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Acidification of primeval forests in the Ukraine Carpathians: Vegetation and soil changes over six decades

Jan Šebesta [a,*], Pavel Šamonil [b], Jan Lacina [a], Filip Oulehle [c], Jakub Houška [a], Antonín Buček [a]

[a] Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic
[b] Department of Forest Ecology, The Silva Tarouca Research Institute for Landscape and Ornamental Gardening, Lidická 25/27, 657 20 Brno, Czech Republic
[c] Department of Environmental Geochemistry and Biogeochemistry, Czech Geological Survey, Klárov 3, 118 21 Prague 1, Czech Republic

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ABSTRACT

Changes to vegetation and soil were assessed in primeval forests of the Eastern Carpathians after a period of 59–68 years. We hypothesized that forest ecosystems were acidified through the long-distance transport of air pollutants. A total of 141 relevés and 20 soil profiles that had been studied in 1938 in spruce- and beech-dominated forests along an altitudinal gradient ranging from 1085–1575 m a.s.l. were re-surveyed from 1997 to 2006. Relevés were analyzed using multidimensional statistics and plant community characteristics (Shannon–Wiener's index, equitability, fidelity, Ellenberg indication values – EIV); soil reaction and sorption complex properties were analyzed in soils.

A total of 159 vascular plant taxa were recorded in 1938, of which 35 were not found during the repeat survey. During the later survey, 137 taxa were found, of which 13 were new findings. The upper mineral (A) as well as cambic or spodic (B) horizons were considerably acidified in both forest types. Both active and exchange soil reaction decreased by 0.1–0.3 units on average, exchangeable acidity significantly increased and the sum of base cations decreased in both soil horizons and forest types. Base saturation decreased by more than half of original values, with a maximum decrease of 68% found in the B-horizon of spruce forests. Whereas the herb layer developed along with soils in beech-dominated forests, EIV values for soil reaction increased in spruce-dominated forests, probably due to the movement of broadleaf woody species to higher elevations or due to the higher resistance of herb species to soil acidification. Significant changes to EIVs also occurred in the beech- and/or spruce-dominated forests for the factors of nitrogen, light moisture and temperature.

There was an expansion of the lower tree and shrub layers, primarily *Fagus sylvatica*, *Picea abies* and *Sorbus aucuparia* in intermediate and higher elevations, which can be explained by reduced cattle grazing. Also, the dissipation of *Juniperus communis* and marked decline of *Abies alba* are interpreted as being related to gradual changes in landscape management along with the effect of acid deposition. Since 1938, all stands have shown a significant increase in nitrophilous taxa such as *Rubus idaeus*, *Athyrium distentifolium*, *Urtica dioica*, *Calamagrostis arundinacea*, *Stellaria nemorum*. Significant decreases in the number of species, Shannon–Wiener's index and equitability were only observed in spruce-dominated forests. Neophyte taxa were not detected in either the 1930s or the 1997–2006 period.

1. Introduction

Scientific questions relevant to the dynamics of natural vegetation are usually approached through observational methods, and the ability to find causal relationships between vegetation and influencing factors is limited. In order to better understand vegetation-environment interactions, it is valuable to study changes in both vegetation and the environment over longer time scales. Knowledge of their long-term development can be subsequently used to generate relevant hypotheses about the role of biological processes in the site under study (Aldrich et al., 2003; Dale, 1999).

Long-term research into vegetation dynamics is predominantly limited by a lack of authentic historical data. Hence, most studies have originated from regions with a long tradition of vegetation research, such as densely populated Central, Southern and Western Europe (Firm et al., 2009; Hédl, 2004; Schaffers and Sýkora, 2000; Šamonil and Vrška, 2007, 2008; von Oheimb et al., 2005), Southern Scandinavia (Klanderud and Birks, 2003; Nygaard and Ødegaard, 1999; von Oheimb and Brunet, 2007) or the Northwest

* Corresponding author. Tel.: +420 545 134 058; fax: +420 545 212 293.
E-mail addresses: sebestijan@centrum.cz (J. Šebesta), pavel.samonil@vukoz.cz (P. Šamonil), jan.lacina@mendelu.cz (J. Lacina), filip.oulehle@geology.cz (F. Oulehle), jakubh@mendelu.cz (J. Houška), antonin.bucek@mendelu.cz (A. Buček).

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USA (Rogers et al., 2009; Rooney et al., 2004; Taverna et al., 2005). As far as we know, such long-term studies from Eastern Europe are generally lacking.

European vegetation studies have demonstrated significant changes over the past few decades in the α-, β-, and γ-diversity of plant communities, extinctions of rare species, an increase of nitrophilous, acidophilous, soil desiccation-tolerant species and herb generalists (e.g. Hédl et al., 2010; Kwiatkowska, 1994; Nygaard and Ødegaard, 1999). These changes have been usually interpreted in direct linkage to visible human activities – e.g. the type of historical or recent management (Hédl, 2004; Hédl et al., 2010; Ross et al., 2010), game pressure (Hédl et al., 2010; Janík et al., 2008, 2011; Šamonil and Vrška, 2008; Unar and Šamonil, 2008) or large-scale air pollution (Wamelink et al., 2009). Both the character of human activities and associated changes over time are important factors in vegetation development. The frequent changes of land use in many European regions and ecosystems during the last decades caused changes in the accessibility of resources for plant species. This is considered to be an important factor in the success of invasions to ecosystems by neophytes (e.g. Rooney et al., 2004; von Oheimb and Brunet, 2007). Where the remnants of natural forests were studied, intensive direct or indirect human activities in prehistorically populated regions also understandably affected some results. Also in the highly valued Boubínský prales and Žofínský prales forest reserves (protected since 1858 and 1838, respectively; e.g. Král et al., 2010a; Šebková et al., 2011), game pressure associated with the presence of game-parks at the beginning of the 20th century has continued to be the most important factor in their vegetation dynamics.

We succeed in retrieving and repeating historical relevés and soil surveys established in the 1930s in primeval fir-beech-spruce forests in the Ukraine Carpathian Mountains along the Romanian border. Phytosociological and soil surveys were repeated after a period of 59–68 years, but despite this long time interval, we were able to locate the original plots to within about 5 m (see Section 2.1). These forests have never been logged and are situated far away from any large industrial air polluter. The studied forests are still uncultivated and the surrounding managed forests and non-forest areas are still managed using traditional techniques. However, the intensity of traditional management techniques – especially cattle grazing on upland pastures – has gradually decreased during recent years (Elbakidze and Angelstam, 2007). These forests are regarded as the last remnants of the European primeval forests (http://whc.unesco.org).

Despite the considerable distance from large industrial air-pollution sources, surprisingly we found high acid S- and N-deposition in the studied forests, likely peaking in the 1980s (Oulehle et al., 2010). Measured S- and N-throughfall inputs in 2008 reached 10 and 5.6 kg ha^{-1} year^{-1}, respectively; inputs in the 1980s were surely higher. Although these amounts are substantially lower than have been measured in Central European ecosystems (e.g. Hruška and Krám, 2003) they could have serious consequences for plant community dynamics. Significant impacts from similar S-depositions due to remote transport to natural ecosystems were unexpectedly recently demonstrated by Savva and Beninger (2010) in Siberian and Scandinavian forests. Oulehle et al. (2010) also suggested that primeval Eastern Carpathian forests seem to be vulnerable to anthropogenic acidification and to the adverse effects of Al on forest root systems, especially in areas with low mineral weathering.

We were therefore interested in determining what changes occurred to the vegetation and soils in the Ukraine Carpathian primeval forest from 1938 to 1997–2006. We hypothesized that forests soils were acidified through long-distance transport of air pollutants. In addition, we supposed that there would be a decrease of plant species diversity and an increase in the proportion of acidophilous plant species and generalists (see Berge et al., 1999; Bobbing et al., 1998; Köchy and Bråkenhielm, 2008; Wamelink et al., 2009). We also anticipated that neophytes would play a marginal role in these ecosystems. Therefore, any prospective new dominant understory species would have been recruited from the original plant community. The alternative hypothesis would be that the studied forest ecosystems remained resistant to acid deposition. Finally, we supposed that the low level of direct historical human impact would enable us to distinguish between impacts on the forest plant community from indirect land changes due to air pollutions and natural forest dynamics.

2. Material and methods

2.1. Description of the locality

Our research took place in the Carpathian biosphere reserve in the massif of Maramuresh Pop-Ivan (coordinates 47° 56′ 20″ N, 24° 18′ 20″ E) at the Ukrainian-Romanian border (Fig. 1). In the past, timber harvesting was concentrated in lower-situated parts of the mountains with better access, and the studied forests have never been exploited in the past. At the highest altitudes, the forests were only affected by livestock grazing in alpine meadows situated on wide mountain ridges (Elbakidze and Angelstam, 2007; Zlatník, 1934). Today, these forest ecosystems are considered the last remnants of primeval forests in the Eastern Carpathians (http://whc.unesco.org). However, according to our latest findings, the forests have been affected by human activities indirectly – through atmospheric pollution. Oulehle et al. (2010) estimated that throughfall inputs of sulphur in the period from 1900 to 1950 reached 10 kg ha^{-1} year^{-1} followed by dramatic maxima in the 1980s. Based on the concentrations of Al and base cations (Ca, Mg, K) in soil waters, they concluded that spruce forest ecosystems in the area are vulnerable to anthropogenic acidification.

The Maramuresh Pop-Ivan massif has an area of 8,990 ha (http://cbr.nature.org.ua) and is built of crystalline rocks (gneiss, phyllite, mica schist, rarely crystalline limestone). In the 1930s, four research plots were established there along a height gradient from 1085–1575 m a.s.l., with a total area of 24.9 ha (Fig. 1). Original research plots were bordered by stone mounds and accurate detailed geodetical plans were created in the 1930s (Zlatník et al., 1938). In the 1990s, we found the remains of these historical stone mounds as well as marks on trees, and restored the research plots and internal phytocoenological and soil sampling points with an estimated accuracy of within 5 m. Soils on the plots were classified as Haplic Cambisols (Dystric), Entic Podzols or rarely – and only at the highest altitudes – as Albic Podzols (according to Driessen et al., 2001; Michéli et al., 2006). The moder humus form dominated at lower elevations while mor prevailed at higher elevations and particularly on plots dominated by *Picea abies* (Green et al., 1993; Klinka et al., 1997; Zanella et al., 2011). The thickness of the forest floor never exceeded 10 cm, and the upper mineral A-horizon was frequently uncovered on exposed slopes.

According to the Braun-Blanquet approach (1921), vegetation can be classified mainly in the associations of *Calamagrostio villosae-Piceetum* Hartmann in Hartmann et Jahn 1967 and *Dentario glandulosae-Fagetum* Matuszkiewicz ex Guzikova et Kornaś 1969. Mean annual precipitation reaches 1.9 m (annual mean bulk deposition from 2008 to 2010 in spruce-dominated forests, Oulehle et al., 2010); mean annual temperature is 2 °C.

2.2. Data collection

2.2.1. Phytocoenological data

Relevés were made in the 1930s (Zlatník et al., 1938) on 141 square plots sized 10 × 10 m. These relevés were preferentially