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Are climatic factors responsible for the process of oak decline in Poland?

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ABSTRACT

Oak decline, a complex process leading to increased mortality of this species, has been observed in Europe for many years. Previous studies suggest that climate conditions, especially drought, may be one of the most important factors that trigger this phenomenon. The paper investigates the radial growth and wood anatomy features of pedunculate oak (*Quercus robur*) trees of various health status as well as their response to climate conditions. Wood samples including all annual increments were taken at two sites (western and central Poland, 15 trees each). Based on the crown defoliation level, three health groups (healthy, weakened and dead oaks) were distinguished. Cross-sections were prepared with sliding microtome and Cell P image analysis software was used for the measurements. Tree-ring width (TRW), earlywood vessels density (VDen) and non-weighted vessels diameter (VD) were determined and correlated with mean monthly values of temperature, precipitation, vapour pressure, and Palmer Drought Severity Index (PDSI). Radial increment and anatomical parameters were significantly higher for the healthy oaks than for the weakened and the dead trees. TRW showed smaller dependence on climate than analysed anatomical attributes. No obvious pattern of relationship was found between oak radial growth and climate regarding tree health status. Our results revealed that the drought has a weak impact on the process of oak decline on investigated sites in Poland.

1. Introduction

Large-scale oak (*Quercus* sp.) decline has widely been observed in Europe (Siwecki and Ufnalski, 1998; Siwecki and Liese, 1991; Landmann and Dreyer, 2006; Drobyshev et al., 2007; Thomas, 2008; Sonesson and Drobyshev, 2010; Sohar et al., 2014a, 2014b) and in North America (Starkey et al., 2004; Catton et al., 2007) for a long time. There are also some reports about this phenomenon from Asia (Mosca et al., 2007). In Poland, a significant decline phenomenon has been noticed within natural oak stands in central Poland, especially on the Krotoszyn Plateau (Ważny and Eckstein, 1991; Opydo 1996), where the largest area is occupied by native oak species. Shortage of rainfall, especially in May-June period was suggested as the most influential factor that contributes to their decline. However, an increased oak mortality is considered to be a complex process that may involve several biotic and abiotic factors, among them climate, air pollution, forest management practice and biotic agents (Gutkowski and Winnicki, 1997; Opydo, 1994; Opydo et al., 2005). These factors mentioned interfere with physiological processes occurring in trees, causing severe structural anomalies that could lead to the elimination of the individuals or the whole stands (Brasier, 1996; Wargo 1996). Thomas et al. (2002) reviewed in detail factors and their interactions as causes of oak decline in Central Europe and reported that so far no single cause had been recognized as being responsible for that phenomenon. However, the adverse climatic conditions (drought, spring frosts, or high temperature during the vegetation period) are considered to be important for the development and spread of this phenomenon or at least weakening the trees against e.g. pathogenic fungi or insect pests (Przybył, 1989; Ważny and Eckstein, 1991; Wargo, 1996; Siwecki and Ufnalski, 1998; Drobyshev et al., 2007). On the other hand, oaks are known to have developed morphological and physiological adaptations that enable them to delay the impact of unfavourable factors (e.g. drought). These adaptations include deep root system or the ability of twigs shedding (cladoptosis) (Klugmann and Roloff, 1999; Rust and Roloff, 2002) or transpiration mechanisms effectively controlled by regulation of the stomatal closure (Maseda and Fernndez, 2006). However, these defensive reactions become less important along with the increase of the

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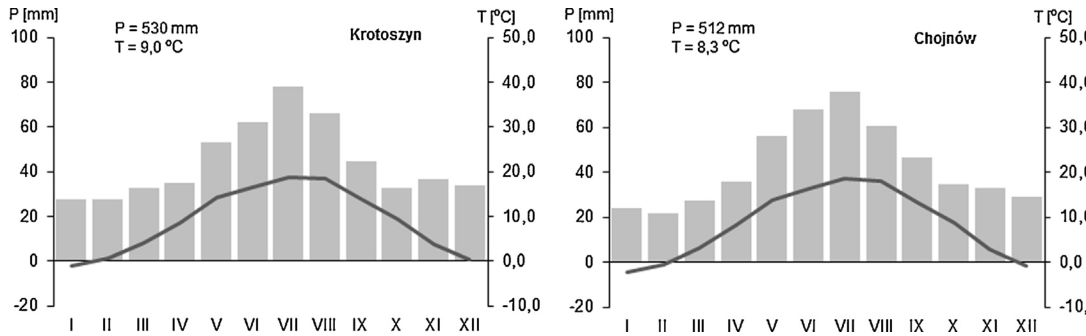

Fig. 1. Mean monthly temperature (lines) and precipitation (bars) for Krotoszyn and Chojnów sites.

drought stress that makes the trees even more vulnerable to the other stress agents (Thomas et al., 2002).

Trees constitute a part in the soil-plant-atmosphere continuum (SPAC) model that reflects interactions between environment (soil and atmosphere) and plants (Sperry et al., 2003; Nobel, 2009). This model also describes the mechanism of water transport from the soil, through the conductive structures of the plants into the atmosphere (Maseda and Fernández, 2006). As a consequence, any disruption of hydrographic conditions in soil or atmosphere implies changes of the water transport in a plant (Bréda et al., 2006).

Earlywood vessels, produced by a vascular cambium are composed of a member, and they are the main elements of the hydrosystem in broadleaved trees. In ring-porous species, the diameter of these structures can reach ca. 500 μm what makes them distinguishable even with the naked eye (Jacquiot et al., 1973). Due to the fact that oak has ring-porous wood type, the water transport takes place mainly through the earlywood vessels in the outermost tree ring. Wider vessels are more effective conductors than the smaller ones (Sperry et al., 1994), but on the other hand, they are more vulnerable to cavitation (Tyree and Sperry, 1989). The vessel members, as the cambial derivatives, have to die to become functional. Prior to their death, they undergo the differentiation process. The vessels formation, especially the phase of their growth both in radial and tangential directions, is controlled by the water availability as this process depends on turgor pressure (Doley and Leyton, 1968; Hsiao, 1973; Fritts, 2001). Hence, the deficit in the amount of moisture available for trees can result in production of vessels of smaller diameter (Gonzales and Eckstein, 2003). The Hagen-Poiseuille formula shows that the stem-hydraulic conductance is proportional to the 4th power of the vessel radius (Tyree and Zimmermann, 2002). As the result, even small decrease in vessel dimensions can cause a significant reduction in the efficiency of water transport. The last phase of vessel member formation concerns the secondary cell wall deposition and lignification, and ends up with autolysis of its protoplast (Plomion et al., 2001).

Trees record the information concerning environmental conditions and developmental processes take part in cambium in the structure of their secondary wood (Thomas et al., 2002; Tulik et al., 2010; Koprowski et al., 2012). This data is encoded in the dimensions, numbers and arrangements of the wood cells (Corcuera et al., 2004; Fonti et al., 2009). Because of the short- and long-term environmental disturbances, trees may change their hydrosystem, particularly the size and number of the vessels and, in consequence, the efficiency of water transport (Oladi et al., 2014). The anatomical traits of the wood are useful tools in dendrochronological investigations to evaluate e. g. climate-growth relationships in trees as they enrich the information obtained from traditionally used tree-ring widths (Gonzales and Eckstein, 2003; Fonti et al., 2009).

The objectives of the presented study were to analyse whether the radial growth and the structure of secondary wood of the declining oaks exhibit any dependence on climate conditions. Water shortage is assumed as the factor that has the largest impact on the increase in oak mortality. Moreover, as within the oak stands, trees with varying severity of dieback symptoms occur, it seems therefore interesting to study their wood structure in terms of sensitivity of cambial cells and its derivatives on the influences of stress factors.

2. Material and methods

2.1. Study sites

The research material was collected in 2008 and 2009 in two roughly 40-years-old pedunculate oak (*Quercus robur* L.) natural stands located in the western and central part of Poland, where symptoms of oak decline have been observed for several years (Siwecki and Ufnalski, 1998). Trees at Chojnów site (52°01′13″N, 21°05′16″E) grew on proper pseudogley (Stagnosol) soil developed from stony loamy sand shallowly overlying on the silty loam. Forest habitat type was defined as mesoeutrophic. In turn, oaks in Krotoszyn (51°41′37″N, 17°25′54″E) grew on brownish rusty (Cambic Arenosol) soil developed on sandy loam underlying on loamy sand that formed eutrophic forest habitat type.

Investigated sites differed slightly in terms of climate conditions. Krotoszyn that is located further westwards than Chojnów characterises with a slightly higher annual precipitation and mean annual temperature (Fig. 1). Despite these small discrepancies, both study sites are located within the same Cfb Köppen-Geiger climate zone (Kottek et al., 2006).

2.2. Sampling and data acquisition

Based on the crown condition (i.e. its defoliation, abundance of dead branches), we distinguished three vigour groups of trees within each study site. The first group included trees with crowns without dead branches and defoliation up to 20%. These trees were considered as the healthy ones. The other consisted of individuals with visible symptoms of the dieback. The defoliation of their crowns ranged from 70 to 90% and some dead branches were noticed. These trees were considered as the weakened ones. Finally, the last group included dead oaks without leaves and with withered branches. Trees belonging to this group had died in a year prior to material collection.

At each site, in each of these groups we selected five representative individuals that belonged to co-dominant trees in the canopy layer (II class according to Kraft's biosocial classification). In total, 30 trees were selected. The bark of dead oaks form Chojnów was affected by *Agrilus biguttatus*, while *Operophtera brumata*, *Erannis defoliaria*, *Tortix viridana* and *Euproctis chrysorrhoea* were observed on the foliage of Krotoszyn oaks. These insects are believed to be harmful for oak trees (Bugała, 2006).