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OVERVIEW OF DENDROCLIMATOLOGICAL STUDIES IN THE BALKAN PENINSULA

SUMMARY

To develop climate models and improve the decision-base for future forestry and agronomy strategies, information on the frequency, intensity and duration of extreme events from the time before instrumentally measured meteorological data should be assessed. The science of acquiring this information is dendrochronology. It is used by various disciplines, such as archaeology and climatology, to date old wooden objects, compare individual climatic factors to tree-ring proxies on an annual scale or to reconstruct past climate. Dendrochronological investigations on the Balkan Peninsula have been made in several sites and species. Scientists have discovered a clear temperature signal on temperature sensitive sites, droughts as the most limiting growth factor in inner parts of the Balkan Peninsula and, on some sites, sunshine/moisture stress as the most influential factor for tree growth. Analysing years of extremely enhanced or reduced tree growth has revealed events such as instability of the climate signal in time, extreme droughts or wet summers, the influence of volcanic eruptions or past fire damage. Combining new results from the latest studies and extending chronologies further back in time, using wood from archaeological excavations, will improve the atlas of past droughts or extreme climatic events, in both spatial and temporal dimensions and will ease the creation of future climate adaptation policies.

Keywords: Reconstruction, tree-ring widths, density measurements, stable isotopes, needle trace method

INTRODUCTION

Forestry, agronomy and other environmentally-based disciplines are affected by climatic and environmental extremes. Climatic extremes in the Balkan Peninsula are forecast to become more intensive, frequent and longer lasting. In order to mitigate climate induced damage to forests and crops, future adaptation strategies must take into account climate change scenarios that are based on measured climate data (IPCC, 2013). Current meteorological data enable spatial and temporal analysis but are limited to the period of existing instrumental measurements and restricted by missing data and the length of the data set. In order to improve climatic models, information on the frequency,

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intensity and duration of extreme events from the time before meteorological data were measured is essential (Luterbacher et al., 2012). To reconstruct past climate and identify extreme events, we need to make a so-called climate reconstruction, which is an area in which dendroclimatology has proved to be particularly useful.

Dendroclimatology is a science that uses cross-dated and synchronised tree-ring chronologies to investigate the climate signal stored in the radial increments of trees growing in extreme conditions. By comparing individual climatic factors, such as precipitation, temperature, sunshine hours and/or drought indexes, to annually resolved tree-ring proxies, such as tree-ring widths (Fritts, 1976), density measurements (McCarroll et al., 2002; Schweingruber et al., 1978), needle traces (Jalkanen et al., 2000) or stable isotopes (McCarroll and Loader, 2004), it is possible to identify the most important climate variables for tree growth and reconstruct them back in time, to the pre-instrumental period; that is, of course, if the developed tree-ring chronology contains a significant climate signal and exceeds the length of instrumental climate data.

MATERIAL AND METHODS

The Balkan Peninsula is an excellent place to study climate-tree growth relationships. Its size, location, and geographical and species diversity make it a natural laboratory on the junction of two climatic zones, continental and Mediterranean. Combining various sites (bedrock, altitude, aspects, latitude and climatic properties) and tree species, growing on their margins or in the centre of their distribution, current, past and even future climate impact on forests can be investigated. Using trees, data can be measured on a century to decadal scale (inventories), or annual or even intra-annual scale. Annual scale data are tree-ring widths (TRW), densities and isotopic compositions. Intra-annual data, for example, include needle shedding of different age classes, width and density of early/latewood and anatomic features of the tree-rings. Each measured tree–ring proxy is cross-dated, synchronised and compared to climate data. A linear model is then developed and its performance tested using split calibration and verification procedures (Cook et al., 1994; Fritts, 1976). The developed model is then applied to a tree-ring proxy chronology and past variations in climate are calculated. The last step is identification of extreme events and investigation of how trees reacted to factors that predisposed the extreme event and the outcome of the situation.

Tree-ring widths

TRW are a measure of how much trees grew in width in one growth season. Annual radial increments have been measured, investigated and published for various species and sites throughout the Balkan Peninsula. The oak chronologies network, for example, is known to extend from Slovenia (Čufar et al., 2008) over Croatia (Goršić, 2013) and Serbia (Pearson et al., 2014; Stojanović et al., 2015) to Greece (Kuniholm and Striker, 1983). On mountainous sites, conifer chronologies have been developed for the eastern edges of the Alps

(Hafner et al., 2011), for the Dinaric mountains (Levanič and Toromani, 2010; Poljanšek et al., 2012a), Greek Mountains (Klesse et al., 2014) and eastern part of the Balkan Peninsula above the Danube valley (Levanič et al., 2012). On such extreme sites with shallow soil and low soil moisture due to non-water-bearing bedrock, old conifers are found, while deciduous species are found below mountain tops and have been the subject of other silvicultural investigations (Bottero et al., 2011; Nagel et al., 2007).

Density measurements

Cell wall thickening and lignification of early and latewood cell walls, similar to cell division and enlargement, is influenced by climatic conditions, which is ultimately recognized as a climate signal in tree rings. The thickness of cell walls in early/latewood is measured with a method called blue intensity (McCarroll et al., 2002; Sheppard et al., 1996) or by x-ray densitometry (Schweingruber et al., 1978). Blue intensity has already been used on the Balkan Peninsula, in its north-western part, in Slovenia and Croatia (Poljanšek and Levanič, 2012; Poljanšek et al., 2015), while in Bulgaria (Trouet et al., 2012) and Greece (Klesse et al., 2014) x-ray densitometry has been used instead.

Isotopes

Atoms of elements with different numbers of neutrons are called isotopes. Despite the small difference in their atomic mass, trees can discriminate between heavier and lighter isotopes. When in drought stress, the stomata close and trees can no longer discriminate the heavier carbon isotope. The ratio between lighter and heavier isotopes in photosynthetic products produced in time of drought stress is therefore different from products synthesised in a time of available water. Isotope discrimination leads to a specific climate signal in tree-rings. Despite the strong spatial climate signal that isotope chronologies can contain, the use of stable isotopes in tree rings has been rare on Balkan Peninsula

RESULTS AND DISCUSSION

Climate signal

Comparing annual tree-ring parameters (width, density, isotopes) or other tree related parameters, such as height increment or needle shedding, with climate gives an insight into how different climatic factors influence physiological processes in trees. In an overview of published climate reconstructions, two major responses to climate are apparent on the Balkan Peninsula: one with a clear precipitation/drought signal from its continental part and the other with a less pronounced drought signal from mountainous sites above the sea coast. The climate signal in tree-rings from trees growing in the mountainous region is approximately equally strong in precipitation, temperature and even sunshine hours domains.

The amount of precipitation decreases from the Mediterranean Sea towards the continental part of the Balkan Peninsula, after the majority of rainfall is blocked by the mountains. Trees in the inner parts of the peninsula react to variations in summer precipitation, with a significant climate signal in TRW and/or early/latewood. Although Tegel et al (2014) reported a contradiction between beech increment and drought stress, other investigations have found a significant relationship between tree-ring width and drought for many species - silver fir (Abies alba) from the mountain Bokšanica (Ducić et al., 2014), bald cypress (Taxodium distichum (L.) Rich.) (Popović et al., 2012) from Serbia and black pine (Pinus nigra Arn.) from Serbia (Ćirković-Mitrović et al., 2013) and W Romania (Levanič et al., 2012). The last named constructed a 396-year long drought sensitive TRW chronology back to 1688 and identified extremely dry and wet years.

On mountainous sites, characterized by steep slopes, shallow soil and non-water-bearing bedrock, trees receive abundant rainfall all year long due to orographic precipitation but in summer, the water quickly evaporates and trickles down, and drought stress again increases. This triggers similar response to temperature and precipitation in, for example, black pine trees (Poljanšek et al., 2012b; Shishkova and Panayotov, 2013), Bosnian pine (P. heldreichii) (Seim et al., 2012), Aleppo pine (P. halepensis) (Klesse et al., 2014; Toromani et al., 2015), and Bulgarian fir (Abies borisii-regis (Mattf.)) (Pasho et al., 2014). Sunshine is not the most growth limiting factor on such sites but its values are closely connected to temperature and precipitation and therefore to moisture stress, as the most logical driver of tree growth on mountainous sites of the western part of the Balkan Peninsula, as well as in the eastern Alps (Hafner et al., 2013). A strong correlation between tree-ring widths and the sunshine signal was calculated for black pine sites in Bosnia and Herzegovina, where mean June–July sunshine hours were recognized as the most stable and influential factor on radial increment (Poljanšek et al., 2013). However, slightly more to the south, in Albania, June–July temperature was identified as the most influential climate factor, and reconstructed for the 1583–2010 period (Levanič et al., 2014), while in Greece, 400 years of summer temperature and precipitation variability on Mt. Olympus was calculated (Klesse et al., 2015).

Change of climate signal

Annually resolved tree-ring data and monthly climatic data, available in meteorological data centres, enable a signal stability check over time to see how trees respond to climate through time. An unstable climate signal refers to a “divergence problem”, expressed as an offset between instrumental data and reconstruction models based on tree rings (D'Arrigo et al., 2008). On the Balkan Peninsula, a slight decrease in the stability of the precipitation signal in Romania, between 1903 and 1950, and an increase after 1965 until 2009 has been reported (Levanič et al., 2012). Minor differences in the temperature/precipitation signal have also been reported for Greece (Klesse et al., 2014). Decreased sensitivity of radial growth to summer sunshine between 1977 and 1985 was also observed in the western part of the Balkan Peninsula, where a weaker sunshine signal was explained by changes in solar radiation due to increased cloud cover (Poljanšek et al., 2013). On the other hand, there is a very stable relationship between tree-ring indices and June–July temperature in Albania (Levanič et al., 2014).

Extreme events

In dendrochronology term extreme events is used in association with, climatic factors that promote or suppress growth. Hot and dry summers usually result in a narrow ring, while humid and cooler summers result in wider rings. Heat waves, extremely warm and dry summers in the Balkan Peninsula are usually connected with the blocking conditions and the presence of an anomalous trough over North Atlantic and associated anticyclonic conditions over Euro-Mediterranean region. On the other hand, humid and cooler summers are connected with the blocking regime between Scandinavian Peninsula and British Isles and anticyclonic circulation over North Atlantic (Poljanšek et al., 2013, Ubrich et al. 2012). Reconstruction of summer sunshine for the period 1660–2010 for the western part of the Balkan Peninsula (Poljanšek et al., 2013) enabled identification of pointer years, connected to historical data on drought and rainy events, as well as to some volcanic eruptions. Wetter than normal years occurred during or immediately after years with the largest volcanic eruptions (Köse et al., 2013) and, on the Balkan Peninsula, volcanic eruptions coincided with distinct negative peaks in the temperature reconstruction (Klesse et al., 2014) or less-sunny summers (Poljanšek et al., 2013). Not all extreme years were connected to climate. Extreme growth reductions can also be a consequence of forest fires. In crown fires, the majority of needles are shed and, if the trees survive, significant growth reduction is recorded in both radial and height growth (Poljanšek et al., 2014). It is expected that the frequency of forest fires will increase in the future, as climate will change towards warmer and drier weather. Studies on stand density, drought sensitivity and tree mortality are therefore important for adapted forest management.

CONCLUSIONS

Balkan Peninsula is due to its North-South orientation and well preserved biodiversity ideal region for studying effects of climatic changes on natural ecosystems. It can be used as a large laboratory to study tree-growth and develop climate reconstructions, and scenarios for the future. The climate signal embedded in the growth rings of different tree species, ranging from a mixed temperature/precipitation/sunshine signal from the mountainous area, to a precipitation (drought) signal in the continental part of the Balkan Peninsula, can help us:

- Understand and compare current extreme climatic events with past climate variability and put the current changes of climate to appropriate time perspective and context,
- decide on the future suitability of individual tree species and forest ecosystems in a climatically changed environment,
- and most importantly, dendroclimatology can help us pass the new knowledge to the end-users, whether this are foresters, agronomists, historians or policy makers, in order to improve future management with forests, soils and other natural resources.

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