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Influence of drought on radial growth of Norway spruce in north-eastern Poland

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Introduction

The course of weather elements exhibits various pace and intensity over time and space, and therefore influences tree-ring formation in different ways. Ongoing climate change does and undoubtedly will affect growth of trees in great measure as climate is considered as the most influential natural factor that shapes this process (Saxe et al. 2001, Aitken et al. 2008, Mohan et al. 2009). Long-term scenarios, although still yet deficient and unsure, allow the assessment of the most probable climate conditions in the future. This, in turn, may serve in forecasts of forest development based on known relationships between tree growth and climate conditions, since factors that influence growth, productivity, mortality and germination of trees are responsible for the adaptation ability of forest ecosystems (Chmura et al. 2010).

According to even moderate scenarios (Christiansen et al. 2007, Meehl et al. 2007), temperature in Poland will rise by the end of the current century by 3-4°C depending on season. Although precipitation in that period will increase by up to 15% in some places, the total evapotranspiration will also rise and more droughts may occur (Hobbins et al. 2008). Together with overall poor water supply this may lead to deterioration of conditions of Polish forests including massive decline of tree species and reduction of forest cover. This drought-induced decline may especially affect species that are very vulnerable to moisture deficit, i.e. oak (Drobyshev et al. 2008). Norway spruce (*Picea abies* (L.) Karst.) is widely addressed as a species vulnerable to the moisture deficit, especially during the vegetation period (e.g. Solberg 2004, Vitas 2004). Summer droughts are sometimes identified as direct causes of extremely narrow tree-rings (negative pointer years). The response of trees to the limited amount of water may differ with regard to the habitat type. High moisture content in the soil may reduce unfavourable effects of low precipitation and high temperature. In turn, trees on drier sites may suffer significant decrease in growth or even stop growing under drought conditions. Recognition of these potential dangers is crucial from the point of view of forest economy.

The objective of this study was to investigate the influence of drought during the vegetation period on radial growth of Norway spruce in north-eastern Poland and to analyse the role of the moisture deficit in formation of significantly narrower tree-rings.

Material and methods

Material representing four habitat types was collected on 12 plots in three forest complexes in north-eastern Poland. At each plot, 15 dominant, healthy and undamaged trees were sampled. One increment core per tree was taken. The cores were sanded and scanned. CooRecorder image analysing program (www.cybis.se) was used for measuring tree-ring widths. CRUTS 2.1 database (Mitchell & Jones 2005) provided mean monthly air temperature and precipitation data. In total, 139 individual tree-ring width series were used to construct chronologies according to the conventional procedures (Cook & Kairiukstis 1990) with CRONOL software (Holmes 1999).

Residual chronologies were correlated with series of a simple moisture availability index (ratio between precipitation and temperature; the lower the index value, the drier conditions index describes) calculated for each month during the vegetation season (May-August) as well as with the total sum of precipitation in that period. DendroClim2002 (Biondi & Waikul 2004) software was used for correlation calculation. Negative pointer years defined as the situation when the majority of trees at an individual site formed a conspicuously narrower tree-ring were compared with the moisture surplus/deficit index calculated as a deviation of May-August sum of precipitation from the 1901-2000 mean.

Results

Growth of analysed spruces turned out to be strongly dependent on water conditions during the vegetation season. The strongest positive correlation between the moisture availability index and tree-ring width was found for June (Tab. 1). For the majority of the investigated sites this relationship was significant. In general, positive but not significant character of this relationship was also observed for May and July. In August, a surplus of available water does not favour growth of the analysed trees, but this relation was not statistically significant (Tab. 1). Similar pattern was found for correlation between ring width and total precipitation during May-August period. Again, almost all of the analysed chronologies exhibited significant positive correlation with water availability (Fig. 1). No clear the role of habitat type in modification of described relations was observed.

Table 1: Influence of water availability during the vegetation period on Norway spruce growth.

Month	PA1	PA2	PA3	PA4	PK1	PK2	PK3	PK4	PR1	PR2	PR3	PR4
correlation coefficients												
V	0,147	0,061	0,149	0,121	0,173	0,156	0,020	**0,372**	0,117	0,078	-0,153	0,136
VI	**0,379**	**0,307**	**0,351**	0,225	0,225	**0,248**	0,192	**0,296**	**0,408**	**0,285**	0,066	**0,392**
VII	0,177	**0,319**	0,282	0,194	0,062	0,258	-0,083	**0,237**	0,037	0,077	0,118	0,056
VIII	-0,026	0,132	-0,003	0,078	-0,019	0,047	-0,096	0,048	-0,077	-0,185	-0,068	-0,054
response function coefficients												
V	0,133	0,093	0,145	0,138	0,158	0,158	-0,008	**0,361**	0,079	0,019	-0,174	0,109
VI	**0,341**	**0,252**	**0,302**	0,180	0,190	**0,205**	0,170	**0,226**	**0,382**	**0,293**	0,096	**0,355**
VII	0,164	**0,232**	**0,253**	0,127	0,038	0,180	-0,039	0,135	0,066	0,153	0,135	0,072
VIII	-0,167	-0,065	-0,187	-0,035	-0,060	-0,070	-0,092	-0,054	-0,158	**-0,278**	-0,145	-0,148

PA – Augustowska Primeval Forest, PK – Knyszyńska Primeval Forest, PR – Romincka Primeval Forest; habitat types: 1 – fresh mixed coniferous, 2 – fresh mixed deciduous, 3 – swampy mixed deciduous, 4 – fresh deciduous forest habitat types; values significant at the 0.05 level were bolded.

For the 20th century, 8 individual (1906, 1912, 1931, 1941, 1954, 1964, 1992 and 2000) as well as one consecutive (1979-1980) negative pointer years of spruce in north-eastern Poland can be distinguished. A few pointer years coincide with water availability deficit (Fig. 2). Only 1964 turned to be a drought-induced pointer year observed in all three analysed forest complexes. However, in Romincka Primeval Forest it is not so profound. Interesting situation occurred in that forest complex in the years 1952-54, when rather poor increment coincides with three consecutive years of severe water deficit (Fig. 2, PR – panel). In turn, in Knyszyńska Primeval Forest, a narrow ring in 1984, which itself has average precipitation during May-August, is proceeded by two years of drought during the vegetation season.

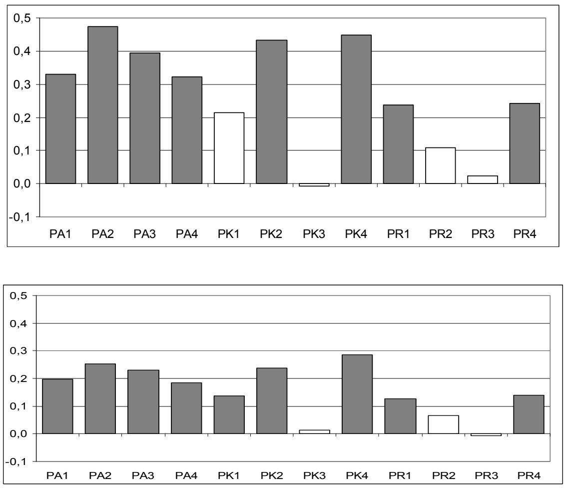

Figure 1: Influence of precipitation during the vegetation period on Norway spruce growth. Top – correlation coefficients, bottom – response function coefficients, grey bars indicate values significant at the 0.05 level. For site description see Table 1.

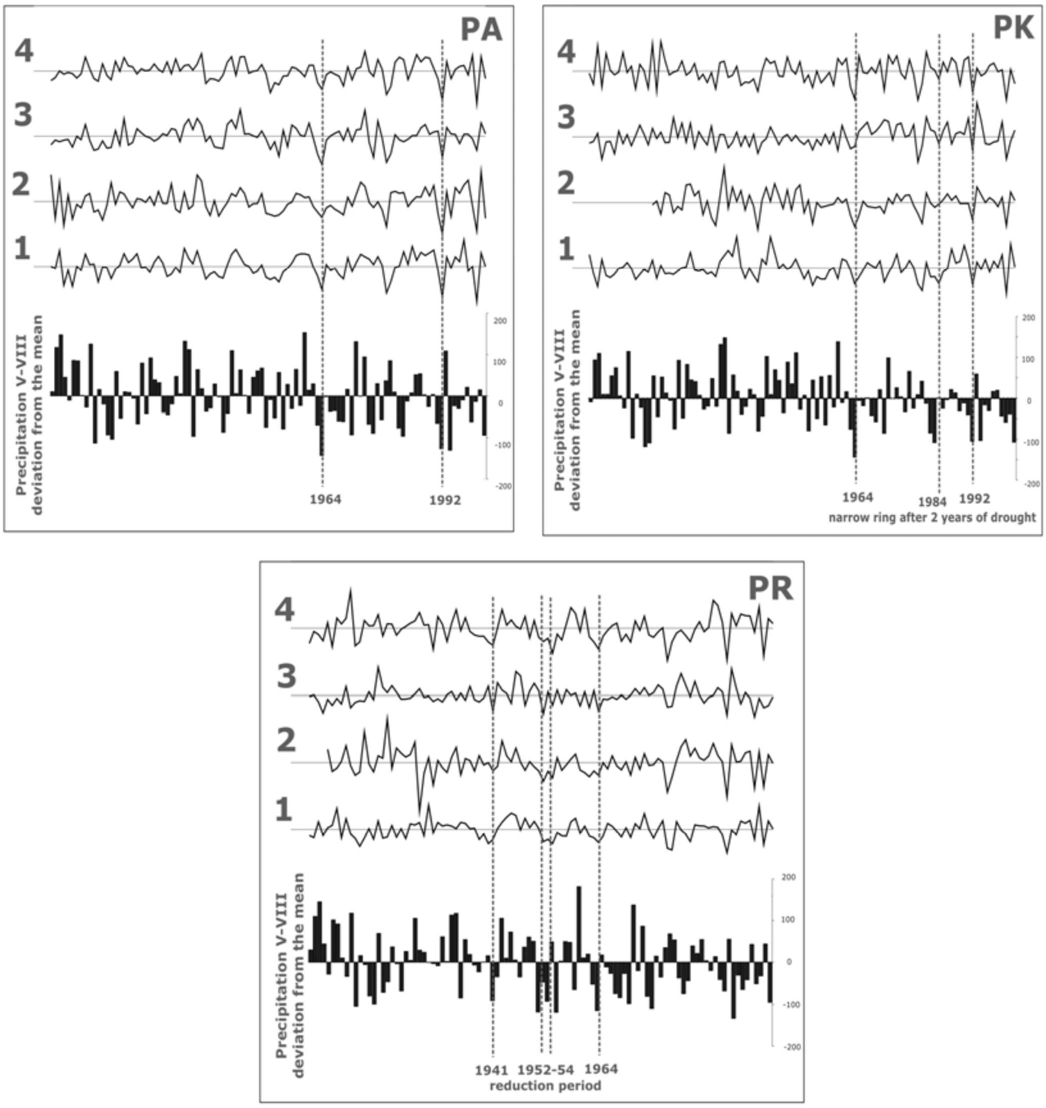

Figure 2: Comparison of Norway spruce growth (standard chronologies) and water conditions during the vegetation season in the 1901-2000 period. Vertical dashed lines indicate years when very narrow tree rings coincide with unusually low May-August precipitation. For site description see Table 1.

Discussion

Spruces in north-eastern Poland grow under average (not extreme) climate conditions and hence, in general, they do not respond very strongly to climate varaitions (Bijak 2007, 2010), which is in accordance with the concept presented by Mäkinen et al. (2003). However, ongoing climate change may alter this situation as weather may become more harsh. According to some of the available scenarios (e.g. Christiansen et al. 2007, Meehl et al. 2007), both precipitation and temperature in north-eastern Poland will rise, which may lead to increased evapotranspiration. This, in turn, may result in higher drought occurrence (Hobbins et al. 2008). Since Norway spruce is widely addressed as a species vulnerable to the moisture deficit, especially during the vegetation period (e.g. Zielski & Koprowski 2001, Solberg 2004, Vitas 2004, Čejková & Kolář 2009), such evolution of climate conditions probably will have negative consequences for growth of that species.

Analysed spruces showed significant response to low precipitation and high temperature in early summer (Bijak 2010). Similar observations were reported for north-eastern Poland by Koprowski & Zielski (2006), for neighbouring Lithuania by Vitas (2004) and for Belgium by Laurent et al. (2003). Present study reveals that overall precipitation during the vegetation season as well as moisture availability in the May-July period is very important for spruce tree-ring formation. Especially pluvial and thermal conditions in June turn out to be the most crucial and seem to be the main driving force for ring formation in the investigated spruces. Water deficit and warmth in late spring and summer increase the dehydration of the plant (Dittmar & Elling 1999). This, in turn, may cause restriction or even cessation of cambium activity and, as a result, xylem production.

Soil fertility and moisture conditions of the studied sites seem to have no prominent influence on the relationship between water availability and growth of the analysed spruces. No clear pattern indicating that specific habitat sharpens or softens the impact of drought can be noticed. Since no significant effect of habitat conditions on climate-growth relations was found for analysed spruces (Bijak 2010), other factor(s) must be important for climate-growth relationships. Drought vulnerability of spruce suggests that bedrock and hence, ground water table level might be such factors. This hypothesis can be supported by high correlation of growth rates with both the water availability index and May-August precipitation observed for Augustowska Primeval Forest sites (Tab. 1, Fig 1). These sites are located on sandy glacial outwash plain (sandur) originating form the last glacial period. This well permeable substrate may cause fast seepage of rain water that is not stored in the soil, and hence, is not available for trees.

Detected negative pointer years are, in general, similar to those found in natural, unmanaged stands of Białowieża National Park (Koprowski & Zielski 2008). Authors link most of the pointer years with low precipitation, especially in the May-July period. Despite of the observed dependence of analysed trees on moisture availability, a comparison of the occurrence of very narrow tree rings with drought events indicates that only a few negative pointer years are drought-induced (Fig. 2). This may suggest that although spruces in north-eastern Poland are vulnerable to poor water availability, they are able to resist most drought conditions. Such situation may be influenced by silvicultural treatments. Laurent et al. (2003) state that thinning improved the resistance of spruce stands from central France to drought. However, moisture shortage may affect trees in indirect ways. Drought may weaken a tree and make it more sensitive to the attacks of fungi or insects, which in turn may result in poorer increment in the current or in the following year (Rolland & Lemperiere 2004).

Conclusions

Spruces in north-eastern Poland exhibit similar radial growth patterns and generally uniform response to moisture availability during the vegetation period. The most important time in terms of water conditions is in June. Majority of analysed trees showed strong dependence on water deficit in that month. The habitat type did not influence the character of growth-drought relationship.

Only a few negative pointer years can be directly linked with water deficit during the whole vegetation period or with drought conditions in an individual month. However, even short-time moisture shortage may weaken a tree and make it more sensitive to the attacks of fungi or insects, which in turn may result in poorer increment in the following year(s).

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