to the uncertainty in this field or to lowest birch trees adaptation to the favorable climatic conditions.

CONCLUSIONS

The obtained results revealed that spruce trees demonstrated a higher growth rate during the period of investigation at both considered forest sites. Increase in stem circumference was positively related to precipitation, relative humidity, and negatively to temperature and solar activity. These growth reactions indicated that coniferous tree species are most likely the most sensitive species to environmental changes. It proved also that Norway spruce trees due quite to their high resiliency is quite well adapted to recent climatic conditions in temperate forest.

Key factors responsible for birch tree growth peculiarities were precipitation amount and humidity. Least significant was the effect of temperature. The fact that favorable meteorological conditions did not result in higher rate of tree ring width formation could be attributed to the lowest birch trees adaptation to the favorable climatic conditions.

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