Dendrochronologia 44 (2017) 31–38

Contents lists available at ScienceDirect

Dendrochronologia

journal homepage: www.elsevier.com/locate/dendro

ORIGINAL ARTICLE

The climate to growth relationships of pedunculate oak in steppe

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ARTICLE INFO

Article history:
Received 11 March 2016
Received in revised form 22 February 2017
Accepted 8 March 2017
Available online 10 March 2017

Keywords:
Quercus robur
Dendroclimatology
Radial growth
Age

ABSTRACT

Pedunculate oak (*Quercus robur* L.) is a long-lived species that dominates the extra–zonal natural forests in the steppe landscape of southeastern Ukraine. Although *Q. robur* is considered to be one of the most important species in European dendrochronology, it has received little attention in the steppe zone because of its scarcity in the often-degraded steppe forests. Nevertheless, a small and unique patch of old-growth oak exists within the boundary of Donetsk, a large industrial center in Eastern Europe. This forest is a remnant of an ancient wood and includes several dozen old-age trees that can contribute to filling some of the spatial gaps in pedunculate oak dendrochronology in Eastern Europe. In this study, we aim to determine the effect of climatic variables on pedunculate oak growth in the steppe zone, and to estimate the longevity of this species in the heterogeneous conditions of an urban forest. A total of 20 trees were cored for this study, varying in age from 55 to 254. The resulting tree-ring chronology correlates strongly with local precipitation in spring and summer, and with local temperature in April, June and July. Moving correlation analysis indicates a shift over the last 80 years in the relationship between oak growth and late winter and early spring temperatures, as well as between oak growth and precipitation in February and August. These findings imply that warming has caused both an advance in oak phenology and changes in the climatic conditions in early spring.

1. Introduction

Pedunculate oak (*Quercus robur* L.) is one of the most common and long-lived tree species in European temperate woodlands. The natural distribution range of this species spans much of Europe, extending from the British Isles and northern Portugal to the Ural Mountains, and from the southern coastal regions of the Scandinavian Peninsula and Finland to Turkey and Sicily (EUFORGEN, 2009). Pedunculate oak plays a key role in the structure and function of forest ecosystems (Nilsson et al., 2002), providing habitat, food and shelter for a number of organisms and species (Le Roux et al., 2014) and contributing to soil erosion control (Belova and Travleev, 1999). Pedunculate oak is also a key species in urban greening efforts, as it grows well in a variety of conditions (see review by Haneca et al. (2009)) and provides habitats that are important for maintaining biodiversity.

The impact of climate change on pedunculate oak growth is complex and not well understood, as different factors are at play in different parts of its range. Climate change, as manifested by a decrease in precipitation and an increase in temperature, is thought to be the main driver behind the shift in the distribution of this species (Urli et al., 2015). Several authors have noted a decrease in peduculate oak radial growth across major parts of its range (Rozas, 2005; Friedrichs et al., 2009; Čufar et al., 2014). In northwestern Spain, a decrease in the growth of oak in different age classes has been linked to a significant seasonal increase in precipitation associated with El Niño, which leads to an excess of soil moisture (Rozas and García-González, 2012). In addition, global warming advances the onset of spring and prolongs the growing season (Menzel et al., 2006), resulting in changes in the growth-climate relationship. Matisons et al. (2013), for example, have shown that the growth of pedunculate oak is positively correlated with March temperature near its northern distribution limit. A direct correlation with precipitation and a negative response to summer temperatures is likely to become the most typical relationship between oak growth and climate throughout much of its range (Friedrichs et al., 2009; Helama et al., 2009; Čufar et al., 2014; Cedro and Nowak, 2015).

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http://dx.doi.org/10.1016/j.dendro.2017.03.004
1125-7865/

We can only speculate that this tendency is likely to be even more dramatic on the eastern edge of the dry steppe zone, where few studies of pedunculate oak have been conducted to date. This uncertainty and the potential ecological consequences all favor detailed dendrochronological studies at the eastern edges of this species' distribution range.

Considering the rarity of forests in the steppe, old-growth urban forests represent an important source of material for assessing the response of pedunculate oak radial growth to climatic or meteorological variations in this part of the species' natural range (Gillner et al., 2013; Rozas, 2005). An analysis of tree ring series from the oldest trees in such urban stands allows for (1) a better understanding of the climatic conditions that are crucial for oak stand vitality in the steppe region, (2) the prediction and prevention of potential risks to forests from climatic extremes, and (3) an estimation of the longevity of tree species as they respond to changing environmental conditions in urban and natural forest ecosystems. Such studies are essential for the effective management of urban forests (Roloff et al., 2009) and offer new insights into how native woodland ecosystems or planted stands affect biodiversity and wildlife maintenance within city boundaries.

In this study, we explore the relationship between radial growth and climatic variables in an old-growth oak woodland in the city of Donetsk, Ukraine. The objectives of our study are threefold: (1) to understand the climatic drivers of *Quercus robur* growth in an urban space at the eastern edge of its natural distribution range, (2) to determine whether variations in the oak growth-climate relationship can be attributed to current climatic changes, and (3) to estimate longevity and the average radial growth rate of the species in one of the warmest (summer) and harshest (winter) parts of its distribution range.

2. Materials and method

2.1. Study site

The study was carried out in the Putilovsky forest, which is located in the city of Donetsk in southeastern Ukraine (48°03′53″N, 37°47′34″E). According to cartographic material available from the late 1700 s (General Survey Plans) to the mid-1800s (Theodor Friedrich von Shubert maps), the studied forest existed and was exploited for wood well before the foundation of the city in 1869. This stand was a part of a woodland that extended across ravines and along rivers into the steppe landscape until the onset of industrialization in the region in the mid-19th century. The region was mainly deforested due to a demand for wood for construction and charcoal production. The presence of foresters before the revolution in 1917 and the partial conversion of the forest into a park before World War II enabled the preservation of the Putilovsky forest during the Soviet Union period.

Today, the forest encompasses about 80 ha, including ravines with streams that flow into the Kalmius River. The area is dominated by pedunculate oak, common ash (*Fraxinus excelsior* L.) and field maple (*Acer campestre* L.). Introduced species *Robinia pseudoacacia* L. and *Acer negundo* L. were planted in areas depleted of trees by logging after World War II. The surviving 100–120 pedunculate oak trees of large size (dbh > 100 cm) represent the core of the forest.

The region is characterized by a moderate continental climate, with a total mean annual precipitation of 524 mm and a mean annual temperature of 8.2 °C. The mean temperature in the coldest month of the year (January) varies between −6.0 and −7.8 °C; in the warmest month (July), mean temperature ranges from 20.9 to 22.9 °C. The mean minimum winter temperature is −9 °C. Snow cover in winter averages 3–9 cm, and the period with a mean daily temperature above 0 °C lasts for about 171 days. The soil type in the forest is chernozem and the depth of the humus horizon is about 0.5 m. The elevation of the forest ranges from ∼200 to ∼250 m above sea level.

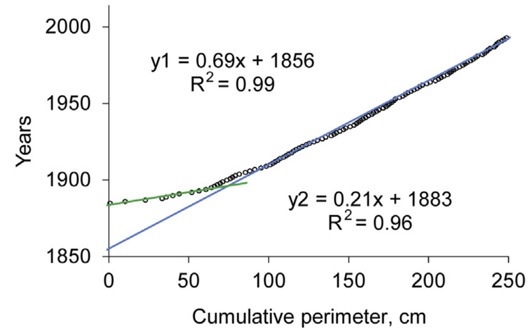

Fig. 1. Cumulative growth of sampled oak with preserved pith. Regression lines are: y1 for the rings produced after the first 12 years; y2 for the earliest rings (intercept point matches the year of the first ring after birth).

2.2. Field sampling and data analysis

Twenty large-diameter pedunculate oaks with little to no external damage were selected for sampling. During winter 2013–2014, we obtained one or two core per stem at 1.3 m above the ground using a Pressler increment borer. The sampled trees all exhibited regular stem and crown growth, suggesting low stem eccentricity. The cores were placed in paper straws to prevent damage and brought to the laboratory. After drying, the cores were glued to wooden plates and their cross-sections smoothed by sanding with progressively finer grades of sandpaper (100–400 grit).

The samples were scanned at a resolution of 3200 dpi using an Epson V33 scanner. Ring width was measured using AxioVisionLE tools (Carl Zeiss Imaging Solution GmbH) with 0.01 mm precision. Data from twelve oaks that had two radii extracted were cross-dated and combined into single tree-ring series. The individual tree-ring series were cross-dated, standardized and checked using the COFECHA program (Holmes, 1983) and the dplR package (Bunn, 2010). The long-term growth trend in series with early life rings was eliminated by fitting a negative exponential or linear curve. A total of 32 radii from 20 trees were used to compile the Putilovsky forest residual chronology. Age-related and other non-climatic low-frequency variations in the raw individual series were reduced by introducing a negative exponential and/or cubic spline.

2.3. Age estimation

The number of rings in off-center cores was estimated using Duncan's (1989), Clark's and Hallgren's (2003), and Rozas' (2003) techniques. The number of missing rings in partial cores is usually defined as the difference between the geometric radius at 1.3 m height and the length of the partial core divided by the mean ring width (Abrams and Orwig, 1996). The calculation of the intercept (b) in linear regression for cumulative growth ($y = ax + b$) gives a similar result. The estimation error in these two methods is determined by the variation of tree radial growth caused by stand dynamics, abrupt changes in environmental conditions, or life cycle. Events occurring in the middle of a tree's life do not influence the accuracy of the age estimation. However, the intensive growth that occurs during the early life of a tree has a significant effect on the expected age at 1.3 m height (Fig. 1).

To evaluate the upper age bounds for trees with rotted pith, we considered the regression lines for the two periods of life with different radial growth rates, $y_1 = a_1x + b1$ and $y_2 = a_2x + b_2$.