Changes in O horizon mass, thickness and carbon content following fire in northern hardwood forests

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Abstract

This study examines temporal changes in the thickness, mass, and organic carbon content of the O horizon (forest floor) of eight forested plots in northern Michigan, USA. Each plot had experienced a recent burn (prescribed or accidental); burn dates ranged from 1798 to 1980. The climax forest in this region is mixed Pinus-Acer-Betula-Tsuga, whereas the fire successional species are predominantly Populus spp. and Betula papyrifera. O horizon data were fit to logarithmic functions (chronofunctions) that depicted rapid accumulations of mass and thickness in the first years after the fire, followed by decreasing rates of increase after ≈100 years. Extension of the chronofunctions to ≈5000 years allowed for a theoretical examination of forest floor conditions, e.g., steady state and time to steady state, after long periods without disturbance. The models predicted greater O horizon thicknesses and slightly lower mass for steady state conditions than have been reported for old-growth stands elsewhere. Steady state accumulations of litter in these mixed, temperate forests requires at least 200 and possibly >1000 years, which is markedly longer than most other estimates. Although frequent disturbance by fire in these forests would likely preclude such values from being attained, these data provide theoretical maximum values for forest floor conditions in these ecosystems.

Introduction

The major reservoirs of organic carbon in forest ecosystems are the standing biomass, the mineral soil, and the forest floor (Grigal & Ohmann 1992). Studies of carbon cycling through such ecosystems have illustrated, for different forest types, various amounts held in each of the three compartments (e.g., Bormann et al. 1970; Sollins et al. 1980; Alban & Perala 1992). In most instances, the mineral plus organic soil (litter) horizons contain the great majority of the carbon, organic matter, and nutrients for the ecosystem. Disturbance factors, whether anthropogenic or natural, have been shown to alter the carbon pathways and stores of these systems (Johnson 1992). Given the increasing importance that disturbance factors are thought to have on the dynamics of such systems (Falinski 1978; Bormann & Likens 1979; Foster 1985; Schaetzl et al. 1989), additional information on their recovery and the concomitant sequestering of carbon is warranted (Alban & Perala 1992).

This study examines rates of recovery of the O horizon (accumulation of organic matter) following fire in mixed forest ecosystems in northern Michigan, USA. Numerous studies have focussed on litter production in various forested ecosystems (see reviews by Bray & Gorham (1964) and Jordan & Murphy (1978)), some of which have reported data on litter mass per unit area. Most of the latter types of studies either did not explicitly examine rates of litter accumulation (e.g., Alway & Kittredge 1933; Blow 1955; Gradusov 1958; Lang & Forman 1978), or are based in tropical areas (e.g., Peet 1971; Fox et al. 1979; Raison et al. 1986; O’Connell 1987), thereby limiting the extension of their data to midlatitude forests. This study addresses the rate at which litter and organic carbon (OC) are accumulated and/or sequestered in the O horizons of a mixed coniferous/deciduous forest.
Information on organic matter and carbon accumulation in these stands will assist in the modelling of carbon cycling in temperate forest ecosystems elsewhere (e.g., Schlesinger 1985). Because of the importance of O horizons to fire probabilities and fuel loadings (Brown 1966; O’Connell 1987), nutrient cycling in general (O’Connell 1989), geomorphology (Walsh & Voigt 1977; Mitchell & Humphreys 1987), hydrology (Curtis 1960; Dabral et al. 1963; Reynolds & Knight 1973), as well as soil temperature (MacKinney 1929), development (Petersen 1976) and erosion (Sims 1932), the results may have wide application.

Study area soils and vegetation

Two sites in northern lower Michigan were studied: one at the University of Michigan Biological Station (UMBS), near Pellston in the northern lower peninsula (near Lake Michigan), and the other near Roscommon, ∼78 km to the SSE. Soils at the study sites have formed in glacial outwash (Tardy 1991). Podzolization is the dominant soil-forming process in this cool, humid climate with deep winter snows (Schaeztl & Isard 1991; Barrett & Schaeztl 1992). All plots were located on well- and somewhat excessively-drained, sandy soils (Rubicon series: sandy, mixed, frigid, Entic Haplorthods) on slopes of less than 8%. None of the soils have been cultivated. The typical horizon sequence for Rubicon sand in this region is: Oi, Oe, A or Oa, E, Bs1, Bs2, BC, C (horizon designations as defined by the Soil Survey Staff 1992). The O horizons of the Rubicon soils at the study sites were of the mor type, although because of their relative youth, acid Oa horizons have not yet formed. Gates’ study (1926) of the vegetation near the Pellston study area concluded that Pinus resinosa Ait. and P. strobus L. formed the bulk of the forest. Plots at Pellston that had been burned at different periods in the past showed a vegetative succession from nearly pure stands of aspen (Populus grandidentata Michx. and P. tremuloides Michx.) and white birch (Betula papyrifera Marsh.) to mixed stands of aspen-white pine (Pinus strobus)-red maple (Acer rubrum L.) in 30–60 years. Scheiner and Teeri (1981) noted that Populus grandidentata Michx. is the usual pioneering species following fire in the study area. Plots burned within the last 30 years also had thick understoreys of bracken fern (Pteridium aquilinum). Those burned before 1930 had considerable quantities of aspen, red maple, and white pine in the overstory, but also contained a component of white birch, red oak (Quercus rubra L.) and red pine, all fire-successional species in this region (Scheiner & Teeri 1981; Loope 1991). Understory vegetation on the oldest plots was sparse and often restricted to areas beneath canopy gaps. In the absence of disturbance, aspen (Populus spp.) is eventually replaced by a mixed Pinus-hardwood assemblage (Harman & Nutter 1973).

The study area near Roscommon is in the Michigan Department of Natural Resources’ Red Pine Natural Area (RPNA). It is an old-growth stand of red pine with some white pine in the overstory and scattered individuals of red maple as subcanopy species. Rubicon soils dominate the site. Whitney (1986) described the typical soil-vegetation assemblages during the late 19th century in and around the Roscommon site as various admixtures of pine and northern hardwood species, dependent in large part on substrate and disturbance history.

Methods

The recovery of the litter layer following fire was studied by sampling O (organic) horizons on eight ‘burn plots’ on the UMBS, each one ha in area, and at the RPNA. The seven UMBS plots had been burned in 1901, 1911, 1923, 1936, 1948, 1954, or 1980 and have been relatively undisturbed since. The four post-1923 plots had been clearcut and burned. The 1901, 1911 and 1923 plots were burned by accidental wildfires; detailed information on these fires is lacking. The RPNA represents an old-growth stand that had experienced incomplete burns (probably ground fires) in 1798, 1888 and 1928 (MacMullan 1966). I used the 1798 burn as the base age of the presumably largest fire because (1) the largest trees in the stand are at least 150 years old, and (2) the 1928 fire must have been either cool or localized in extent, since the litter layers at the RPNA were much thicker than in areas burned prior to 1928 at the UMBS.

The O horizon was sampled by removing all litter from 10, 1000 cm² square quadrats in each plot. Sample sites were located somewhat randomly by tossing a 1000 cm² board some distance into the forest and sampling the litter beneath. Dead woody materials were included in the sample unless it was apparent that the wood dated from before the fire (i.e., charred), in which case the sample was discarded and a new site chosen. Oi and Oe samples were not differentiated during the bulk sampling procedure, although thickness of Oi and Oe horizons were noted at 40 random locations within