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Forecasting tree growth in coppiced and high forests in the Czech Republic. The legacy of management drives the coming *Quercus petraea* climate responses

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ABSTRACT

Climate extremes are expected to increase, which will affect oak forest ecosystems in Central European areas. Intensively managed forests, such as sessile oak stands, may alter their structure and function under a warming scenario. Here we analyse and project the climate-growth relationships of sessile oak (*Quercus petraea*) from high forests, originated from seed, and coppice forests, originated from vegetative reproduction in the Czech Republic. Dendrochronological data and linear mixed-effects models show similar effects of precipitation for April–May (positive) for both seedling- and coppice-origin trees. Previous autumn and current June temperature show significant negative correlations to growth in coppice forests. Nonetheless, trees from high forest stands showed increasing drought sensitivity and tended to show a stronger response to the previous autumn's temperature during the 20th century. The positive effect of warmer autumns, only found on high stands, might be related to the extended growing season, suggesting improved adaptive capacity to cope with impending warmer conditions. In contrast, coppice trees might be able to buffer soil water shortage during spring and summer by higher root/shoot ratio. The obtained models were used to estimate the impact of 21st century-emission scenarios on tree basal area increments and stand basal area dynamics under different stand structures. Our results support that growth responses to climate warming are age and/or structure-dependent in sessile oak, particularly with regards to coppiced stands. Converting coppice forests to high stand structures, as well as thinning high stands, would enhance sessile oak forest adaptive capacity to cope with warming in Central Europe.

1. Introduction

The increase in temperatures, shifting precipitation patterns, and land-use changes have been reported as major limiting factors to forest growth and productivity in temperate zones in recent decades (Babst et al., 2013). These factors have been linked to a decline in growth and increased tree mortality in oaks species (Kabrick et al., 2008; Doležal et al., 2010; Stojanović et al., 2015; Hosseini et al., 2017) and a general lack of natural regeneration on the global scale (Annighöfer et al., 2015). Climate change models predict a temperature increase from 2.3 °C to 5.3 °C in Central Europe in the 21st century, accompanied with about one half of total amount of precipitation during spring and summer (IPCC, 2013). Consequently, Central and Eastern European forests systems are expected to suffer an increase in extreme climatic events (Leuzinger et al., 2005), causing episodes of forest dieback affecting oak forests and other species (Thomas et al., 2002; Stojanović et al., 2015).

In addition to changing climate, past management may be an essential driver for the expected dynamics of several oak forests, currently subjected to potential climate-induced declines (Sjölund and Jump, 2013; Hosseini et al., 2017). Several Central European oak forests were formerly managed by coppicing (Matthews, 1991), which has significantly shaped the present structure and composition of these forest ecosystems (Buckley, 1992). Contrasting to the forest originated from

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seed or planted seedlings (thereafter referred as high forests), coppice forests develops from vegetative reproduction by re-growth of trees cut down periodically (Bond and Midgley, 2001). As a result, despite coppicing maintains trees at an aboveground juvenile stage, coppice stools may reach very old ages and the stand should have limited genetic diversity (Sjölund and Jump, 2013).

The repeatedly cut down to near ground level of coppice trees may has drastic consequences on tree biomass allocation, for instance as regards the root to shoot (R/S) ratio (Salomón et al., 2016; Vrška et al., 2016). Higher R/S biomass ratios present in aged coppices, compared to high forest trees, might affect the climate sensitivity of the older and more repeatedly coppiced trees. Specifically, it has been hypothesised that increased belowground biomass mitigates the effect of water shortage (Pietras et al., 2016; Stojanović et al., 2016). Furthermore, increasing root biomass per unit of leaf area allows for higher stored compounds (as non-structural carbohydrates) in roots, while new assimilates could be used for aboveground biomass development (Bond and Midgley, 2001). Notwithstanding, these initial advantages of coppices could be limited and they could gradually disappear according to the number of coppicing cycles experienced in aged coppice forests (Salomón et al., 2016).

At the beginning of the 20th century, coppice oak forests from Central and Eastern Europe were largely abandoned primarily due to changes in market demands for coppice products and the increased use of fossil fuels (Müllerová et al., 2014). Most of these coppice oak forests were converted to stored coppices whose structure resembles that of a high forest due to the absence of coppicing cycles (Matthews, 1991; Buckley, 1992). Although several studies concerning oak growth-climate responses have recently been conducted in Central Europe (Doležal et al., 2010; Mérian et al., 2011; Rybníček et al., 2016), there has still scarce information as regards overaged oak coppice forests comparing them to high (i.e., seed origin) forest stands under future climate scenarios.

Restoring overaged coppices is a current management concern due to their high nature conservation values (Kopecký et al., 2013), and the increasing importance of producing renewable energy and biomass (Suchomel et al., 2012). Today, more than 14.8% (about 28 million hectares) of the total European forest area is reported as coppices and only 10% is actively managed (FAO, 2010). There is a lack of knowledge about the role of past management acting as a predisposing factor (*sensu* Manion, 1981) on forest decline processes (Thomas et al., 2002; Sánchez-Salguero et al., 2013). Although, tree species and site quality may influence re-sprouting ability, several works have found oaks to have a good sprouting ability in Central European coppices after long periods of abandonment (Matula et al., 2012). Nonetheless, continuously managing coppices seems to be essential for their long-term survival, due to age-related decline in re-sprouting ability since the last coppicing cycle (Sjölund and Jump, 2013).

Due to the increasing risks (windthrow, bark beetle attacks, drought events; Klimo et al., 2000), forest owners and stakeholders require new adaptation guidelines to increase the resilience of abandoned oak forests subjected to potential decline under the expected future climate conditions (Sjölund and Jump, 2013; Hosseini et al., 2017). Improving our knowledge about past management effects on climate-growth responses would help to better forecast which will be the most vulnerable forests in response to warmer and drier conditions (IPCC, 2013). Notwithstanding, contrasting climate sensitivity and tree growth remain poorly understood in formerly managed Central European oak forests (but see Rybníček et al., 2016). Therefore, it is essential to understand the effect of forest management practices and know what their advantages are to be able to cope with expected climate change in the future (Millar et al., 2007).

Assuming that the repeatedly cut down and further abandonment of coppice trees may have significant consequences on tree climate sensitivity, we aimed to identify the main climatic variables affecting the secondary growth of sessile oaks (*Quercus petraea* (Matt.) Liebl.) trees from coppice forests and high forests. We focused on the growth responses to past forest management practices and climate change using dendrochronology as a long-term integrative method (Fritts, 2001). Our specific aims were: (i) to test whether sessile oak trees from coppice and high stands experienced different long-term growth trends in the 20th century, (ii) to examine if sessile oak trees from different origins exhibited contrasting growth responses to climate, and (iii) to evaluate whether growth patterns and climate sensitivity allow to forecast growth trends and stand basal area throughout the 21st century, based on expected climate scenarios. We hypothesized that climate sensitivity (i.e., the growth responses to climate) is modulated by coppice and high origins (cf. Bréda et al., 2006). We expect that sessile oak trees from high stands are more sensitive to warm and dry conditions than sprouted sessile oak trees (i.e., coppice), likely related to lower aboveground to belowground biomass ratio.

2. Material and methods

2.1. Study area

The study area is located in the South Moravian region in the south-eastern part of the Czech Republic (Fig. 1a and b) in a mixed *Carpineto-Quercetum* forest (Plíva, 1987). The study was carried out in two comparable sessile oak (*Q. petraea*) forest stands with contrasting past management practices (Table 1): high stand (i.e., seed origin) and coppice stand. The two stands are spaced 3 km apart. The soils are acidic and rocky, mainly illimerized on loamy aluvium and granodiorite with an inaccessible ground water table, drying out in summer (Plíva, 1987). The region has a continental moist climate with mild winters and precipitation in all seasons (CHMI, 2014) (Fig. 1c; Appendix A1, Fig. A1). According to Brázdil et al. (2012), this is one of the driest regions in the Czech Republic. The total annual precipitation ranges between 550 and 650 mm (360 mm during the growing season) and the mean annual temperature is 8.2 °C, with December–January (a mean temperature of −3.4 °C) and July–August (a mean temperature of 18.2 °C) being the coldest and the warmest months, respectively. The rainiest and driest months are July and February with 85.3 mm and 28.9 mm, respectively. Frost and snow are frequent from November to March.

The coppice and high sessile oak stands were of comparable age (ranged from 90 to 120 years old) (Table 1). Historical evidence shows that the Moravian forests have been intensively managed with different silvicultural systems for centuries (Müllerová et al., 2014). Seed-regenerated forests have been managed by a shelterwood system (a rotation of 120 years and 20-year regeneration periods) and never coppiced. The high stand analysed in this study was extensively managed/spontaneously developed, without treatment until 2003, when the first regeneration cut was conducted (Březina and Dobrovolný, 2011) (Appendix A1, Fig. A2). On the other hand, many coppice forests have been managed by clear cut (a 30- to 40-year rotation period) in the same region. However due to socio-economic changes coppicing was gradually abandoned by the mid-20th century (Müllerová et al., 2014). The analysed coppice stand was actively coppiced for at least 200 years until the early 20th century (Kadavý et al., 2011), when, most coppices were transformed into something resembling “high forests” by singling out one or two large trunks (Müllerová et al., 2014), prolonging the usual rotation period and producing a more uniform canopy structure (Buckley, 1992). Although the aboveground structures in coppice stand are about 100 years old, the root systems are at least 200 years old. However, it is unknown when the coppicing in this area initially started (Kadavý et al., 2011).

2.2. Field sampling and dendrochronological methods

In autumn 2014, sampling was carried out in both sessile oak stands with different past management systems (Table 1). Four randomly