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The manifestation of drought events in tree rings of beech and oak in northern Bavaria (Germany)

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Introduction

The frequency and intensity of climatic extreme events is expected to increase in the near future in central Europe as a consequence of climate change (Schär et al. 2004). For northern Bavaria, an increase of summer temperatures of up to 2.4°C is expected, while summer precipitations are predicted to decrease (Rennenberg et al. 2004). Some climatic events manifest themselves by characteristic features such as frost rings, light rings, false rings or reaction wood. Droughts or severe storms are expressed by abrupt growth reductions which might alter growth for a number of years (Schweingruber 2001). Drought events might alter the intrinsic water use efficiency of trees and document themselves in variations of stable isotopes in wood cellulose (Bonn 2000, Skomarova et al. 2006). We present first results of a project (“FORKAST”) studying the effects of extreme drought events on trees of edaphically dry sites in northern Bavaria (Germany) during the last century. Special emphasis is laid on the resilience time needed by different tree species for recovering from extreme drought. We investigate a spatial network of chronologies of common beech (*Fagus sylvatica* L.) and sessile oak (*Quercus petraea* (Mattuschka) Liebl.) by applying a multi-parameter approach including quantitative analyses of intra-annual variations of wood anatomy, wood density and carbon isotopes. The final goal of this study is to assess the adaptability of these tree species if frequency and intensity of drought events will increase in the near future. This will lay a dendroecological basis for forest management actions that may have to be taken in order to modify the forest structure on drought-prone sites as an adaptation to future climate change.

Material and Methods

Study sites and climate data

The study sites selected (Fig.1) show intermediate or shallow soil depths on clay, sand or limestone and cover an annual precipitation range from ~600 mm (Markt Zellingen) up to ~900 mm/a (Geisfeld Ottobrunnen) and an annual mean temperature range from 7.6°C up to 9.1°C. At each site, fifteen dominant and five subdominant trees of each species were sampled with two cores per tree obtained at breast height As predictor variables for growth/climate analyses, monthly temperature and precipitation series from the nearest climate stations (obtained from Germany's National Meteorological Service (DWD)) and the self-calibrating Palmer Drought Severity Index (scPDSI; a measure of regional soil moisture availability; van der Schrier et al. 2006) are used. The most severe drought events are defined as years in which the annual precipitation sum departs more than one standard deviation from the mean annual precipitation sum .

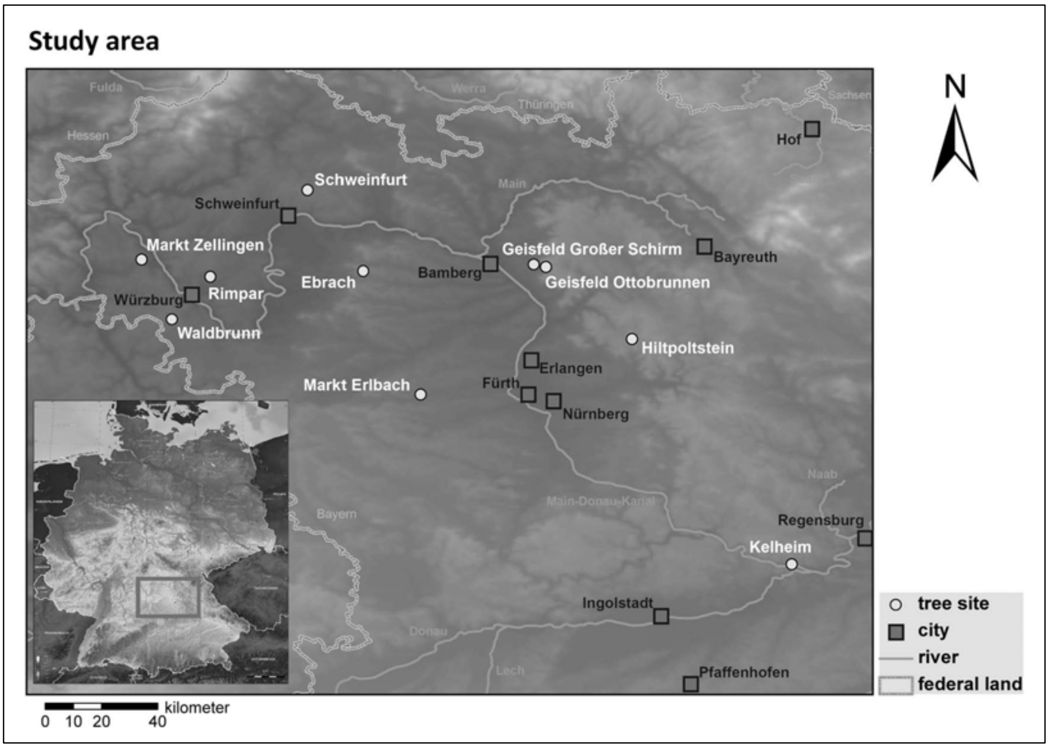

Figure 1: Network of study sites established in northern Bavaria for the FORKAST-project.

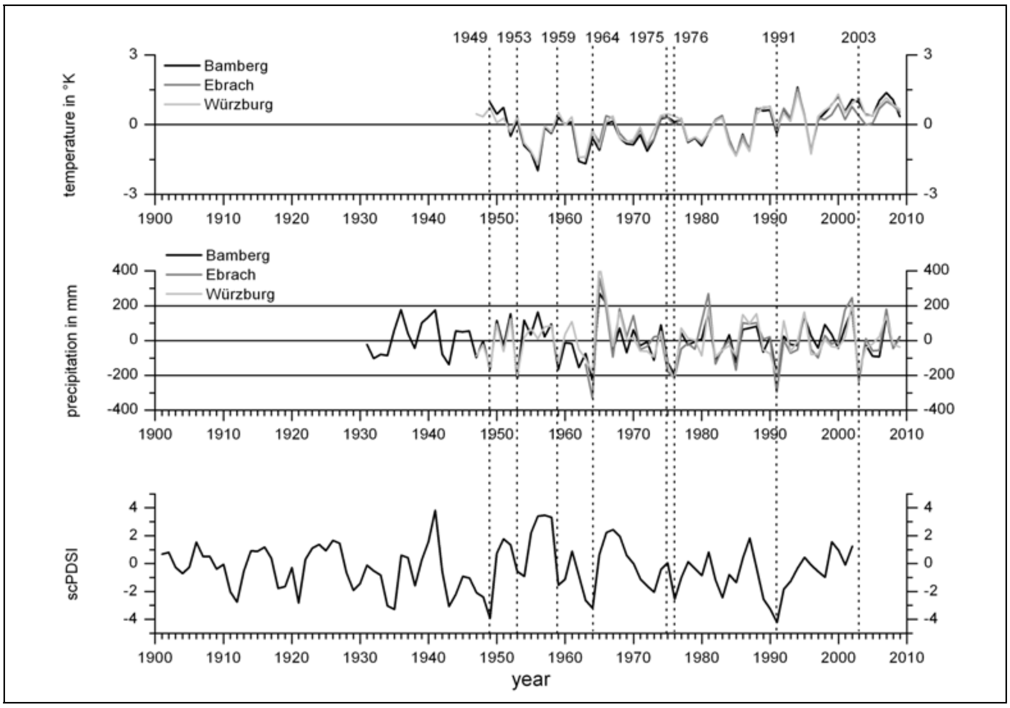

Figure 2: Deviation of annual temperature and precipitation of the climate stations Würzburg, Ebrach and Bamberg from mean, scPDSI and most severe drought events (dashed vertical lines).

Tree-ring data

The samples were prepared according to standard procedures (Cook & Kairiukstis 1990). Individual tree-ring width measurements were visually cross-dated (Fritts 1976) prior to tree ring standardization using the program ARSTAN (Cook 1985). A cubic smoothing spline with a 50% frequency cut-off at 67% of the individual tree ring series length was applied to remove biologically induced age-trends and to retain high-frequency variations (Cook & Peters 1981). Standard chronologies were computed using a bi-weight mean removing the effects of endogenous stand disturbances and enhancing the common signal contained in the data (Cook & Holmes 2008).

Statistical analysis

Pointer years after Cropper (1979) were calculated using a threshold of +/- 0.75 and regional pointer years identified when more than 50% of the study sites showed the same reaction. Pearson´s correlation coefficients between tree-ring chronologies and climatic data were calculated using DENDROCLIM2002 (Biondi & Waikul 2004). Superposed epoch analysis testing for mean growth response during the most severe drought events was calculated and the significance levels (p<0,05) were estimated from confidence intervals derived from bootstrap sampling with 1000 samples using dplR-package in R (Bunn 2008).

Results

The tree-ring chronologies of each species show a clear synchronicity among the study sites, but significant differences between the two species and only few common negative regional pointer years (Fig. 3). The negative regional pointer years and other strong declines of *F. sylvatica* coincide with (most) severe drought events (Fig. 3), their consecutive year (1953, 1960, 1964, 1971, 1976, 1986, 1992, and 2003) and/or with regional mast years (1948, 1960, 1992, and 2009, Dittmar & Elling 1999). For *Q. petraea*, however, the pattern is less clear: only few negative regional pointer years of *Q. petraea* coincide with (most) severe drought events (1964, 1976, and 2005). Some pointer years occur during wetter and colder conditions (1956, 1968, and 1996), whereas others have probably to be attributed to mast years or insect calamities for which no data were available.

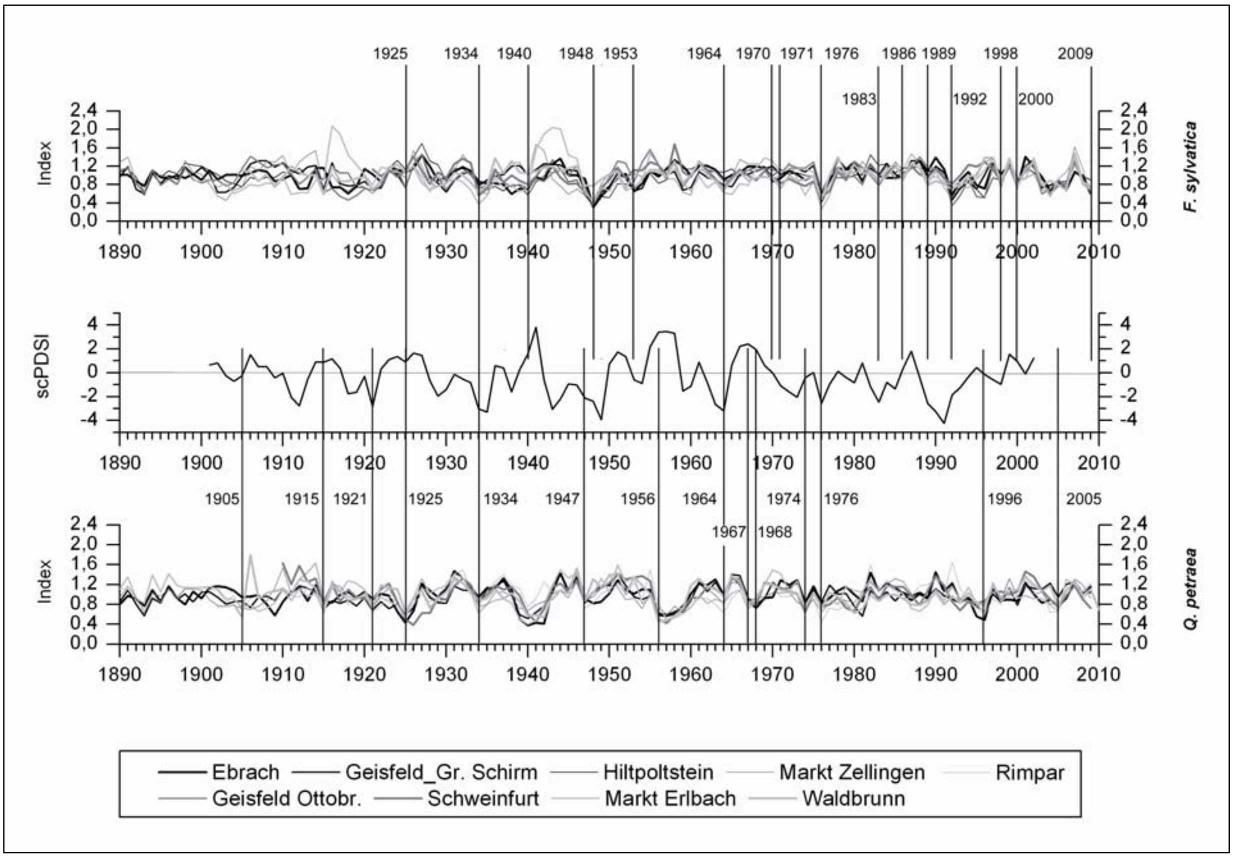

Figure 3: Standardized tree-ring chronologies, scPDSI and negative regional pointer years (vertical lines).

These observations are confirmed by the results of the superposed epoch analysis. For *F. sylvatica* (Fig. 4A), the majority of sites show a highly significant growth decrease in the most severe drought event years (year 0) and/or in the consecutive year (year 1). Only at site Hiltpoltstein, trees do not show such a pronounced growth decline. This might be attributed to a major die-off phase after the drought year 2003, so that the remaining trees sampled might be better adapted to drought events. The recovery reaction on all sites is accomplished two years after the extreme event (year 2). In contrast, *Q. petraea* is much less affected by the most severe drought events as only few sites show a weak, statistically non-significant decrease in tree-ring width in the event year or its consecutive year (Fig. 4B).

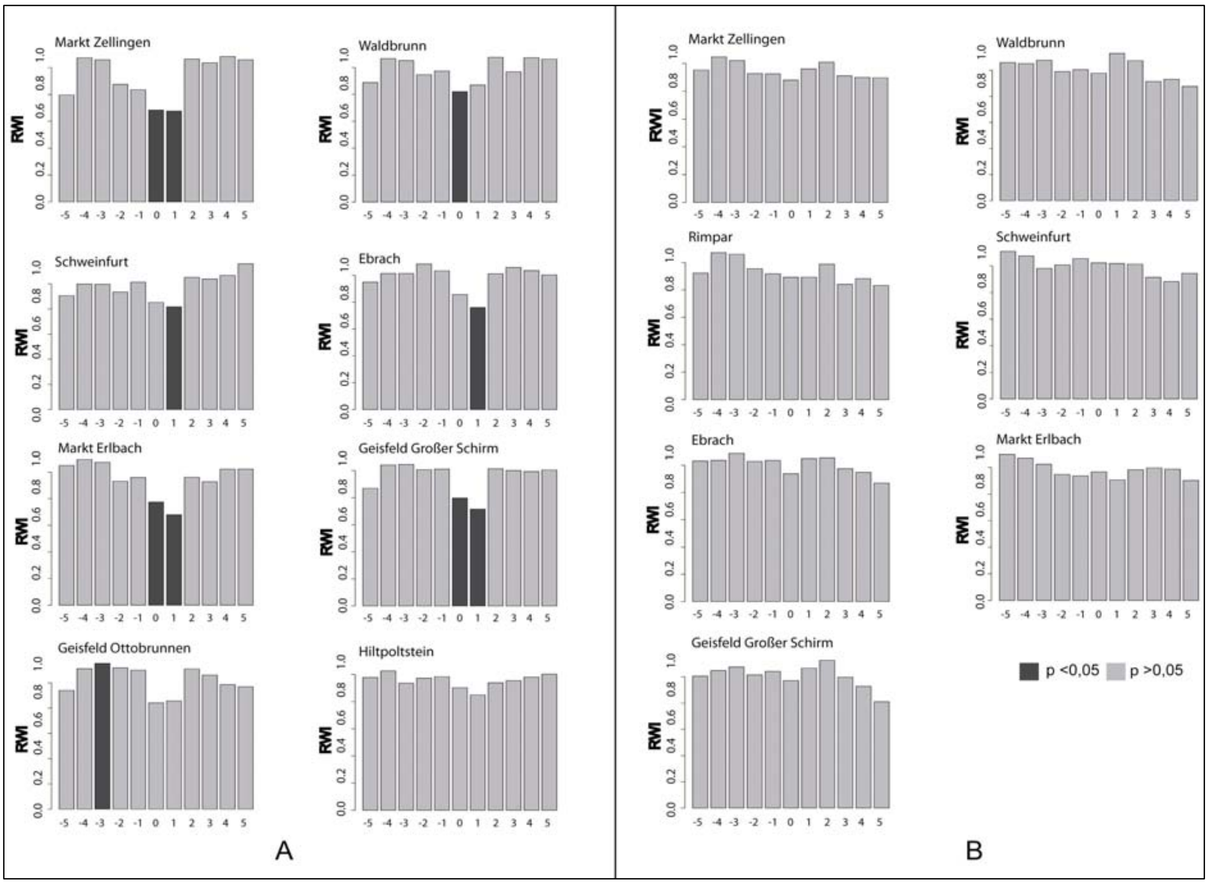

Figure 4: Superposed epoch analysis of the eight most severe drought years for F. sylvatica (A) and Q. petraea (B).

The Pearson´s correlations between tree-ring width, temperature, precipitation and the scPDSI (Fig. 5) reveal significant differences between *F. sylvatica* and *Q. petraea* which are in line with the results discussed above. *Fagus sylvatica* shows a strong positive correlation with the scPDSI (whose high auto-correlation can be seen in the diagram) especially during late summer and autumn of the previous year and during the summer months of the actual year. This means that high available soil moisture favors growth, especially when the soil water reserves are replenished in winter to provide water reserves during the hottest months. The negative correlation between tree-ring width and temperature and the positive correlation with precipitation during the summer months of the previous and actual year confirm the sensitivity of this species to summer drought.

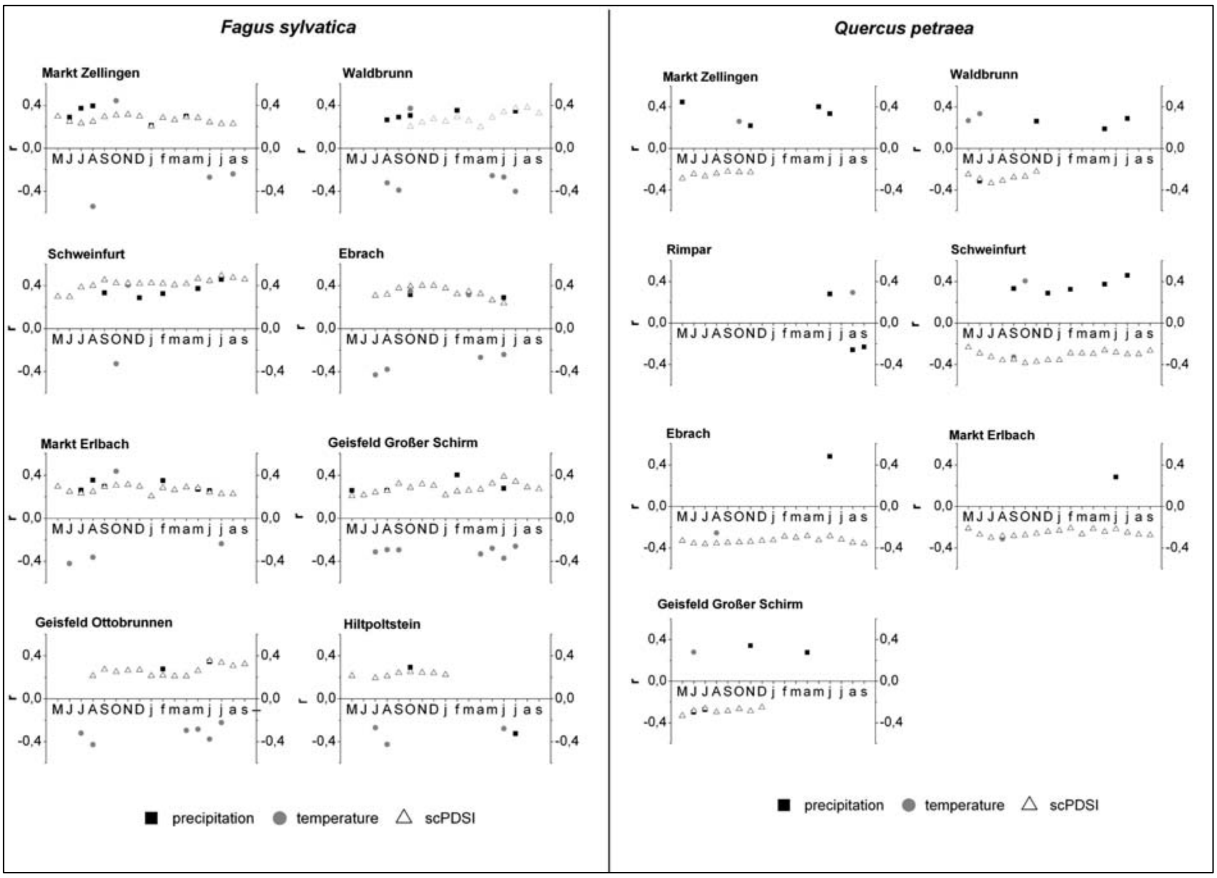

Fig. 5: Pearson´s correlation coefficient between annual precipitation, mean temperature and scPDSI and tree-ring width of F. sylvatica and Q. petraea.

Conclusions

Our results confirm those of previous studies revealing the sensitivity of *F. sylvatica* to drought and the importance of the previous year conditions for physiological processes (Friedrichs et al. 2009). Moreover, they clearly show that *Q. petraea* is much less affected by extreme drought events and seems to be better adapted to actual and possibly future prevailing climatic conditions on edaphically dry sites. Under present conditions, the recovery reaction of *F. sylvatica* still seems to be fast enough to recover between consecutive drought events. However, observations on severe damages of beech after drought events have been made by foresters, which points to an increasing risk of drought damage. These results will have to be reconfirmed and refined by successive analyses of wood anatomy, δ^{13}C isotope variations and species-specific intrinsic water use efficiency.

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