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Long-term changes in vegetation and site conditions in beech and spruce forests of lower mountain ranges of Central Europe

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ABSTRACT

In the study of vegetation changes in European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* (L.) Karst.) forests in the Orlické hory Mts. (the Sudetes range, Czech Republic), 34 research plots were surveyed in 1951–2011 using the seven-point Braun-Blanquet scale. The long-term research was motivated by studying the effects of the pollution disturbance in the mountains of the Sudetes system in the 1980s, but also by the understanding of autonomous development of vegetation differing in human interventions. On the studied plots, soil samples were collected periodically from particular soil horizons for physical and chemical analyses. The results document the fact that beech forests showed a slow and almost one-way succession change in 1951–2011 while in spruce stands more pronounced tendencies of cyclic development and much varied dynamics were evident at the level of particular sites. In recent 20 years, the populations of younger tree species have augmented both in beech and spruce forests. Especially during the air-pollution disturbance, the species diversity decreased moderately and almost returned to the original values at the end of observations. Moderately increasing continentality of the vegetation composition and retreat of warmth-requiring species are typical of beech forests while an increase in nutrient-demanding species and retreat of light-requiring and moisture-demanding species are characteristic of spruce forests. Undergrowth in beech forests is rather more conservative from the aspect of developmental stages than undergrowth in spruce forests. The effect of forest origin on the temporal development of vegetation and species diversity was not statistically significant in either of the forest types. The test of the effect of chemical properties of soil showed the most important role of available potassium and calcium content in humus horizon and magnesium content in B horizon in beech forests and the crucial role of nitrogen content and soil reaction in A horizon in spruce forests.

1. Introduction

The natural environment of forest ecosystems in Central Europe has been influenced and limited for a long time by many, usually interactive natural and anthropogenic ecological factors (Tranquillini, 1979; Matesanz et al., 2010; Primack, 2012; Jantsch et al., 2013; Bosela et al., 2016). In the meantime, their abiotic (climatic changes, site conditions), biotic (insect defoliation, fungal pathogens, game damage, borer attack, microorganisms) and anthropogenic conditions (air pollution, soil chemical stress, acidifying deposition, nitrogen eutrophication, forest management, land use) have been changing (cf. Walther et al., 2002; Thomas et al., 2002; Kimmins, 2003; Perry et al., 2008; Baeten et al., 2010). The crucial factors influencing the present condition of forest ecosystems to the largest extent are especially climatic extremes (winter frost, summer drought), air pollutants (SO_2, NO_X, O_3), bark beetle disturbances, losses caused by wildlife and many times unsuitable management methods (cf. Gadow, 2000; Puhe and Ulrich, 2001; Flechard et al., 2011; Krejčí et al., 2013; Lüttge, 2014).

For the reasons above, long-term research plots are the most valuable objects for monitoring changes in forest ecosystems (cf. Bakker et al., 1996). Long-term research on vegetation dynamics is mostly limited by the lack of authentic historical data. Currently the increasing trend in publishing long-term vegetation dynamics in forests of Europe is obvious (Vacek and Matějka, 2003; von Oheimb and Brunet, 2007; Šamonil and Vrška, 2008; Šebesta et al., 2011; Becker et al., 2017; Hédl et al., 2017; Heinrichs and Schmidt, 2017). These studies were conducted in areas with the long-term tradition of vegetation research, especially in central and western Europe, in southern Scandinavia, and to a lesser

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extent in southern and eastern Europe. There are also single long-term vegetation studies from the U.S. northwest (Rooney et al., 2004; Taverna et al., 2005; Rogers et al., 2009).

In the last decades, European vegetation studies of forest ecosystems demonstrated significant changes in diversity of plant communities, extinction of rare species, an increase in nitrophilous and acidophilous species, an increase in drought-tolerant species and vegetation generalists (e.g. Kwiatkowska, 1994; Vacek et al., 1999; Hédl et al., 2010; Jantsch et al., 2013). These changes are usually interpreted as reaction to both the historical and current management of forest ecosystems (Vacek and Matějka, 2003; Hédl, 2004; Taverna et al., 2005; Hédl et al., 2010; Ross et al., 2010), great pressure of hoofed game (Heinken and Raudnitschka, 2002; Janík et al., 2008, 2011; Šamonil and Vrška, 2008; Unar and Šamonil, 2008; Vacek et al., 2014) or air pollution (Galloway et al., 2004; Bernhardt-Römermann et al., 2007; Wamelink et al., 2009; Vacek et al., 2013; Hůnová et al., 2014; Král et al., 2015). Particularly the acidification of forest ecosystems due to air pollution has a significant effect on vegetation dynamics mainly in mountain ecosystems of Europe and the U.S.A. (Kärenlampi and Skärby, 1996; Vacek et al., 1999; Rogers et al., 2008; De Schrijver et al., 2012; Hruška et al., 2012) and also on the dynamics of soil changes accompanying or causing changes in vegetation dynamics along with a change in the species composition (Augusto et al., 2002). Changes in environmental conditions and availability of resources to many plant species can be a significant trigger factor of neophyte invasion to forest ecosystems (Rooney et al., 2004; von Oheimb and Brunet, 2007; Chmura and Sierka, 2007; Van Calster et al., 2008; Šebesta et al., 2011).

A substantial part of the study locality of Orlické hory mountain range (ca. 90%) – prior to human interventions in the landscape in the 13th century – was covered by European beech (*Fagus sylvatica* L.) forests with an admixture of silver fir (*Abies alba* Mill.), sycamore maple (*Acer pseudoplatanus* L.) and of Norway spruce (*Picea abies* (L.) Karst.) at higher altitudes (for vegetation reconstructions see Mikyška et al., 1968; Neuhäuslová et al., 1998).

At the times of more intensive forest exploitation in the 15th century, the process of conversion of the beech-dominated forests to the 19th century spruce-predominant stands started (Roček et al., 1977). Air pollution in the 1970s and 1980s severely damaged mostly spruce stands in summit areas (above 900 m a.s.l.), leading to an extensive-area deforestation (ca. 2 000 ha; Vacek et al., 2015). Disturbances and the forest decline were primarily caused by synergic effects of air pollution and climate extremes (strong winter desiccation, wind-caused damage). Synergism of air pollution and insect pests, especially spruce bark beetle (*Ips typographus*) in spruce forests in very dry years and beech scale (*Cryptococcus fagi*) in beech stands, only worsened the situation. After 1987, stress factors decreased markedly due to a significant reduction of sulphur-compounds air pollution load. After 2000, there was a major increase in nitrogen deposition and ozone concentrations (cf. Vacek et al., 2003, 2015). In the Orlické hory Mts., only remnants of natural vegetation types have survived until now, mostly in reserves (Vacek et al., 2014; Králíček et al., 2017).

For this research, an important long-term data set of the soil and vegetation conditions was available. Moreover, these data come from the most valuable objects for monitoring changes thanks to the location of the study area (having been exposed to air pollution), the environmental variability (altitude, stand conditions, vegetation types) and stand variability (developmental stage, stand origin, species composition). The start of exact vegetation and soil research of the Orlické hory Mts. forests date back to 1951, when A. Zlatník and J. Pelíšek from the Faculty of Forestry of the University of Agriculture in Brno established 462 research plots in the Orlické hory Mts. area. These plots represented a very broad spectrum of site and stand conditions at altitudes from 250 to 1115 m a.s.l., not only in natural forest stand types but also in secondary spruce and Scots pine (*Pinus sylvestris* L.) monocultures (Zlatník, 1951; Pelíšek, 1973). Among the above-mentioned plots, 34 plots that were localized in the field by marking the central tree and the soil pit suited well the conditions of phytosociological monitoring in European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* (L.) Karst.) stands in the Orlické hory Mts. (cf. Vacek and Matějka, 2003).

The objective of the presented paper is to evaluate the current situation and changes in phytocoenoses in relation to soil and structural conditions in beech and spruce forests in the Orlické hory Mts. in 1951–2011 and to answer the following research questions:

(1) What were the overall major changes of vegetation dynamics in studied beech and spruce stands during the observation period?
(2) How have the mast years and subsequent natural regeneration influenced the vegetation dynamics in beech and spruce stands since the late 1980s?
(3) What is the effect of developmental stage (forest cycle) and stand origin on the condition of phytocoenoses and their dynamics in beech and spruce forests during the observation period?
(4) Which species decreased and which increased in beech and spruce forests in the course of development and especially during the air pollution disaster and after it?
(5) What changes of β-diversity occurred in beech and spruce stands during the observation period?
(6) What were the major changes in soil chemistry (nutrient content) and how do the soil conditions in upper horizons (humus, A and B) influence the dynamics of herb layer in beech and spruce stands?

2. Material and methods

2.1. Study area

The territory with the remnants of the studied beech and spruce forests (Fig. 1) is situated in the northwestern part of the Orlické hory Mts. ridge, which belongs to the Deštenská hornatina Mts. in the Czech Republic. The studied forest complexes are large private forest estates and owned by the Colloredo-Mansfeld and Kolowrat families.

A major part of the territory is formed by the crystalline basement – gneiss of mica schist type, granitic gneisses, and to a lesser extent by orthogneisses, paragneisses and migmatites (Opletal et al., 1980; Chlupáč and Vrána, 1994). In the lowest and medium parts of the territory, oligotrophic and mesotrophic modal Cambisols prevail, followed by entic Podzols and, in the highest parts, modal Podzols have developed. On elevated plateaus or in the moderately sloping terrain there are soils influenced by water: Pseudogleys, Gleys and Organosols (Pelíšek, 1973; Vacek et al., 2003). These are mostly oligotrophic and mesotrophic, highly acidic soils (Pelíšek, 1984; Borůvka et al., 2005).

The territory of interest has warm-summer humid continental climate (Dfb) according to Köppen climate classification (Köppen, 1936), or rather – by a detailed region Quitt classification (Quitt, 1971) – it belongs mostly to a moderately warm district (MT 2), while the highest parts belong to the cold district (CH4-7). The average annual temperature ranges from 5.8 to 3.8 °C, and 13 to 10 °C in the growing season. In the highest parts, the average air temperature decreases below −5 °C in January, and increases to 13 °C in July. The total annual precipitation is 875–1040 mm, and 410–600 mm in the growing season. The number of days with snow cover ranges from 60 to 160 days. The length of the growing