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Radial growth response of horse chestnut (*Aesculus hippocastanum* L.) trees to climate in Ljubljana, Slovenia

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A B S T R A C T

Horse chestnut (*Aesculus hippocastanum* L.) is a common urban tree species in Ljubljana, the capital of Slovenia. This area is forecast to experience a general reduction in precipitation and an increase in temperature, which increases water demand in plants. Because *A. hippocastanum* is known for its drought vulnerability, the question of the future suitability of this urban tree species in Ljubljana has arisen. To investigate how climate has influenced *A. hippocastanum* radial growth and how trees responded to extreme climatic events, standardized precipitation-evapotranspiration index (SPEI) was used as a proxy for water demand. Climatic signal and its stability through time were calculated using Pearson's correlation coefficient. Additionally, to investigate whether the trees had a common response to extreme climatic events, pointer years were calculated using Cropper values. We sampled 19 trees that were growing in Tivoli Park in Ljubljana. After successful cross-dating of 15 trees, the ring count showed that the trees had up to 201 tree-rings and had 130 on average. Climate-tree growth analysis showed that in July, 3-month SPEI had the strongest influence on radial growth, but its influence on radial growth decreased over time, possibly due to the die-off process of trees. The narrowest tree-rings were a result of unusually dry periods at the time of cambium activity and/or new cell growth. With the forecast of longer, more frequent summer drought periods in Ljubljana, soil moisture stress will increase, and as a result, a decrease in radial tree growth of *A. hippocastanum* trees from Tivoli Park is expected.

1. Introduction

Trees are an important part of green urban areas with numerous positive social, economic and climatic effects. Only healthy trees can fully provide all of the positive effects and prosper under the influence of specific urban and climate stress factors. Tree species are vulnerable for various reasons in urban spaces and have variations in such characteristics as winter robustness and drought resistance (Roloff et al., 2009). In view of global warming, trees will have to cope not only with urban stress factors but also with increased climatic stress (Gillner et al., 2013; Helama et al., 2012), such as increasing pests and diseases (Tubby and Webber, 2010). Many methods are used to investigate how climate influences tree growth. One of these methods is dendroclimatology, a branch of dendrochronology, which investigates tree-ring parameters and their response to climatic factors (Fritts, 1971). Using tree-ring width (TRW) measurements, individual tree species from a particular urban site can be assessed regarding how they react to climatic factors in the present, as well as how they reacted in the past. Such studies can help to evaluate the suitability of tree species for urban space requirements in light of the forecast of climate change. Dendroclimatological investigations of the interactions between urban trees and climate have already been performed in, for example, Poland (Cedro and Nowak, 2006), Germany (Gillner et al., 2014), Finland (Helama et al., 2012) and the United States (Copenheaver et al., 2014).

Tree mortality is a result of the influence of many factors, and climate is one of them (Helama et al., 2012). This factor's importance is increasing with climate change. In order to maintain or increase the number, diversity and health of urban trees in Ljubljana, it is essential to select the right tree species for urban planting schemes. One of the urban tree species growing on streets, in parks and other green areas in Ljubljana (Pirnat, 2005) is horse chestnut (*Aesculus hippocastanum* L.). This species is already known to not be highly suitable for an urban habitat, as it has low drought tolerance (Roloff et al., 2009), but it was widely used and planted across Slovenia. Combining high summer temperatures and irregularity of precipitation, frequent soil moisture stress or droughts have started to afflict central Slovenia, where they did not previously normally occur (Ogrin, 2004). In Ljubljana, the capital of Slovenia,

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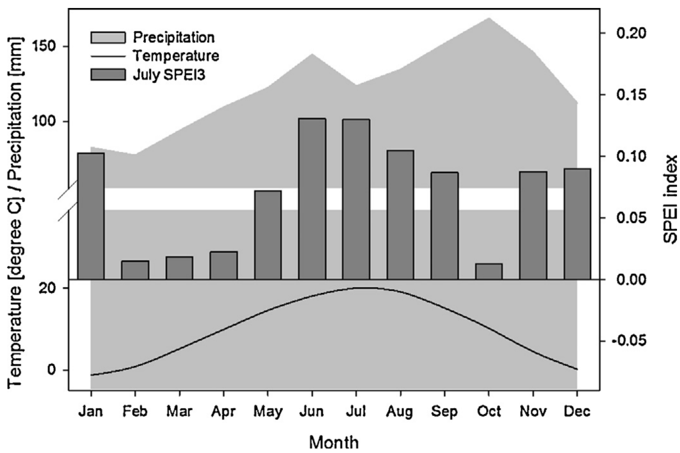

Fig. 1. Long-term climate for Ljubljana area.

the average annual temperature in the last 150 years has risen by 1.4 °C, while the annual amount of precipitation has declined by 36 mm/100 years with a higher decrease in spring and autumn and a slight increase in summer precipitation (Ogrin, 2004). Forecasts predict even more warming in the cold half of the year, a changed precipitation regime, as well as more frequent and more intensive extreme weather events, such as droughts, floods and thunderstorms (Kajfež-Bogataj, 2001). In light of the forecasted intensifying summer soil moisture deficit, the question concerns the influence of drought on the radial growth of *A. hippocastanum* trees in Ljubljana currently, as well as in the past. Thus, our goals were to

- investigate the age of *A. hippocastanum* trees and radial growth through their lifetime,
- analyse the influence of soil moisture on TRW,
- investigate the response to extreme summer seasons using pointer years analysis, and
- inspect whether the response of trees to soil moisture was changing over time.

2. Materials and methods

2.1. Site and climate description

Despite its relatively small size, Slovenia is characterized by great diversity in climate, geology, hydrology and biodiversity. In the middle of the country, where Ljubljana is located at approximately 300 m a. s. l., a temperate continental climate prevails (Ogrin, 2004). Monthly values of standardized precipitation-evapotranspiration index (SPEI), calculated for the Ljubljana site by the KNMI Climate research unit- CRU (van Oldenborgh, 1999), are strongly based on Ljubljana climate station data. It should be noted that this station has not been in the same location of the period with available SPEI data from 1902 to 2012. Between 1850–1922, especially in the early part of the period, the climate station was moved several times (Cegnar and Kovač, 2000). It was finally moved from the centre to the outskirts of the city after the Second World War, but the data were never corrected (Ogrin, 2004). The short distance that the climate station was moved did not greatly affect the long-term annual mean temperature for Ljubljana; 9.6 °C and mean May–August 18 °C, or mean annual precipitation rates; 1500 mm and mean May–August 525 mm (Fig. 1).

Trees from Tivoli Park were growing on the south-eastern edge of the forested hill of Rožnik (Hladnik and Pirnat, 2011), influenced by an adjacent railway, a four-lane road, streets and avenues of the city centre (Fig. 2). Trees sampled were growing along Jakopič, a tree-lined avenue/promenade dividing the parking lot from the

Fig. 2. Sampling site (black and white vertical line) in Ljubljana city centre with castle hill (bottom right part of figure) and Tivoli Park (upper left part of figure) .

green park areas. The promenade was originally one of the main roads toward the city centre but was later transformed into a cycle and walking path. Influenced by numerous urban connected stress factors, we can emphasize that trees from this site were probably enriched with a complex environmental history.

2.2. Species description

A. hippocastanum is a deciduous tree, up to 30 m high and 1 m thick, usually with a short stem and dense rounded crown (Brus, 2004). This tree is a native species of the Balkan Peninsula, but Slovenia is outside its natural distribution. The species prefers deep, nutritious and humid sandy-clay soil with air pockets. The tree is best grown individually in full sunlight, although it also grows well in the shade. This species can survive winter temperatures below −20 °C, although is not a winter hardy tree species (Roloff et al., 2009; Wilczyński and Podlaski, 2007). The recent temperature rise in central Slovenia has already affected the physiology of the species. Based on a 10-year average of observations, trees in Ljubljana develop leaves in the middle and blossom at the end of April (ARSO, 2014). A temperature rise of 1 °C in April causes leaf unfolding to occur 3.4 days earlier, 1 °C in March the start of blossoming 5 days earlier and 1 °C in the October–November period leaf senescence 5.2 days earlier (Vilhar and Kajfež-Bogataj, 2003). Depending on the growth season, the period from the first leaves unfolding until leaf fall is 141–178 days, but no temperature influence on the length of the growing season has been identified (Vilhar and Kajfež-Bogataj, 2003).

2.3. Sampled trees

The trees growing in a promenade had been grown under the protection of Slovenian natural and cultural heritage legislation and thus were not accessible for sampling with an increment borer. After reaching a great age, with a loss of vitality, a portion of the trees became rotten, unstable or started to die off. Due to safety measures, old trees were finally felled and replaced with young ones. Altogether, 28 trees were felled in March 2013, with the last fully formed tree-ring in 2012. From 28 trees, the sample size was

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