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The effects of thinning and soil disturbance on enzyme activities under pitch pine soil in New Jersey Pinelands

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ABSTRACT

Disturbance is an important factor in changing ecological processes. Forested ecosystems undergo natural disturbances of fire and windthrow and disturbances involved in management (thinning, harvesting, control burning). Using the New Jersey pine barrens as model system for eastern US mixed forests, we have observed that under conditions of repeated physical soil disruption or control burning, the pine barrens forest understory can change from ericaceous to graminoid species dominance through suppression of the ericaceous plants. In order to predict changes in soil properties and assess the potential to maintain this alternate herbaceous layer community, replicate manipulation plots were established the Franklin Parker Preserve in the New Jersey pine barrens. The manipulations consisted of: intact forest controls (CONT), canopy tree thinning (THIN) and canopy tree thinning plus ercicaceous stem removal and soil tilling (THIN & PLOW). The manipulations were designed to increase sunlight penetration to the forest floor and to encourage graminoid plant species establishment. Soil active carbon, microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN), six hydrolytic enzyme activities and two oxidative enzyme activities under three different treatments were measured. In the 0–10 cm soil depth, we observed that protease and arylsulfatase activity showed a significant decrease in the THIN and THIN & PLOW treatments compared to CONT, the activities of cellulase and phenol oxidase were significantly lower in THIN than CONT and THIN & PLOW, whereas the trend of peroxidase activity was opposite. There were no significant differences between treatments for glucosaminase, glucosidase and acid phosphatase activities. For the 10–20 cm soil depth only acid phosphatase and phenol oxidase activity significantly differed between treatments. We found that all enzyme activities except for peroxidase were significantly lower in the 10–20 cm soil horizon than in the 0–10 cm; peroxidase activity was significantly higher in the lower soil horizon. We demonstrated the activities of cellulase, phenoloxidase, arylsulfatase and protease were significantly and positively related to active C, but peroxidase activity was negatively correlated. Less expected is that only phenol oxidase was related to soil MBC, whereas the correlations between peroxidase, phenol oxidase, arysulfatase, protease activities and soil MBN were obvious. By understanding the relationships between microbial activity (enzyme production) and disturbance, we can determine the beneficial effects of many management practices on the potential nutrient availability for subsequent tree growth, since these enzymes are key to nutrient mineralization and carbon dynamics in soil.

1. Introduction

Although the New Jersey pine barrens is protected as a unique natural forest in the center of America's most populous region (Forman and Boerner, 1981; Good and Good, 1984; Motzkin and Foster, 2002; Russell, 1994), the forest is representative of a series of similar pine dominated mixed forests on nutrient poor sandy soils that exist along the eastern seaboard of the USA. The forest has similar characteristics to coniferous forests on sandy soils in other parts of the world. Ecosystem restoration and sustainable forest management are important research issues under the Pinelands Comprehensive Management plan (NJ Pinelands Commission, 1980), an agency created to protect this region. A renewed emphasis on commercial timber extraction from these forests is currently a controversial issue among conservationist, so forest manipulations to increase forest productivity or alter structural properties of forest stands and promote ecosystem functions such as vegetative diversity are an important part of current debates.

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Forest management in the NJ pine barrens includes thinning and harvesting along with low intensity prescribed burning to reduce fuel load (Skowronski et al., 2007). In both cases repeated disturbance has been shown to reduce the ericaceous shrub community dominance and conversion to a graminoid understory Conventional thinning can accelerate understory regeneration and increase shrub layer density (Bailey and Tappeiner, 1998) by enhancing soil nutrient resource availability (Gautam et al., 2003). On the other hand, the dominant ericaceous shrub community maintains site dominance by germination space and nutrient preemption and is characterized by positive feedbacks that limit nitrogen and phosphorus availability (*sensu* Latham et al., 1996; Johnson and Wedin, 1997), which may restrict tree growth. Under conditions of physical soil disturbance or repeated disturbance by fire, such as annual control burning, or by, the pine barrens ecosystem changes to a graminoid dominated ground vegetation with suppression of ericaceous plants. Renewal of tree thinning and forest harvesting practices in this forest as a management technique is becoming more important, questions are being asked about the long term benefits or disbenefits of these practices.

Tree thinning changes forest microclimate conditions (Ma et al., 2010), which both directly and indirectly influences soil properties. Soil nutrient availability is the dominant driver in long-term site productivity and maintenance of forest ecosystem structure and function (Jokela et al., 2004). Thinning intensity and residue removal often result in changes in nutrient cycling by reducing nutrient pools resulting from removal of large quantities of organic matter (Blanco et al., 2008; Finkral and Evans, 2008; Gautam et al., 2003; Jacobsona et al., 2000; Valinger et al., 2000; Walmsley et al., 2009). Smith et al. (2000) reported that whole-tree harvest plus forest floor removal treatment reduced nutrient availability to trees, whereas slash addition may improve their nutrient status. Thinning reduced nutrient returns via litterfall, however, significant differences in nutrient availability were seldom created with thinning intensities of less than 30% of standing basal area (Smith et al., 2000). The reason may be that the remaining vegetation benefits from reduced competition for nutrients in the mineral soil and remaining forest litter layer (Blanco et al., 2008). However there is large site to site variability (Vesterdal et al., 1995), but the negative effects of residue removal have been shown to be greater on nutrient poor sites than on fertile sites in Finnish forests (Smolander et al., 2010).

We elected to investigate the impact of thinning and soil disturbance treatments on soil enzymes, as soil processes determine forest ecosystem functions (van Bruggen and Semenov, 2000; Schoenholtz et al., 2000; Knoepp et al., 2000). Soil enzymes participate in almost every transformation process of litter decomposition and play a central role in maintaining forest soil fertility by releasing mineral (plant available) nutrients from complex organic resources (Baldrian and Štursová, 2010). Additionally the mycorrhizal symbionts of a number of tree and ericoid plant species produce protease and acid phosphatase enzymes, enabling them to access complex forms of N and P (Read, 1991), which are likely to be disrupted by mechanical soil disturbance. Changes in nutrient availability affect tree performance, especially in oligotrophic ecosystems. A wide range of enzymes have been found in soil, which are liable to change due to soil management techniques (Mosca et al., 2007; Maassen et al., 2006). Boerner et al. (2006) and Gial and Boerner (2007) reported some soil enzyme activities in post-thinning treatment were greater than in pre-thinning, however, opposite trends were shown by Boerner et al. (2008) and Hassett and Zak (2005). This inconsistency of results probably resulted from many different factors such as soil type, sampling time after thinning and research methods. Limited and controversial evidence exists as neither short- or long-term impacts of harvest practices on soil enzymes have been systematically studied.

Few enzyme studies have been conducted in the NJ pine barrens (Kourtev et al., 2002; Lucas et al., 2007; Sedia and Ehrenfeld, 2006). We chose eight soil enzyme assays based on their function in organic matter decomposition and nutrient cycling and their sensitivity to soil management (Bandick and Dick, 1999). Cellulase and β-glucosidase were chosen because they hydrolyze cellulose, the most prominent organic compound in forest litter, particularly as the final product of β-glucosidase is glucose which is an essential carbon source for microbial growth. β-Glucosaminase which is involved in chitin degradation and carbon and nitrogen cycling by hydrolyses of N-acetyl-β-D-glucosamine residues. Protease is related to organic nitrogen mineralization, and is also produced by ecto- and ericaceous mycorrhizae (Smith and Read, 1997). Acid phosphatases dominate in acid soil and hydrolyze organic phosphate esters and are also produced by ectomycorrhizae. Arylsulfatase is involved with the mineralization of aromatic sulfate esters to phenols and sulfate, releasing plant available SO_4–S. These six soil enzymes function in carbon, nitrogen, phosphorus and sulfate cycling, respectively. Additionally, both phenol oxidase and peroxidases are oxidative enzymes involved in the breakdown of lignin and other aromatic compounds and the formation of humic materials (Sinsabaugh, 2010), influencing accumulation of soil recalcitrant carbon.

The aim of this project is to evaluate the effect of forest management (thinning and soil disturbance) on the potential establishment of a permanent graminoid understory vegetation. A secondary aim is to evaluate the effects of this forest management on soil microbial and faunal activity. This paper reports the effect of thinning and soil disturbance on soil enzyme activity as it relates to overall changes in microbial function (fungi, bacteria and mycorrhizae), especially as incorporation of organic matter into soil and mechanical disturbance of roots has bene shown to influence organic matter decomposition rates (Sollins et al., 1996; Conn and Dighton, 2000; Salinas-García et al., 2002). In order to assess the potential of establishing an alternate state of graminoid understory vegetation, we established a forest manipulation experiment of tree thinning, shrub removal and soil disturbance to encourage grasses.

2. Materials and methods

2.1. Site description

The study site was located at the Franklin Parker Preserve which encompasses almost 14 square miles in Woodland Township, Burlington County, in the New Jersey pine barrens. Mean monthly temperatures are 0.3 °C and 23.8 °C in January and June, respectively (1930–2004; State Climatologist of NJ, USA). Mean annual precipitation varies between 1123 and 1820 mm. The mixed conifer–hardwood forests consist of pitch pine (*Pinus rigida*), shortleaf pine (*Pinus echinata*) and black oak (*Quercus velutina*) with an understory of mostly ericaceous shrubs of huckleberry (*Gaylussacia* spp.), blueberry (*Vaccinium* spp.), and scrub oak (*Quercus ilicifolia*) (Robichaud-Collins and Anderson, 1994; Jordan et al., 2003; Landis et al., 2005; Matlack et al., 1993). The topography lies on a coastal plain with gentle undulations with a mean attitude of 40 m. The soils have developed from the unconsolidated sandy geologic deposits and are classified as Entisols (Markley, 1971) with low levels of soil nutrients, low water holding capacity and a low pH.

2.2. Field designing and sampling

In 2009, we selected a site with overstory dominated by pitch pine and understory dominated by ericaceous shrubs in the Franklin Parker Preserve, which is representative of large areas of upland pitch pine dominated ecosystems within the NJ pine