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Impacts of old, comparatively stable, treethrow microtopography on soils and forest dynamics in the northern hardwoods of Michigan, USA

Pavel Šamonil [a,*], Martin Valtera [a], Randall J. Schaetzl [b], Dušan Adam [a], Ivana Vašíčková [a,c], Pavel Daněk [a,d], David Janík [a], Václav Tejnecký [e]

[a] Department of Forest Ecology, The Silva Tarouca Research Institute for Landscape and Ornamental Gardening, Lidická 25/27, 602 00 Brno, Czech Republic
[b] Department of Geography, Michigan State University, 128 Geography Building, East Lansing, MI 48824, USA
[c] Department of Forest Botany, Dendrology and Geobiocoenology, Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemedelska 1, 613 00 Brno, Czech Republic
[d] Department of Botany and Zoology, Faculty of Science, Masaryk University, Kotlářská 267/2, 611 37 Brno, Czech Republic
[e] Department of Soil Science and Soil Protection, The Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, Kamýcká 129, 165 21 Praha 6, Czech Republic

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ABSTRACT

Uprooting represents a key disturbance process in forests, forming pit-mound microtopography, which can then dramatically impact pedogenesis and the forest ecology. At our study sites in northern Michigan, where well-drained, sandy Spodosols dominate, pit-mound microtopography tends to persist for millennia. Because of its persistence, the influence of this type of microtopography is greater here than in most forests. In that respect, our sites represent an end member along a continuum of forest soil disturbance by uprooting. We studied post-uprooting pedogenesis (at 14 dated pit-mound pairs), mapped and characterized the pit-mound topography (over 2.8 ha), the soils below (within 317 soil profiles), and the trees above, to better understand the complex interactions among this type of disturbance regime and forest dynamics.

We used a pair correlation function and chi-square test approach to study the relationships between treethrow features and the living trees at one of these sites. Soil variability as affected by microtopography, was studied using geostatistics.

Pit-mound microtopography here covers 17% of the surface and are generally randomly distributed across the forest floor. Mounds are more prominent features of the forest floor than are pits. Pits infill with sediment and litter, obscuring them, whereas mounds persist for millennia in the sandy sediment because runoff is limited, and litter forms a protective armor. Treethrow features had volumes of roughly 214–225 m^3/ha, and on average, each uprooting event translocated 0.6 m^3 of soil about 0.8 m laterally and 0.1–0.2 m vertically. Areas of the pit-mound features did not differ between slope aspects, supporting an idea that on the gentle slopes of the study sites, uprooting does little to affect the movement of sediment downslope. The exceptional longevity of the treethrow features is probably a factor in the statistical randomness with which treethrow features are distributed on the forest floor, as footprints of many uprooting events are interlaced across the forest floor.

As reported elsewhere, soil development was accelerated in pits, leading to increasingly greater differences in soil development between pits and mounds, over time, and illustrating the concept of locally divergent pedogenesis. In older pits, the abnormally thick soil profiles extent so far below the depth of rooting that they are unlikely to be disturbed by future uprooting events. On the coarser spatial scale of the forest stand, uprooting decreased the ranges and increased the sills of spatial autocorrelation for O, E and Bhs horizon thicknesses. The effect of treethrow dynamics on soil characteristics was greatest and statistically most significant for E horizon thicknesses, where the range was decreased from 13 m to 10 m, whereas the maximal level of semivariance (sill) increased by 42%. All tree species preferred treethrow mounds to pits or undisturbed microsite for regeneration, especially *Acer saccharum*.

1. Introduction

Tree uprooting represents a key disturbance process in many forests (see reviews by Schaetzl et al., 1989a, 1989b; Ulanova, 2000; Šamonil et al., 2010b; Pawlik, 2013). For example, in some European temperate forests, a third of all trees die due to uprooting and the entire area is so disturbed every 900–1400 years, i.e., its turnover period (Šamonil et al., 2009, 2013). In Alaska (USA), the rotation period of this phenomenon is even much shorter — only 200–400 years (Bormann et al., 1995). Under this type of disturbance regime, soil texture represents an important modifying factor, as it impacts post-disturbance pedogenesis as well

* Corresponding author.
E-mail address: pavel.samonil@vukoz.cz (P. Šamonil).

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as post-disturbance erosion and sedimentation processes (e.g. Šamonil et al., 2015). Microtopography caused by uprooting also causes unique microclimate conditions within pits and on mounds (Beatty and Stone, 1986; Clinton and Baker, 2000). Pit–mound microtopography also dramatically influences localized pedogenesis (e.g. Schaetzl, 1990; Šamonil et al., 2010a; Tejnecký et al., 2015) as well as the biodiversity of organisms that eventually inhabit the microsites (e.g. Nachtergale et al., 2002; von Oheimb et al., 2007; Lõhmus et al., 2010; Simon et al., 2011; Šebková et al., 2012).

In northern Michigan (Fig. 1), many forests are developed on nutrient-poor, sandy outwash. These parent materials, when combined with mixed coniferous-deciduous forest, thick snow cover in winter, and a strong leaching regime, have led to strongly developed Spodosols (Schaetzl and Isard, 1996; Schaetzl et al., 2015). The coarse parent materials not only enhance deep percolation and leaching, but they probably also minimize runoff and hence, slow the leveling of the pit-mound microtopography. As a result, the oldest known treethrow features reported to date, older than 6000 years, exist in this area (Šamonil et al., 2013). In comparable studies from other regions, the longevity of treethrow pit–mounds commonly reaches only about 500–2000 years, and often considerably shorter (see review by Šamonil et al., 2010b).

In our study, we reasoned that sandy textures, and great pit-mound longevity derived probably from this texture (studied in detail by Šamonil et al., 2013), act to modify the role of uprooting-related disturbances in forest dynamics. For example, long-lasting pits and mounds could dramatically impact seedling establishment and mortality and hence, overstory tree composition and distribution. Thus, one of our study goals was to examine the density and distribution of these long-lived pit–mound features in forest stands, and to determine (statistically) their impact on the forest. Spatial relationships between soils, treethrow disturbances and woody species community have never been studied in this region.

A key aspect of long-lived microtopography is its impact on soil properties over short-distances and small scales (in Michigan studied in detail by Šamonil et al., 2015). Some studies of the effects of pit–mound microtopography on soil development (see review by Šamonil et al., 2010b) have shown that pits tend to be sites of enhanced leaching, and thus old pits may have the strongest developed soils on such landscapes (e.g. Schaetzl, 1990). Conversely, mounds tend to be site of less intense leaching and weakly developed soils. Šamonil et al. (2015), suggested based an analysis of soil morphology, that post-disturbance pedogenesis could be divergent within the pit–mound pairs in regions undergoing podzolization. Microtopography also affects other soil parameters that can also impact forest ecology, such as soil temperature and moisture conditions, litter depth, and nutrient accessibility (e.g. Clinton and Baker, 2000). All of these impacts are likely to be more pronounced when the microtopography is more semi-permanent on the landscape, as at our study sites. Thus, a second goal of our study was to examine local soil development using soil morphological and chemical analyses, and to examine soil variability, as affected by microtopography. We will compare our results with studies from the other regions (e.g. Putz, 1983; Shubayeva and Karpachevskiy, 1983; Small et al., 1990; Vassenev and Targulian, 1995; Šamonil et al., 2008, 2010a, 2015; Ulanova, 2000; Pawlik, 2013) to help understand the role of bioturbation on forest ecosystem dynamics, and on soil evolution.

2. Materials and methods

2.1. Study sites

To obtain more generalizable results we collected data on three study sites located in forest stands near the cities of Munising, Strongs, and Brimley, in the Upper Peninsula of Michigan, USA (Fig. 1). According to the World Reference Base for Soil Resources (FAO, 2014) soils here are primarily Albic Podzols (Typic Haplorthods and Durorthods according to Soil Taxonomy, Soil Survey Staff, 2014). The soils at our study sites have developed on sandy glacial outwash under a mixed northern hardwood stand dominated by maple (*Acer saccharum* Marsh., *Acer rubrum* L.) followed by red oak, black cherry, eastern hemlock and pine (*Quercus rubra* L., *Prunus serotina* Ehrh., *Tsuga canadensis* (L.) Carr. and *Pinus* spp.). The climate here is cool and humid, with a frigid soil temperature regime and an udic–aquic soil moisture regime (Soil Survey Staff, 2014). The National Weather Service (NWS) station at Newberry, nearest to the three study sites, reports an average of 812 mm of annual precipitation and a mean annual temperature of 4.7 °C. The area lies within a Lake Superior snowbelt, with Newberry receiving annually an average of 255 cm of snowfall (Schaetzl et al., 2015). The average seasonal maximum snow cover often exceeds 1.25 m. Tree uprooting is the most important disturbance process in these forest ecosystems, although rare fires or infrequent mammalian burrowing occurs as well. All three study sites are located within managed forests that were last cut no later than 40 years ago. The Munising site has had the least

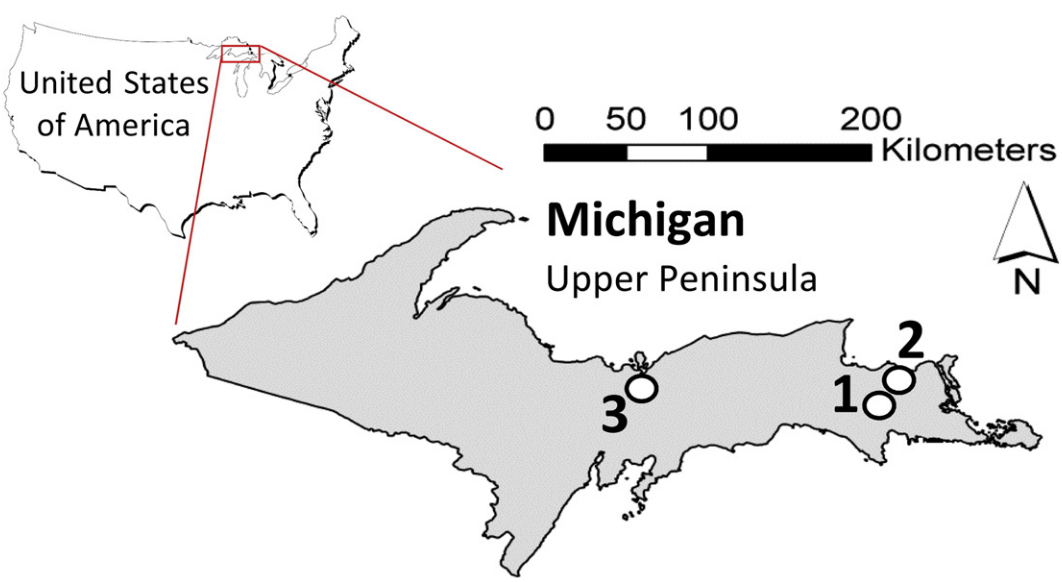

Fig. 1. Locations of the study sites: (1) Strongs (46.44°N, 84.82°W), and (2) Brimley (46.32°N, 85.06°W), (3) Munising (46.37°N, 86.70°W).