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Historical land use and stand age effects on forest soil properties in the Mid-Atlantic US

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ABSTRACT

The conversion of agriculture lands to forest has been occurring in parts of North America for decades. The legacy of management activity during this transition is reflected in soil physical and chemical properties years after abandonment. This study was conducted at the Smithsonian Environmental Research Center, Maryland, USA, to determine land-use history and forest age effects on soil nutrients, carbon, pH, and bulk density. Soils in young and old successional forests and forests with no evidence of historical disturbance were sampled. The young forest stands were abandoned from agriculture 50–70 years ago and the old forest stands had been abandoned from agriculture or grazing 120–150 years ago. The oldest forest stands had no recorded history of disturbance even though it is likely they were at least disturbed by tree removal or grazing of animals in the colonial era. Young forest soils had higher concentrations of Mg, Ca, NO_3 and a higher pH than old, which may be an age effect. The old forest soils that had been abandoned from agriculture and grazing had higher bulk density and lower C content than undisturbed stands indicating a land-use effect. In the stands that were formally agriculture there was evidence of erosion, indicated by a Bt horizon closer to the surface. The most evident difference between stands of different land-use history was the absence of a well-developed O horizon, which we attribute to the presence of earthworms. Land-use legacy set the forest ecosystem in a different trajectory of soil evolution.

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1. Introduction

Land-use history has long term, if not permanent, effects on vegetation and soil properties (e.g. Compton and Boone, 2000; Dupouey et al., 2002; Foster and Aber, 2003; Verheyen et al., 1999). The duration and type of land use, e.g., woodlot, agriculture, and grazing, determines the current soil chemical and physical properties. Provided with detailed land-use records of European land, 700 years of land-use change has rendered differences in soil properties directly related to the duration of forest, grassland, cultivated, and arable land (Verheyen et al., 1999). In the U.S., the recorded land-use history, although not as extensive, is around 400 years but only for the northeastern coastal areas of the country. Within this time frame these effects have been measured and have shown a long lasting signature in the soil (Foster and Aber, 2003) and vegetation (Thompson et al., 2013) due mostly to the impact of agriculture introduced during European settlement (Cronon, 1983; Foster and Aber, 2003). Based on these studies in New England and Europe, it is clear that historical land uses profoundly altered soil chemical and physical properties, including patterns of surface soil horizon development.

Some of the earliest colonial settlements were in the Chesapeake Bay region of Maryland. Before European settlement, 95% of Maryland was covered with forests (Besley, 1916). In the Chesapeake Bay watershed, 40–50% of the land was under agriculture by 1840 (Cooper, 1995), increasing to 80% by the end of the 19th century (Brush, 1986). Currently the forest cover in Maryland is estimated to be 43% of the land area (Stolte et al., 2012). The vast majority of forests in Maryland are secondary at different stages of succession with varying tree species composition (Brush, 1986). At the Smithsonian Environmental Research Center (SERC) in Anne Arundel County, MD, where our research was conducted, there are uncut forest stands which provide a rare opportunity to study the effects of land-use history on the trajectory of soil recovery post anthropogenic disturbances. Here we report on a comparative study in thirteen forest stands at SERC focusing on the changes in soil physical and chemical properties over a 150-year period.

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SERC lies within the watershed of the Rhode River sub-estuary of Chesapeake Bay. The Smithsonian owns 1072 ha on the Rhode River watershed and the land is maintained in a mix of land-uses, including forest stands that have no physical evidence of previous disturbance, stands of mature forests with evidence of previous disturbance and forests that have been undergoing succession since the stands were abandoned from agriculture in the 1940s. Advantages of conducting our study at SERC include: (1) Information on historical uses of the SERC land goes back to the time of European colonization in the 1600s, (2) SERC soil, land use, and vegetation history has been documented (Correll, 1974; Higman, 1968; Pierce, 1974), (3) SERC upland forests are a patchwork of stands of different ages reflecting different times of agricultural abandonment, and (4) small stands of uncut, old growth exist on the property.

Soil formation and soil evolution is a slow process, thus most chronosequence studies have implemented a space-for-time substitution. This approach has been criticized for the lack of consistency in controlling for abiotic and biotic conditions through time (Johnson and Miyanishi, 2008; Pickett, 1989). Despite these difficulties, we believe detailed knowledge of historic land-use patterns can provide a valuable platform for evaluating ecosystem structure and function, especially as they related to differences in soil characteristics.

Our approach was to characterize and compare physical and chemical soil properties of forest stands that differed in age and land-use histories on the SERC property. Our objectives were to determine: (1) the degree to which forest soils retain legacy impacts from past agricultural practices and (2) the degree to which the legacy impacts change over time. We developed a conceptual model to separate the complex interaction effects of stand age, land-use legacy, and other disturbances to understand the present-day soil characteristics and therefore, the trajectory of soil evolution (Fig. 1). The well-documented history of the upland forest mosaic of SERC are a great opportunity to advance our understanding of how forest soils recover in this region. During colonial times and later, many of the forest stands in the area were converted into agriculture fields. This conversion from forest to long-term crop production introduced physical disturbance associated with annual cultivation, nutrient amendments from fertilizer and manure, and bioturbation by introduced soil fauna, mainly non-native earthworms, should have resulted in a transformation of soil properties. To examine how this transformation in soil properties varied by differences of age, we compared young and old forest soils, and for differences related to land use, we compared soils in the young/old to the uncut forests. Unique aspects of this study compared to existing land-use history studies are the comparison of land-use histories, forest ages, and uncut forest stands on similar soil types; and the establishment of non-native earthworm communities in both the young and old forest soils but not the uncut forest soils.

Based on the conceptual model shown in Fig. 1, to compare age effects, we expected that old forest stand soils would have higher carbon, lower nutrient concentrations, bulk densities and pH than the young forest soils. Exposure to weathering and vegetation differences would cause the net loss of nutrients in the old forest soils compared to the young forest soils. To compare land-use effects, we expected that uncut forest soils would contain more SOM related to a thicker O horizon than the old forest stands. We also predicted that uncut forest would have less nutrients, and lower bulk densities and pH than the old forest soils through a combination of weathering, lower quality leaf litter, lack of additional nutrient input from historical cropping and grazing practices, and lack of earthworm mixing and feeding activity.

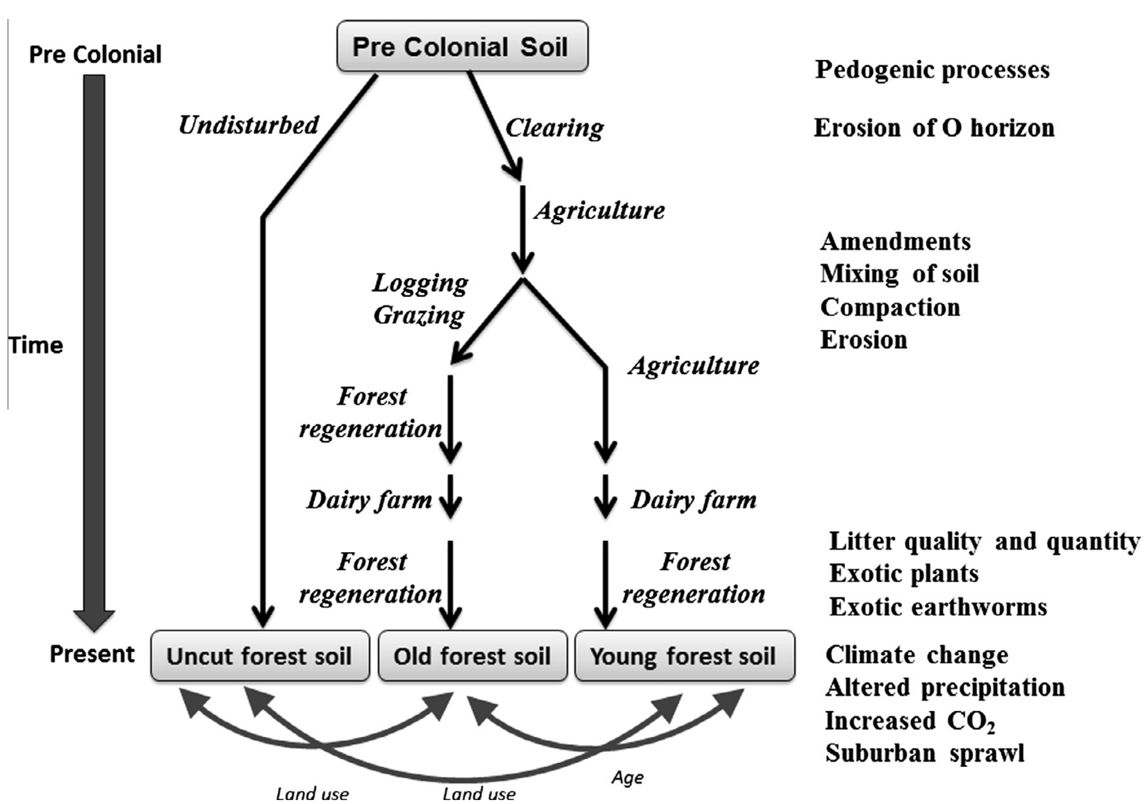

Fig. 1. The general history of the uncut, old, and young forest soils and the comparisons between land use and age, i.e., for land-use comparisons, uncut was compared to old and young forest soil; for age comparisons, old was compared to young forest soils. The evolution of these soils is affected by pedogenic processes.