

Impacts of drought at various time scales on forest growth in the Most coal forest reclamation areas in the Czech Republic

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Abstract. This study evaluated the effect of moisture conditions at various lags on the nine tree species (*Robinia pseudoacacia*, *Pinus strobus*, *Betula pendula*, *Quercus rubra*, *Quercus robur*, *Fraxinus excelsior*, *Tilia cordata*, *Larix decidua* and *Juglans nigra*) dominated in the Most Basin coal forest reclamation areas located in the driest areas of the Czech Republic. The standardized precipitation evapotranspiration index (SPEI) was used to quantify the moisture conditions for each month of the year and 24 accumulated lags during the period 1961–2010. To enhance and extract the climate signal in the tree-ring data, standardization was performed. The response of tree growth to drought largest varied among species, being the maximum growth-drought correlation strong for *J. nigra*, *B. pendula* and *Q. rubra* ($r=0.8$), medium for *Q. robur* and *R. pseudoacacia* ($r=0.6$) and weak *L. decidua* ($r=0.3$). The minimum association between growth and drought was detected for *T. cordata*.

Introduction

- Breshears et al. (2005) and Adams et al. (2009) were introduced a new concept of “global-change-type drought” to describe droughts related to precipitation shortages and warmer conditions. Adams et al. (2009) separated the effect of temperature from other climate variables and biotic agents and showed that the effect of warmer temperature in conjunction with drought can be substantial. They established that with warmer temperatures, droughts of shorter duration, which occur more frequently, would be sufficient to cause a widespread die-off in *Pinus edulis*.
- Generally, there are lacks of studies analyzing the response of radial tree growth to various time scales of moisture conditions (wet/dry).
- The majority scientific researches in forestry reclamations deal only with the importance of ameliorating for individual species, their initial survival rate of seedlings and/or the impact of various measures on their well-being.
- The primary criterion for selection of tree species assortment of reclamation was the resistance in the first year after planting.
- Further, for afforestation tree species priorities were used a large ecological spectrum and also takes into account the tolerance to high air pollution load. However, the very little information can be found in the literature regarding to long-term development and growth dynamics of individual species in these habitats.
- Thereby, in this study was investigated the response of tree growth to different lags of drought, quantified by means of the SPEI, in the Most Basin coal forest reclamation areas in the north-western of the Czech Republic. This approach could improve the knowledge of the long-term responses of tree growth to water availability better than using precipitation data itself.

Material and methods

- This study integrated the long-term experimental dendrochronological data and monthly meteorological dataset recorded in the network of the Czech Hydrometeorological Institute.
- It was selected the oldest forestry reclaimed area in the Most Basin, to evaluate the growth dynamics of individual species in the four dump sites (Fig. 1).
- For each tree species, the mean annual incremental curve was computed and detrended (standardized) using quadratic regression function with the aim to remove non-climatic signals.
- The SPEI (Vicente-Serrano et al., 2010) was used to quantify the moisture conditions for each month of the year and 24 accumulated lags during the period 1961–2010 (from January 1961 to December 2010) (Fig. 2a–b).
- The steps followed for the SPEI calculation were:
 - the parameterization of potential evapotranspiration (*PET*) based on monthly minimum (*T_{min}*) and maximum air temperature (*T_{max}*) and extraterrestrial radiation;
 - monthly water balance, calculated as the difference between monthly precipitation (*P* - the input of water into circulation within the landscape) and potential evapotranspiration (*PET* - the water output component);
 - normalisation of the water balance into a log-logistic probability distribution to obtain the SPEI series from Kopisty station located in study area (Fig. 2a–b).
- Effect of drought on dynamics of growth was determined on standardized anomalies of annual increment series of nine tree species.
- Since we cannot know in advance the growth responses to drought at various lags, the SPEI series at timescales between 1 to 24 months was correlated with the standardized increment of trees (SIT) series (Fig. 3).
- A negative drought effect on dynamics of trees growth was detected when the SIT values was ≤ -1 . While a drought episode was defined as a period longer or equal to 1 month when the SPEI value was ≤ -1 .

Results and discussion

- Summarized our results, we can state that a stressed tree may take a year (12 month lag) or two (24 month lag) recover from a drought period, this problem can be dealt with more complex modeling and/or e.g. the SPEI at different lags.
- We found delayed response of trees growth to drought. The negative effect of extreme drought of 2003 on the increment of trees for the majority of species appeared to the next year. To summarize the correlation analyses and compare to drought effect among species, we found differences in the responses of tree growth to different lags of the SPEI (Fig. 3).
- Tree species growing in coal forest reclamation areas showed relative high relationship ($r>0.66$) with SPEI ≤ -1 drought series at longer time scales, which it shows that cumulative water deficit during one year affect tree growth. Nevertheless, for *L. decidua* significant correlations only appeared in April–May and July–October ($r=0.3-0.6$) at short- to mid-term droughts, the period when growth rates are usually maximum and when water deficit in dry years is markedly (Fig. 3).
- High correlation were found between the SPEI and the SIT of *J. nigra*, *B. pendula* and *Q. rubra* (maximum $r=0.8$), while for *T. cordata* did not show significant correlation (less than 0.4). A moderate growth response ($r=0.6$) to drought was obtained for *Q. robur* and *R. pseudoacacia* since they showed significant correlation at lags up to 14 month, mostly during early-spring months. High level dependence of water availability of *P. strobus* was only reported in short time scales.
- The Potop et al. (2012) obtained a strong relationship between productivity of the majority of market vegetable crops and the SPEI over short time scales. The SPEI from 1 to 6-month lags also showed a high correlation with the variations in soil moisture, which determine water availability for vegetable crops. Consequently, the SPEI has the advantage of determining exactly the time scale in which the antecedent conditions are affected the values of the index. The use of the different time-scales allows one to reproduce the different times of response of agricultural crops and natural vegetation to the availability of water.

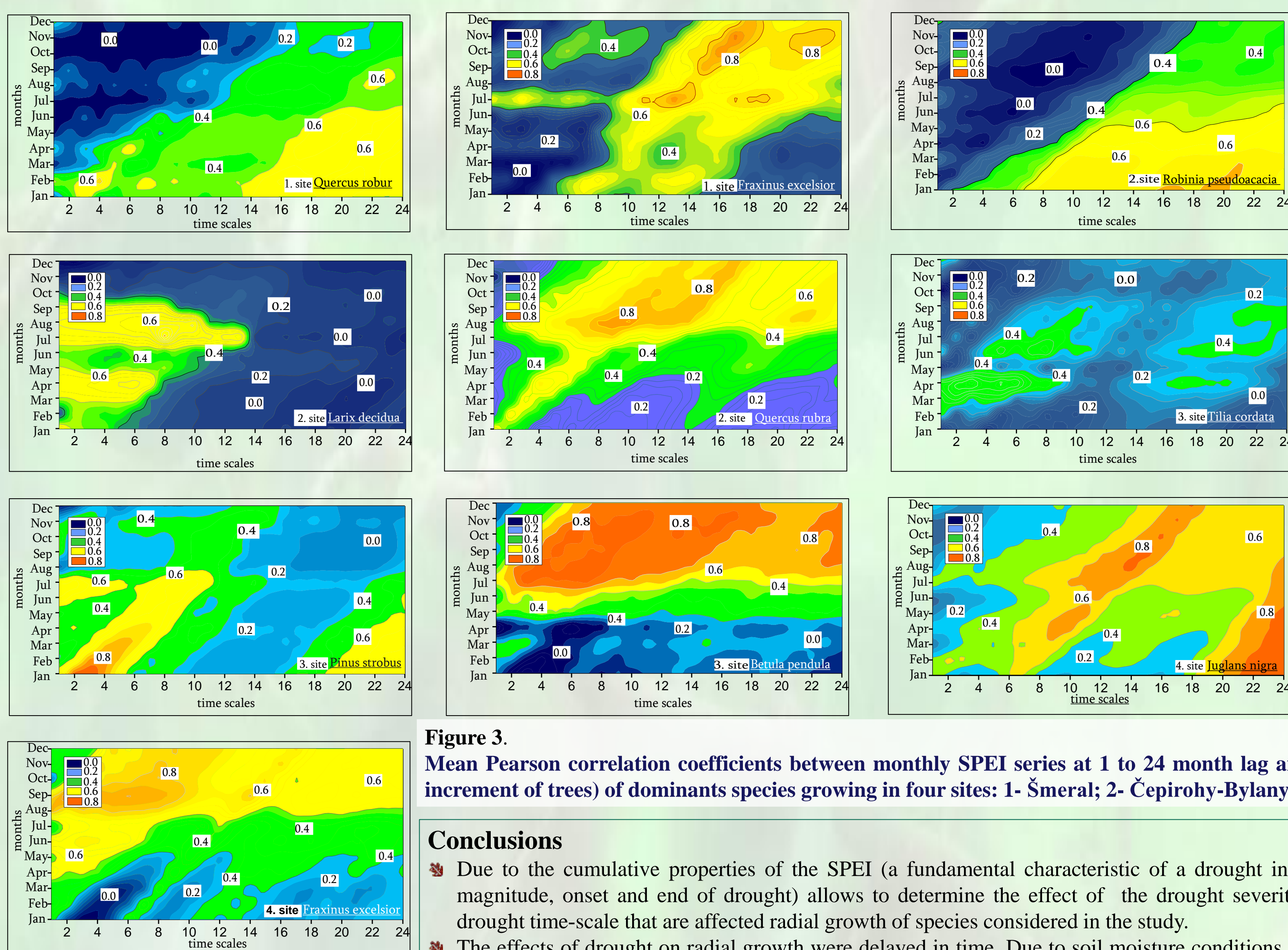


Figure 3. Mean Pearson correlation coefficients between monthly SPEI series at 1 to 24 month lag and annual SIT (standardized increment of trees) of dominants species growing in four sites: 1- Šmeral; 2- Čepirohy-Bylany; 3- Větrák; 4- Užín.

Conclusions

- Due to the cumulative properties of the SPEI (a fundamental characteristic of a drought index to determine the duration, magnitude, onset and end of drought) allows to determine the effect of the drought severity on tree growth, but also the drought time-scale that are affected radial growth of species considered in the study.
- The effects of drought on radial growth were delayed in time. Due to soil moisture conditions varies slowly, on time scales of months to seasons and thus carries memory from the previous month's climate, reduced soil moisture in autumn–winter, due to the lack of precipitation, can affect the availability of moisture conditions of forests in next season or year.
- High growth-SPEI correlation can be explained as follows: (i) forest reclamation area is situated in the driest region; (ii) due to unfavourable properties of soil substrate (with low water holding capacity) leads to shallower rooting near all trees and (iii) unavailability of groundwater level for the active part of the root system.

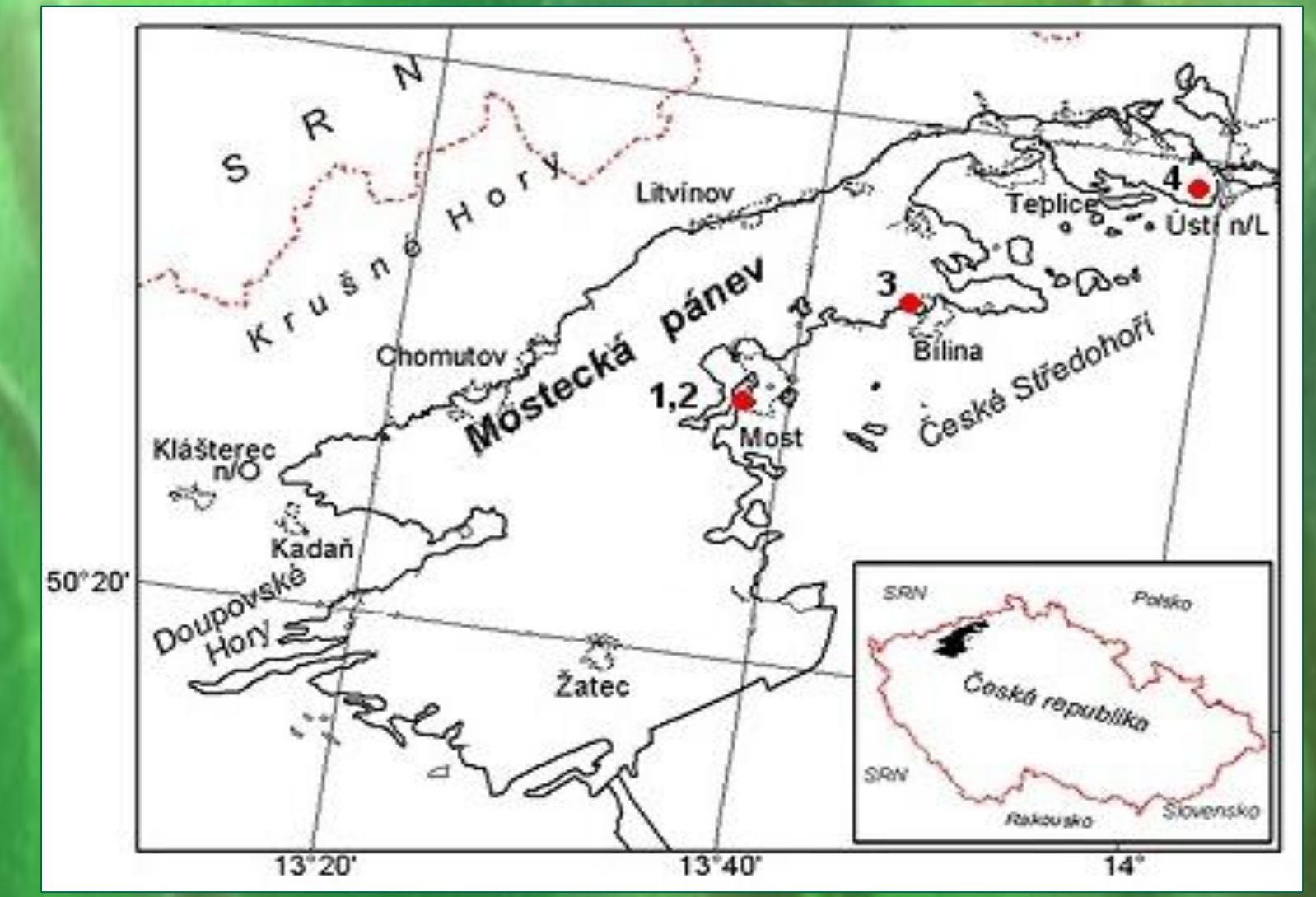


Figure 1. Distribution of forest sites (red points) in the Most Basin coal forest reclamation areas in the north-western of the Czech Republic. The four dump sites: 1 - Šmeral, 2 - Čepirohy-Bylany, 3 - Větrák, 4 - Užín.

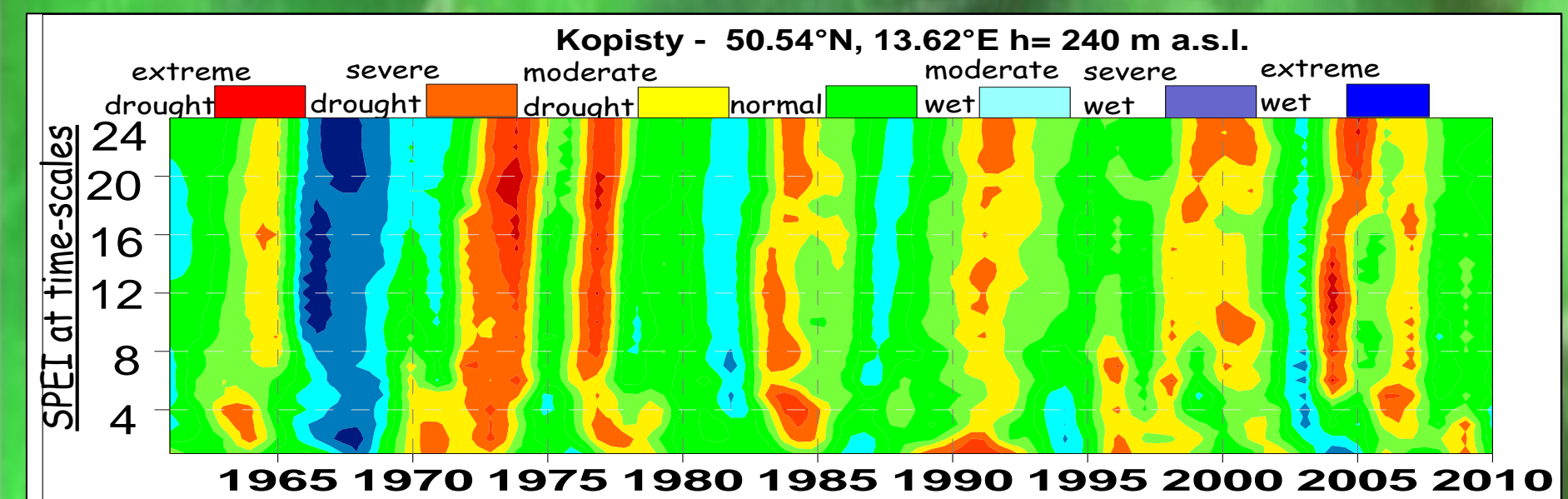


Figure 2a. Temporal evolution of the SPEI at time scales from 1 to 24-month for the period 1961–2010.

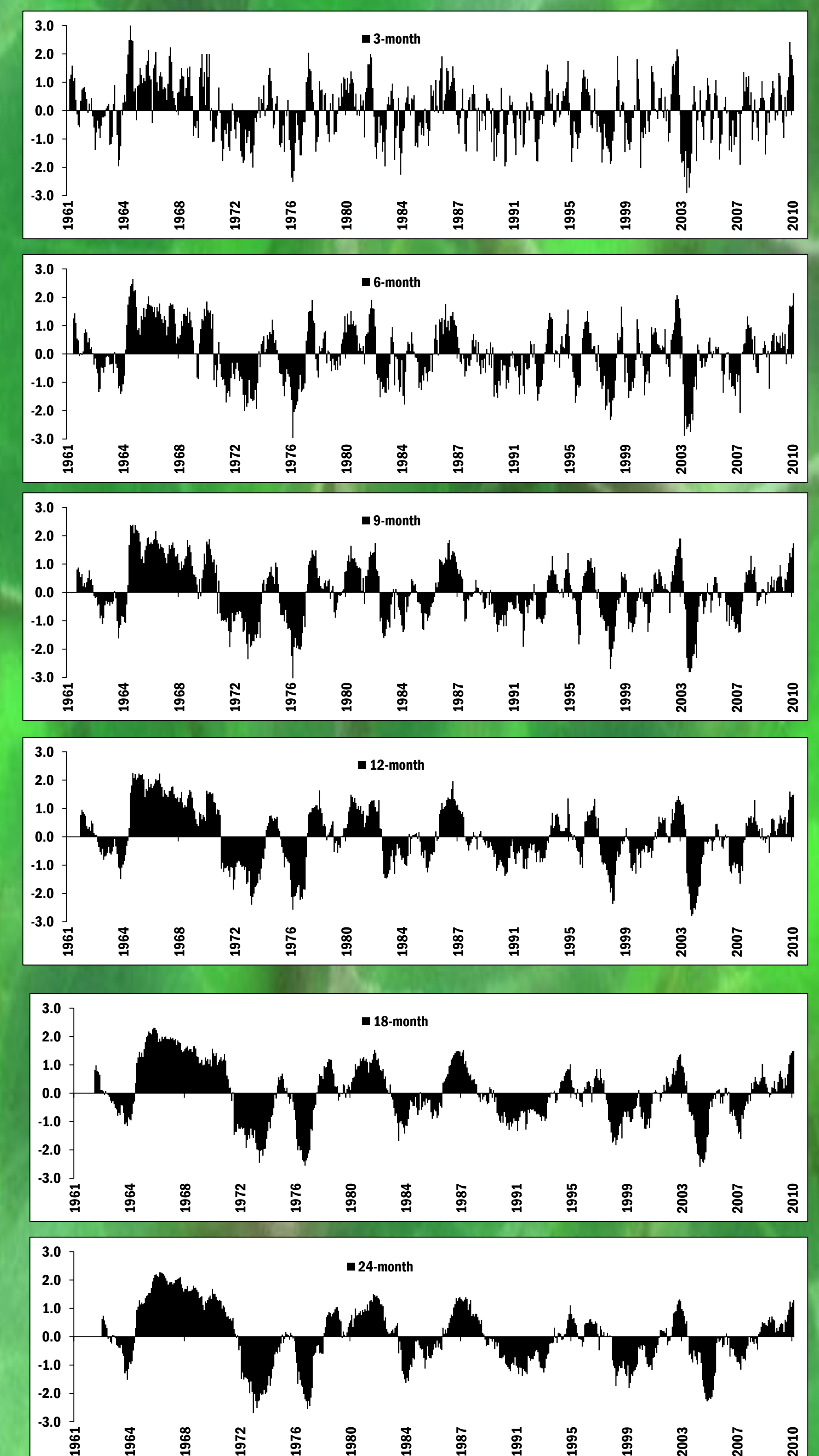


Figure 2b. Evolution of the moisture conditions quantified in multi-scalar way using the SPEI in study area.

- The plots showed that the period in which dry conditions were identified tended to increase by some months as the time scale became longer.
- This resulted from the procedure for calculation of the multi-scalar drought index, because longer time scales generated smoother fluctuations and thus a larger sequence of anomalies with the same sign.

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