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CHARCOAL-RICH MOUNDS IN LITCHFIELD COUNTY CT RECORD WIDESPREAD HILLSLOPE DISTURBANCE IN THE IRON CORRIDOR FROM MID 18TH TO EARLY 20TH CENTURY

MARY IGNATIADIS, Williams College
Research Advisor: David Dethier

INTRODUCTION

The widespread construction of earthen charcoal mounds in northwestern Connecticut (NWC) from the 18^{th} to 20^{th} centuries fueled both the industrialization of the United States and lasting geomorphic change (Fig. 1; Kirby, 1995). Iron production in the Housatonic River valley required vast amounts of charcoal to refine and smelt iron ore until high-quality coal became available in the late 19^{th} century (Straka, 2014). The charcoaling industry supported the economic growth and western settlement of southern New England and contributed to the overall deforestation of hillsides and damming of waterways - modifications that mark the onset of the Anthropocene around New England (Foster and Aber, 2004). Human settlement of New England is likely the largest geomorphic event in the region since the retreat of the Laurentide Ice Sheet at the end of the Holocene (Foster and Aber, 2004).

Figure 1. (1) Men standing with a charcoaling mound that they have covered in sediment and are preparing to burn (Cornwall Historical Society). The mound likely holds 100-130 m³ of wood (Straka, 2014). (2) Field photo of relict charcoal mound residing on a reforested hillslope in Housatonic State Forest, Canann, CT.

Despite its economic importance, the geomorphic effects of the iron industry in NWC remain unexplored (Johnson and Ouimet, 2015). More than 20,500 relict charcoaling mounds (RCMs) have been mapped across Litchfield County, Connecticut in an area of 1170 km^2 (Johnson and Ouimet, 2014), an average of 17 mounds/km^2. RCMs studied elsewhere in the U.S. and in Europe are characterized as microtopographic features that influence soil mixing and soil chemistry for hundreds of years after their construction (Young et al., 1996; Ludemann, 2003; Rösler et al., 2012; Hirsch et al. 2015). Large-scale charcoal production is therefore important to understanding regional forest and hillslope dynamics (Johnson and Ouimet, 2015).

METHODS

I conducted my fieldwork during July 2015 in four areas of Litchfield County, CT, and one in Ashford, Windham County, CT. We surveyed and sampled a total of 68 RCMs previously located using 1m LiDAR DEMs (Fig. 2). These sites represent a variety of slopes and soil types. I supplemented field measurements with laboratory studies of soil samples and GIS analysis.

At 21 RCMs, we described and sampled soil profiles by horizon using a 6 cm diameter orchard sampler. Changes in soil texture and chemistry relative to soils on adjacent slopes allowed us to approximate the depth of disturbed sediment (D_D) at each mound. Each sampled profile contained three to five layers or soil horizons. We dried samples for 24 hr at 80°C, sieved them into a >2-mm and <150-µm component, then recombined a small amount of each sample according to its original grain size ratio for loss on ignition (LOI)

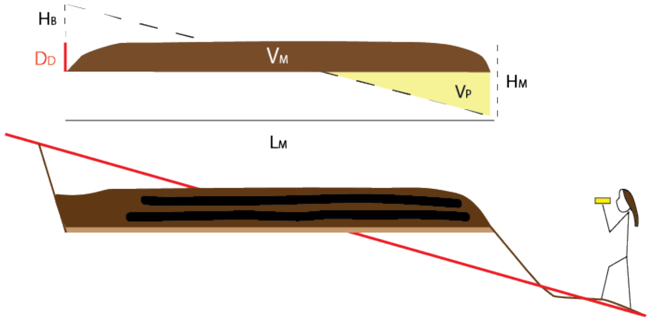

Figure 2. A sketch illustrating field measurements of a relict charcoal mound and generalized cross-section: we measured the vertical distance from the base of the mound to its current surface (H_M) with a TruePulse360 Rangefinder while standing just downhill of the mound. We also measured the vertical distance from the surface of the mound to the top of the back cut (H_B) and the horizontal distance from H_M to H_B (L_M). The depth of disturbed sediment (D_D) is the distance from the surface of the mound to the sandy substrate (beige) of the original platform surface. Sediments used to make the original platform (V_P) are between the original hillslope (red line) and mound sediments (V_M; brown). Black lines inside the mound sediments are charcoal-rich layers.

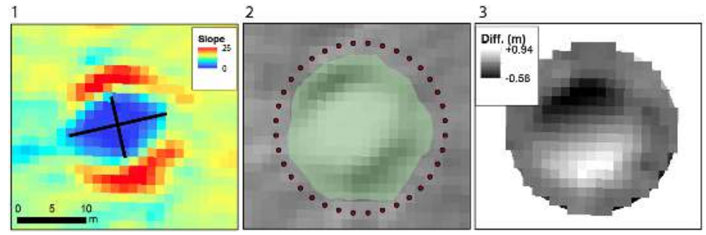

Figure 3. (1) Plan view of charcoal mound slopes from 1m resolution LIDAR DEM. The vertical black line is L_M (6.5 m); the horizontal black line is W_M (10 m). (2) Elevation data from the RCM was extracted from the DEM using the shapefile (green) as a mask. We added elevation data from the DEM to points around the RCM shapefile, and inferred the original hillslope elevations by interpolating these points. (3) Difference in elevation between the original DEM and the pre-charcoal mound interpolated hillslope.

testing. All weight lost during burning at 500ºC for 12 hours was attributed to organic matter. For selected samples, we characterized sample organic matter by measuring C:N ratios for both the horizons and for individual pieces of charcoal within each horizon; we ran five subsamples per horizon from five samples through a FLASH 1112 Elemental Analyzer (FLASH).

Mounds on steep slopes sit atop platforms carved into the hillslope. We modeled the total mound volume (V_T) as the sum of the volume of platform sediment (V_P) and the volume of charcoal layers mixed with sediment used to insulate the wood stack during charcoaling (V_M) (Fig, 2). We assume that none of the original sediment has been lost; the volume of space between the surface of the RCM and the inferred hillslope is therefore equal to the sediment that went into the platform (V_P) and mound (V_M) (Fig. 2). We approximate the platform as a prism defined by the width of the mound, the original hillslope, and the present mound surface (Fig. 2). The product of average D_D (0.5 ± 0.1 m) and the mound surface area (SA) is the sediment from the charcoaling mound, V_M (Fig. 2). We calculated SA from field measurements of mound length (L_M) and mound width (W_M) and corroborated them with SA measurements done in ArcGIS (Figure 3).

We measured RCM volume in ArcGIS by interpolating the original hillslope from the surrounding area and subtracting the interpolated raster from the DEM; the sum of the positive values of the resulting values is ~ V_T.

We also used the inferred slope angle to find the center of mass (CM) of the hillslope prior to charcoaling. Using similar techniques, we estimated the present CM in the mounds, then subtracted the current CM from the original to find the vertical distance the CM moved during charcoaling activity, ΔCM_Y.

RESULTS

RCMs built from till-derived local soils are high in organic C as deep as 0.8m, with a mean depth of ~0.5m. Two or three charcoal-rich horizons were often visible in a single soil sample. The average sample grain size was dependent on depth and consistently differed from that of background sediments by ~10%. Samples averaged 3% organic matter by weight (LOI), with charcoal-rich layers producing samples up to 25% organic matter by weight. Our estimates are based on the assumption that soil organic matter is 50% C, and therefore may be too low.

We found the greatest concentrations of C in black, charcoal-rich loamy layers. Values of C:N from charcoal-rich layers of three soil columns ranged from 19.1 to 43.6, with no obvious dependence on depth. Values of C: N from individual charcoal pieces within those same layers ranged from 162.7 to 301.0, an

	Volume (m^3)	Surface Area (m^2)	Slope	ΔCM_Y (m)
Field	54.3 - 86.5	61.1 - 70.7	10.4 - 15.4	0.066 – 0.147
GIS	52.4 - 76.7	66.3 - 81.4	14.9 - 21.9	0.309 – 0.521

Table 1. 95% Confidence intervals for average volume, surface area, slope, and change in the vertical center of mass (ΔCM_Y) from the field-based and the GIS-based models; n=37

average increase of ~180x.

Bootstrapped statistics for both models show overlap between field and GIS measurements, with the exception of ΔCM_Y (Table 1). Field measurements are more conservative than GIS estimates of the vertical change in the center of mass.

DISCUSSION

Intensive charcoaling activity in Litchfield County lasted from the mid-18th to late-19th century. A single mound could produce 43,000- 55,000 kg of C from ~110 m^3 of wood. Our results show a change in the accumulation of carbon and redistribution and sediment at charcoaling sites compared to adjacent soils. Raab et al. (2016) reported that organic-rich horizons were 2.6X thicker in RCM sediments than neighboring sediments.

We estimate the total mass of C sequestered in RCMs in the Johnson and Ouimet (2014) study area (1170 km^2 and 20,543 relict mounds) as the product of the average thickness of organic sediment (m), average mound surface area (m^2), sediment density (kg m^{-3}), average fraction of C in mound sediment, and the total number of mounds:

$$1)\quad 0.5 \times 64 \times 1600 \times 0.03 \times 20{,}543 = 3.15 \times 10^7$$

The net sequestration of C per year from the ~150 years of intensive charcoaling activity was therefore 157 kg km^{-2} yr^{-1}, 2.9% - 3.6% of the total C produced. The addition of so much C likely altered the net flux of carbon to and from forest soils (Fan et al., 1998; Compton and Boone, 2000).

Charcoaling mounds contributed to local hillslope sediment transport by resulting in a net downslope movement of soil over the period of time from initial platform formation to burning to abandonment. We approximate thw downslope distance of transport to be

$$2)\quad \Delta CM_X = \Delta CM_Y)/\tan(\text{slope})$$

calculate hillslope sediment transport (q_s) using a similar approach as has been used for large-scale bioturbation (Gabet et al., 2003) and tree-throw (Hellmer et al., 2015):

$$3)\quad q_s = (\text{mound volume} \times \Delta CM_Y)/(\text{area} \times \text{time})$$

Values for CM_x range from -0.90 to 1.77 and average 0.44. Using equation 3, the average rate of sediment transport due to charcoaling activity in Litchfield County over 150 years is 2.8×10^{-6} m^2 yr^{-1} to 10.5×10^{-6} m^2 yr^{-1}. High local rates of sediment transport averaged over ~150 years of intensive charcoaling are one to two orders of magnitude lower than those caused by large tree throw events (1×10^{-5} - 6×10^{-4} m^2 yr^{-1}; Hellmer et al., 2015). Hellmer et al. (2015) found that sediment transport rates from tree throw in an analogous New England forest depended on slope steepness and forest structure. Their finding is consistent with higher biogenic sediment transport rates of 4.4×10^{-3} m^2 yr^{-1} (Gabet et al., 2003) and 1.6×10^{-3} m^2 yr^{-1} (Gallaway et al., 2009) in steeper, ecologically different terrain.

RCM volume increases ~linearly with slope in our GIS model and decreases non-linearly with slope in our field-based model (Fig. 4). The increase in GIS volumes with slope may reflect local variations in topography, or a large V_P not captured by the field model. The vertical displacement of sediment to build the platform may have been out of proportion to the horizontal displacement as we have defined it in our field model; indeed, field ΔCM_X increases more steeply with slope than does GIS ΔCM_X.

The charcoaling process mixed hillslope soil and sediment and sequestered C. After charcoaling, relict mounds were susceptible to erosive processes, and likely contributed to the sediment loads of nearby channels. The loss of fine sediments to erosion could explain why mounds contain fewer fine sediments than the soils from which they were made. The amount of run-off erosion near charcoaling sites likely increased due to the trails and roads associated with the transportation of wood and charcoal.

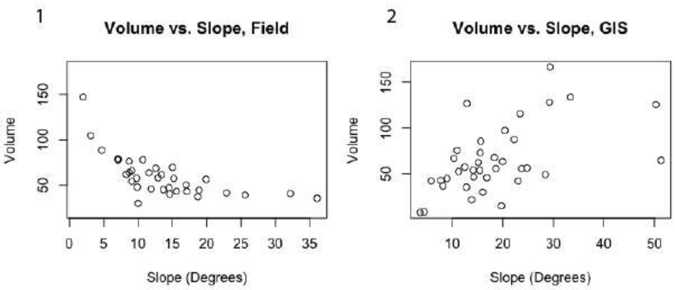

Figure 4. The volume (m^3) of redistributed charcoal mound sediment decreases non-linearly with slope in our field-based model (1) and increases ~linearly with slope in our GIS–based model (2).

RCMs still lack the mature forest cover of adjacent slopes; large trees are rarely seen on the mounds today. Mounds therefore continue to affect biogenic processes of sediment mixing and C cycling.

CONCLUSION

Changes to soil formation and hillslope diffusion resulting from historic charcoaling activity highlight the influence of past land use practices on the evolution of Connecticut's landscape. Understanding these changes informs our understanding of the Anthropocene in southern New England, with the potential to inform environmental studies in places where earthen charcoaling mounds occurs today.

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