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Temporal variations and spatial differentiation in the black alder and silver birch pollination pattern-the impact of local climate or something more?

K. Borycka[a], B. Ortyl[b], I. Kasprzyk[a,*]

[a] University of Rzeszow, Department of Ecology and Environmental Biology, 4 Zelwerowicza St., 35-601 Rzeszow, Poland
[b] University of Rzeszow, Department of Agrobiology and Environmental Protection, 4 Zelwerowicza St., 35-601 Rzeszow, Poland

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ABSTRACT

Numerous abiotic factors have an important impact on the phenology of woody plants with temperature as the main driver of their development. Furthermore, the biological factors connected with phenotypic plasticity and genetic heterogeneity might be the cause of differentiation in phenological response to abiotic factors. As objects of our study, we chose black alder and silver birch trees. The main aims of the study were to demonstrate the spatial and temporal diversity in the timing of *Alnus glutinosa* and *Betula pendula* pollination as well as to identify factors affecting these variations. We focused on abiotic factors such as thermal conditions: air and surface temperatures, within and between population variability. Phenological observations were carried out in Rzeszów (SE Poland) in a period of four years at over a dozen locations. Stands differed in their thermal conditions and prevalent land use types. The pollination pattern in the study area was presented against the background of local thermal conditions which were described by Land Surface Temperature (LST) and maximum daily air temperature. LST was estimated with a single-channel algorithm using satellite images obtained from Landsat 7 and 8. Our results showed great spatial and temporal diversity in the pollination pattern in the study area. Year-to-year variations in the *B. pendula* pollination pattern were less pronounced than in the case of *A. glutinosa.* The pollination pattern was strongly influenced by temperature before and during pollination. In the study area, the variability of LST was greater than that of air temperature but the relationships between the timing of pollination phenophases and LST or land use types were weak. It was observed that the same sites were similar in their pollination pattern − the timing of phenophases was *'accelerated'* or *'delayed'* during the whole study period. The same individuals were the first or the last that began to pollinate independently of the year. We concluded that despite the impact of temperature on *A. glutinosa* and *B. pendula* development, the phenotype of an individual tree might be as important for phenological variability as local climate.

1. Introduction

The geographical range of *Alnus* and *Betula* species mostly overlaps and covers mainly temperate and boreal zones. However, the range of *Betula* is restricted to the Northern Hemisphere, while *Alnus* also occurs but rarely in South America (Seneta and Dolatowski, 2011). *Alnus glutinosa* Gaertn. and *Betula pendula* Roth. are pioneer tree species that participate in the first forest stage of succession. Owing to their wide ecological scale, both species are important in Polish forestry, which is confirmed by the existence of many cultivation and breeding manners recommended for nurseries (Suszka, 1979).

Numerous abiotic factors have an important impact on the phenology of woody plants, among them the following: soil structure, content and availability of micro and macroelements in the soil, foliar nutrition rate and light availability (Jochner et al., 2013b; Jochner and Menzel, 2015). However, it is the climate and its changes that have been found to explain the majority of variability in dates of spring phenophases, and temperature seems to be the main driver of plant development (Gazal et al., 2008; Heide, 2003; Jabłońska et al., 2015; Jochner et al., 2013b). According to some authors, the timing of bud burst of some tree species is correlated with autumn temperature (Heide, 2003). In the case of silver birch, flower bud formation occurs in June of the year preceding flowering, and the temperature and sunlight hours in this month are significant for the number of catkins (Ranta et al., 2008; Suszka, 1979). Flowering dates of male and female birch catkins are strongly dependent on heat accumulation during winter and early spring (Rousi et al., 2011). During the full pollination phenophase, precipitation is also significant (Hájková, 2015). The direct influence of air temperature on the silver birch pollination pattern has been found by numerous authors (Hájková et al., 2015; Jato et al.,

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[*] Corresponding author.
E-mail address: idalia@univ.rzeszow.pl (I. Kasprzyk).

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2007; Jochner et al., 2013b; Ranta et al., 2008). Black alder phenology has been rarely studied; however, as an early flowering species, it is also sensitive to air temperature fluctuations (Juknys et al., 2012; Puc and Kasprzyk, 2013).

Recently, studies concerning the relationship between phenological events and local environmental parameters have been supplemented by satellite data. Remote sensing mainly focuses on Land Surface Temperature (LST) as well as parameters indirectly related to it, such as land cover type (Bogawski, 2016; Fisher et al., 2006; Gazal et al., 2008; Jochner et al., 2012; Zhang et al., 2004). Differentiation in land cover types strongly modifies convection efficiency (Zhao et al., 2014) and results in great variability in surface and air temperature (Majkowska et al., 2016; Walawender et al., 2014) that might provoke huge differentiation in the timing of the pollination pattern (Bogawski, 2016). The connection of remote sensing data with flowering phenology has been rarely explored (Bogawski, 2016; Jochner et al., 2012). The so-called 'satellite phenological observations' are the most often made on the basis of canopy greenness in the context of climate change (Fisher et al., 2006; Zhang et al., 2004).

Although the abiotic factors (mainly temperature) influencing tree phenology have been commonly studied (Hájková et al., 2015; Juknys et al., 2012; Ovaska et al., 2005; Ranta et al., 2008; Rousi et al., 2011; Rousi and Heinonen, 2007; Skre et al., 2006; Vitasse et al., 2009), the role of biological ones has been taken into account very rarely. Phenotypic plasticity and genetic heterogeneity might be the cause of differentiation in phenological response to the action of abiotic factors within the species (Chuine et al., 2000; Possen et al., 2014; Rousi et al., 2011; Rousi and Pusenius, 2005; Skre et al., 2006; Vitasse et al., 2009). The researches concerning silver birch phenology indicate a similarity in phenological response to the temperature of genetically identical individuals and variability among genetically different ones (Chuine et al., 2000; Possen et al., 2014; Rousi and Pusenius, 2005). While in the case of silver birch this problem has been investigated a few times, in the case of alder only by Chuine et al. (2000).

Many studies have proved that variability in tree phenology between populations exists and has linked it with various latitudes, altitudes, continental or oceanic provenances (Leinonen 1996; Heide, 2003; Ovaska et al., 2005; Porter et al., 2013; Skre et al., 2006). The study made by Chuine et al. (2000) is in opposition to the cited ones. They found that the timing of flowering of four anemophilous species (*A. glutinosa* among them) did not differ between populations. Little variability was observed only when populations from very distinct provenances were compared. Some authors emphasize that in the case of *B. pendula* within-population phenological and genetic variability is higher than among populations (Chuine et al., 2000; Mejnartowicz, 1979; Palmé et al., 2003). King and Ferris (1998) revealed that within-population genetic differentiation of *A. glutinosa* is stronger than among-population differentiation. Within-population genetic variability in anemophilous species is often associated with the high potential for gene flow (high dispersion of pollen grains and seeds). Light alder and birch pollen can be transported even several hundred kilometers from the site of origin (Jato et al., 2007). This ultimately results in high genetic variation within the local population.

As objects of our study, we have chosen black alder and silver birch trees. Although many studies concerning silver birch phenology have been made so far, none of them has included within-population variability in the pollination pattern in strongly differentiated urban ecosystems. The phenology of black alder has been studied less frequently. In Poland, phenological observations on a large spatiotemporal scale are not common and no relationships between land surface temperature, urban land use, and pollination phenophases have been examined in Poland so far, apart from Poznań for *B. pendula* and *Artemisia vulgaris* L. (Bogawski, 2016). According to our knowledge, Bogawski (2016) was the first who linked the pollination pattern with LST differentiation. To fill the gaps in current knowledge we decided to link the results of four-year phenological observations conducted at sites of different land use type with meteorological and remote sensing data. The main research problem is contained in the question: What is the relationship between the black alder and silver birch pollination pattern and local climate as well as land use type? The main aims of the study were to demonstrate the spatial and temporal diversity in the timing of black alder and silver birch pollination as well as to identify factors affecting these variations. We focused on abiotic factors such as thermal conditions: air and surface temperatures, and a biological factor, notably population variability. The implementation of these goals will verify the following research hypotheses: (i) there is between- and within-population variability in terms of pollination patterns of the tree species under study; (ii) local climate, mainly thermal conditions, is not the only factor strongly affecting the variation in the pollination pattern; this phenomenon also depends largely on phenotypic plasticity or genetic variability of an individual tree.

2. Material and methods

2.1. Study area

The study was carried out in Rzeszów (50°02′28″N, 021°59′56″E), SE Poland (Fig. 1). Rzeszów is a medium-sized city, ranking 20th among Polish cities in terms of occupied area. It spreads over 116.33 km^2 and is inhabited by about 185.000 citizens. The city has a typically urban structure with a predominance of industrial and commercial areas as well as discontinuous urban fabric. The urbanization index is 0.41. There are several little green spaces in the city. The largest ones are leisure facilities beside the river and a few small parks in the city center (UAMG, 2006). A large amount of agricultural land, situated mainly in the suburbs, accounts for about 59% of the whole city area. They are predominantly arable lands and also pastures, meadows and orchards. The Wisłok River with a reservoir splits the city into the eastern and western parts. The percentage of water bodies is below 0.1% (UAMG, 2006). Wide spaces of natural ecosystems occur in the surroundings of the Wisłok River. The majority of them are classified as alluvial forests with a large proportion of alder forest (*Alnetea glutinosa*). Many species forming fertile deciduous forests (*Querco-Fagetea*) and shrub communities (*Rhamno-Prunetea*) grow in the vicinity of the river. The occurrence of endangered species and the low anthropophytization index make the Wisłok ecosystems more valuable (Ziaja and Wójcik, 2015).

2.2. Climate of Rzeszów and the weather pattern during the study period

Rzeszów has a temperate, transitional climate between continental and maritime. The mean annual temperature is 7.8 °C and the mean annual amplitude 21.2 °C. The mean total precipitation is approximately 620 mm. The warmest month is July with a mean temperature of 19.5 °C and the highest total precipitation of 110 mm. The coldest month is January with the mean −1.9 °C. The lowest precipitation is recorded in February and April, slightly above 30 and 26 mm, respectively (Fig. 2). The months that are the most important to our study are February, March and April, the period of alder and birch pollination. During 2000–2015, the average monthly temperature was −1.0 °C, 3.3 °C and 7.5 °C, respectively (Fig. 2). In spite of the monthly average above 0 °C, in March, frost days (< 0 °C) may occur in Rzeszów (3.8 on average) and the last days with ground frost may occur until the beginning of May (Woś, 2010).

Meteorological data were obtained from three meteorological stations located as follows: (i) about 4 km from the city center in the suburbs (s. I); (ii) near the city center (s. II; data for 2014 were obtained from Wisz and Zięba, http://www.pl-by-ua.rescluster.eu, for 2015-2016, http://stacje.wios.rzeszow.pl/dane-pomiarowe/automatyczne/stacja/5/parametry/wszystkie for 2015–2016); and (iii) about 10 km from the city center at the airport, outside the city borders (s. III). Fig. 3 shows the course of weather in the city suburbs (s.I). The year 2013 differed distinctly in the weather pattern from the other years. Only