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Physical properties and spatial controls of stone walls in the northeastern USA: Implications for Anthropocene studies of 17th to early 20th century agriculture

Katharine M. Johnson*, William B. Ouimet

Department of Geography, University of Connecticut, 422 Austin Building, 215 Glenbrook Road, U-4148, Storrs, CT, 06269, United States

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ABSTRACT

English-style agriculture in the northeastern United States spurred widespread deforestation beginning in the 17th century. Heavy plowing within a rocky, glacial till-mantled landscape resulted in soil erosion and deep frosts. For hundreds of years, stones exposed at the surface due to these processes were built into walls that have become an iconic feature of this landscape, and indicative of past human impacts and land use dynamics in areas that are now reforested. We investigate stone walls in five towns in Connecticut, USA, using airborne Light Detection and Ranging (LiDAR), field measurements, surficial geology maps, and historic agricultural census data. Stone walls are prevalent throughout the study region (~2113 km over ~569 km^2), but spatial density ranges widely from 0 to 12 km/km^2. Important controls on the density of stone walls include surficial materials (e.g., ~4.0 km/km^2 on glacial till compared to 1.5 km/km^2 on floodplain alluvium), and whether land had been "improved" for agriculture (~5.2 km/km^2). The length of stone walls derived from analysis of LiDAR data combined with field measurements (average height of 0.76 ± 0.23 m; width of 0.96 ± 0.50 m), indicates that an average of $\sim 1.4 \times 10^6\ m^3$ of stone was moved for constructing walls in the study towns alone. Overall, this study highlights the spatial distribution of 17th-20th century agriculture and Anthropocene landscape change in the northeastern USA, providing important implications for human-environment studies in other deglaciated regions of the United States and landscapes with stone-rich soils on a global scale where historic agriculture occurred.

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1. Introduction

Humans are proven geomorphic agents in the magnitudes of material they are capable of moving over time both directly and indirectly (Dotterweich, 2013; Hooke, 2000, 1994; Hooke et al., 2012; Jefferson et al., 2013; Merritts et al., 2011). The degree of these impacts varies in different locations around the world, and continues to escalate (Barnosky et al., 2012; Ruddiman et al., 2015; Smith and Zeder, 2013; Steffen et al., 2015). Measurable human impacts vary regionally and spatially by hundreds to thousands of years. Thus, assessing these impacts is important to distinguish markers of human-induced change from perceived natural processes (Certini and Scalenghe, 2011; Erlandson, 2014; Fraser et al., 2014; Ma et al., 2014; Perroy et al., 2012; Streeter et al., 2015). Quantifying past human impacts is fundamental in considering the proposed 'Anthropocene' geologic epoch. Such studies characterize the magnitude and intensity of human-environment interaction in contrast to natural variation and background processes through observations on climate, ecology, geochemistry, sedimentology and geomorphology (Brown et al., 2013; Chin et al., 2013; Crutzen and Stoermer, 1999; Edwards, 2015; Erlandson and Braje, 2013; Foley et al., 2013; Lightfoot et al., 2013; Smith and Zeder, 2013; Waters et al., 2016).

In the northeastern United States (a region, with the exception of the state of New York, commonly known as "New England"), the landscape has been shaped by human-environment interactions that have occurred continuously since humans first inhabited the region ~12,000 years ago (Boisvert, 2012; Chapdelaine, 2012; Lothrop et al., 2011). Despite the environmental changes that occurred over thousands of years as a result of Native American land use (Boulanger and Lyman, 2014; Braje and Erlandson, 2013; Chilton, 2002; Cooper et al., 2015; Cronon, 1983; Delcourt and Delcourt, 1987; Donahue, 2004; Jones and Forrest, 2003; Little, 2010; Mrozowski, 1994; Pagoulatos, 1990; Petersen and Cowie,

* Corresponding author.
E-mail address: katharine.johnson@uconn.edu (K.M. Johnson).

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2002), the most drastic human-induced geomorphic changes in this region since deglaciation began with its colonization by Europeans in the early 17th century. Colonization induced the forceful dissolution of Native American strategies of land management, as well as ecological and geomorphological changes, similar to impacts elsewhere (Etter et al., 2008; Given, 2004; Lightfoot et al., 2013). This process is one of the defining moments in the landscape history of this region culturally, geomorphologically, and ecologically (Cronon, 1983; Donahue, 2004; Foster, 1992; Krech, 1999; Merchant, 1989; Sluyter, 2001; Thorson et al., 1998). English-style agriculture involved widespread clearance of forest, ditching and draining of swamps, introduction of domesticated livestock, and planting of non-native crops and grasses (Cronon, 1983; Donahue, 2004). The resulting soil erosion and sediment mobilization are well-documented, even in 19th century accounts (Allen, 2003; Foster, 1999; Langevin, 2011; Merritts et al., 2011; Norton, 2003; Thorson et al., 1998). These impacts illustrate how humans during the 17th to early 20th centuries drastically altered the landscape.

The stone walls in the northeastern United States that resulted from these land use practices have long been considered an iconic landscape feature of the region and an enduring geomorphic legacy of 17th through 20th century English-style agriculture, coupled with the predominance of glacial till that is typical of this deglaciated landscape (Thorson, 2002). A majority of walls in this region were built over a period of ~250 years between the late 17th and early 20th centuries, with a majority estimated to have been built between 1775 and 1825, depending on settlement patterns and population distribution (Allport, 1990; Thorson, 2002). Early fences made during field clearance were built of roots, stumps, and brush that were all then replaced with more permanent structures over time, such as rail fences, stone and rail fences, or stone only (Cronon, 1983; Dodge, 1872; Foster, 1999). Stone walls were built by moving stones from piles in or on the edges of fields, or gradually as they were removed from the soil as land was cleared, plowed, and underwent the yearly frost heaves common in the northeast. Stones were added to walls or sometimes left in the fields as clearance piles or cairns (Allport, 1990; Cronon, 1983; Ives, 2015; Thorson, 2002). Farmers and their families or laborers performed this work, often during times between larger farm tasks, or by enslaved or indebted individuals, women and children, and by individuals of a variety of nationalities and ethnicities (Allport, 1990; Bonfield, 2004; Thorson, 2005). Farms in marginal areas may have been abandoned before stone piles in fields were transferred to walls; piles are still extant in these areas that have now become reforested (Ives, 2015, 2013; Thorson, 2005). By the early 20th century, many farms had been abandoned as younger generations moved west, or towards the burgeoning cities in the region driven by industrialization (Bell, 1989), leaving the fields to revert back to forest. Foster (1999) noted that “Few sights capture the extent of the transformation that has occurred in landscape character and human activity in New England as well as that of an ancient stone wall snaking across a forest hillside”.

Estimates regarding the dimensions and volume of stone walls have been a topic of debate since at least the 18th century, both anecdotally and in official government records (Allport, 1990; Bowles, 1939; Dodge, 1872; Thorson, 2002). Systematic measurements coupled with regional geospatial data have not been previously used to analyze the dimensions and spatial distribution of walls in this region, despite the fact that traits such as length, height, width, and volume have been estimated and discussed. Measurement and analysis has been hindered due primarily to the overwhelming magnitude and extent of walls in this region, as well as the dense forest canopy which obscures most walls in aerial photography with the highest available resolutions.

This study addresses the following questions toward a more explicit understanding of the processes and implications of stone wall building and associated historic agricultural land use in the northeastern United States. First, what are the physical attributes of stone walls in the northeastern United States, such as length, spatial density, width, porosity and volume? Second, how does the surficial geology and extent of historic agriculture control the spatial distribution and density of stone walls? Third, how can this dialectical relationship between physical controls and human impacts with regard to stone walls reveal the extent to which historic land use, and specifically European-style agriculture, affected landscape change in this region and elsewhere in the English colonial sphere?

To answer these questions, we analyze 1 m digital elevation models (DEMs) derived from ground-filtered airborne Light Detection and Ranging (LiDAR) data in conjunction with field measurements and regional geospatial data. LiDAR has become a vital tool in studying cultural landscape features in densely forested regions of the world (Chase et al., 2012; Crow et al., 2007; Doneus et al., 2008; Evans et al., 2013; Gallagher and Josephs, 2008; Opitz et al., 2015; Randall, 2014), including the northeastern United States (Johnson and Ouimet, 2014), because of its ability to map topography below the forest canopy. Whereas height, type, and seasonality of vegetation can influence the visibility of certain landscape features (Hutson, 2015; Prufer et al., 2015), stone walls, building foundations, dams, relict charcoal hearths, and abandoned roads are identifiable in LiDAR and confirmed in the field with high certainty in the study areas (Johnson and Ouimet, 2014). LiDAR therefore provides an unprecedented opportunity to capture the landscape in ways that provide insights into past human impacts in this region.

2. Study areas

2.1. Topography and surficial geology

The towns analyzed in this study are Ashford and Eastford in northeastern Connecticut, and Cornwall, Goshen, and Sharon in northwestern Connecticut. Additional data are taken from the towns of Mansfield in northeastern Connecticut, and Tiverton in the southeastern part of the state of Rhode Island (Fig. 1A). We made field measurements in Ashford, Mansfield, and Tiverton. For Ashford, Cornwall, Eastford, Goshen, and Sharon, we digitized the datasets for stone walls. Northeastern Connecticut (Ashford, Eastford, and Mansfield) has topography comprised primarily of hilly uplands, ~65 km from the coast, with mixed deciduous-coniferous forest (Table 1), with an average elevation of ~350 m above sea level. The highest elevations in the state exceed 700 m. The southern extent of the Laurentide ice sheet covered the entire state of Connecticut during the last glacial interval and began to recede from the region between 17,000 and 18,000 years ago (Thorson, 2002). The movement of the ice and associated meltwater on different bedrock types in this region are responsible for the topographic character of the landscape, which influenced subsequent land use and settlement patterns following deglaciation (Bell, 1985; Donahue, 2004; Thorson, 2002). Available Quaternary and surficial geology data (DEEP, 2015) indicate that 81–90% (average 85%) of the area in the study towns is covered by glacial till.

2.2. Settlement and land use history

English colonists and their descendants settled and incorporated the towns in the uplands of Connecticut, much later than their coastal or littoral counterparts, though parts of northeastern Connecticut were often traversed on the way from the cities of

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