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Investigating Historic Human-Land Use Dynamics in Southern New England Using LiDAR and Geospatial Analysis

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High resolution Light Detection and Ranging (LiDAR) datasets have revolutionized the ability to discern fine-scale landscape features in densely reforested regions around the world. In southern New England, features representative of intensive land use following the European colonization of the region in the 17th century are clearly visible in LiDAR data. The imposition of radically different land use types in this region during that time period, including widespread deforestation and agriculture, resulted in a departure from previous disturbance regimes and drastic changes to the landscape. On a global scale, both agriculture and deforestation are significant factors of the proposed geologic epoch termed the "Anthropocene," or conceptual "anthropocene," indicating that studies investigating of their spatial extent, magnitude and timing are vital.

This study presents detailed mapping and analysis of extant land use features in southern New England. Stone walls and relict charcoal hearths reveal the spatial extent to which deforestation occurred due to 17th to early 20th agriculture and charcoal production, thus allowing for the detailed study of historic human-land use dynamics. Important controls on the distribution of these features include surficial geology, relief, and slope, as well as settlement patterns and local resource extraction and industry. Comparison with historic data demonstrates that relict land use mapping matches, but also greatly enhances, census records of past land use practices and extent.

Overall, this study demonstrates the magnitude and extent of historic land use practices in southern New England, highlighting that Anthropocene land use change in the region occurred on an unprecedented scale with a high degree of spatial variability. The cumulative distribution of mapped features suggests that over time, >90% of many towns were deforested for agriculture, lumber harvesting, and charcoal production. These land use practices have led to erosion, soil alteration, and changes in ecology and biodiversity. Understanding the distribution of relict land use features allows for future research that examines the impacts and dynamics of human-land use at broader scales, with wide-ranging implications for the historic and cultural landscape of southern New England, and elsewhere in the world where landscapes have been dynamically altered by human activity.

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Investigating Historic Human-Land Use Dynamics in Southern New England Using LiDAR and Geospatial Analysis

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CHAPTER 1

Introduction

The use of Light Detection and Ranging (LiDAR) has become an increasingly common tool on a global scale in identifying and analyzing cultural land use features, especially in landscapes that have become heavily reforested since human habitation (Chase et al., 2011; Devereux et al., 2005; Doneus et al., 2008; Gallagher and Josephs, 2008; Millard et al., 2009). While the ability to identify features in densely forested landscapes has revolutionized the field of archaeology, and continues to provide new discoveries in a myriad of other disciplines including geography, geomorphology and forest ecology (Dotterweich et al., 2015; Merritts et al., 2011; Parent and Volin, 2014; Pekin et al., 2012), there are few studies that quantify these relict land use features, or examine their spatial distribution with regard to influential factors such as topography and historical data, and even fewer still that do so in the northeastern United States.

The northeastern United States exhibits a unique, iconic landscape due to the ways in which human land use has interacted with this deglaciated landscape over the course of the last ~11,000 years (Boisvert, 2012; Cronon, 1983; Jones and Forrest, 2003; Lothrop et al., 2011; Thorson, 2002). Despite measurable changes occurring over thousands of years as Native Americans inhabited the region, such as widespread burning, hunting and alteration of ecosystems, and introduction of maize and associated agriculture (Chilton, 2002; Cronon, 1983; Delcourt and Delcourt, 1987; Donahue, 2004; Ives, 2013; Little, 2010), the most drastic impacts occurred following the colonization of the region in the 17th century by Europeans as they had in other regions as a result of the introduction of agriculture and various types of resource extraction (Casana, 2008; Dotterweich, 2008; Dotterweich et al., 2015; Lightfoot et al., 2013; Merritts et al., 2011; Ruddiman et al., 2015). These changes imposed a radically different land use regime on the landscape than had been practiced by Native Americans in the thousands of years prior (Cronon, 1983; Donahue,

2004), and initiated widespread deforestation for English-style husbandry, which consisted primarily of tilled and pasture land coupled with managed woodlots, and marshy areas and meadows for mowing (Donahue, 2004; Foster, 1992).

This study uses several high resolution LiDAR datasets (CT ECO, 2016) to map, analyze and quantify patterns of historic land use associated with agriculture and resource extraction during the period following European colonization. Stone walls and relict charcoal hearths, both visible in high resolution LiDAR data for the region, are representative of different types of land use, and provide a means to study the human-land use dynamics associated with agriculture as well as timber harvesting and charcoal production. The distribution of these features was controlled initially by topography and surficial or bedrock geology but was also influenced by the timing and magnitude of European settlement and associated industry. Geospatial data for mapped features are supported by historical accounts, census data, field measurements and observations, aerial photographs, and maps to provide a comprehensive understanding of human-land use dynamics in Connecticut, with implications for southern New England and the northeastern United States.

The following chapters present examples and analysis of historic land use features throughout southern New England (CT, MA, RI), with particular focus in eastern and western Connecticut. Chapters 2 and 3 examine the methods associated with using LiDAR data to detect historic land use features. In doing so, discuss how to interpret those features within broader theoretical landscape contexts with supplementary data, and demonstrate how the discovery of these features contributes to broader discussions regarding the use of LiDAR and cultural land use features on a global scale, which is further explored in Chapters 4 and 5. Chapter 2 discusses the overall implications for use of LiDAR in southern New England with regard to observed historic land use features such as stone walls, building foundations, dams, and roads. Additionally, Chapter 2 discusses how LiDAR can be used to complement fieldwork, or be used in concert with existing datasets that are currently commonly used in historical or archaeological research. Chapter 3,

meanwhile, examines the use of LiDAR data more broadly within the theoretical context of landscape as a palimpsest, and in doing so demonstrates that an interpretive theoretical context for using LiDAR data is important in drawing conclusions from the data. Landscapes generally exhibit features from a range of time periods on and below their surface, thus it is vital to use complementary datasets such as maps, aerial photographs, and field measurements to provide additional interpretive context.

Chapters 4 and 5 delve more deeply into analyzing and quantifying the patterns, distributions, and extents of historic land use inferred by the presence of relict land use features indicative of deforestation that are revealed by LiDAR. Chapter 4 examines the dimensions and spatial distribution of stone walls in Connecticut with regard to surficial geology and 19th century agricultural census data. Using these data, it is possible to quantify the spatial extent of stone walls as well as the amount of material moved by humans to build them. Additionally, the strong relationship between wall distribution and length with surficial geology and historical census data suggests that the distribution of walls could be estimated throughout southern New England in future studies. Chapter 5 analyzes the spatial distribution of both stone walls and relict charcoal hearths in northwestern Connecticut with regard to historic agricultural and manufacturing data, and discusses the implications of both types of land use for interpreting human-land use dynamics associated with agriculture and deforestation in southern New England. The distribution of both types of features demonstrates the extent of deforestation in the region, and suggests that this may have been of much greater magnitudes than if the area had been cleared for agriculture alone.

Overall, this thesis demonstrates the unprecedented magnitude and extent of post-17th century land use in southern New England using an interdisciplinary approach combining LiDAR, geospatial analysis, historical documents, and field measurements. This combined approach has revealed strong correlations between the presence of relict land use features and historical information and provides a unique contribution to the body of work that has examined historical

land use in the northeastern United States, but also to studies that examine human-land use relationships, LiDAR and cultural heritage of landscapes, and Anthropocene processes (Bellemare et al., 2002; Chin et al., 2013; Donahue, 2004; Foster, 1992; Thorson, 2002). This work provides a fundamental framework for future studies that examine the impacts of deforestation associated with agriculture or resource extraction in the region, including erosion, sediment mobilization and associated changes in fluvial systems, alteration of soil characteristics, or changes in ecology and biodiversity.

References

Bellemare, J., Motzkin, G., Foster, D.R., Forest, H., 2002. Legacies of the agricultural past in the forested present: an assessment of historical land-use effects on rich mesic forests. J. Biogeogr. 29, 1401–1420.

Boisvert, R.A., 2012. The Paleoindian Period in New Hampshire, in: Chapdelaine, C. (Ed.), Late Pleistocene Archaeology and Ecology in the Far Northeast. Texas A&M University Press, College Station, TX, pp. 77–94.

Casana, J., 2008. Mediterranean valleys revisited: Linking soil erosion, land use and climate variability in the Northern Levant. Geomorphology 101, 429–442.

Chase, A.F., Chase, D.Z., Weishampel, J.F., Drake, J.B., Shrestha, R.L., Slatton, K.C., Awe, J.J., Carter, W.E., 2011. Airborne LiDAR, archaeology, and the ancient Maya landscape at Caracol, Belize. J. Archaeol. Sci. 38, 387–398.

Chilton, E.S., 2002. "towns they have none": Diverse Subsistence and Settlement Strategies in Native New England, in: Hart, J.P., Rieth, C.B. (Eds.), Northeast Subsistence-Settlement Change: A.D. 1700-1300. New York State Museum, Albany, pp. 289–300.

Chin, A., Fu, R., Harbor, J., Taylor, M.P., Vanacker, V., 2013. Anthropocene: Human interactions with earth systems. Anthropocene 1, 1–2.

Cronon, W., 1983. Changes in the Land. Hill and Wang, New York.

Delcourt, P.A., Delcourt, H.R., 1987. Late-Quaternary Dynamics of Temperate Forests: Applications of Paleoecology to Issues of Global Environmental Change. Quat. Sci. Rev. 6, 129–146.

Devereux, B.J., Amable, G.S., Crow, P., Cliff, A.D., 2005. The potential of airborne lidar for detection of archaeological features under woodland canopies. Antiquity 78, 648–660.

Donahue, B., 2004. The Great Meadow: Farmers and the Land in Colonial Concord. Yale University Press, New Haven, CT.

Doneus, M., Briese, C., Fera, M., Janner, M., 2008. Archaeological prospection of forested areas using full-waveform airborne laser scanning. J. Archaeol. Sci. 35, 882–893.

Dotterweich, M., 2008. The history of soil erosion and fluvial deposits in small catchments of central Europe: Deciphering the long-term interaction between humans and the environment — A review. Geomorphology 101, 192–208.

Dotterweich, M., Ivester, A.H., Hanson, P.R., Larsen, D., Dye, D.H., 2015. Natural and human induced prehistoric and historical soil erosion and landscape development in southwestern Tennessee, USA. Anthropocene in press, 1–19.

Foster, D.R., 1992. Land-use history (1730-–1990) and vegetation dynamics in Central New England, USA. J. Ecol. 80, 753–771.

Gallagher, J.M., Josephs, R.L., 2008. Using LiDAR to Detect Cultural Resources in a Forested Environment: an Example from Isle Royale National Park, Michigan, USA. Archaeol. Prospect. 15, 187–206.

Ives, T.H., 2013. Remembering Stone Piles in New England. Northeast Anthropol. 79–80, 37–80.

Jones, B.D., Forrest, D.T., 2003. Life in a postglacial landscape: settlement-subsistence change during the Pleistocene-Holocene transition in Southern New England, in: Clements, D.L., Hart, J.P. (Eds.), Geoarchaeology of Landscapes in the Glaciated Northeast. University of the State of New York and State Education Department, Albany, pp. 75–90.

Lightfoot, K.G., Panich, L.M., Schneider, T.D., Gonzalez, S.L., 2013. European colonialism and the Anthropocene: A view from the Pacific Coast of North America. Anthropocene 4, 101–115.

Little, E.A., 2010. Limestone, Shell, and the Archaeological Visibility of Maize and Beans in New England: A Fertilizer Hypothesis, in: Chilton, E.S., Rainey, M.L. (Eds.), Nantucket and Other Places: The Legacy of Elizabeth Alden Little. SUNY Press, Albany, pp. 181–200.

Lothrop, J.C., Newby, P.E., Spiess, A.E., Bradley, J.W., 2011. Paleoindians and the Younger Dryas in the New England-Maritimes Region. Quat. Int. 242, 546–569.

Merritts, D., Walter, R., Rahnis, M., Hartranft, J., Cox, S., Gellis, A., Potter, N., Hilgartner, W., Langland, M., Manion, L., Lippincott, C., Siddiqui, S., Rehman, Z., Scheid, C., Kratz, L., Shilling, A., Jenschke, M., Datin, K., Cranmer, E., Reed, A., Matuszewski, D., Voli, M., Ohlson, E., Neugebauer, A., Ahamed, A., Neal, C., Winter, A., Becker, S., 2011. Anthropocene streams and base-level controls from historic dams in the unglaciated mid-Atlantic region, USA. Philos. Trans. R. Soc. 369, 976–1009.
Millard, K., Burke, C., Stiff, D., Redden, A., 2009. Detection of a low-relief 18th-century British siege trench using LiDAR vegetation penetration capabilities at Fort Beauséjour-Fort Cumberland National Historic Site, Canada. Geoarchaeology 24, 576–588.
Parent, J.R., Volin, J.C., 2014. Assessing the potential for leaf-off LiDAR data to model canopy closure in temperate deciduous forests. ISPRS J. Photogramm. Remote Sens. 95, 134–145.
Pekin, B.K., Jung, J., Villanueva-Rivera, L.J., Pijanowski, B.C., Ahumada, J.A., 2012. Modeling acoustic diversity using soundscape recordings and LIDAR-derived metrics of vertical forest structure in a neotropical rainforest. Landsc. Ecol. 27, 1513–1522.
Ruddiman, W.F., Ellis, E.C., Kaplan, J.O., Fuller, D.Q., 2015. Defining the epoch we live in. Science348, 38–39.
Thorson, R.M., 2002. Stone by stone: the magnificent history in New England's stone walls. Walker & Company, New York.

CHAPTER 2

Rediscovering the lost archaeological landscape of southern New England using airborne Light Detection and Ranging (LiDAR)[1]

1. Introduction

Airborne light detection and ranging, more commonly known as LiDAR, has become a well-established resource used to enhance spatial knowledge of the archaeological and cultural landscape in Europe, Central America, Canada and limited locations in North America including the United States (Chase et al., 2011; Crutchley, 2009; Devereux et al., 2008, 2005; Doneus et al., 2008; Gallagher and Josephs, 2008; Harmon et al., 2006; Lasaponara et al., 2010; Masini et al., 2011; Millard et al., 2009; Opitz and Cowley, 2013; Pluckhahn and Thompson, 2012; Rosenswig et al., 2013; Werbrouck et al., 2009). Many of these archaeological studies make use of LiDAR as a means to view the terrain and archaeological features below the forest canopy, though there are also studies that have been undertaken in non-forested landscapes (Harmon et al., 2006), and new research has shown it is possible to locate underwater archaeological sites as well (Doneus et al., 2013). Case studies vary by geographic location, time period and culture, yet all have used LiDAR data in a similar manner. Digital visualization and processing techniques have also been developed and refined that allow archaeologists or interested parties to manipulate the data in different ways after it is collected (Bennett et al., 2012; Hesse, 2010; Kokalj et al., 2011; McCoy et al., 2011; Štular et al., 2012; Verhagen and Drăguţ, 2012). Despite the growing literature and range of studies regarding the use of LiDAR that examine cultural resources and archaeology with LiDAR, very few have used data gathered in the United States, and few published studies exist for New England and its unique landscape. The disparity of published literature regarding LiDAR use in the United States and New England specifically for any type of archaeological analysis is unprecedented given its

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history and apparent widespread use in Europe and Central America. As a result, there is a great need for such research in this region to not only complement existing international studies, but to provide an assessment of the archaeological and cultural landscape in New England as measured through LiDAR.

This study will contribute to the growing international dialogue regarding LiDAR and its use for studying the archaeological landscape, and specifically will contribute new data regarding the types of features present in New England's unique historical and geomorphological landscape and their relationship to how humans have historically shaped and experienced the New England landscape. Prior to European colonization, small areas of forest were cleared for agriculture, and landscape-altering agricultural activities were conducted by Native American groups (Cronon, 1983; Garman et al., 1997; Merchant, 1989). The arrival of European colonists in the seventeenth century brought drastic changes to the predominantly-forested landscape as English-style agriculture was imposed and thousands of acres were cleared of forest (Cronon, 1983). Agricultural lifeways gradually declined beginning in the mid-nineteenth century, causing once-maintained fields and agricultural landscapes to revert back to forest. Forests now prevail on the landscape in many parts of southern New England, obscuring features of that once-agrarian past such as old roads, building foundations, stone walls, mills, or dams – reminders that the landscape is itself an artifact (Rubertone, 1989). In aerial and satellite imagery, these features are often hidden from view by a dense forest canopy; but by using LiDAR as others have done, these features become visible for identification and analysis.

Recently, airborne LiDAR data has been made publicly available for the New England states of Connecticut, Massachusetts, and Rhode Island. In this geographic region, which is predominantly forested, LiDAR is a vital tool for archaeological landscape studies because it allows the archaeologist or interested party to see not only the terrain beneath the dense New England forest canopy, but also to see that terrain at a much higher resolution than was previously possible. This

paper presents preliminary results regarding the use of airborne LiDAR in southern New England to identify and interpret specific types of archaeological and cultural features that comprise the unique New England landscape. This will not only lead to a more comprehensive understanding of the historical human impact on the unique New England landscape, but will also allow for the identification of new archaeological sites or landscape features prior to archaeological reconnaissance surveys and analysis in areas that are inaccessible for fieldwork. This study will contribute to the growing international dialogue regarding LiDAR and its use for studying the archaeological landscape. Specifically, it contributes new data on the visualization and analysis of the types of features associated with New England's unique historical and geomorphological landscape, which also have global applications.

2. Study areas

Though southern New England has been considered part of the growing "megalopolis" encompassing cities and towns from Boston to Washington D.C., forests tend to dominate the southern New England landscape, obscuring features of a once-agrarian past. Northeastern Connecticut, specifically, has been called "America's megalopolitan park" because of its extensive forests and lack of development (Berentsen, 1996). Though this area did not see the wide-spread industrialization of the nineteenth century, it has not always been as forested as it is today. Some areas still maintain their agricultural landscapes of fields and pastures lined with stone walls; others have become completely reforested. Reforestation of this region appears to have varied both temporally and spatially, and by using LiDAR, the variability of reforestation can be assessed at the scale of individual fields in many cases.

The three towns chosen for this study were Ashford, Connecticut (CT); Tiverton, Rhode Island (RI); and Westport, Massachusetts (MA) **(**Figure 1**).** Because this was a preliminary study, small representative areas of each town were chosen for data visualization and analysis. These

towns were all chosen because of their rural character; a trait typically indicative of low levels of urban or industrial development that is associated with excellent preservation of archaeological landscape features (Johnson, 2009). Tiverton, RI and Westport, MA were also given preference because the authors had performed previous research in these areas and therefore possessed a large number of comparative documents that could be useful in this study.

Ashford is a town in northeastern Connecticut, and though forested, appears to have once had a relatively large acreage of cleared agricultural land. The town is comprised of approximately 100 km^2 of land. The 2006 land cover data for the town indicates that 80.2 km^2 are currently forested (includes deciduous, coniferous, and forested wetlands) (Center for Land Use Education and Research, 2012), while in contrast, the agricultural schedule from the Federal Census of 1870 denotes that 67.3 km^2 were listed as “improved,” indicating that it had been cleared for agriculture (United States Department of Agriculture, 1870). This indicates that over half of the town has become reforested since 1870. In terms of population, the town was never very large; and in the 1840s it was divided into two towns – Ashford and Eastford. Combined, the population for both towns was only 2,225 in 1870 (United States Bureau of the Census, 1870). It continued to decline to its lowest point in 1910 when the population for Ashford alone was 673 people – a population density of 17.34 people per square mile. In 2010, Ashford alone had 4,317 residents. Similarly, both Westport and Tiverton also experienced population declines during the agricultural abandonment and population outmigration so commonplace in late 19th century New England. Unlike Ashford, the northern areas of both Westport and Tiverton were traversed by railroad, which contributed to industrialized areas in the northern sections of both towns that are now suburbs. However, their southern portions have remained coastal agricultural areas that became tourist destinations in the late 19th century and remain so today. The reforestation there is not quite as dramatic as Ashford, but has occurred nonetheless. Topography in Tiverton and Westport is similar, both being generally low-lying coastal towns with low topographic relief. In contrast, Ashford is approximately 64

kilometers inland with hilly terrain, colder on average, and with higher percentages of coniferous forests that contain less underbrush.

3. Methods

3.1 LiDAR processing and visualization

The data used in this paper are publicly available in each of the three states (CT, MA, and RI) and was not flown specifically for our study. A LiDAR aerial survey to collect data was undertaken for all of Rhode Island and eastern Massachusetts in late April and early May 2011 as part of the Northeast LiDAR Project. Data was collected for eastern Connecticut separately in November and December 2010 for the USDA Natural Resources Conservation Service (NRCS). The point data was processed and classified by a vendor subcontracted by the USDA and has a vertical accuracy of 0.0344 RMSEz at 95% confidence (Dewberry, 2011). Both the CT and RI/MA sets of LiDAR data have a 1 m^2 resolution and an average point spacing of 2 points per meter (Dewberry, 2011). Point spacing and resolution are both crucial elements of this study, because many of the archaeological landscape features can only be resolved with a resolution of 1m or better due to their size or shape. For example, many stone walls in this area are not much wider than 1m and so as a result they, as well as other features, are not visible in digital elevation model (DEM) datasets that have lower resolutions of 3, 5 or 10 meters (e.g., Figure 2). Prior to LiDAR data being acquired and distributed for these states, these were the highest resolutions available.

For our study, the data was initially downloaded as pre-processed individual DEM tiles from state GIS websites, including MassGIS and Rhode Island GIS (RIGIS), and the University of Connecticut (UConn) for the towns of Westport, MA; Tiverton, RI; and Ashford, CT respectively. Using ArcGIS 10.1 (ESRI, 2013), the tiles were then mosaicked and hillshaded using default settings (azimuth: 315, altitude: 45). As has been done with other studies (Hesse, 2010; McCoy et al., 2011), slope rasters were created to aid in visualization of specific landscape features, and relief rasters

were also created to more comprehensively understand the topographic relief and measurements of the landscape. Ongoing analyses for areas of Ashford have required the use of first-return data, so .LAS files were obtained from the University of Connecticut. All .LAS files for the study area in Ashford were added to an LAS Dataset in ArcGIS 10.1. For the analysis in this paper, first-return digital canopy models (DCMs) were created in order to create digital height rasters by subtracting the DEM from the DCM. Though we understand that other studies have been done to test which visualization methods work best (Bennett et al., 2012; Challis et al., 2011b; Hesse, 2010; Kokalj et al., 2011; McCoy et al., 2011; Štular et al., 2012; Verhagen and Drăguţ, 2012), we wanted to start with the most common methods first since no other visualization studies using LiDAR have been done in this region before.

3.2 Historical documents

Different types of historical documents were used to assess temporal ranges and spatial distribution for different types of cultural landscape features, though the availability of such sources varied. For analysis in Westport, a property survey map from 1712 was georeferenced (New Bedford Public Library, 2009); and in Ashford, digital copies of an historic map from 1858 as well as historic aerial photographs from 1934 were downloaded and georeferenced (Map and Geographic Information Center, 2012). The LiDAR hillshade for each study area was then examined in conjunction with these historic maps or photographs. This process allows for a more thorough understanding of the spatial arrangement of the landscape, and allowed comparison between features which we suspected to be building foundations and old roads against historical sources that had previously documented not only the location of the features, but information about them which can then be compared to census records, land evidence, and other historical documents.

3.3 GIS analysis and preliminary field work

We conducted field work in select locations to identify features and compare their physical properties and dimensions to their representation in the LiDAR data. We traveled to the coordinates of at least 10 suspected building foundations and positively identified them as historical foundations (Figure 2e and Figure 3). To obtain more data for statistical analysis, ongoing fieldwork will thoroughly map and measure their dimensions, in addition to the dimensions of stone wall networks and old roads. Initial GIS analysis has included the digitization of stone walls, building foundations, and old roads visible from the LiDAR DEM hillshades (e.g., Figure 2e).

4. Results and Discussion

4.1 Types of cultural features

The preliminary examination of the hillshaded LiDAR data for these three areas revealed many types of post-17th century archaeological features, stone wall networks, building foundations, old roads and pathways. These features of the "lost" New England landscape, usually hidden in satellite and aerial imagery, are clearly visible in hillshaded LiDAR-derived DEMs in each of the three selected towns. In the hillshaded LiDAR data, building foundations appear as small clusters of shaded pixels indicating locally decreased elevation (black with the color scheme for this paper's hillshade maps) surrounded by a small ridge of locally higher elevations and high slope values. In many cases it is even possible to see and measure the shape and dimensions of the building foundations (Figure 3), which are also visible in both slope and relief rasters. Dimensions derived using 3D Analyst and LiDAR Profile Viewer in ArcGIS 10.1 also closely correspond to the foundation as measured by hand in the field, indicating that it is possible to achieve accurate measurements for these cultural landscape features through LiDAR remotely. Foundations are different sizes based on both age and what type of structure they were part of. Many foundations located using the LiDAR

data belong to houses; however there are also known mills and associated dams, barns, and other structures, possibly outbuildings, visible as well (Figure 4).

Stone walls appear as thin linear ridges of raised elevation that can form polygonal or linear patterns dependent on field or farmstead layout or arrangement. The presence of the walls indicates that the land nearby was likely used for agriculture and was cleared at one point in time (Thorson, 2002). Stone piles are also visible in the corners of many enclosed areas, indicating that they were used historically for agriculture. Stone walls also vary in their construction, type, and height as well. Some walls are as much as 50cm thick, or 1.5m tall; others are no more than 20cm tall and barely visible on the ground surface (see **Figure 4C**). Despite the range of construction techniques or preservation states, these walls are all visible by using LiDAR data with at least 1m point spacing. Roads, now no longer in use, that were once main thoroughfares tend to be lined by stone walls on either side, and appear as concave linear features in the DEM hillshade. Other, smaller roads or paths that once led to farmsteads from main thoroughfares are still visible as concave linear features, but could be confused with all-terrain vehicle or other types of trails without fieldwork or other historical research; though it is likely that these original paths may have later been re-appropriated for modern recreational use.

Farmsteads have a structure that is generally recognizable from an aerial perspective (Figure 5). In the LiDAR hillshade for our three study areas, and most certainly elsewhere in New England, a farmstead is usually characterized by a relatively dense cluster of stone walls which surround a central pair or cluster of building foundations, and includes a road or path to a main road or other thoroughfare (see Garrison, 1991:141). The farmstead usually would consist of a house and barn and several smaller more peripheral outbuildings which in general are more ephemeral in the archaeological record and difficult to identify. The actual layout and structure of most farmsteads might vary regionally or temporally depending on the farm's function (subsistence only, dairying, poultry), and some might vary based on vernacular or individual preference. Within

historical agricultural literature, spatial arrangement of farmsteads and ideal locations for buildings in relation to field types or roads has always seemed to be up for discussion (Adams, 1990). Using LiDAR, further research to assemble information regarding spatial layout of farmsteads would be useful to assess how farms were actually arranged versus how agricultural literature suggested they should be (see also McMurray, 1988).

Figure 5c depicts a building foundation (center) surrounded by networks of stone wall enclosures and an old road or pathway in Westport MA. The hillshaded data suffers from a LiDAR data processing issue which has been documented by Doneus et al. (2008). The authors found that in areas with a high density of low shrubs and brush, the threshold in separating true terrain elevations from those atop of small shrubs required data manipulation in order to view subtle variations in the landscape (2008:886–887). Often, points that are not truly from the terrain are classified as "ground," especially in areas such as Westport where the LiDAR pulses may never actually hit the ground in areas of dense underbrush.

4.2 Implications for archaeological reconnaissance surveys

The implications for the use of LiDAR as an archaeological reconnaissance and analysis tool in New England are vast. As others have previously shown, LiDAR allows researchers to observe landscape features beneath the forest canopy that are otherwise not visible in aerial or satellite imagery. This in and of itself is useful for an archaeological reconnaissance survey since the layout of stone walls and other features is evident prior to any fieldwork, and they are commonly encountered during archaeological walkover surveys in forested areas. Indeed, one of the most common landscape features characteristic of New England is stone walls (Thorson, 2002). Examining LiDAR data prior to an archaeological walkover survey or prior to a site visit would aid not only in developing a more comprehensive map and historical narrative for potential areas of interest, but would also serve as a useful tool in planning a walkover or impact statement, thus

allowing for a more cost-effective approach. Examination of LiDAR data has also preliminarily shown to be a powerful tool in identifying historic archaeological sites in inaccessible areas such as privately owned land, or land that has not yet been surveyed for an archaeological project.

In Massachusetts, Rhode Island, and Connecticut both prehistoric and historic archaeological sites are recorded as they are found, and kept on file at the Massachusetts Historical Commission, Rhode Island Historical Preservation and Heritage Commission, and Office of the State Archaeologist respectively. Most sites currently on file were reported by either professional or amateur archaeologists who found them through strategic surveys, personal interest, or other means. As an example, in 2004 the Public Archaeology Laboratory, Inc. performed a town-wide cultural resource survey of Westport, MA (Herbster and Heitert, 2004). Their methods consisted of talking to local residents and amateur or professional archaeologists, compiling as much information as possible about archaeological resources and sensitivity in specific areas, and developing historic research contexts within which to understand archaeological sites and events in the town. This report was responsible for a bulk of recorded archaeological sites in Westport. By examining a map of all the recorded sites in the town, it is obvious that many are close to roads, and not many are in forests; as previously mentioned recorded historical archaeological site locations are skewed based upon ease of access, land ownership, or survey area locations. An examination of LiDAR data has the potential to offset this bias.

Through examination of the hillshaded LiDAR data, the authors of this paper were successful in locating ten new historic archaeological sites that have not been previously recorded in the archaeological records of the Massachusetts Historical Commission for Westport; and forty-eight new sites that were not recorded with the Office of the State Archaeologist in Connecticut for a 4,065 acre (16.45 km^2) study area in Ashford and Eastford, CT. There are only three sites in total recorded for the entire town of Ashford because much of the land is privately owned and there is not much development. There were sixteen sites recorded from one archaeological survey in

Eastford, though none were recorded in the area that we reviewed. Most of the sites are limited to historic farmsteads, because the topographic signature of building foundations and dense stone wall networks is evident in the LiDAR hillshades. Once a potential farmstead was located in the LiDAR data, historic maps from different time periods were georeferenced to ascertain property ownership. Many historic maps affirmed there had indeed been a house in each location at a point in time. Unlike maps, which usually give a small dot and a name, LiDAR data provides the user with potential building foundations, stone walls which indicate agricultural field layout, roads, and other features that could be analyzed or interpreted. Such analysis would be infinitely helpful for both cultural resource companies and state agencies. These sites can also now be reported and recorded so that agencies are aware of them should any projects arise that might impact them.

4.3 Use with historical documents

LiDAR is not only a powerful tool on its own; it can also be used in conjunction with the many types of historical documents available to those performing research in this geographic area. As one example, Figure 6 shows an area in Ashford, CT that was a working farmstead in 1934, as shown in the aerial photographs from that time period. The photograph shows cleared fields, forest, stone walls or fences, a house, a barn and other outbuildings, and a road running through the farm. In aerial photographs from 2012, the farmstead is now completely abandoned and overgrown by forest; however as Figure 6d shows, features such as the building foundations, stone walls, and old road are visible using LiDAR. Ongoing research suggests preliminarily that individual abandoned fields might impact the modern vegetation patterns. This is just one example of farm abandonment, a process that took place on a much smaller scale in Ashford, where entire portions of the town that were once cleared are now completely forested.

Figure 7 shows several building foundations along a now-abandoned road, with stone walls demarcating fields and the road itself. As is shown in the figure, these features are not visible in the

2012 aerial photography, but by comparing the LiDAR data with a map from 1856, a more comprehensive picture of the historical landscape emerges. Not only are the road networks visible, but approximate locations of farmsteads and individuals' names as well as place names are visible. More research is needed to fully understand the degree of agricultural abandonment in this town and others that were also subject to this agricultural abandonment following industrialization of cities in the mid-nineteenth century. Common interpretations suggest that the availability of land on the frontier, or the proximity of many of these agricultural Connecticut towns to Providence or Hartford likely contributed to this abandonment, though more research is needed to understand this phenomenon.

The rapid deforestation that occurred across New England in the late eighteenth and early nineteenth century is well documented specifically in Massachusetts by many first-hand descriptive accounts, and additionally through a series of maps drawn in 1830. In 1830, the Massachusetts General Assembly voted that each town in the Commonwealth should draw up a map illustrating its land use (Hall et al., 2002). These maps generally show forest, cleared land, meadows, rivers or streams, roads, buildings, and other features of the landscape, though maps for individual towns do vary in what they depict and in what detail. Though generalized, these maps provide significant information that can be used in reconstructing land cover for a town. Westport's map from 1830 was modified in 1831 by S. Bourne to include buildings; it is from this modified map that the authors digitized land use types for Westport as part of an earlier project. Harvard Forest has also scanned and digitized all of the maps for the state, publicly available through their website, providing an invaluable data source to GIS users (Harvard Forest, 2002). The stone walls and other features visible in the LiDAR data can be used with this and other land cover maps to assist in understanding how the agricultural landscape may have been divided, and in turn understand other broader social and historical trends. Land cover in Westport is documented for 1831, 1951, and 2005 at the very least. Preliminary buffer analysis with stone walls derived from the LiDAR

data has shown that stone walls could be used as a proxy for determining cleared land in a town. Further analysis with GIS models might allow for the prediction or reconstruction of past land use by mapping temporal changes in forest cover versus land that has been cleared at one point in time. In turn, this would aid in deriving a history of how agricultural abandonment influenced the forest coverage in the town. Figure 8 shows the hillshaded LiDAR data overlaid by a partially transparent USGS topographic map from 1951. Stone walls from the LiDAR data are visible, and it is evident they are used to demarcate agricultural fields. Some fields have already been reforested by this time period, as evidenced by the stone walls in completely forested areas.

In addition to the land cover maps, Westport is unique in that it also was the subject of a property boundary survey in 1712–1716 by a surveyor named Benjamin Crane (Crane, 1910). The resulting map indicates property ownership, boundaries, dates, and acreages for that time period. Crane also recorded a description of each parcel in his notes, sometimes describing plots of land as homesteads, or with descriptions of physical boundaries markers such as trees, rivers/streams or rock outcrops. The property boundaries on the Crane map actually match dozens of modern parcel boundary lines (Figure 8). This raises many questions about the continuity of historic and modern landscapes, and how the structure and partitioning of historic agricultural landscapes has influenced the landscape we experience today. This is quite a complex issue and cannot be fully addressed here. It is, however, an issue that LiDAR can help to elucidate with future studies. In addition to modern parcel boundaries, the Crane map property boundary lines also correspond with currently standing stone walls that are visible in the LiDAR data. This means that many of the stone walls currently in Westport's forests could actually date to at least 1712–1716 if not prior to that time. In conjunction with deeds and probate records, other descriptions of these parcels of land can be derived as well. For instance, a portion of one of the tracts in the below figure was described in deed from 1726 as having "…housing, orchards, timber wood & fences…" (Southern Bristol County Registry of Deeds, 3:237).

5. Conclusion

It is evident that like other areas of the world, there are many applications of LiDAR data for archaeology in New England. The new data that have been made available by various state GIS agencies in southern New England can be downloaded for free, and could allow for more efficient and informed survey planning prior to walkover surveys in the field. Some of these applications include: looking at the data generally in the project area to see and understand the topography and cultural features that are part of the landscape; digitizing and reconstructing stone wall patterns on the landscape to aid in historic landscape cover reconstruction; or comparison of the data with historic maps and aerial photographs to reconstruct past settlement patterns and land cover history. As the research in this paper has shown, incorporating LiDAR with other available historical data that is normally used in archaeological or historical research enhances not only the quality of the research but provides additional details about the landscape in a particular area.

Additionally, though numerous articles have regarded LiDAR as methodologically remarkable, few interpret the data or results in terms of theoretical anthropological questions regarding landscape. The use of LiDAR as a method to see the landscape and its archaeological features at such high resolution is a vital contribution to answering the theoretical anthropological questions regarding how humans have interacted with, shaped, viewed, and even divided the landscape in New England and how these processes can be applied on a broader scale both geographically and temporally. This research will enable us to contribute new data analysis and interpretations of specific archaeological features common to New England's landscape to the rapidly growing body of literature regarding archaeological research using LiDAR data. The use of this data is imperative to comprehensively quantify the historical human impact on the landscape by studying the landscape at much finer resolutions than have been previously available, and to provide contributions to anthropological theory regarding how humans have interacted with and

divided the landscape historically which has in turn influenced modern and will influence future land use.

As evidenced by the results of various visualization techniques, the implications for the use of LiDAR data in New England are vast, as they have been elsewhere in the world. As with other studies, the use of LiDAR to locate, identify, and analyze archaeological landscape features requires further study but has initially proven to be successful as well as time efficient and cost effective. The use of historical documents such as maps and aerial photography has proven successful in interpreting and starting preliminary analysis to understand the spatial dimension of New England history but it is also known that the terrain and hillshading data is not the only derivative product from LiDAR and not the only information that can be used to study the archaeological landscape. Further studies regarding LiDAR intensity or returns could also benefit archaeologists in southeastern New England as they have for archaeologists elsewhere in the world.

References

Adams, W.H., 1990. Landscape Archaeology, Landscape History, and the American Farmstead. Historical Archaeology 24, 92–101.
Bennett, R., Welham, K., Hill, R.A., Ford, A., 2012. A Comparison of Visualization Techniques for Models Created from Airborne Laser Scanned Data. Archaeological Prospection 19, 41–48.
Berentsen, W.H., 1996. Northeastern Connecticut: America's "Megalopolitan Park". Stadt und Wirtschaftsraum, Berliner geographische Studien 22, 283–294.
Center for Land Use Education and Research (CLEAR). 2012. http://clear.uconn.edu/projects/landscape/index.htm. Accessed 2 December, 2012.
Challis, K., Forlin, P., Kincey, M., 2011. A Generic Toolkit for the Visualization of Archaeological Features on Airborne LiDAR Elevation Data. Archaeological Prospection 18, 279–289.
Chase, A.F., Chase, D.Z., Weishampel, J.F., Drake, J.B., Shrestha, R.L., Slatton, K.C., Awe, J.J., Carter, W.E., 2011. Airborne LiDAR, archaeology, and the ancient Maya landscape at Caracol, Belize. Journal of Archaeological Science 38, 387–398.
Crane, B., 1910. The Field Notes of Benjamin Crane, Benjamin Hammond, and Samuel Smith. New Bedford Public Library, New Bedford, MA.
Cronon, W., 1983. Changes in the Land. Hill and Wang, New York.
Crutchley, S., 2009. Ancient and modern: Combining different remote sensing techniques to interpret historic landscapes. Journal of Cultural Heritage 108, 65–71.
Devereux, B.J., Amable, G.S., Crow, P., 2008. Visualisation of LiDAR terrain models for archaeological feature detection. Antiquity 82, 470–479.
Devereux, B.J., Amable, G.S., Crow, P., Cliff, A.D., 2005. The potential of airborne lidar for detection of archaeological features under woodland canopies. Antiquity 78, 648–660.
Dewberry. 2011. Project report for the U.S. Corp of Engineers high resolution LiDAR data acquisition & processing for portions of Connecticut. Prepared for USDA NRCS.
Doneus, M., Briese, C., Fera, M., Janner, M., 2008. Archaeological prospection of forested areas using full-waveform airborne laser scanning. Journal of Archaeological Science 35, 882–893.
Doneus, M., Doneus, N., Briese, C., Pregesbauer, M., Mandlburger, G., Verhoeven, G., 2013. Airborne laser bathymetry – detecting and recording submerged archaeological sites from the air. Journal of Archaeological Science 40, 2136–2151.
ESRI. 2013. http://resources.arcgis.com/en/help/main/10.1/index.html#//015w0000003z000000. Accessed 30 June 2013.
Gallagher, J.M., Josephs, R.L., 2008. Using LiDAR to Detect Cultural Resources in a Forested Environment: an Example from Isle Royale National Park, Michigan, USA. Archaeological Prospection 15, 187–206.
Garman, J.C., Russo, P.A., Mrozowski, S.A., Volmar, M.A., 1997. "This Great Wild Tract": Henry David Thoreau, Native Americans, and the Archaeology of Estabrook Woods. Historical Archaeology 31, 59–80.
Garrison, J.R., 1991. Landscape and Material Life in Franklin County, Massachusetts 1770-1860. University of Tennessee Press, Knoxville.
Hall, B., Motzkin, G., Foster, D.R., Syfert, M., Burk, J., 2002. Three hundred years of forest and land-use change in Massachusetts, USA. Journal of Biogeography 29, 1319–1335.
Harmon, J.M., Leone, M.P., Prince, S.D., Snyder, M., 2006. LiDAR for Archaeological Landscape Analysis: A Case Study of Two Eighteenth-Century Maryland Plantation Sites. Historical Archaeology 71, 649–670.
Harvard Forest. 2002. 1830 Map Project. Harvard Forest Archives, Petersham, MA.
Herbster, H., Heitert, K., 2004. Archaeological Reconnaissance Survey, Town of Westport, MA. PAL Report No. 1494. Pawtucket, RI.

Hesse, R., 2010. LiDAR-derived Local Relief Models - a new tool for archaeological prospection. Archaeological Prospection 17, 67–72.
Johnson, K.M., 2009. That Charm of Remoteness: A Study of Landscape Stability in Little Compton, RI. University of Massachusetts Boston.
Kokalj, Ž., Zaksek, K., Ostir, K., 2011. Application of sky-view factor for the visualisation of historic landscape features in lidar-derived relief models. Antiquity 85, 263–273.
Lasaponara, R., Coluzzi, R., Gizzi, F.T., Masini, N., 2010. On the LiDAR contribution for the archaeological and geomorphological study of a deserted medieval village in Southern Italy. Journal of Geophysics and Engineering 7, 155–163.
Little Compton Land Evidence [LCLE], Town of Little Compton, RI.
Map and Geographic Information Library (MAGIC). http://magic.lib.uconn.edu/. Accessed 9 December 2012.
Masini, N., Coluzzi, R., Lasaponara, R., 2011. On the Airborne Lidar Contribution in Archaeology: from Site Identification to Landscape Investigation, in: Wang, C.-C. (Ed.), Laser Scanning, Theory and Applications. InTech Online Publishers.
MassGIS. http://www.mass.gov/mgis/. Accessed 11 November 2012
McCoy, M.D., Asner, G.P., Graves, M.W., 2011. Airborne lidar survey of irrigated agricultural landscapes: an application of the slope contrast method. Journal of Archaeological Science 38, 2141–2154.
McMurray, S., 1988. Families and Farmhouses in 19th century America. Oxford University Press, Oxford, England.
Merchant, C., 1989. Ecological Revolutions: Nature, Gender, and Science in New England. University of North Carolina Press, Chapel Hill.
Millard, K., Burke, C., Stiff, D., Redden, A., 2009. Detection of a low-relief 18th-century British siege trench using LiDAR vegetation penetration capabilities at Fort Beauséjour-Fort Cumberland National Historic Site, Canada. Geoarchaeology 24, 576–588.
New Bedford Public Library. 2009. Benjamin Crane Property Survey Map, 1712. Library Archives. Photograph used with permission.
Opitz, R.S., Cowley, D.C., 2013. Interpreting archaeological topography: lasers, 3D data, observation, visualisation, and applications. Oxbow Books, Oxford, England.
Pluckhahn, T.J., Thompson, V.D., 2012. Integrating LiDAR data and conventional mapping of the Fort Center site in south-central Florida: A comparative approach. Journal of Field Archaeology 37, 289–301.
Rhode Island GIS [RIGIS]. http://www.edc.uri.edu/rigis/. Accessed 11 November 2012.
Rosenswig, R.M., López-Torrijos, R., Antonelli, C.E., Mendelsohn, R.R., 2013. Lidar mapping and surface survey of the Izapa state on the tropical piedmont of Chiapas, Mexico. Journal of Archaeological Science 40, 1493–1507.
Rubertone, P.E., 1989. Landscape as Artifact: Comments on "The Archaeological Use of Landscape Treatment in Social, Economic and Ideological Analysis". Historical Archaeology 23, 50–54.
Southern Bristol County Registry of Deeds [SBCRD]. Book 3, 1723–1733/4. New Bedford, Massachusetts.
Štular, B., Kokalj, Ž., Oštir, K., Nuninger, L., 2012. Visualization of lidar-derived relief models for detection of archaeological features. Journal of Archaeological Science 39, 3354–3360.
United States Bureau of the Census. 1870. http://www.ancestry.com/. Accessed 9 December 2012.
United States Department of Agriculture. 1870. http://www.agcensus.usda.gov/Publications/Historical_Publications/index.php. Accessed 9 December 2012.
Thorson, R., 2002. Stone by stone: the magnificent history in New England's stone walls. Walker & Company, New York.

Verhagen, P., Drăguţ, L., 2012. Object-based landform delineation and classification from DEMs for archaeological predictive mapping. Journal of Archaeological Science 39, 698–703.
Werbrouck, I., Eetvelde, V.V.A.N., Antrop, M., Maeyer, P.D.E., 2009. Integrating Historical Maps and LiDAR Elevation Data for Landscape Reconstruction : a case study in Flanders, in: European Landscapes in Transformation: Challenges for Landscape Ecology and Management. IALE, Salzburg, Austria.

Figures

Figure 1.

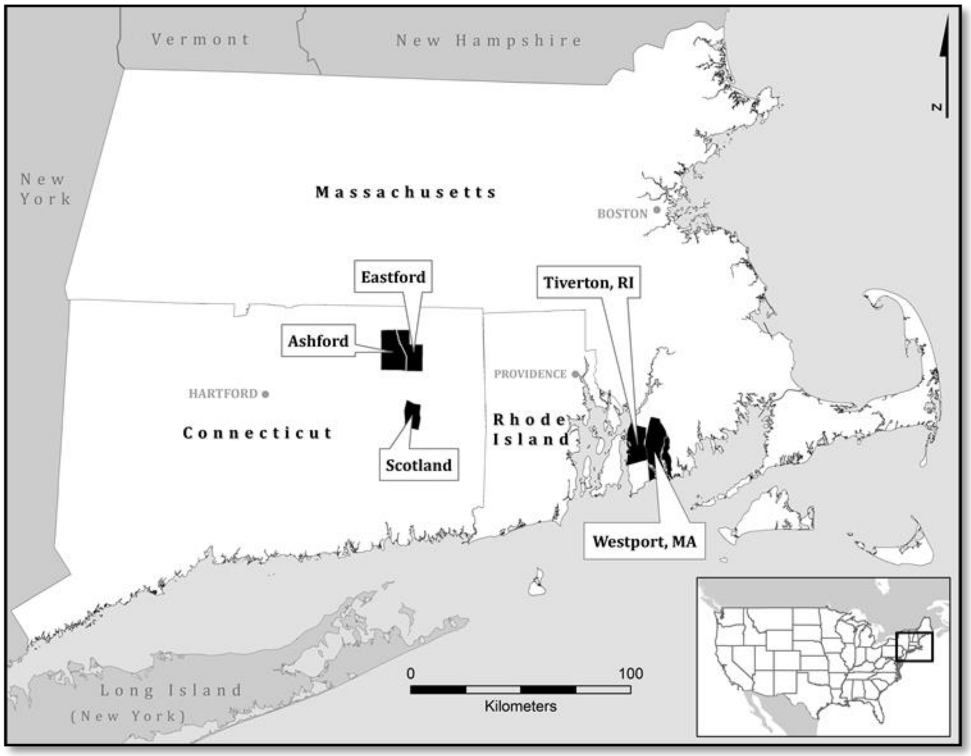
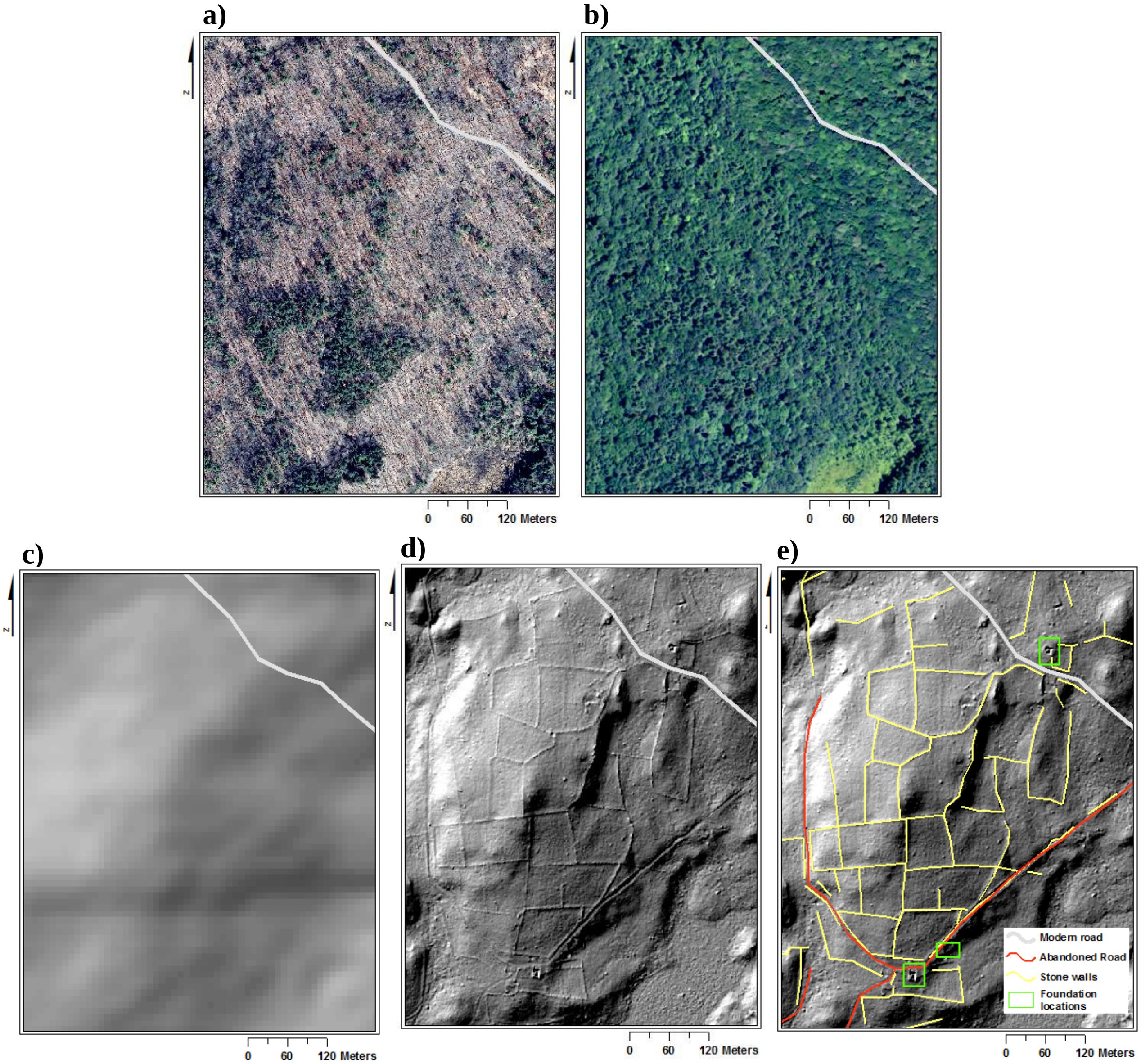


Figure 2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Stone walls
Foundation locations

Figure 3

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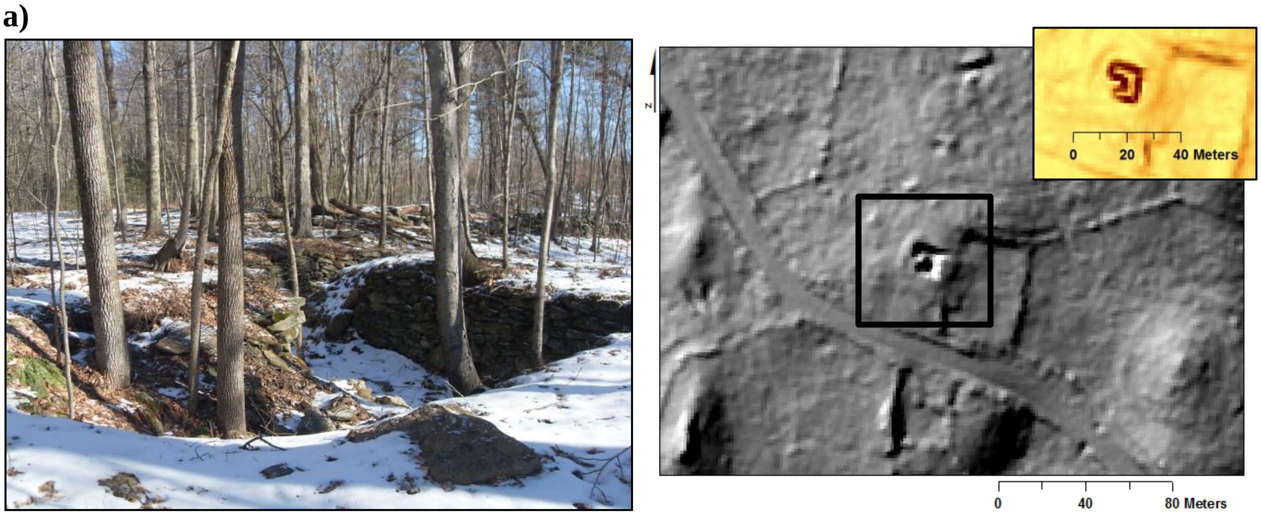
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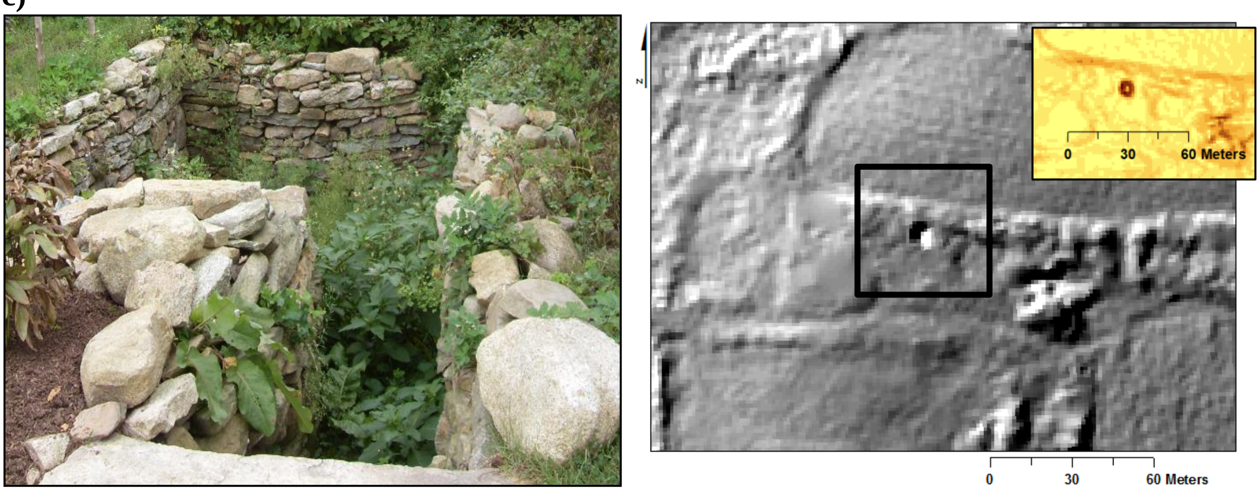
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Figure 4

a)

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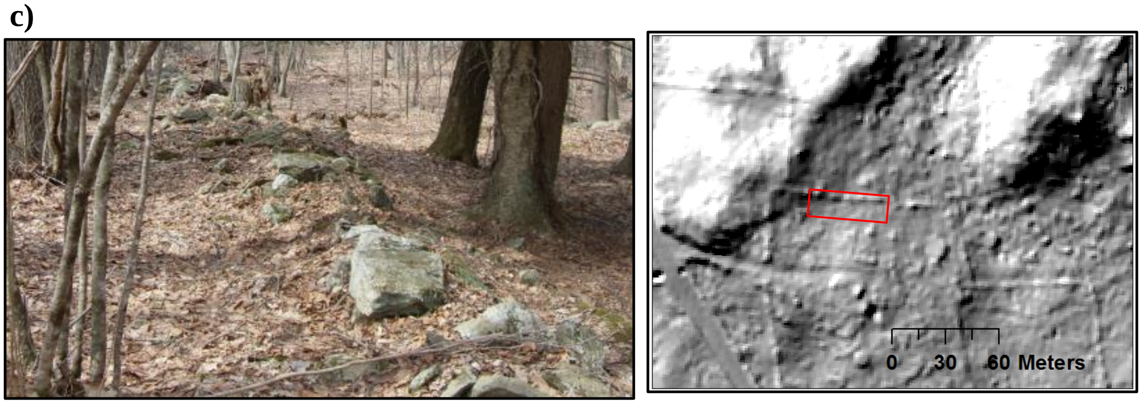

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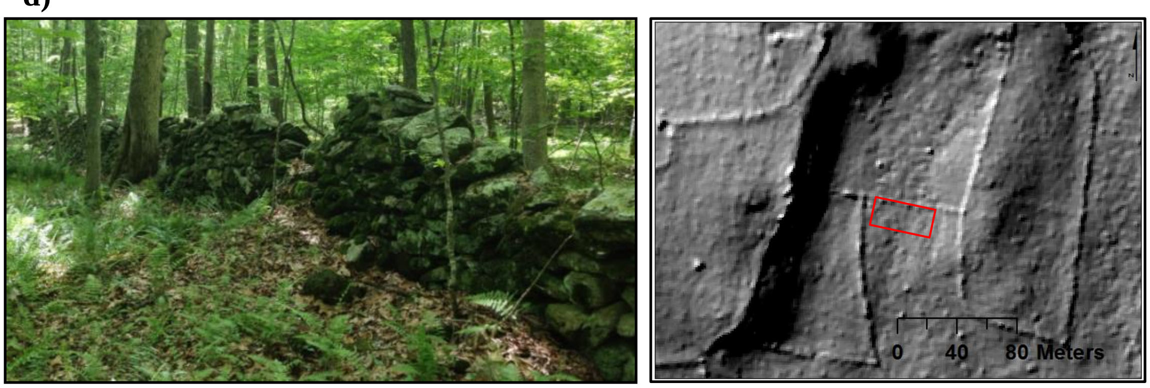

Figure 5

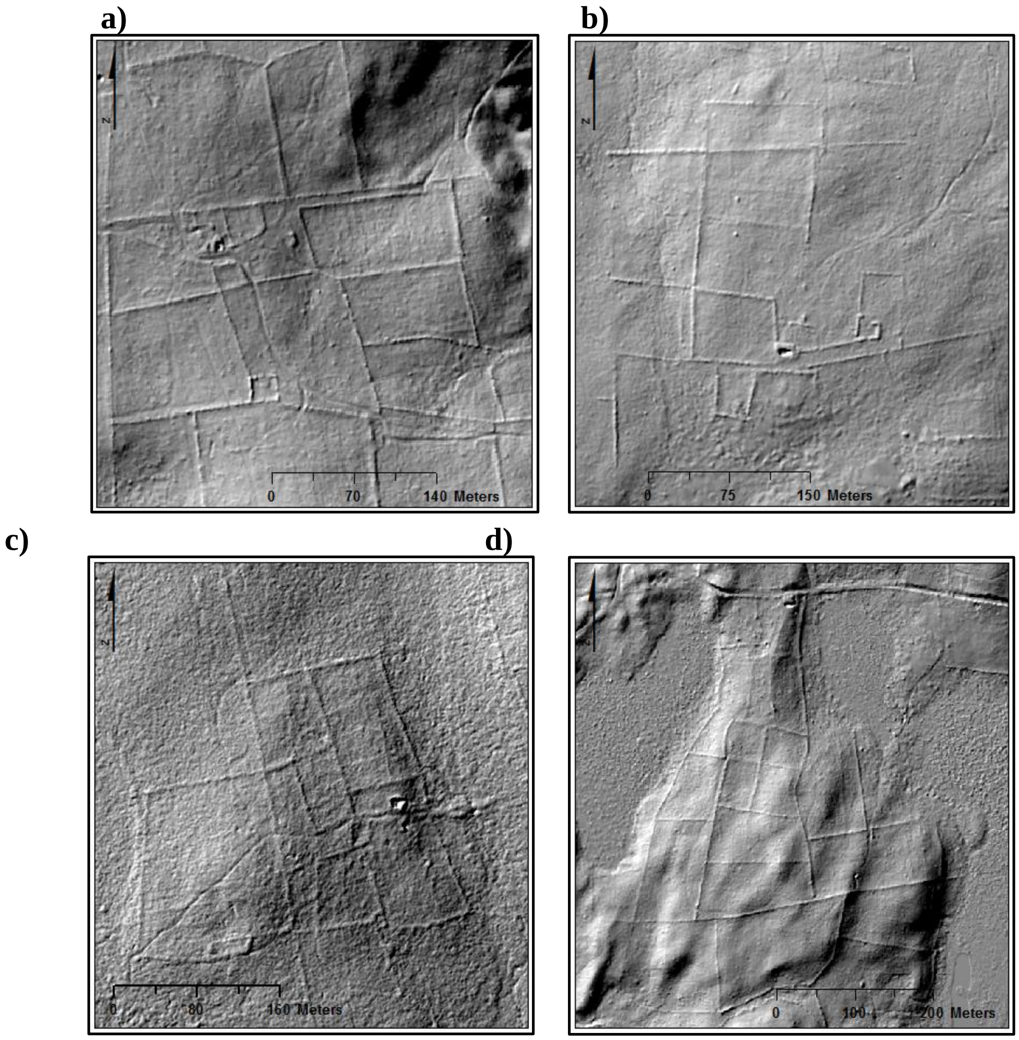
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Figure 6

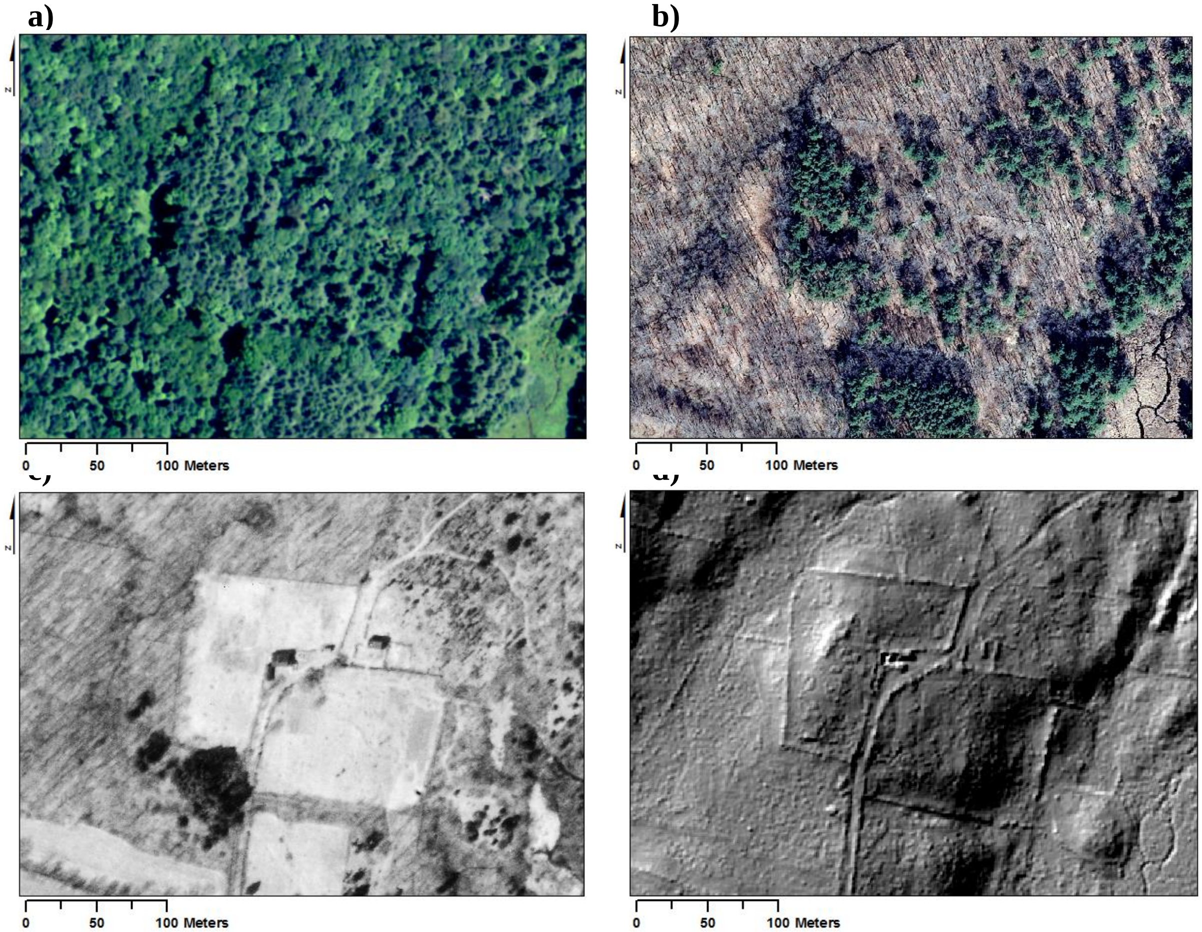
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Figure 7

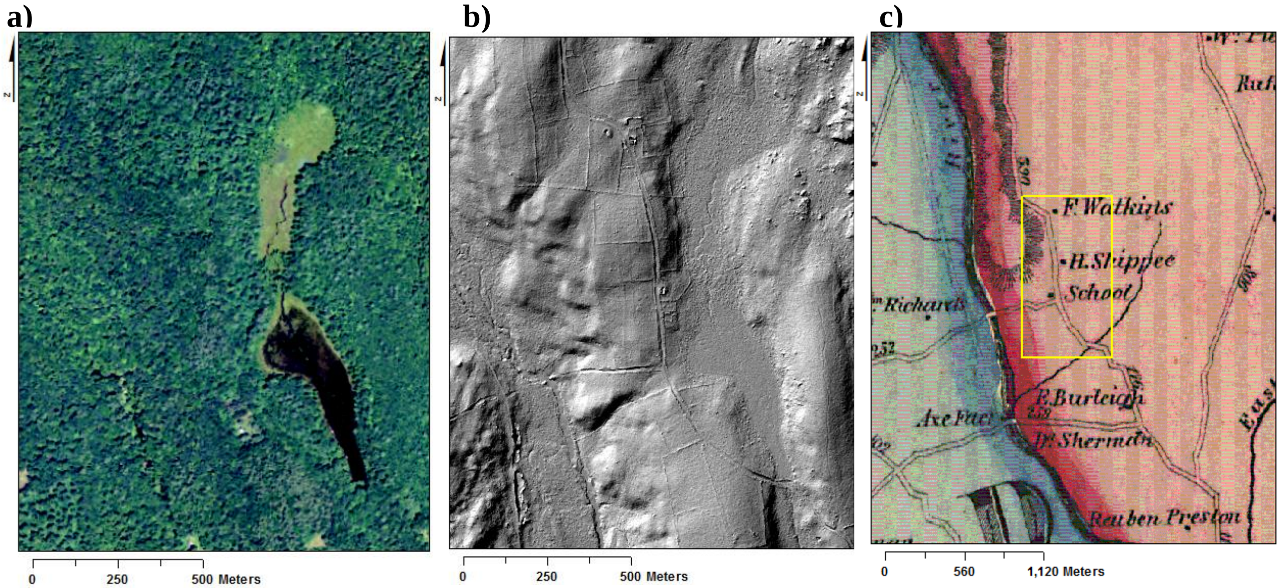
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Figure 8

a) b)

Figure Captions

Figure 1: Study area with focus areas indicated.

Figure 2: This figure illustrates the advantage of LiDAR data with a point spacing of 1m or better over traditional map views of the landscape for archaeological purposes. 2a and 2b show leaf-off and leaf-on aerial photographs with a modern road superimposed through the northeast corner of the image for reference. 2c shows a hillshaded DEM derived from the 10m pixel resolution USGS National Elevation dataset; this is the highest available DEM pixel resolution available for the entire United States. Most archaeological features cannot be seen at such a low DEM resolution and are masked by forest cover in aerial photographs, but the hillshaded DEM created from LiDAR data with 1m resolution (2d) depicts many features quite clearly and they can then be digitized (2e). In 2e, stone walls are yellow, abandoned roads are red, and building foundations are outlined by green squares.

Figure 3: 3a and 3b show building foundations found using the Connecticut LiDAR, which has a higher point density per square meter (0.7 m point spacing) than that for Massachusetts (1 m point spacing), an example of which is seen in 3c. All three examples also have slope rasters, which are better in showing the shapes and dimensions of the actual foundations. The shapes of both Connecticut foundations are discernible; however the foundation in Massachusetts is somewhat more ambiguous. The foundation in 3c is somewhat smaller, and this coupled with a lower point density seems to impact its visibility.

Figure 4: In addition to building foundations, LiDAR allows us to see other archaeological features such as dams, mills, stone walls and old roads. 3a shows a dam and walls in Ashford, CT that were once part of a mill complex; 3b shows a race for an 18^{th} century sawmill in Tiverton, RI; 3c shows two different stone walls, reflecting either different initial constructed heights, or various states of preservation.

Figure 5: LiDAR has also shown to be vital in understanding the spatial layout of historical farmsteads. Most historical research yields only a small point on a map for reference; LiDAR reveals not only the foundation where that point was, but the surrounding fields and enclosures that create irregular polygonal patterns, in addition to secondary building foundations. Farmsteads are one of the most ubiquitous features encountered on the New England landscape; they also have a recognizable layout in the LiDAR data as shown by these examples from a) Ashford, CT; b) Scotland, CT; c) Westport, MA and d) Eastford, CT. Note that all of these locations are currently densely forested and overgrown.

Figure 6: LiDAR can be used in conjunction with historical documents to more thoroughly understand the history of landscape change as well. 1934 aerial photography (c) shows that this area was a working farm with a house, barn, outbuildings, and cleared fields at that time. 2012 leaf-on and leaf-off aerial photography (a and b) shows the area is now densely forested. In (d), a hillshaded DEM created from LiDAR data.

Figure 7: LiDAR is a powerful tool by itself, but also when used in conjunction with historical documents. This area of Ashford, CT is now densely forested as shown in the 2012 aerial photograph (a). However, this historical map from 1858 (c) shows that the area once had a road running through it with several homesteads and even a school. A LiDAR hillshade in (b) reveals not only the road, but the building foundations, that are all now within the forest. The yellow box in (c) outlines the extent of air photo and LiDAR maps.

Figure 8: By using LiDAR data, we can compare stone walls with historical property boundaries and land divisions. In this example from Westport, MA, many stone walls that have been digitized from LiDAR data (a) correspond to property boundaries shown on this map from 1712 (b). This not only gives an approximate date for the walls, but allows us to understand how land was divided and how that has influenced the modern landscape. Map courtesy of the New Bedford Public Library

CHAPTER 3

An observational and theoretical framework for interpreting the landscape palimpsest through airborne LiDAR[2]

1. Introduction

Light detection and ranging (LiDAR) data has been used over the course of more than a decade in cultural heritage and archaeological landscape studies (Risbøl, 2013; Sittler, 2001), with an increasing popularity during the last several years (Cowley 2011). It has been particularly useful in heavily forested areas such as Belize (Chase et al., 2014, 2011), Cambodia (Evans et al., 2013), Mexico (Rosenswig et al., 2013), Germany (Sittler, 2001), Austria (Doneus et al., 2008), Norway (Risbøl, 2013), Montserrat (Opitz et al., 2015), England (Bewley et al., 2005; Devereux et al., 2005; Schindling and Gibbes, 2014), Italy (Coluzzi et al., 2010), Canada (Millard et al., 2009), and the United States (Gallagher and Josephs, 2008; Johnson and Ouimet, 2014; Pluckhahn and Thompson, 2012; Randall, 2014). Despite exciting new applications and an overwhelming number of recent case studies, it must be remembered that any imagery derived from LiDAR data portrays the landscape as it appears today; not truly as it appeared during time periods that many of these studies are examining (Harmon et al., 2006). The concept of landscape as a palimpsest or as an accumulation of physically-expressed events provides a theoretical framework through which to interpret LiDAR data and associated derivatives such as commonly-used hillshaded digital elevation models (DEMs).

Landscapes have often been likened to palimpsests due to the rich history of physical and cultural events that are expressed upon and just below the surface (Anschuetz et al., 2001; Brierley, 2010; Harmon et al., 2006; Holtorf and Williams, 2006; Hritz, 2014; Johnson, 2007; Kantner, 2008; Mlekuz, 2013a). This simile originates from manuscripts that were scraped clean and written over, though trace elements of the original script remained (Schein, 1997). Because humans have altered

[2] Johnson, K.M. and Ouimet, W.B. in preparation to be submitted to *Applied Geography*.

their environments and landscapes for thousands of years (Foley et al., 2013; Smith and Zeder, 2013), it is critical to recognize the temporal range and possible cultural affiliations of features that might be encountered in examining data derived from LiDAR. Because it allows for such high resolution imaging of the ground surface, the landscapes we see through it are often a "mess of temporalities", "traces" of events with "differential duration" (Mlekuz, 2013a, 2013b), an "assemblage" of materialized events that have remained resilient to disruptive forces (Aldred and Lucas, 2010), or a "temporal collage" (Holtorf and Williams, 2006). Of note are events or processes that leave subtle or no topographic signatures on the land surface yet still result from human interaction with the landscape; these include the production of memory, mythologies, or experiences (Holtorf and Williams, 2006; Ingold, 1993), power dynamics (Given, 2004; Spencer-Wood and Baugher, 2010), as well as human settlements or habitation sites that lack widespread or localized surficial topographic signatures. This makes it difficult or impossible to discern these processes using LiDAR. Those features that remain are expressed as a collection on the land surface, and as a result often make it difficult to interpret surface or elevation models derived from LiDAR data or locate and identify specific features of interest without supplementary information. These limitations to landscape interpretation can be partially overcome for more recent time periods by using sequential satellite or aerial photography, historical maps, field validation studies, or other physical or environmental data (e.g., Pluckhahn and Thompson 2012; Challis et al. 2008), while also acknowledging that our own histories, worldviews, and values influence these interpretations as well (Holtorf and Williams, 2006). Many studies have used aerial photographs and historic maps to examine land use change through time (e.g., Etter, McAlpine, and Possingham 2008; Hamre et al. 2007; Swetnam, Allen, and Betancourt 1999), though this has not been common practice amongst landscape studies that utilize LiDAR. While a limited number have indeed used these methods (Crutchley, 2006; Harmon et al., 2006; McNeary, 2014; Millard et al., 2009; Randall, 2014; Werbrouck et al., 2009), even fewer employ or mention in passing the concept of a

palimpsest as a theoretical framework to examine LiDAR data (Cowley, 2011; Ladefoged et al., 2011; Mlekuz, 2013a, 2013b; Stichelbaut et al., 2016).

This study presents several examples from the northeastern United States to examine the complexities of using LiDAR data in a heavily forested environment with respect to historic landscape studies, while demonstrating the necessity of using historic maps, documents, and aerial or satellite imagery to provide improved contextual interpretation. As with all landscapes, that of the northeastern United States ought to be viewed as a palimpsest due to the rich land use history that is expressed on and below the surface. There are thousands of archaeological sites in this region dating to between 12kya up to the colonization of the region by Europeans in the 17th century that remain unexpressed topographically, or have such subtle topographic variation that they may be impossible to see with even 1m pixel resolution. We recognize the critical importance of these sites in the development and history of this region and landscape, and must acknowledge LiDAR's ability to map surficial topography as a limitation in this regard since the features expressed on the landscape in southern New England predominantly show a record of post-17th century land use. This of course does not preclude the possibility of pre-17th century Native American sites and probable areas of habitation, or portions of the topographic landscape that may have been included in oral histories and the production of memory for Native Americans and other groups as well (Brierley, 2010; Byrne, 2003; Holtorf and Williams, 2006; Pauls, 2006). LiDAR is critical in understanding the post-17th century landscape in this region and has revealed thousands of features of historic land use, such as stone walls, building foundations, relict charcoal hearths, and other surface features preserved in the forested areas that comprise over half of the region's land cover (Johnson and Ouimet, 2014). These features mark a profound cultural shift in this region resulting from colonization by Europeans in the 17th century (Cronon, 1983; Donahue, 2004), but their impacts also remain widely unstudied in understanding geomorphic and ecological effects related to the Anthropocene. The fine scale of the features in this region makes high-resolution

LiDAR data coupled with contextual resources critical in identifying and interpreting them (Figure 1). While other regions may have varying contextual resources, this study provides an observational and theoretical framework to interpret historical landscapes studied using LiDAR.

2. Contextualizing the landscape palimpsest and airborne LiDAR

Though the studies that emphasize various visualization techniques are numerous (Bennett et al., 2012; Challis et al., 2011b; Doneus, 2013; Hesse, 2010; Kokalj et al., 2011; McCoy et al., 2011; Štular et al., 2012), few provide critiques of LiDAR landscapes and their correlation (or difference from) associated historical materials such as aerial or satellite imagery, or historic maps, though these are the time periods that many landscape studies seek to examine. It may seem relatively straightforward to identify certain features of interest on the landscape, but it is difficult to interpret the derivative imagery objectively, or even at all without the proper context (Cowley, 2012; Doneus and Kühteiber, 2013). As a result, comprehensively understanding or interpreting the full temporal span of the landscape itself can be challenging (Risbøl, 2013), especially in instances where extant landscape features predate documentary evidence. In 2006, studies in the Witham Valley, UK (Crutchley, 2006), and Maryland, USA (Harmon et al., 2006) made the point that while LiDAR was fast becoming an integral tool for cultural landscape studies, it was best used in conjunction with other contextual information because while it records topographic elevations, it is only through interpretation that temporal or cultural information can be obtained (Crutchley, 2006; Harmon et al., 2006). Understanding the context in which these processes occurred is vital in then beginning to interpret any LiDAR dataset that depicts a particular landscape (Doneus and Kühteiber, 2013).

2.1 Interpreting palimpsests and the landscape

The term “palimpsest” has been used for decades to describe landscapes in a range of disciplines including archaeology, geography, and geomorphology (Bailey, 2007; Brierley, 2010; Clevis et al., 2006; Goudie and Viles, 2010; Hunt and Royall, 2013; Johnson, 2007; Massey, 2005; Schein, 1997). The term has also been used generally to refer to the landscape as seen using LiDAR (Barnes, 2003; Bernardini et al., 2013; Ladefoged et al., 2011; Megarry and Davis, 2013; Mlekuz, 2013a, 2013b). The word “palimpsest” was first used to describe a “manuscript or piece of writing material on which the original writing has been effaced to make room for later writing but of which traces remain” (OED 2014). Interpretations of landscape palimpsests have ranged from the above-defined remnant traces of past activity, to the more cumulative “superimposition[s] of successive activities” or “assemblage of dispersed and gathered eventful objects” (Aldred and Lucas, 2010; Bailey, 2007; Lucas, 2008; McDonagh and Daniels, 2012). Dynamics of colonization, power, and human emotion are often also present in understanding processes of resistance or erasure, production of memory, and other aspects of human-landscape interaction that are not topographically expressed (Given, 2004; Hirsch and O’Hanlon, 1995; Holtorf and Williams, 2006; Spencer-Wood and Baugher, 2010; Tuan, 1977). Landscapes are complex and constantly evolving, and are physical expressions of both human and natural processes, having been termed “artifacts” in and of themselves (Rubertone, 1989). Over centuries these landscapes often become “messy” (Mlekuz, 2013a) in that they become an assemblage of various events and processes (Aldred and Lucas, 2010; Beck Jr. et al., 2007). Understanding the history of a region’s landscape is integral in understanding its present (Sauer, 1941) because the landscape that exists today is the result of “particular circumstances [that] determine the survival of remnant forms” as well as the magnitude of those circumstances or events (Brierley, 2010).

These activities, circumstances, and their physical expressions represent complex human-environmental or sociocultural interactions and processes comprising material expressions of

recurrent or unique events. Some examples include colonial expressions of resistance and dominance (Given, 2004, 2002; Lightfoot et al., 2013; Massey, 2005; McIntyre-Tamwoy and Harrison, 2004), climate change (Barnosky et al., 2012; Dugmore et al., 2012; Yellen et al., 2014), or changes in land use decisions (Bellemare et al., 2002). In interpreting one remnant feature on the landscape, the other spatially-related features should also be considered to understand the processes that have allowed both to exist contemporaneously (see Lucas, 2008). Variation in expression of features surficially can also be expected based on geographic location, history of land use, cultural affiliations, and a variety of other factors influencing the interactions of humans and the land surface.

2.1.1 Types of palimpsests

The current landscape is the continuously-changing cumulative result of complex processes involving coupled human-environment systems and feedbacks, and is not necessarily always "scraped clean" (McDonagh and Daniels, 2012). As a result it may come as little surprise that multiple types of palimpsests have been described and proposed in an attempt to describe these complex earth surface processes and their human constituents. Bailey (2007) gives the example of "true palimpsest" as a Neolithic house where the floor is "regularly swept clean" (though some material may have remained). Each depositional layer of activity would have been mostly removed, until the house is abandoned and collapses, preserving the final activity layer (Bailey 2007:203). Remnants of any activity would be a "biased selection of the original materials" and the final activities might have been much different than those that came first (Bailey 2007:203). Bailey provides several other examples of palimpsests, all slightly different from one another in their process and extent, though he notes that their criteria can often overlap. These include: "cumulative palimpsest," an example where all temporal elements are extant, but have occurred in the same location, thus they blur together making it difficult to discern the signature for each event; "spatial

palimpsest," where events can occur in discrete locations with differential preservation potential based on weathering or human disturbance; and "temporal palimpsest," where objects of varying ages occur in a singular deposit. Landscapes as seen through LiDAR more often than not are a combination of two or more of the types that Bailey defines. LiDAR landscapes provide a view of a variety of landscape elements, however only when we combine this data with other sources or knowledge do we begin to discern the full temporal range of that landscape and its associated material culture.

In addition to being palimpsests of human land use, landscapes also represent a range of dynamic geological events and processes, and often are comprised of numerous landforms that did not originate at the same time though they now exist concurrently (Knight and Harrison, 2013). Conceptually, palimpsests are often used in geology to discuss the dynamics of landscape evolution and change (e.g., Kleman, 1992). Landscape-scale analyses with both historic aerial photography and LiDAR have also revealed complex topographic relationships amongst geologic features that intersect with those created by humans (Panno and Luman, 2012; Shilts et al., 2010). Humans and their land use practices have shaped landscapes drastically, to such extents that the term "Anthropocene" has been introduced as a geological epoch to capture such dramatic geomorphological and climatic change (Chin et al., 2013; Crutzen and Stoermer, 1999; Harden, 2014; Hooke, 2000, 1994; Hooke et al., 2012).

2.1.2 The landscape palimpsest and LiDAR

The use of LiDAR to study landscapes from a historical perspective has shown that complex overlapping topographic signatures exist on modern landscapes on a global scale, in many cases making it difficult to interpret or date features on those landscapes (Cowley, 2012; Crutchley and Crow, 2009; Daukantas, 2014; Mlekuz, 2013b). Difficulties in interpretation or identification have arisen not only from complexity of land use but also as a result of the resolution of LiDAR data

(Anderson et al., 2006), or vegetation type and density (Prufer et al., 2015). Even in areas of high preservation with relatively low developmental impact, it still remains necessary to understand the history of that landscape to then be able to interpret topographic features on that landscape. Many published studies that use LiDAR to interpret landscapes from a historical perspective have discovered or mentioned features that were created during varying time periods or events, or that have been partially destroyed or removed. For example, in Italy, traces of agricultural fields that had been laid out using Roman centuriation practices were discovered while utilizing LiDAR to examine paleochannels (Coluzzi et al., 2010), and in New Forest National Park in Bournemouth, UK, LiDAR revealed Bronze Age burial mounds, Iron Age earthworks, as well as medieval and 19th century field systems.

Other studies have mentioned complementary sources in their interpretations of various features. In Ireland, a recent study utilized 19th and 20th century historic Ordnance Survey maps to interpret field boundaries that were discovered using LiDAR data (McNeary, 2014). A similar study by Werbrouck and colleagues in Belgium used a series of historic maps ranging from 1775 to 1984 to reconstruct historic land use and land cover during that period. Through comparison with the LiDAR data, the study found that existing microtopographic signatures corresponded to field boundaries on an 1850 topographic map, thus elucidating the origins of some of the features discovered by the LiDAR survey. Millard and colleagues (2008) also made use of historic maps in their rediscovery and identification of an 18th century British siege trench in Canada. A study of prehistoric shell mounds in Florida, USA, used a combination of LiDAR data and historic aerial photos to trace the development of the landscape surrounding prehistoric shell mound landforms since the 1930s (Randall, 2014). All of these studies benefitted greatly from the use of supplementary contextual information to both interpret features, and to confirm ages of both known and unknown landscape features that were seen in imagery derived from LiDAR data.

3. Interpreting LiDAR and the landscape palimpsest in southern New England

3.1 Overview and study area

The availability of LiDAR for southern New England in the northeastern United States has made it possible to visualize the landscape beneath the dense forest canopy that is common throughout much of the region (see **Figure 1**). Many features related to historic land use and Anthropocene processes exist (Johnson & Ouimet, 2014) in addition to those landforms and deposits associated with Pleistocene glacial processes, Holocene environmental change, and of course the underlying geology (Bell, 1985; Stone et al., 2005). The New England landscape was shaped by a period of glaciation that ended approximately 20,000 years ago, and that left its mark on and below the surface in the form of numerous glacial landforms, till, and fluvial systems (Stone, 2005; Thorson, 2002). Glacial processes were in turn influenced by the underlying bedrock geology of the region (Bell, 1985). All subsequent land use decisions made by humans were thus constrained by the glacial and geologic history of New England, a history marked by various processes that had occurred thousands to millions of years before. The current terrain in southern New England varies from rugged, hilly uplands at relatively higher elevations in the western and eastern portions of Massachusetts and Connecticut, to the flat Connecticut River Valley, and finally coastal lowlands (see **Figure 1**). Over half of the New England landscape is currently forested, the result of widespread farm abandonment during the industrialization and westward movement of the late 19th century in this region (Bell, 1989). While once mostly cleared for agriculture and other types of land use, the area is heavily reforested, obscuring thousands of historic features in addition to glacial landforms, geology, and other geomorphic features - making any type of topographic analysis exceedingly difficult.

Studies in the region have used LiDAR to study forest structure (Weishampel et al., 2007), fluvial geomorphology (Snyder, 2009), and current studies have begun to discern thousands of topographically-expressed historical land use features which predominantly have a post-17th

century date (Johnson and Ouimet, 2014). The availability of LiDAR in this region has created an unparalleled opportunity for detailed analysis of these features and the landscape, but in order to more broadly interpret and understand the extent and magnitude of these features it is critical to establish an interpretive framework. The wide range of features, primarily those associated human activity, that have been identified on the landscape make comprehensive interpretation difficult without the use of supplementary materials. As an example, the complexities of feature interpretation in LiDAR-derived digital elevation models (DEMs) can be seen in New England when attempting to visually identify 17^{th} to 20^{th} century building foundations that in some cases do not look much different from modern in- or above-ground swimming pools even in DEMs with pixel resolutions of as fine as 1m (**Figure 2**).

3.2 Data and Processing

LiDAR data is available in southern New England for the entire states of Connecticut and Rhode Island, and partially for Massachusetts. Multiple surveys have been flown since the early 2000s, but the most recent surveys between 2010 and 2014 have provided the data with the highest point densities to date, exceeding 2 points per m^2 on average (CT ECO 2016). The examples in this manuscript draw upon two different datasets in Connecticut and Rhode Island. The first, acquired by the USGS in 2011 and partially funded by the 2009 American Recovery and Reinvestment Act, covers the entire state of Rhode Island and parts of Massachusetts, Connecticut, Maine, New Hampshire, and New York (RIGIS 2016). This dataset was flown in April and May of 2011 when there are typically no leaves on the trees of the predominantly deciduous forests. However, because it is a coastal location, these forests contain both American holly and mountain laurel that remain green all winter, in addition to dense shrubs and briars. Thus it is likely that the current point classifications may not discriminate entirely between actual ground and low vegetation well enough for identification of fine-scale cultural landscape features in some cases

(Doneus et al., 2008). The Connecticut dataset used here was flown in November and December of 2010 for the USDA Natural Resource Conservation Service and covers an area of approximately 2,851 square kilometers in the northeastern portion of the state. As with the dataset in Rhode Island, this was also classified using proprietary algorithms by the distributing vendor (Dewberry 2011).

The three-dimensional point cloud data were processed in ArcGIS 10.2 as LAS Datasets to create digital elevation models (DEMs) with a 1m pixel resolution from 2-Ground classified points. Derivative hillshade rasters were then created using the DEMs. While these tend to be the most commonly used visualization technique, we find that it allows for a clear initial overview of the data in our region prior to any further image processing. Recent publications have assessed the efficacy of local relief models (Hesse, 2010), sky-view factor (Kokalj et al., 2011; Zakšek et al., 2011), principal components analysis (PCA) (Devereux et al., 2005), slope contrast (McCoy et al., 2011), intensity of returns (Challis et al., 2011a), openness (Yokoyama et al., 2002; Doneus, 2013), and global/direct radiation (Challis et al., 2011b) for locating cultural landscape features. Many have compared these techniques with one another (and more) to discern best practices (Bennett et al., 2012; Challis et al., 2011b; Štular et al., 2012). Researchers have also performed field validation studies to discern detection rates between human interpretation of LiDAR-derived relief models and the actual ground surface (Gallagher and Josephs, 2008; McNeary, 2014; Risbøl et al., 2013; Rosenswig et al., 2013). Most of these studies emphasize the need for multiple visualization techniques in order to identify and analyze all of the natural and human-related landscape features more comprehensively (Kokalj et al., 2013), or when examining features on different types of terrain (Štular et al., 2012). Our study used both slope and openness (Doneus, 2013; Yokoyama et al., 2002) in addition to hillshaded DEMs to identify features from the derivative imagery. Historic maps (Library of Congress, 2016) and aerial photographs (MAGIC, 2016; RIGIS, 2016) were also

downloaded and processed using ArcGIS 10.2. Each resource was georeferenced based on at least 3 ground control points (GCPs) in order to attain a satisfactory RMSE value (< 5).

3.3 Interpreting LiDAR and the landscape palimpsest in southern New England

The examples presented here are observations of general landscape palimpsest types that are evident in examining LiDAR data, and exemplify the human and landscape dynamics that have historically defined the region since the 17th century. Further examples compared with aerial photographs and historic maps allow for more comprehensive interpretation of these landscapes, though by definition a palimpsest does not always preserve every activity or meaningful event, thus there will always be limitations.

New England's landscape typifies several types of palimpsests discussed by Bailey (2007) through its complex nature of both time and human-environment dynamics on the landscape. Geological formations, glacially-deposited and altered features, and other features resulting from human-environment feedbacks exist contemporaneously on the landscape's surface (**Figure 3**). This typifies Bailey's example of a "temporal palimpsest" on a landscape scale: "an assemblage of materials and objects that form part of the same deposit but are of different ages and 'life' spans (Bailey 2007:207). As a singular image, the conflation of time is evident in most LiDAR-derived imagery for this area in the outcroppings of bedrock next to glacial landforms, 17th–19th century stone walls, and modern subdivisions and highways. In Figure 2, the hillshaded DEM depicts the land surface as it appeared in 2010, though a wide range of features still exist on the surface contemporaneously. The underlying Devonian (360–410 mya) bedrock is overlain by glacially deposited till and meltwater deposits (21–17kya) as evidenced by the esker that is partially submerged in a man-made reservoir, built sometime between 1854 and 1893 based on an examination of historic maps. To the west, a cluster of abandoned 19th century farm foundations lies in the backyard of a newer residential structure built in the 1980s as well as to the north. Stone

walls from the 19^{th} century (or earlier) delineate once-farmed fields. While they likely exist below the surface in this image, cultural features with detectable topographic signatures are rare prior to the 17th or 18th century in this region, and thus it is difficult to discern those that predate the time period in southern New England using LiDAR.

New England's landscape also partially exemplifies a "true palimpsest" through the preservation of stone walls, building foundations, and other features built over the course of hundreds of years and then left on the landscape during widespread farmstead abandonment that occurred in the region during the mid-19^{th} and early 20^{th} century; these are now found in forested areas that are preserved (see **Figure 1**). In other areas where development has occurred, the preservation of these features varies across a broad spectrum ranging from completely destroyed with no trace left behind, to being reincorporated as part of a new land use entirely (**Figure 4**).

3.3.1 Interpreting the landscape palimpsest with supplementary datasets

When interpreting LiDAR data, it is essential to integrate information from time-series aerial photographs or historic maps to understand the landscape. The additional data points through time greatly increase the temporal resolution of the landscape and allow for better interpretation of surface features that are large enough to be topographically expressed in the LiDAR data depending on its resolution. As with Bailey's (2007) definition of a "cumulative palimpsest," successive land use in one location resulting from various processes can result in a blurring of individual events or loss of resolution (Bailey, 2007). Because LiDAR provides a current view of these landscapes, it may fail to depict these blurred or erased events, making supporting contextual data crucial in its interpretation.

In southern New England, the continuation of agricultural practices, though it has declined since the beginning of the twentieth century, has been responsible for drastic changes in the landscape and loss of visibility of certain types of features in LiDAR data, specifically field boundary

stone walls. It has been conjectured (James, 1929) that fields created prior to mechanized plowing and harvesting would have been smaller and more irregular and thus a hindrance to farmers in the later parts of the 19th century as farming became increasingly mechanized (Barger, 2013). Often, fields were expanded to account for these new practices; it has been well documented that more energy and labor were required with more turns of the plow (Thorson, 2002; Warren, 1914). Late 19th and early 20th agricultural resources advocated enlarging fields by removing stone walls that not only made plowing difficult, but also took up valuable acreage that could be planted, and required more maintenance (Myers, 1920; Warren, 1914). The prohibitive amount of labor required to remove walls may be one of the many contributing factors to their resilience and their prolific existence on the landscape today (see Aldred and Lucas, 2010). Mechanized labor likely allowed for easier removal, and in the early 20th century many stone walls as well as building foundations were removed or buried and plowed over to create more room for tillage. Despite farmers' best efforts to remove walls and even old building foundations from fields, subtle variations in the ground surface are visible in LiDAR data and reveal the demarcations of earlier fields even though the surface stone has been removed. These microtopographic features are similar to findings reported in England and Ireland where subtle topographic variations indicative of earthworks or field boundaries have been discovered using LiDAR; these were previously thought to have been destroyed through plowing, and not recorded in previous archaeological surveys (Bewley et al., 2005; Crutchley, 2006; Megarry and Davis, 2013). In Connecticut, though traces of these past features can be seen in the LiDAR data, it is through comparison with aerial photographs over a period of time that the process of gradual field expansion and boundary change can be better interpreted and understood (**Figure 5**).

In areas where suburban sprawl and development have made interpretation of extant historic landscape features difficult, a combination of maps, aerial photographs, and LiDAR is invaluable in interpretation of the features on that landscape. As an example, Middletown, Rhode

Island was the site of important conflicts between the Continental Army and French allies against the British during the American Revolution in the late 18th century. Relict topographic features of these engagements, such as earthworks, are scattered throughout this landscape, though intensive development in the 20th century onward has made reinterpretation difficult (**Figure 6**). Low-relief hills comprised of glacial till covering Aquidneck Island served as tactical military locations and encampments where earthworks and semi-permanent forts were constructed. One earthwork, once part of a complex system of fortifications used strategically by first American, and then British forces, is still extant. Comparison of its location with 18th century maps reveals significant differences in the landscape since that time. Nearby ponds were much smaller in the 18th century, and one map (**Figure 6A**) indicates three "Bartard d'eau," now known as batardeau, or cofferdams, across the small brook just north of the pond during that time period which would have made military operations and other movement throughout the landscape quite different from today. By the late 19th century, this marshy area was flooded for the present reservoirs and there is no topographic indication of these earlier 18th century structures. However, the extant earthworks stand out in the LiDAR hillshade in the midst of post-WWI suburban patterned development on the outskirts of Newport. Both of the above examples depict landscapes with features that have been partially or fully erased from the land surface as a result of changing land use and socio-cultural practice through time. The examples also demonstrate that despite the erasure of some related elements, the resilience or partial resilience of others allows for some limited interpretations of past landscapes and events when coupled with contextual data.

4. Discussion and Conclusions

Despite the wide range of LiDAR data that now allows for visualization and mapping of features in densely forested landscapes and otherwise, there are a range of limitations that must be recognized when interpreting this data. Foremost, LiDAR primarily allows for topographically-

based landscape interpretations, unless using associated intensity data, which has been used infrequently for examining cultural landscape features (Challis et al., 2011a; Coren et al., 2005) though there is great potential. The examples presented above show features that have been partially or fully erased topographically, though it is likely that they have a substantial subsurface archaeological record which is not visible using LiDAR. Additionally, there are obvious limitations for areas or time periods where contextual information is scarce or unavailable. In cases such as these, field observations, environmental data, or oral histories could also complement interpretations of LiDAR data. These contextual sources allow for temporal resolutions that LiDAR is not able to provide, and account for landscape processes that might have occurred before or after the time period of interest since LiDAR data depicts the land surface during a discrete window of time. The resolution of LiDAR data, while extremely high for some projects, also presents limitations in areas with dense year-round or low vegetation, for microtopographic features or features whose relief does not contrast with the land surface, or in areas that have been highly developed.

As these examples have shown, LiDAR is a powerful tool for historical landscape studies; however the data has its limitations in interpreting past landscapes because it depicts the landscape as it exists today. Thus the data can be easily misinterpreted or misread without the proper context. In areas that have been inhabited for hundreds or thousands of years, this presents an issue if trying to interpret past landscapes because time becomes conflated into an image with a single layer of information. Historical aerial photography, maps, or documents can provide an additional dimension of data for interpretation, but even then there are still limitations for the identification of sites that are small, subsurface, relatively low topographic relief, or predating the available information. Examples from southern New England show that LiDAR is a revolutionary tool in landscape studies, but even more so when accompanied by aerial photography, maps, or other historical or environmental data. These examples reveal a wide temporal variation of features

that appear in one layer of the derivative LiDAR data; interpretation with complementary historical data is integral to fully understanding these landscapes and the features from which they are comprised.

References

Aldred, O., & Lucas, G. (2010). Events, Temporalities, and Landscapes in Iceland. In D. J. Bolender (Ed.), Eventful Archaeologies: New Approaches to Social Transformation in the Archaeological Record (Vol. 086, pp. 189–198). Albany: State University of New York Press.

Anderson, E. S., Thompson, J. A., Crouse, D. A., & Austin, R. E. (2006). Horizontal resolution and data density effects on remotely sensed LIDAR-based DEM. Geoderma, 132, 406–415. doi:10.1016/j.geoderma.2005.06.004

Anschuetz, K. F., Wilshusen, R. H., & Scheick, C. L. (2001). An Archaeology of Landscapes: Perspectives and Directions. Journal of Archaeological Research, 9(2), 157–211.

Bailey, G. (2007). Time perspectives, palimpsests and the archaeology of time. Journal of Anthropological Archaeology, 26(2), 198–223. doi:10.1016/j.jaa.2006.08.002

Barger, L. C. (2013). Life on a Rocky Farm: Rural Life near New York City in the Late Nineteenth Century. (P. A. Rogerson, Ed.). Albany: University of New York Press.

Barnes, I. (2003). Aerial remote-sensing techniques used in the management of archaeological monuments on the British Army's Salisbury Plain Training Area, Wiltshire, UK. Archaeological Prospection, 10(2), 83–90. doi:10.1002/arp.197

Barnosky, A. D., Hadly, E. A., Bascompte, J., Berlow, E. L., Brown, J. H., Fortelius, M., …Smith, A. B. (2012). Approaching a state shift in Earth's biosphere. Nature, 486(7401), 52–8. doi:10.1038/nature11018

Beck Jr., R. A., Bolender, D. J., Brown, J. A., & Earle, T. K. (2007). Eventful Archaeology. Current Anthropology, 48(6), 833–860. doi:10.1086/520974

Bell, M. M. (1985). The Face of Connecticut. Hartford: State Geological and Natural History Survey of Connecticut.

Bell, M. M. (1989). Did New England Go Downhill? Geographical Review, 79(4), 450–466.

Bellemare, J., Motzkin, G., Foster, D. R., & Forest, H. (2002). Legacies of the agricultural past in the forested present: an assessment of historical land-use effects on rich mesic forests. Journal of Biogeography, 29, 1401–1420.

Bennett, R., Welham, K., Hill, R. A., & Ford, A. (2012). A Comparison of Visualization Techniques for Models Created from Airborne Laser Scanned Data. Archaeological Prospection, 19, 41–48. doi:10.1002/arp

Bernardini, F., Sgambati, A., Montagnari Kokelj, M., Zaccaria, C., Micheli, R., Fragiacomo, A., … De Min, A. (2013). Airborne LiDAR application to karstic areas: the example of Trieste province (north-eastern Italy) from prehistoric sites to Roman forts. Journal of Archaeological Science, 40(4), 2152–2160. doi:10.1016/j.jas.2012.12.029

Bewley, R. H., Crutchley, S. P., & Shell, C. A. (2005). New light on an ancient landscape: lidar survey in the Stonehenge World Heritage Site. Antiquity, 79(305), 636–647.

Brierley, G. J. (2010). Landscape memory: the imprint of the past on contemporary landscape forms and processes. Area, 42(1), 76–85. doi:10.1111/j.1475-4762.2009.00900.x

Byrne, D. (2003). The Ethos of Return: Erasure and Reinstatement of Aboriginal Visibility in the Australian Historical Landscape. Historical Archaeology, 37(1), 73–86.

Challis, K., Carey, C., Kincey, M., & Howard, A. J. (2011). Airborne Lidar Intensity and Geoarchaeological Prospection in River Valley Floors. Archaeological Prospection, 18, 1–13. doi:10.1002/arp

Challis, K., Forlin, P., & Kincey, M. (2011). A Generic Toolkit for the Visualization of Archaeological Features on Airborne LiDAR Elevation Data. Archaeological Prospection, 18, 279–289. doi:10.1002/arp

Challis, K., Kokalj, Z., Kincey, M., Moscrop, D., & Howard, A. J. (2008). Airborne lidar and historic environment records. Antiquity, 82(318), 1055–1064.

Chase, A. F., Chase, D. Z., Awe, J., Weishampel, J., Iannone, G., Moyes, H., … Fernandez Diaz, J. (2014). Ancient Maya Regional Settlement and Inter-Site Analysis: The 2013 West-Central Belize LiDAR Survey. Remote Sensing, 6(9), 8671–8695. doi:10.3390/rs6098671

Chase, A. F., Chase, D. Z., Weishampel, J. F., Drake, J. B., Shrestha, R. L., Slatton, K. C., … Carter, W. E. (2011). Airborne LiDAR, archaeology, and the ancient Maya landscape at Caracol, Belize. Journal of Archaeological Science, 38(2), 387–398. doi:10.1016/j.jas.2010.09.018

Chin, A., Fu, R., Harbor, J., Taylor, M. P., & Vanacker, V. (2013). Anthropocene: Human interactions with earth systems. Anthropocene, 1, 1–2. doi:10.1016/j.ancene.2013.10.001

Clevis, Q., Tucker, G. E., Lock, G., Lancaster, S. T., Gasparini, N., Desitter, A., & Bras, R. L. (2006). Geoarchaeological Simulation of Meandering River Deposits and Settlement Distributions : A Three-Dimensional Approach. Geoarchaeology, 21(8), 843–874. doi:10.1002/GEA

Coluzzi, R., Lanorte, A., & Lasaponara, R. (2010). On the LiDAR contribution for landscape archaeology and palaeoenvironmental studies: the case study of Bosco dell'Incoronata (Southern Italy). Advances in Geosciences, 24, 125–132. doi:10.5194/adgeo-24-125-2010

Coren, F., Visintini, D., Prearo, G., & Sterzai, P. (2005). Integrating LiDAR intensity measures and hyperspectral data for extracting of cultural heritage. In Italy-Canada 2005 Workshop on 3D Digital Imaging and Modeling: Applications of Heritage, Industry, Medicine and Land (p. 8). Padova, Italy.

Cowley, D. C. (2011). Remote Sensing for Archaeological Heritage Management. In D. C. Cowley (Ed.), EAC Occasional Paper No. 5 (5th ed.). Brussels: Europae Archaeologia Consilium.

Cowley, D. C. (2012). In with the new, out with the old? Auto-extraction for remote sensing archaeology. In C. R. Bostater, S. P. Mertikas, X. Neyt, C. Nichol, D. Cowley, & J.-P. Bruyant (Eds.), Proceedings of SPIE, vol. 8532 (Vol. 8532, pp. 853206–1 – 853206–9). doi:10.1117/12.981758

Cronon, W. (1983). Changes in the Land. New York: Hill and Wang.

Crutchley, S. (2006). Light Detection and Ranging (lidar) in the Witham Valley, Lincolnshire: an Assessment of New Remote Sensing Techniques. Archaeological Prospection, 13, 251–257. doi:10.1002/arp

Crutchley, S. P., & Crow, P. (2009). The Light Fantastic: Using airborne LiDAR in archaeological survey. Swindon.

Crutzen, P. J., & Stoermer, E. F. (1999). The "Anthropocene." IGBP Newsletter, 4(7), 17–18.

Daukantas, P. (2014, January). Lidar and Archaeology. Optics and Photonics News, (January 2014), 32–39.

Devereux, B. J., Amable, G. S., Crow, P., & Cliff, A. D. (2005). The potential of airborne lidar for detection of archaeological features under woodland canopies. Antiquity, 78(305), 648–660.

Donahue, B. (2004). The Great Meadow: Farmers and the Land in Colonial Concord. New Haven, CT: Yale University Press.

Doneus, M. (2013). Openness as Visualization Technique for Interpretative Mapping of Airborne Lidar Derived Digital Terrain Models. Remote Sensing, 5(12), 6427–6442. doi:10.3390/rs5126427

Doneus, M., Briese, C., Fera, M., & Janner, M. (2008). Archaeological prospection of forested areas using full-waveform airborne laser scanning. Journal of Archaeological Science, 35(4), 882–893. doi:10.1016/j.jas.2007.06.013

Doneus, M., & Kühteiber, T. (2013). Archaeological laser scanning and archaeological interpretation — bringing back the people. In R. S. Opitz & D. C. Cowley (Eds.), Interpreting Archaeological Topography: Airborne Laser Scanning, 3D Data and Ground Observation (pp. 32–50). Oxford: Oxbow Books.

Dugmore, A. J., McGovern, T. H., Vésteinsson, O., Arneborg, J., Streeter, R., & Keller, C. (2012). Cultural adaptation, compounding vulnerabilities and conjunctures in Norse Greenland. Proceedings of the National Academy of Sciences of the United States of America, 109(10), 3658–63. doi:10.1073/pnas.1115292109

Etter, A., McAlpine, C., & Possingham, H. (2008). Historical Patterns and Drivers of Landscape Change in Colombia Since 1500: A Regionalized Spatial Approach. Annals of the Association of American Geographers, 98(1), 2–23.

Evans, D. H., Fletcher, R. J., Pottier, C., Chevance, J.-B., Soutif, D., Tan, B. S., … Boornazian, G. (2013). Uncovering archaeological landscapes at Angkor using lidar. Proceedings of the National Academy of Sciences, 110(31), 12595–12600. doi:10.1073/pnas.1306539110

Foley, S. F., Gronenborn, D., Andreae, M. O., Kadereit, J. W., Esper, J., Scholz, D., … Crutzen, P. J. (2013). The Palaeoanthropocene – The beginnings of anthropogenic environmental change. Anthropocene, 3, 83–88. doi:10.1016/j.ancene.2013.11.002

Gallagher, J. M., & Josephs, R. L. (2008). Using LiDAR to Detect Cultural Resources in a Forested Environment: an Example from Isle Royale National Park, Michigan, USA. Archaeological Prospection, 15, 187–206. doi:10.1002/arp

Given, M. (2002). Maps, Fields, and Boundary Cairns: Demarcation and Resistance in Colonial Cyprus. International Journal of Historical Archaeology, 6(1), 1–22.

Given, M. (2004). The Archaeology of the Colonized. London: Routledge.

Goudie, A., & Viles, H. (2010). Landscapes and Geomorphology: A Very Short Introduction. Oxford: Oxford University Press.

Hamre, L. N., Domaas, S. T., Austad, I., & Rydgren, K. (2007). Land-cover and structural changes in a western Norwegian cultural landscape since 1865, based on an old cadastral map and a field survey. Landscape Ecology, 22(10), 1563–1574. doi:10.1007/s10980-007-9154-y

Harden, C. P. (2014). The human-landscape system: challenges for geomorphologists. Physical Geography, 35(1), 76–89. doi:10.1080/02723646.2013.864916

Harmon, J. M., Leone, M. P., Prince, S. D., & Snyder, M. (2006). LiDAR for Archaeological Landscape Analysis: A Case Study of Two Eighteenth-Century Maryland Plantation Sites. American Antiquity, 71(4), 649–670.

Hesse, R. (2010). LiDAR-derived Local Relief Models - a new tool for archaeological prospection. Archaeological Prospection, 17, 67–72. doi:10.1002/arp

Hirsch, E., & O'Hanlon, M. (Eds.). (1995). The Anthropology of Landscape: Perspectives on Place and Space. Oxford: Oxford University Press.

Holtorf, C., & Williams, H. (2006). Landscapes and memories. In D. Hicks & M. C. Beaudry (Eds.), The Cambridge Companion to Historical Archaeology (pp. 235–254). Cambridge: Cambridge University Press.

Hooke, R. L. (1994). On the efficacy of humans as geomorphic agents. GSA Today, 4(9), 217, 224–225.

Hooke, R. L. (2000). On the history of humans as geomorphic agents. Geology, 28(9), 843–846. doi:10.1130/0091-7613(2000)28<843:OTHOHA>2.0.CO;2

Hooke, R. L., Martin-Duque, J. F., & Pedraza, J. (2012). Land transformation by humans: A review. GSA Today, 22(12), 4–10. doi:10.1130/GSAT151A.1.Figure

Hritz, C. (2014). Contributions of GIS and Satellite-based Remote Sensing to Landscape Archaeology in the Middle East. Journal of Archaeological Research. doi:10.1007/s10814-013-9072-2

Hunt, K., & Royall, D. (2013). A LiDAR-Based Analysis of Stream Channel Cross Section Change Across an Urban-Rural Land-Use Boundary. The Professional Geographer, 65(2), 296–311. doi:10.1080/00330124.2012.681517

Ingold, T. (1993). The temporality of landscape. World Archaeology, 25(2), 152–174.

James, P. E. (1929). The Blackstone Valley: a study in chorography in southern New England. Annals of the Association of American Geographers, 19(2), 67–109.

Johnson, K. M., & Ouimet, W. B. (2014). Rediscovering the lost archaeological landscape of southern New England using airborne Light Detection and Ranging (LiDAR). Journal of Archaeological Science, 43, 9–20. doi:10.1016/j.jas.2013.12.004

Johnson, M. (2007). Ideas of Landscape. Malden, MA: Blackwell.

Kantner, J. (2008). The Archaeology of Regions: From Discrete Analytical Toolkit to Ubiquitous Spatial Perspective. Journal of Archaeological Research, 16(1), 37–81. doi:10.1007/s10814-007-9017-8

Kleman, J. (1992). The Palimpsest Glacial Landscape in Northwestern Sweden. Late Weichselian Deglaciation Landforms and Traces of Older West-Centered Ice Sheets. Geografiska Annaler. Series A, Physical Geography, 74(4), 305–325.

Knight, J., & Harrison, S. (2013). "A land history of men": The intersection of geomorphology, culture and heritage in Cornwall, southwest England. Applied Geography, 42, 186–194. doi:10.1016/j.apgeog.2013.03.020

Kokalj, Ž., Zaksek, K., & Ostir, K. (2011). Application of sky-view factor for the visualisation of historic landscape features in lidar-derived relief models. Antiquity, 85, 263–273.

Kokalj, Ž., Zaksek, K., & Oštir, K. (2013). Visualizations of lidar derived relief models. In R. S. Opitz & D. C. Cowley (Eds.), Interpreting Archaeological Topography: Airborne Laser Scanning, 3D Data and Ground Observation (pp. 100–114). Oxford, England: Oxbow Books.

Ladefoged, T. N., McCoy, M. D., Asner, G. P., Kirch, P. V., Puleston, C. O., Chadwick, O. & Vitousek, P. M. (2011). Agricultural potential and actualized development in Hawai'i: an airborne LiDAR survey of the leeward Kohala field system (Hawai'i Island). Journal of Archaeological Science, 38(12), 3605–3619. doi:10.1016/j.jas.2011.08.031

Lightfoot, K. G., Panich, L. M., Schneider, T. D., & Gonzalez, S. L. (2013). European colonialism and the Anthropocene: A view from the Pacific Coast of North America. Anthropocene, 4, 101–115. doi:10.1016/j.ancene.2013.09.002

Lucas, G. (2008). Time and the Archaeological Event. Cambridge Archaeological Journal, 18(1), 59–65. doi:10.1017/S095977430800005X

Massey, D. (2005). For Space. London: SAGE.

McCoy, M. D., Asner, G. P., & Graves, M. W. (2011). Airborne lidar survey of irrigated agricultural landscapes: an application of the slope contrast method. Journal of Archaeological Science, 38(9), 2141–2154. doi:10.1016/j.jas.2011.02.033

McDonagh, B., & Daniels, S. (2012). Enclosure stories: narratives from Northamptonshire. Cultural Geographies, 19(1), 107–121. doi:10.1177/1474474011427361

McIntyre-Tamwoy, S., & Harrison, R. (2004). Monuments to colonialism? Stone arrangements, tourist cairns and turtle magic at Evans Bay, Cape York. Australian Archaeology, 59(December), 31–42.

McNeary, R. W. A. (2014). Lidar Investigation of Knockdhu Promontory and its Environs, County Antrim, Northern Ireland. Archaeological Prospection, 21(4), 263–276. doi:10.1002/arp

Megarry, W., & Davis, S. (2013). Beyond the Bend: Remotely Sensed Data and Archaeological Site Prospection in the Boyne Valley, Ireland. In D. C. Comer & M. J. Harrower (Eds.), Mapping Archaeological Landscapes from Space (pp. 85–95). New York.

Millard, K., Burke, C., Stiff, D., & Redden, A. (2009). Detection of a low-relief 18th-century British siege trench using LiDAR vegetation penetration capabilities at Fort Beauséjour-Fort Cumberland National Historic Site, Canada. Geoarchaeology, 24(5), 576–588. doi:10.1002/gea.20281

Mlekuz, D. (2013a). Messy landscapes: lidar and the practices of landscaping. In R. S. Opitz & D. C. Cowley (Eds.), Interpreting Archaeological Topography: Airborne Laser Scanning, 3D Data and Ground Observation (pp. 88–100). Oxford: Oxbow Books.

Mlekuz, D. (2013b). Skin Deep: LiDAR and Good Practice of Landscape Archaeology. In C. Corsi, B. Slapsak, & F. Vermeulen (Eds.), Good Practice in Archaeological Diagnostics: Non-invasive Survey of Complex Archaeological Sites (pp. 113–129).

Myers, W. I. (1920). An Economic Study of Farm Layout. Cornell University.

Opitz, R. S., Ryzewski, K., Cherry, J. F., & Moloney, B. (2015). Using Airborne LiDAR Survey to explore Historic-era archaeological landscapes of Montserrat in the Eastern Caribbean. Journal of Field Archaeology, 40(5), 523–541. doi:10.1179/2042458215Y.0000000016

Panno, S. V., & Luman, D. E. (2012). Mapping palimpsest karst features on the Illinois sinkhole plain using historical aerial photography. Carbonates and Evaporites, 28(1-2), 201–214. doi:10.1007/s13146-012-0107-4

Pauls, E. P. (2006). The Place of Space: Architecture, Landscape, and Social Life. In M. Hall & S. W. Silliman (Eds.), Historical Archaeology (pp. 65–83). Malden, MA: Blackwell.

Pluckhahn, T. J., & Thompson, V. D. (2012). Integrating LiDAR data and conventional mapping of the Fort Center site in south-central Florida: A comparative approach. Journal of Field Archaeology, 37(4), 289–301. doi:10.1179/0093469012Z.00000000026

Prufer, K. M., Thompson, A. E., & Kennett, D. J. (2015). Evaluating Airborne LiDAR for Detecting Settlements and Modified Landscapes in Disturbed Tropical Environments at Uxbenká, Belize. Journal of Archaeological Science, 57, 1–13. doi:10.1016/j.jas.2015.02.013

Randall, A. R. (2014). LiDAR-aided reconnaissance and reconstruction of lost landscapes: An example of freshwater shell mounds (ca. 7500–500 cal B.P.) in northeastern Florida. Journal of Field Archaeology, 39(2), 162–179. doi:10.1179/0093469014Z.00000000080

Risbøl, O. (2013). Cultivating the “wilderness” - how lidar can improve archaeological landscape understanding. In R. S. Opitz & D. C. Cowley (Eds.), Interpreting Archaeological Topography: Airborne Laser Scanning, 3D Data and Ground Observation (pp. 51–62). Oxford: Oxbow Books.

Risbøl, O., Bollandsås, O. M., Nesbakken, A., Ørka, H. O., Næsset, E., & Gobakken, T. (2013). Interpreting cultural remains in airborne laser scanning generated digital terrain models: effects of size and shape on detection success rates. Journal of Archaeological Science, 40(12), 4688–4700. doi:10.1016/j.jas.2013.07.002

Rosenswig, R. M., López-Torrijos, R., Antonelli, C. E., & Mendelsohn, R. R. (2013). Lidar mapping and surface survey of the Izapa state on the tropical piedmont of Chiapas, Mexico. Journal of Archaeological Science, 40(3), 1493–1507. doi:10.1016/j.jas.2012.10.034

Rubertone, P. E. (1989). Landscape as Artifact: Comments on “The Archaeological Use of Landscape Treatment in Social, Economic and Ideological Analysis.” Historical Archaeology, 23(1), 50–54.

Sauer, C. O. (1941). Foreword to Historical Geography. Annals of the Association of American Geographers, 31(1), 1–24.

Schein, R. H. (1997). The place of landscape: a conceptual framework for interpreting an American scene. Annals of the Association of American Geographers, 87(4), 660–680.

Schindling, J., & Gibbes, C. (2014). LiDAR as a tool for archaeological research: a case study. Archaeological and Anthropological Sciences, (February). doi:10.1007/s12520-014-0178-3

Shilts, W. W., Berg, R. C., Luman, D. E., & McKay, D. E. I. (2010). Application of LiDAR Data to Mapping Glacial Landform/Sediment Associations, Champaign County, Illinois. Geological Society of America Abstracts with Programs, 42(5), 154.

Sittler, B. (2001). Revealing Historical Landscapes by Using Airborne Laser Scanning: A 3-D Modell of Ridge and Furrow in Forests Near Rastatt (Germany). In M. Thies, B. Koch, H. Spiecker, & H. Weinacker (Eds.), Laser-Scanners for Forest and Landscape Assessment: Proceedings of the ISPRS Working Group, Freiburg, Germany, October 3-6, 2004, Volume 36, Part 8/W2 (pp. 258–261). Freiburg, Germany: International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS).

Smith, B. D., & Zeder, M. a. (2013). The onset of the Anthropocene. Anthropocene, 4, 8–13. doi:10.1016/j.ancene.2013.05.001

Snyder, N. P. (2009). Studying Stream Morphology With Airborne Laser Elevation Data. Eos, Transactions American Geophysical Union, 90(6), 45. doi:10.1029/2009EO060001

Spencer-Wood, S. M., & Baugher, S. (2010). Introduction to the Historical Archaeology of Powered Cultural Landscapes. International Journal of Historical Archaeology, 14(4), 463–474. doi:10.1007/s10761-010-0125-7

Stichelbaut, B., Gheyle, W., Saey, T., Van Eetvelde, V., Van Meirvenne, M., Note, N., … Bourgeois, J. (2016). The First World War from above and below: Historical aerial photographs and mine craters in the Ypres Salient. Applied Geography, 66, 64–72. doi:10.1016/j.apgeog.2015.11.020

Stone, J. R., Schafer, J. P., London, E. H., DiGiacomo-Cohen, M. L., Lewis, R. S., & Thompson, W. B. (2005). Quaternary Geologic Map of Connecticut and Long Island Sound Basin. Scientific Investigations Map 2784.

Štular, B., Kokalj, Ž., Oštir, K., & Nuninger, L. (2012). Visualization of lidar-derived relief models for detection of archaeological features. Journal of Archaeological Science, 39(11), 3354–3360. doi:10.1016/j.jas.2012.05.029

Swetnam, T. W., Allen, C. D., & Betancourt, J. L. (1999). Applied historical ecology: using the past to manage for the future. Ecological Applications, 9(4), 1189–1206.

Thorson, R. M. (2002). Stone by stone: the magnificent history in New England's stone walls. New York: Walker & Company.

Tuan, Y. F. (1977). Space and Place: The Perspective of Experience. Minneapolis: University of Minnesota Press.

Warren, G. (1914). Farm Management (Third.). New York: The MacMillan Co.

Weishampel, J. F., Drake, J. B., Cooper, A., Blair, J. B., & Hofton, M. (2007). Forest canopy recovery from the 1938 hurricane and subsequent salvage damage measured with airborne LiDAR. Remote Sensing of Environment, 109(2), 142–153. doi:10.1016/j.rse.2006.12.016

Werbrouck, I., van Eetvelde, V., Antrop, M., & de Maeyer, P. (2009). Integrating Historical Maps and LiDAR Elevation Data for Landscape Reconstruction: a case study in Flanders. In European Landscapes in Transformation: Challenges for Landscape Ecology and Management. Salzburg, Austria: IALE.

Yellen, B., Woodruff, J. D., Kratz, L. N., Mabee, S. B., Morrison, J., & Martini, a. M. (2014). Source, conveyance and fate of suspended sediments following Hurricane Irene. New England, USA. Geomorphology, 226(August 2011), 124–134. doi:10.1016/j.geomorph.2014.07.028

Yokoyama, R., Shlrasawa, M., & Pike, R. J. (2002). Visualizing Topography by Openness: A New Application of Image Processing to Digital Elevation Models. Photogrammetric Engineering & Remote Sensing, 68(3), 257–265.

Zakšek, K., Oštir, K., & Kokalj, Ž. (2011). Sky-View Factor as a Relief Visualization Technique. Remote Sensing, 3(12), 398–415. doi:10.3390/rs3020398

Figures

Figure 1

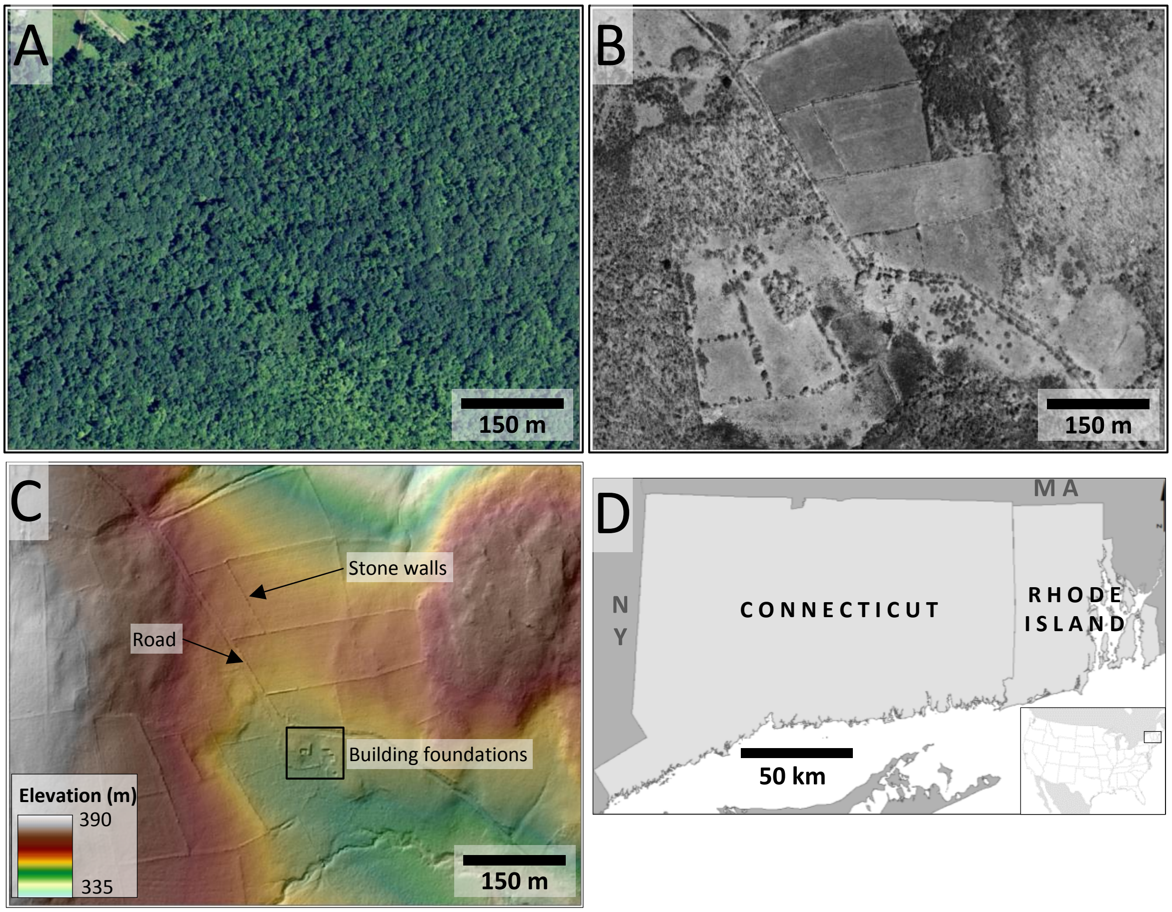


Figure 2

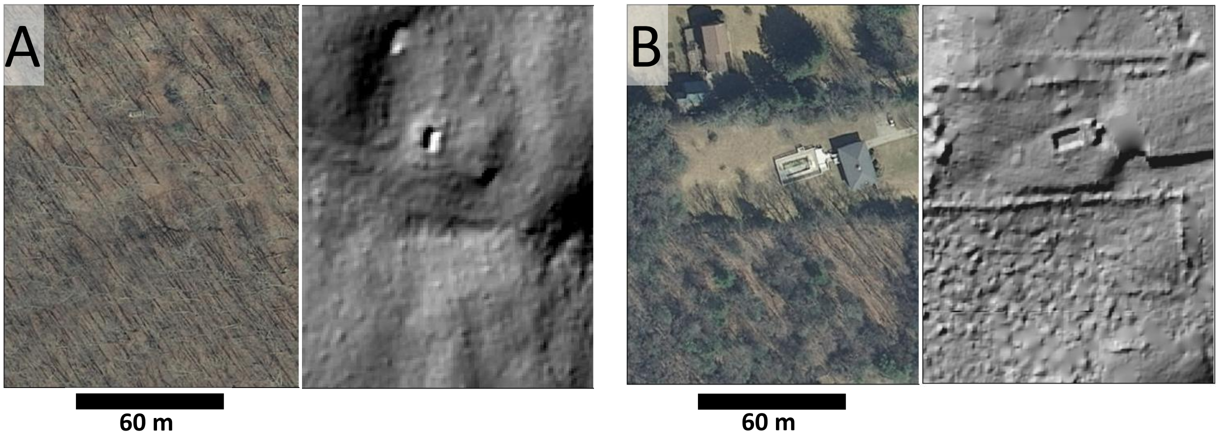
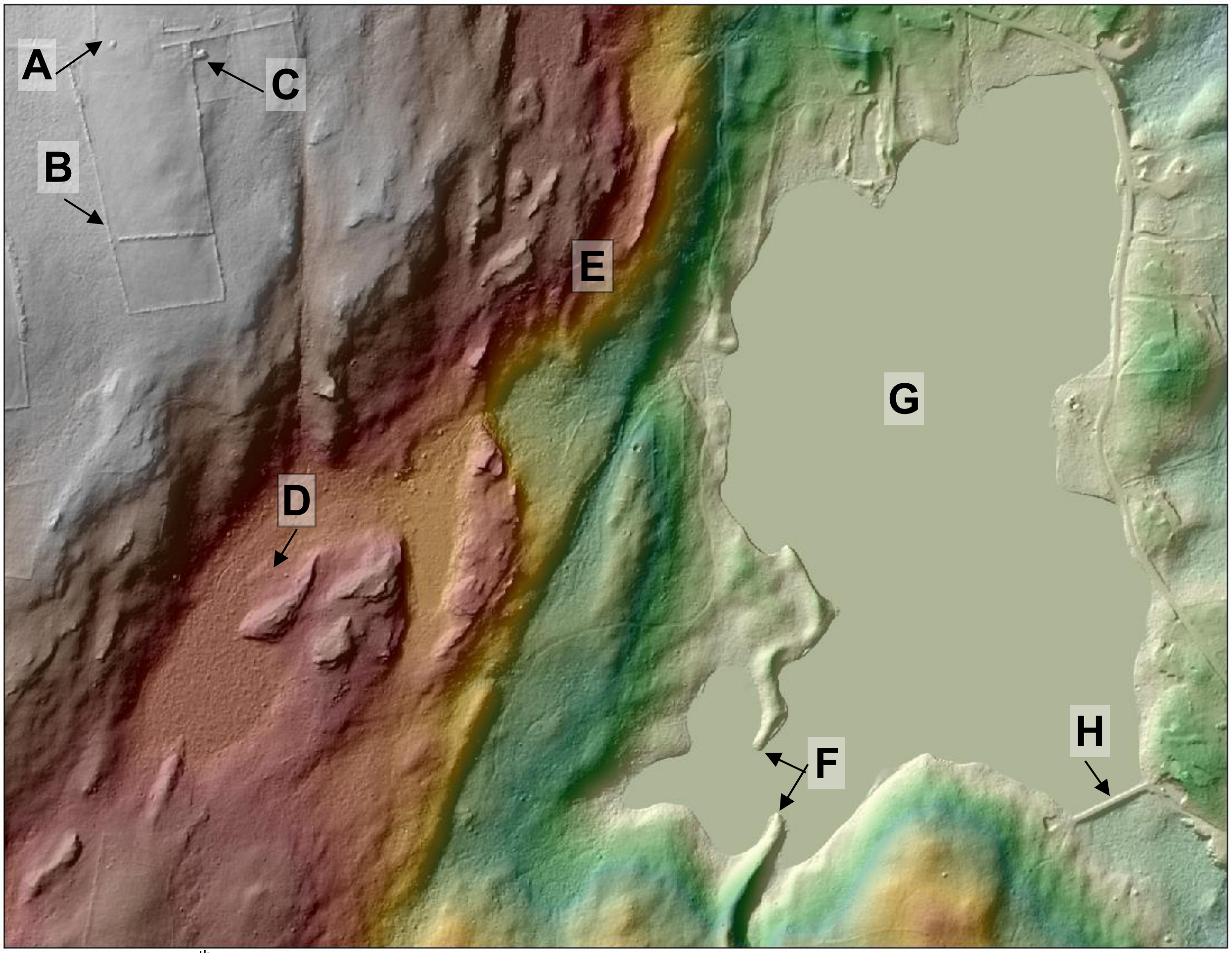


Figure 3



A. **House**, 20th c.
B. **Stone walls**, 17th-20th c.
C. **Foundation,** 17th-20th c.
D. **Relict charcoal hearth**, 17th-20th c.

E. Bedrock outcrop
F. Esker
G. Reservoir, c.1855-1892
H. Dam, c.1855-1892

Figure 4

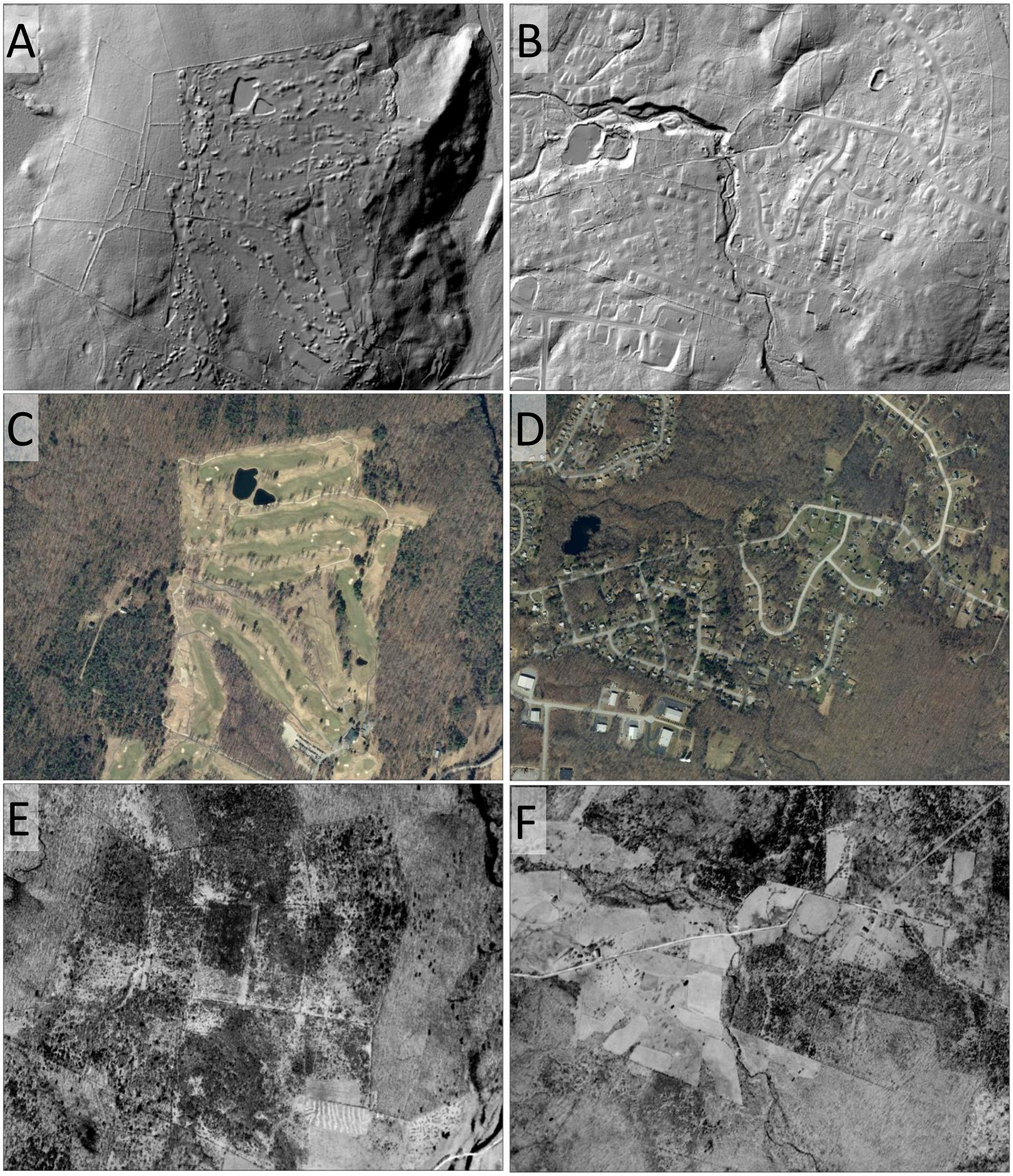


Figure 5

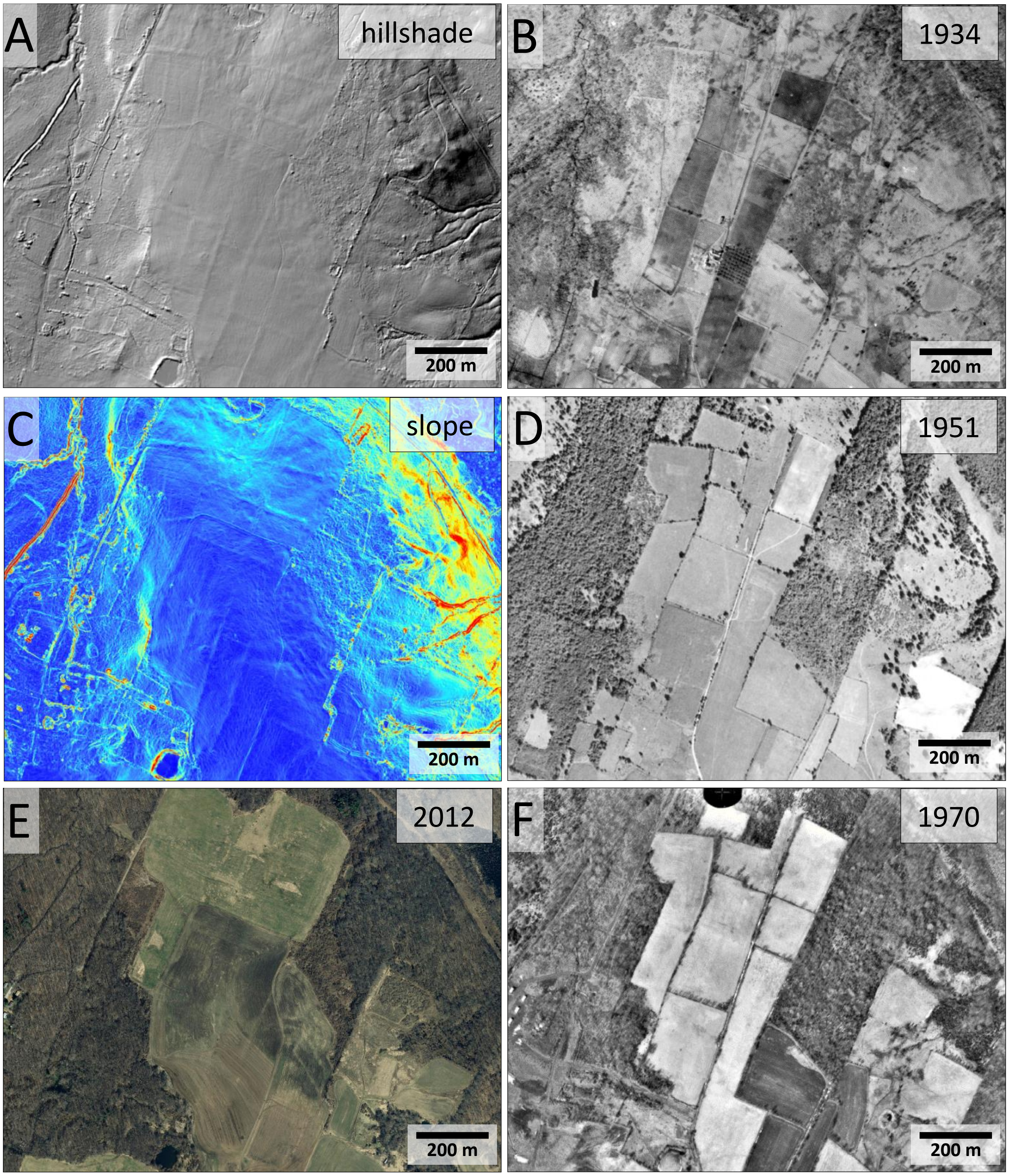

A
hillshade
200 m
B
1934
200 m
C
slope
200 m
D
1951
200 m
E
2012
200 m
F
1970
200 m

Figure 6

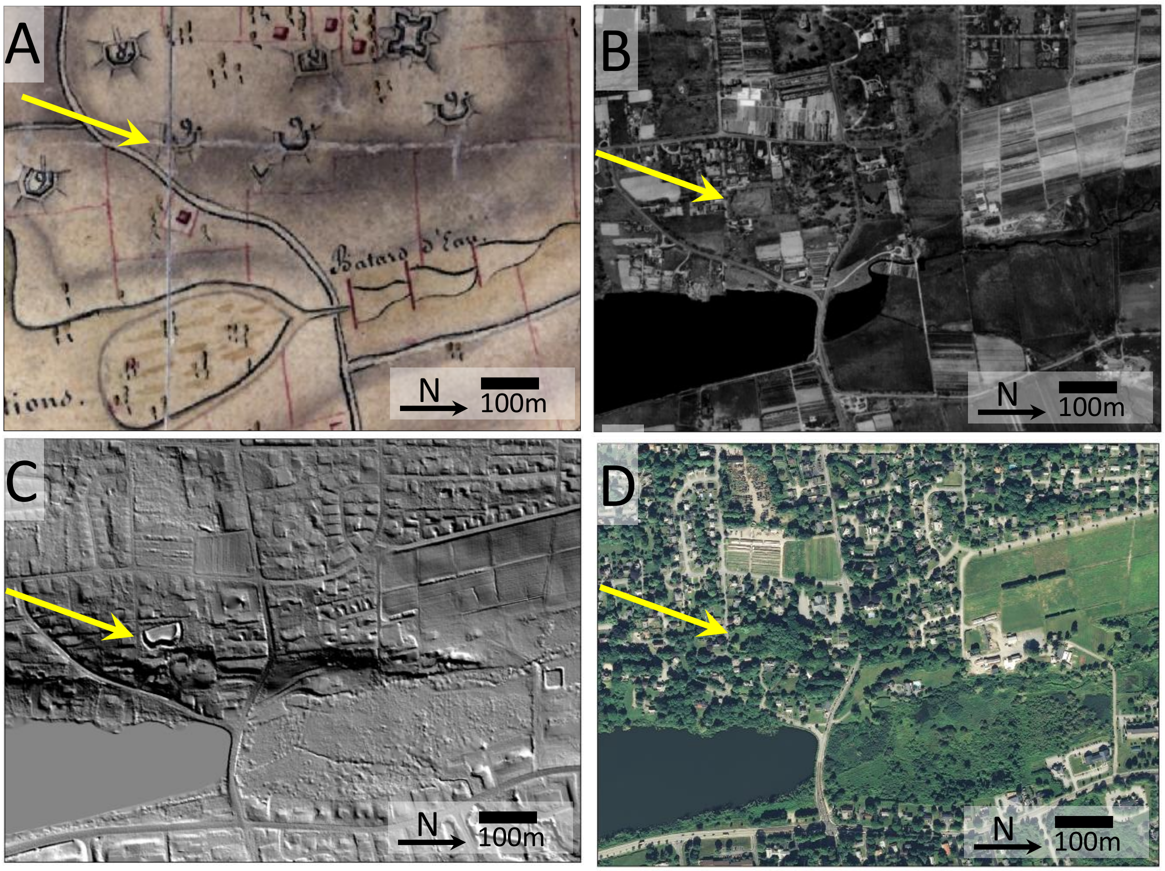


Figure Captions

Figure 1. Example of reforested area in Connecticut showing (A) a 30cm aerial photograph from 2012 (CT ECO, 2016), (B) aerial photograph from 1934 with cleared fields and active farm (MAGIC, 2016), (C) hillshaded LiDAR image showing stone walls, abandoned road, and building foundations (USDA NRCS, 2016). (D) depicts the general location of the study area for this manuscript (MAGIC, RIGIS, MassGIS).

Figure 2. Without contextual information, building foundations found in densely forested areas (A) could potentially be mistaken for modern in-ground swimming pools (B).

Figure 3. A range of features spanning geologic, glacial, and human history in the region.

Figure 4. A golf course (A,C,E) was built in the 1990s and has re-appropriated historic stone wall-lined field boundaries as its own, visible in the hillshaded LiDAR data (A) (USDA NRCS, 2016) and depicted as reforested fields by 1934 (E) (MAGIC, 2016). Stone walls have also been re-appropriated in the suburban neighborhood (B,D,F).

Figure 5. Use of time-series historical aerial photos to examine field expansion in eastern Connecticut. Between 1934 (B) and 1951 (D) an entire farmstead disappears from the center of the image, the foundation plowed in and the surface smoothed; though some traces do remain in the topography on the surface. (E) shows the field layout as it is today, though LiDAR data ((A) and (C)) reveal that earlier traces of the field boundaries still exist.

Figure 6. Examination of historical sources for this area in southeastern Rhode Island reveals a dense post-WWI suburban landscape, though trace elements of the 18th century landscape remain and are visible in historic maps (A) (Library of Congress, 2016) as well as LiDAR data (C) and historic aerial photography from 1939 (B) (RIGIS, 2016).

CHAPTER 4

Quantifying stone walls and 17th to early 20th century agriculture in the northeastern USA[3]

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, and thus assessing these impacts is also important in order 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, which characterizes the magnitude and intensity of human-environment interaction in contrast to natural variation and background processes through recent 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, the present 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;

[3] A revised version of this chapter is currently *in press* as Johnson, K.M. and Ouimet, W.B, 2016. Physical properties and spatial controls of stone walls in the northeastern USA: Implications for Anthropocene studies of 17th to early 20th century agriculture, *Anthropocene*. doi:10.1016/j.ancene.2016.07.001

Cronon, 1983; Delcourt and Delcourt, 1987; Donahue, 2004; Jones and Forrest, 2003; Little, 2010; Mrozowski, 1994; Pagoulatos, 1990; Petersen and Cowie, 2002), the most drastic geomorphic human-induced changes in this region since deglaciation began with the colonization of the northeastern United States by Europeans in the early 17th century. Colonization brought with it the forceful dissolution of Native American land management strategies as well as extreme ecological and geomorphological changes just as it had 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, and the stone walls that resulted from agricultural land use, coupled with the glacial history, are an enduring geomorphic feature of these processes.

The stone walls of the northeastern United States have long been considered an iconic landscape feature of the region and a direct 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). Estimates regarding their dimensions and volume 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). While traits such as length, height, width, and volume have been discussed and estimated, systematic measurements coupled with regional geospatial data have not previously been used to analyze the dimensions and spatial distribution of walls in this region.

Stone walls in this region related to agriculture 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 said to have been 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). The work was done by farmers and their families or laborers, often during the time 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). Some farms in marginal areas may have been abandoned before stone piles in fields were transferred to walls, and 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. It has been 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" (Foster, 1999).

In this study, we use 1m digital elevation models (DEMs) derived from ground-filtered airborne Light Detection and Ranging (LiDAR) data in conjunction with field measurements and regional geospatial data to investigate the spatial distribution, dimensions, and volume of stone walls in the northeastern United States. 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. While 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 presented here (Johnson and Ouimet, 2014). High resolution regional datasets for historic land use features derived from LiDAR have provided an unprecedented opportunity to analyze their spatial distribution and directly quantify past human impacts in this region.

2. Study areas

2.1 Topography and surficial geology

The towns analyzed in this study include Ashford and Eastford in northeastern Connecticut and Cornwall, Goshen, and Sharon in northwestern Connecticut. Additional data are taken from Mansfield, in northeastern Connecticut, and Tiverton, in southeastern Rhode Island (**Figure 1A**). The topography in the study areas ranges from rugged and hilly uplands with bedrock outcroppings to an undulating and flat coastal plain with much less topographic relief. Field measurements were taken in Ashford, Mansfield, and Tiverton, while digitization of stone wall datasets was completed for Ashford, Cornwall, Eastford, Goshen, and Sharon. Ashford, Eastford, and Mansfield are each located in northeastern Connecticut, where topography consists primarily of hilly uplands, ~65 km from the coast, with mixed deciduous-coniferous forest (**Table 1**). Cornwall, Goshen, and Sharon are located in northwestern Connecticut, which is slightly more hilly and rugged than the rest of the state, with an average elevation of ~350m above sea level and the highest elevations in the state at >700m. All of Connecticut was covered during the last glacial interval by the southern extent of the Laurentide ice sheet, which 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 is 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% (mean: 85%) of the area in the study towns is covered by glacial till.

2.2 Settlement and land use history

Towns in the uplands of Connecticut were settled and incorporated by English colonists and their descendants much later than their coastal or littoral counterparts, though parts of Windham County in the northeast part of the state were often traversed on the way from Hartford to Boston as early as 1635 (**Table 1**) (Larned, 1874). Incorporation of towns occurred shortly after most or all surveyed lots had been settled and a town government had been established; after this point, towns would have seen significant population expansion and an increase in both settlement and magnitude of land use. Most towns exhibited relatively low populations in the 18th century with major changes occurring during the mid to late 19th century as a result of industrialization and subsequent abandonment of small, rural farming communities (**Figure 1C**). Areas in the far western and northern parts of New England were considered much more rural and “wild” than their eastern counterparts (Lewis, 2007), and this is certainly evident in their low population numbers in comparison with eastern towns of the same time period (see Greven, 1970).

Lands in western Connecticut and Massachusetts as well as inland New Hampshire, Vermont, and Maine were settled during the 18th century by the descendants of earlier colonists, many of whom found it difficult to obtain adequately-sized tracts of land for their own farms in well-established towns, such as Tiverton, RI, along the coast or near major rivers (Greven, 1970; Merchant, 1989; Thorson, 2002). Though family farms were frequently given to eldest sons, lands were often subdivided amongst each farmer’s progeny, thus dividing valuable portions of meadow,

pasture, woodlot, or tillage land that comprised the English husbandry system (Donahue, 2004). As settlers moved north and west, widespread deforestation and land "improvement" (Forsythe, 2007; Lewis, 2013) occurred as their settlements became more permanent. Improved land, according to the U.S. Federal Census, was "cleared land used for grazing, grass, or tillage, or lying fallow" (United States Census Bureau, n.d.). By 1870, 47% to 89% of the area in the study towns was being farmed, and only 9% to 26% of that land was noted as being "woodland," though by this point in time many farms had begun to be abandoned (**Table 1**) (United States Census Bureau, 1870).

Recent land cover estimates (Center for Land Use Education and Research, 2015; Parent et al., 2015) illustrate a drastic reforestation of these areas (**Table 1**), with forest now comprising over 80% of the landscape in most towns. Most reforestation likely occurred after 1870 as a result of farm abandonment and industrial changes (Bell, 1989), though the process is also mentioned by Henry David Thoreau as early as the 1840s; he likened abandonment, exemplified by his observations of early successional fields and cellar holes, to the fall of the Roman Empire (Foster, 1999). The magnitude of this process in Connecticut has become particularly discernable using LiDAR (Johnson and Ouimet, 2014), which reveals topographic features otherwise obscured by vegetation in aerial photographs, and 1934 historic aerial photographs, which show a landscape that was still widely agricultural, but with many peripheral fields beginning to exhibit early successional and fully reforested characteristics (**Figure 2**).

The five main study towns mentioned above exhibit fairly low levels of modern development, a high percentage of forest, and significant acreages of protected federal, state, or town municipal lands, allowing for maximum preservation potential of stone walls (**Figure 1B**). The University of Connecticut is located in Mansfield, so the town is slightly more developed and residential than either Ashford or Eastford, and over half of the town is still forested. In areas of Connecticut where land has been highly developed such as coastal regions, the Connecticut River

valley, and Quinnipiac and Farmington River valleys, 20th and 21st century roads, building construction and landscaping obscure extant stone walls and threaten those that may remain.

3. Methods

3.1 LiDAR data, processing, and stone wall digitization

In this study, two publicly available LiDAR datasets were used for the digitization of stone walls; one in eastern Connecticut, and one in western Connecticut. These were collected in leaf-off seasons in consecutive years, and the resulting datasets, in .LAS format as three-dimensional point clouds, have standard classification schemes provided by the vendor containing the ASPRS classes of 1-Unclassified, 2-Ground, 7-Noise, and 9-Water. The aerial survey for western Connecticut was flown in December 2011 by Dewberry for the USDA-NRCS and covers a total of 1,703 km^2 (Dewberry, 2011). The eastern Connecticut aerial survey was flown in November and December 2010 by Dewberry for the USDA-NRCS, covers a total of 4,589 km^2 (Dewberry 2011). Point spacing of 2-Ground classified points in the study areas ranges from ~0.7m to ~1.0m for both datasets.

The spacing of ground-classified points in the LiDAR data can vary over small areas as a result of variation in topography, forest coverage, and forest type, and can influence the visibility of stone walls and other features on the land surface. In areas where there is topography with dense underbrush, year-round vegetation, or highly variable surface topography, it is sometimes difficult to distinguish walls from what appears to be the ground surface, but is actually low vegetation. In such cases, results can be supplemented with field observations or geospatial visualization techniques such as slope, principal components analysis (PCA), or sky-view factor to ensure that all walls are observed (Bennett et al., 2012; Štular et al., 2012; Zakšek et al., 2011). The observations in this study use only walls digitized in the upland areas of Connecticut, which are primarily deciduous forests with little underbrush. The LiDAR datasets used were accessed through

Connecticut Environmental Conditions Online (Connecticut Environmental Conditions Online, 2015).

Using the point clouds which were downloaded as .LAS files, we created digital elevation models (DEMs) with a 1m pixel resolution from points classified as 2-Ground using the "LAS Dataset to Raster" function in ArcGIS 10.2.2. Digital elevation models used for stone wall identification were created using a cell assignment type of "MAXIMUM" which assigns the maximum elevation from a LiDAR point to the pixel it is within, thus giving more relief to the digital elevation model. The DEMs were then hillshaded using the default settings of 315° for Azimuth, and 45° for Altitude. In addition to hillshaded DEMs, slope rasters were also created from the 1m DEMs in order to further visualize subtle variations in topography. Although other visualization techniques have been developed for identifying cultural landscape features (Bennett et al., 2012; Štular et al., 2012), we found the hillshaded DEM and slope rasters sufficient for our identification purposes.

Though line extraction algorithms exist (Bachofer et al., 2014; Humme et al., 2006), we found that the most accurate way to create this dataset was through hand digitization. Many of the study areas have steep and rugged topography, and thus differentiating stone walls from bedrock outcrops and modern or historic road-cuts is difficult using automated or even semi-automated procedures. In this study, walls were digitized by hand by examining the hillshaded DEMs, slope rasters, and, when needed, high resolution aerial photography from 1934 and 2012 (Map and Geographic Information Center, 2015; CTECO, 2015) (**Figure 3**). Walls were digitized as single lines with vertices at both end points, at visible changes in direction, and at intersections with other stone walls; this systematic method also creates standardized segments for measuring size frequency and thus possible relationship to topographic roughness.

3.2 Geospatial analysis and data

The digitized dataset was analyzed with available functions in ArcGIS 10.2.2 to extract a variety of characteristics about walls, including: total length, distribution with regard to surficial geology, density within the study region, and frequency distribution of wall segment length. Surficial geology data (Stone et al., 2005; DEEP, 2015) were extracted to each line based on its center vertex, and then summarized by town to determine the proportion of each surficial geology type to the total length of walls. Density was calculated using the Line Statistics tool and a pixel size of 250m, where each pixel is the sum of all stone wall lengths in a 1 km^2 circular area around the center of that pixel. In estimating the density for areas of stone wall prevalence, and to exclude areas of absence, we reclassified the density rasters to isolate all areas where density exceeded 3 km of stone walls per km^2 to obtain new statistics. These areas were likely used intensively as improved land, and it is more appropriate to use these calculations than simply dividing the length of walls per town by the area of the town, as that includes water and other areas not amenable to wall building.

3.3 Field measurements

A total of 163 height and width measurements were acquired at selected field sites within the study towns in Connecticut and Rhode Island. Field measurements were made in areas that had once been cleared for agriculture, but were abandoned, and are now in state, town, or university forest areas that are protected and maintained for recreational or research purposes. Measurements were obtained using handheld measuring tapes at locations along the wall determined to be representative of the wall's overall character (**Figure 4**). An iPhone 5s and HTC One, both mobile phones, were used to document the location of the measurements along each wall to be compared with hillshaded LiDAR DEMs. Coordinates, elevation, and photograph direction were extracted from the photographs using the program Photo GPS Extract (Bart 2015) and

mapped using ArcGIS 10.2.2. These locations were then compared with coordinates taken using a handheld Garmin eTrex GPS as well as the hillshaded LiDAR DEM and high resolution aerial photographs in ArcGIS 10.2.2. We have found that in areas where 3G or LTE service is available, mobile phones provide excellent alternatives to GPS units for taking field coordinates.

3.3.1 Sources of error in stone wall height measurements

Observations from the *Statistics of Fences* (Dodge, 1872), Edwin Teale (Teale, 1974) and Thorson (2005), suggest that stone walls may have "flanking aprons" on either side (Thorson, 2005), and/or a foundation beneath the ground surface that could be as deep as ~0.6m (Dodge, 1872). The stones laid beneath the surface were thought to make the wall more durable and better able to withstand frost action that occurs every New England winter (Norton, 2003; Teale, 1974). Aprons are "composed of fallen stones, soil, and sediment that have accumulated after construction" (Thorson, 2005), and as a result make it difficult to obtain precise wall heights (**Figure 4C**). Repeated annual plowing may have pushed soil up to the edges of stone walls, and in some locations this process is still visible where soil on one side of the wall is higher than on the other (Wessels, 2010). All field measurements reflect height from the top of the apron (if present) to top of stone wall, and at present no archaeological investigations have been undertaken to study the subsurface portions of stone walls; thus further field work is required to determine how common and how deep foundations actually are at any of the study sites. To prevent livestock movement, tops of walls were also often built up with wooden posts or barbed wire, depending on their period of use, so the total height of the structure might have been much taller (Allport, 1990; Dodge, 1872; Thorson, 2002). Field measurements presented here are focused solely on the above-ground portion of the wall built of stone and thus represent a minimum estimate for the quantity of stone actually used.

3.4 Volume calculations

To calculate the volume of stone associated with stone walls in the study region, we combine stone wall lengths extracted from digitized LiDAR data with width and height measurements of stone walls in the field as well as estimates of stone wall porosity and batter.

3.4.1 Porosity and batter variables

We use the term "porosity" to denote the amount of space between stones in a wall (Thorson, 2005) (**Figure 5**). Stone wall "provinces" defined by Thorson (2005) as "…a town-sized-or-larger area where the constellation of stone walls is or should be similar, based on the area's bedrock, glacial background, and human history" are likely the determining factor in a wall's porosity. Material in this area of New England was transported through glacial activity as well, so the glacial till in a specific area is not completely representative of the bedrock there. This is what Thorson refers to as "local mix" versus "bedrock mix" and either or both can be responsible for the ultimate "wall mix" (Thorson, 2005). Porosity may also be a result of the degree of care taken in fitting and stacking the available stones; thus a higher porosity may reflect a more casual stone disposal, while a lower porosity may reflect a more intentional, time-consuming activity of fitting specific stones (Thorson, 2005). In the town of Tiverton, areas closer to the Sakonnet River have walls composed of more tightly-fitting angular gneiss and slate, while in the northern and eastern parts of the town, the walls are made of rounded granitic material similar to those in northeastern and northwestern Connecticut (**Figure 5A**). It is from latter two these locations in Tiverton that our field measurements were taken.

We estimate the observed surface porosity of stone walls using representative lateral-view photographs of walls from each of the study regions. Adobe Photoshop was used to isolate the stone wall from the surrounding scene and then extract black pixels representative of the space between stones observed on the wall's surface using brightness and color thresholds (**Figure 5B**). In some of

the stone walls it was possible to see through the openings to the forest beyond; in these situations, the opening was filled with black pixels to correspond with the adjacent spaces. Pixel percentages were calculated to obtain wall porosity estimates and their inverse which is representative of the amount of stone. While this method utilizes 2D images to obtain estimates for 3D space, studies in soil science using 2D image processing have successfully estimated actual soil pore characteristics in such a manner (Dathe et al., 2001; Latham and Munjiza, 2004; Passoni et al., 2014; Vogel and Kretzschmar, 1996) (**Figure 5C**).

Stone walls are generally slightly broader at their base than at their top, making them trapezoidal rather than rectangular in cross section (Thorson, 2002) (**Figure 6**). Most stone walls were purposefully battered (built with sloping sides) thus lowering their center of gravity and allowing them to withstand frost heaves and general weathering processes over time (Thorson, 2002). In the *Statistics of Fences* (Dodge, 1872) it is noted that stone walls in Hampden County, MA were built a foot wider at their base than at their top. Thorson (2002) presents evidence from a 19th century farmer's journal in which a batter proportion of 1.5 inches to the foot is used for the base to height ratio in wall construction. Because our field measurements for width were taken across the tops of walls, we must consider additional width at the base of the wall. We thus use a "batter correction" in our volume equation to account for this.

3.4.2 Volume calculation and variables

We use the following equations to calculate the volume of stone in stone walls:

$$b = 0.125 * h \tag{1}$$

$$\beta = (h * b * l) \tag{2}$$

$$V = (l * w * h + \beta) * (1 - p_w) \tag{3}$$

where V is the volume of stone in cubic meters; h and w are mean wall height and width respectively, both in meters and derived from field measurements; l is wall length in meters derived

from LiDAR based digitizing and GIS measurements (section 3.1), p_w is reciprocal porosity, and β is the batter correction. Equations (1) and (2) show calculations to obtain the batter correction: (1) uses the batter ratio (1.5 inches to the foot) multiplied by height to give the total area resulting from battering; this is then used in equation (2) to obtain the volume of the batter correction for the entire stone wall. Equation (3) is then used to calculate the volume of stone in stone walls by incorporating the batter correction and reciprocal porosity.

4. Results and Discussion

Stone walls are prevalent throughout the entire study area and exhibit widespread variation in their length, spatial distribution, and dimensions. Our results suggest that the distribution and dimensions of stone walls are highly influenced by the intersection of physical factors such as surficial geology and topography, and by cultural factors such as settlement patterns, wall purpose and construction, and the location of farmed or improved land. In this section, we explore these relationships and compare our results with historical information.

4.1 Stone wall length and spatial distribution

Our LiDAR-based stone wall dataset consists of ~2,113 km of stone walls in the five study towns mapped, with an average of ~423 km of wall per town. This dataset represents the most complete picture of stone walls available for these towns, but our estimates should be considered a minimum. Prior to 2010 and 2011 when the LiDAR data was acquired, many factors could have contributed to the removal of 17th to early 20th century stone walls, including: (i) in areas of suburban and urban development walls were likely dismantled or reused; (ii) many walls and stone piles were sold by farmers to towns in order to create crushed-stone, or "Macadam," roads in the early 20th century due to their availability (Bowles, 1939; USDOT, 2016; Westport Town Records, 2016); (iii) walls were also removed to enlarge older, smaller, fields (James, 1929) as mechanized

agriculture became more popular (Warren, 1914); and (iv) the preservation of stone walls continues to be threatened as they are sold by modern landowners or removed as a result of development. Given that the study towns are rural, relatively undeveloped and mostly forested today, the error associated with these factors is likely small.

Within each town, local density ranges substantially from 0–12 km of wall per km^2. The total length and average density of walls also varies by town, as do the number of wall segments and the average length of those segments (**Table 2, Figure 7**). Overall, our results suggest that spatial distribution of stone walls is well predicted by surficial geology type (i.e., the presence of glacial till) and historic agricultural land use. These controls on stone wall distribution will be discussed in the next two sections.

4.1.1 Distribution with regard to surficial geology and topography

Underlying surficial geology and topography greatly influence the spatial distribution and patterns of stone wall building. Thin and thick till comprise ~95% of areas where stone walls were built, while comprising only ~88% of the total surficial geology for those areas. Wall density averages 4.0 km/km^2 in areas underlain by glacial till, but only 1.5 km/km^2 on floodplain alluvium, terrace, swamp, marsh, and glacial meltwater and pond sediments (**Table 2**). The average density of walls on glacial till in Litchfield County (particularly Sharon and Cornwall) is slightly lower than their eastern counterparts. This suggests that despite these towns having widespread glacial till, walls occurred less frequently across the landscape because these areas were not historically used for farming, but for other types of land use (Johnson et al., 2015).

Stone walls are often geographically constrained to smooth glacial landforms, such as drumlins. It is generally expected that smooth, gentler slopes were cleared for tillage, while rugged, steeper land was likely reserved for pasture or woodlots. Despite this, many farms were in steep areas with thinner, less productive soils. Further analysis of topographic roughness in these areas

could reveal more of these patterns (Johnson and Ouimet, 2015). The lengths of wall segments may also serve as a proxy for determining the type of topography on which walls were built, since the topography would have influenced field size and shape, and thus segment length. Lengths of wall segments differ between towns in the northeast and northwest (see **Table 2**). Greater segment values, as seen in Goshen, suggest long, continuous walls built on even topography, while smaller values suggest short, interrupted walls built on rough topography. Field patterns in Ashford and Eastford are also more polygonal and irregular, while in Cornwall, Goshen, and Sharon, much of the settlement occurred on drumlins and areas of thick till which forms clear NW–SE patterns with long walls running parallel, and shorter walls running SW–NE, perpendicular to glacial till deposits (**Figure 8**).

4.1.2 Distribution with regard to historic agriculture

In addition to surficial geology and topography, the distribution of stone walls is also influenced by historic agriculture (Thorson, 2002). Study towns exhibit many areas with a high proportion of glacial till, yet very few or no stone walls. This may result from variable timing or intensity of European settlement in these areas, differing types of historical land use such as wood lots or charcoal production (Johnson et al., 2015), the presence of non-stone fencing material, or stone wall removal in later times.

The 1850 U.S. Federal Census Non-Population Schedule for Agriculture provides detailed land use records (DEEP, 2015; United States Census Bureau, 1850a; United States Census Bureau, 1850b) and was the first in which agricultural information was reported by individual farm (National Archives, 2016). That decade is also widely considered to represent the period of maximum land improvement and deforestation in the southern New England states (Foster et al., 2008; Merchant, 1989), though northern and western peripheral counties in Maine and New York likely reached their maximum land improvement later according to U.S. Census data from 1870 to

1890 (Minnesota Population Center, 2015). For each study town, in addition to population data, we obtained agricultural data at the individual farm level and calculated: (i) the number of reported farms in each town, (ii) the area of reported improved land in each town, and (iii) the area of reported unimproved land in each town (United States Census Bureau, 1850a; United States Census Bureau, 1850b; United States Census Bureau, 1870) (**Table 3**).

A typical historic farming community is best exemplified by a proportion of both improved and unimproved lands because English-style husbandry necessitated the use of well-managed woodlots coupled with other types of land often listed as "unimproved" in documentary records (Donahue, 2004; Hall et al., 2002; United States Census Bureau, n.d.). In all towns, total land reported in farms rarely equals the total size of that town. These missing areas have also occurred in earlier tax records from Connecticut (Waggoner, 2003), and suggest the presence of other land use types, areas unsettled by European colonists, large waterbodies that might not have otherwise been accounted for, or error in enumeration or estimates (Ginsberg, 1988; Steckel, 1991). There are also small acreages known to have been excluded from the Census; for example, in 1850 only farms that accrued $100 or more were included, and by 1860 the Census excluded farms under 3 acres and producing less than $500 worth of goods (United States Census Bureau, n.d.). There is also a difference in proportion of improved land to total town area in towns known to have other types of historic land use. For example, all three of the Litchfield County towns in the northwestern part of the state were historically part of the Salisbury Iron District, and their wooded hillslopes were used primarily for charcoal production (Gordon and Raber, 2000; Gordon, 2001; Johnson et al. 2015); this might explain the low recorded acreages of improved land, or "land in farms" for those towns during this time period.

As a metric for the amount of land used for agriculture and pasture, the area of reported improved land in each town is the best predictor of total stone wall length (**Figure 9**). Population is not a strong predictor of the observed lengths of stone wall in each town (R^2 = 0.31), the number of

farms (R^2 = 0.26) or the reported acreage of improved land (R^2 = 0.21). However, a strong relationship (R^2 = 0.96) exists between the observed lengths of stone wall in each town and areas of improved land in 1850. Given that improved land is a determined in large part by the number of farms, wall length and the number of farms in 1850 also exhibit a strong correlation (R^2 = 0.78). In 1870, there is a much weaker relationship between wall length and improved land (R^2 = 0.20), suggesting that farm abandonment and subsequent reforestation of improved land had drastically begun to transform the landscape. In addition to historic agricultural census data, there is also a strong relationship between observed wall length and areas of glacial till in each town (R^2 = 0.73).

While the strong linear relationship between observed wall length and improved land in 1850 provides a framework of estimating total stone wall length per town given the area of improved land in 1850, it does not account for the spatial distribution and variable densities of walls across the landscape. We suggest that in estimating wall length and distribution, that the cumulative spatial distribution of land improvement over the period of agricultural intensification should be considered, as the spatial layout of improved land likely varied over that period of time. Reclassification of calculated densities (see **Figure 7**) for areas where wall length exceeds 3 km/km^2 isolates areas of persistent and widespread improved farmland (see **Tables 2** and **3**). The percentage of each town comprised of areas where walls exceed 3 km/km^2 falls within 5% of the percentage of reported improved land in 1850 in four of the five study towns. The exception is Eastford, where the reported improved land in 1850 is 20% less than the area shown by our analysis. This suggests that despite the good agreement between the two datasets, areas where walls exceed 3 km/km^2 may not explain areas in each town that may have been fenced with wood, or improved during previous or later time periods.

The average density of walls in the five study towns is 5.2 km/km^2 in estimated areas of improved land, but can also exceed 11 km/km^2, which is much higher than that for the total length across the total study area (3.7 km/km^2) and length of walls on areas of glacial till alone (4.0

km/km^2). The spatial variation in stone wall density may explain the wide range estimates in the historical literature. Historical estimates of stone wall length per unit area in New England and adjacent states range from 2.7 to 15.3 km/km^2 (**Table 4**). Observation areas range from scales of individual farmsteads (Teale) to towns (Church) and regions (Thorson). The variation present in historical estimates is likely a result of wall density as a function of surficial geology and extent of improved land at specific observer locations.

4.2 Stone wall height, width, porosity, and volume

Widths, heights, and lengths of stone walls vary among the study areas, though the measurements fall within a narrow range. There is no relation between height and width, but there does appear to be differences in these values among the study areas (**Figure 10**). The mean wall height and width are 0.76±0.23 and 0.96±0.50m with medians of 0.70m and 0.75m respectively. Wall height ranges from a minimum of 0.30m to a maximum of 1.37m and width ranges from a minimum of 0.45m to a maximum of 2.50m. Despite this variation, the range of results are consistent with Thorson's (2002) assertion that wall dimensions are predominantly a function of the amount of human labor or energy required to move stones of varying sizes and shapes (Thorson, 2002). He suggests that walls tend to be "thigh-high" as that is the height at which "humans are optimally strong" (Thorson, 2005), and rarely do they rise above chest-height. Walls can also lose their original dimensions due to frost action, gullying, tree fall, or repurposing of stone. The width of the wall may result from functional purpose; if a wall was built by casually disposing of stones through time as a field was plowed, it may be much wider or lower than a wall built in a shorter period of time or for another purpose, such as enclosing livestock.

Wall porosity ranges from 20.1% to 6.2% in the sampled walls, with an average of 11.5%. Stone thus comprises between 79.9% and 93.8% of those walls, with an average of 88.5%. Oliver Bowles speculated in 1939 that only ~25% of a tightly-stacked stone wall would be air space

(Bowles, 1939). We find that this would likely be the case for very loosely-stacked stones in blocky disposal walls, whereas those with angular or well-stacked stones would have a much lower porosity and thus higher proportion of stone (see **Figure 6**). Our porosity results agree with cube-packing modeling of particulate processes performed in laboratory environments, where importance of shape and depositional sequence was demonstrated along with porosity ranges of 0–50% for cubes and 28–46% for spheres (Latham and Munjiza, 2004)(see **Figure 6C**).

The total volume of stone in stone walls for all five study towns is ~1,365,000m^3, with an average volume of ~273,000 m^3 per town (**Table 5**). Table 5 illustrates how variations in height, width, and porosity measurements can affect the volume estimates. We use the mean ± one standard deviation to determine the height and width ranges, and the minimum, mean, and maximum porosity values to create our estimates. The maximum values likely do not reflect the overall distribution of stone walls in our study areas because that calculation is influenced by much greater outliers (2.00m) than the average (0.96m) and median (0.75m) of those we observe. The average volume presented here likely reflects a realistic scenario for the volume of stone in walls within the five study towns. Using the average volume of stone in walls built over the course of 150 years, with peak wall building occurring from 1775 to 1825 (Allport, 1990; Thorson, 2002), ~9,100 m^3 a year was moved over the ~596 km^2 considered here by farmers, their families, laborers, and enslaved individuals in an effort to clear fields and create boundary walls. Volume estimates represent a minimum because a portion of many walls likely lies beneath the ground surface with a wider and deeper base than is possible to observe, and walls succumb over time to surface processes and thus their height is variable and changing in many cases.

5. Implications

While stone walls and clearance piles are found elsewhere in the United States (Dodge, 1872; Hewes and Jung, 1981; Hoard and Prawl, 1998; Murray-Wooley and Raitz, 1992) and in other

countries as a result of agriculture or property division (Bescoby, 2006; Collier, 2013; Given, 2002; Hamre et al., 2007), those in the northeastern United States are particularly well known. This study serves as a basis for quantifying stone walls and exploring the spatial distribution of 17th to early 20th century agriculture throughout the region. Mapping and delineating stone wall extents also serves as the foundation for studies investigating their cultural, geomorphological, and ecological impacts for landscapes in which they are found.

5.1 Inferences for stone walls in the northeastern USA

We have presented stone wall data for five upland, rural towns in southern New England. Areas throughout the northeastern United States where surficial geology is characterized by glacial till and historic agriculture occurring throughout the 18th and 19th centuries are likely to have very similar stone wall lengths, volumes and spatial distributions as the five study towns we present here. However, in Connecticut alone, significant variation exists in the surficial geology and 1850 agricultural data at the county level (**Figure 11**). Counties with very low proportions of glacial till, such as Hartford, may still have had high proportions of improved land in 1850 though stone wall numbers would have been lower on a per km^2 basis despite agricultural improvement. It is expected that land in counties such as Hartford was fenced as extensively as the towns we observe in Litchfield County, however that fencing was likely constructed partially of wood due to the lack of stone in these areas (Dodge, 1872). Digitization of stone walls in towns known to have high areas of reported improved land in 1850, but lower amounts of glacial till, would help to explore this further.

Moving beyond southern New England, variation in both the timing and distribution of European settlement within the northeastern United States must be considered in concert with surficial geology (**Figure 12**). While land improvement reached its peak in southern New England by 1850, this did not occur in western and northern counties until decades later, when

reforestation and land abandonment had already begun southern New England (Minnesota Population Center, 2015) (**Figure 12C**). Although Maine's northern counties are large and possess a high proportion of glacial till, they were not subject to the intensive English-style land use of the counties in southern New England for the lengthy periods of time that produced wall building (Thorson, 2002), and were settled as wire fencing was becoming more popular. As a result, till and improved land based approaches to estimating the length of walls in southern New England may thus be quite different from those used to explain wall distribution in peripheral counties in New York, Maine, Vermont, or New Hampshire which were all settled much later by those of European descent. Steep, mountainous topography in the Berkshire, Green, and White Mountains is also likely to have limited the amount of settlement, improved land use and associated stone walls that occurred regardless of glacial till and county level data.

5.2. Stone walls and the Anthropocene

Stone walls should be considered a contributing feature of the Anthropocene in southern New England because they: (i) represent a profound cultural shift in land use practices and are a defining characteristic of the northeastern landscape; (ii) have a ubiquitous geomorphological presence in this region in terms of their sheer volume and likely influence on surface processes; and (iii) could have an immense ecological impact, which has been studied in Europe and Asia (Collier, 2013; Francis, 2010; Holland, 1972; Jim, 1998; Manenti, 2014), but which is not well-studied in the northeastern United States (Frank et al., 1998; Sinclair et al., 1967; Thorson, 2002). The variation we show in stone wall distribution highlights the temporal and spatial complexity of 17th to early 20th land use that locally characterizes the Anthropocene in southern New England.

Culturally, stone walls not only coincide with English-style agriculture, but are representative features of colonialism. As a result, their expression on the landscape is not just geomorphological, but symbolic of the historic imposition of power on Native American groups and

the landscape beginning in the 17th century (Hasho, 2012; Silverman, 2005, 2003). Colonialism has been recognized in other regions as a catalyst for both the Anthropocene (Lightfoot et al., 2013), and for drastic landscape change resulting from the forceful introduction of different types of different land use (Forsythe, 2007; Given, 2004, 2002; Sluyter, 2001).

Stone walls are also unique geomorphic features, and it has been suggested, though not thoroughly studied, that they greatly impact surface processes in addition to being products of geomorphic processes themselves. Stone walls built on hillslopes directly impacted the topography through differential redistribution of rainwater, while those built in low-lying areas are responsible for the impoundment of small wetlands and buildup of sediment at the bottoms of hillslopes (Thorson and Harris, 1991; Thorson, 2002; Thorson et al., 1998). Stone walls and other features, such as hard-packed abandoned roads, have also recently been shown to have influenced gullying patterns in southern New England (Hill and Ouimet, 2015).

Numerous studies have found that stone walls provide unique ecosystems for plants and animals in a variety of environments (Collier, 2013; Francis, 2010; Jim, 1998; Lundholm and Richardson, 2010; Morse et al., 2014); however very little published scientific research seems to have been done in New England (Sinclair et al., 1967; Thorson, 2002; Wessels, 2010). Overall, the physical presence and cultural implications of stone walls in the northeastern United States marks a profound shift in the history, geomorphology, and ecology of this region. Further study should continue to address their cultural, physical, and ecological impacts on the landscape, and promote their preservation.

Figures

Figure 1

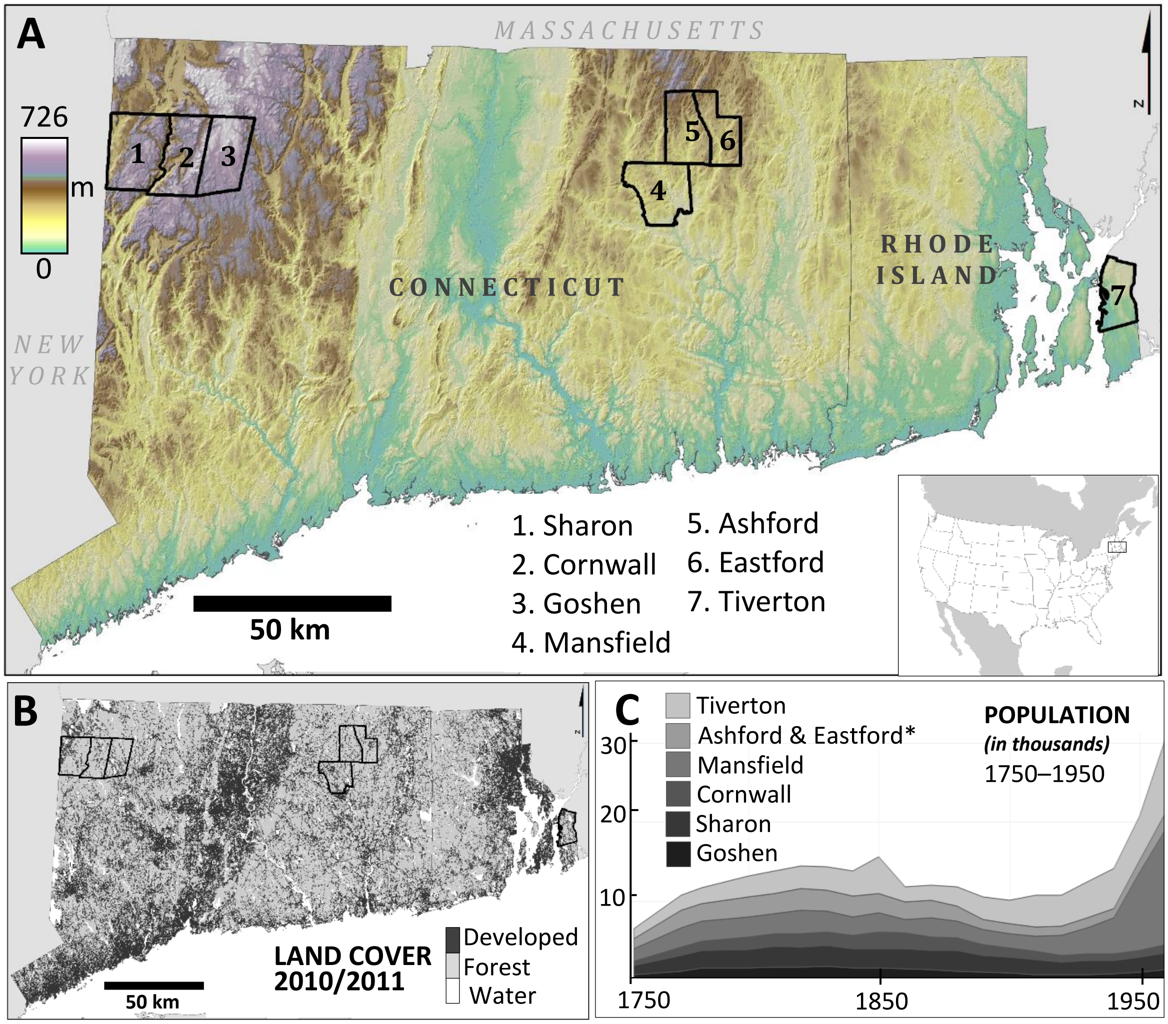


Figure 2

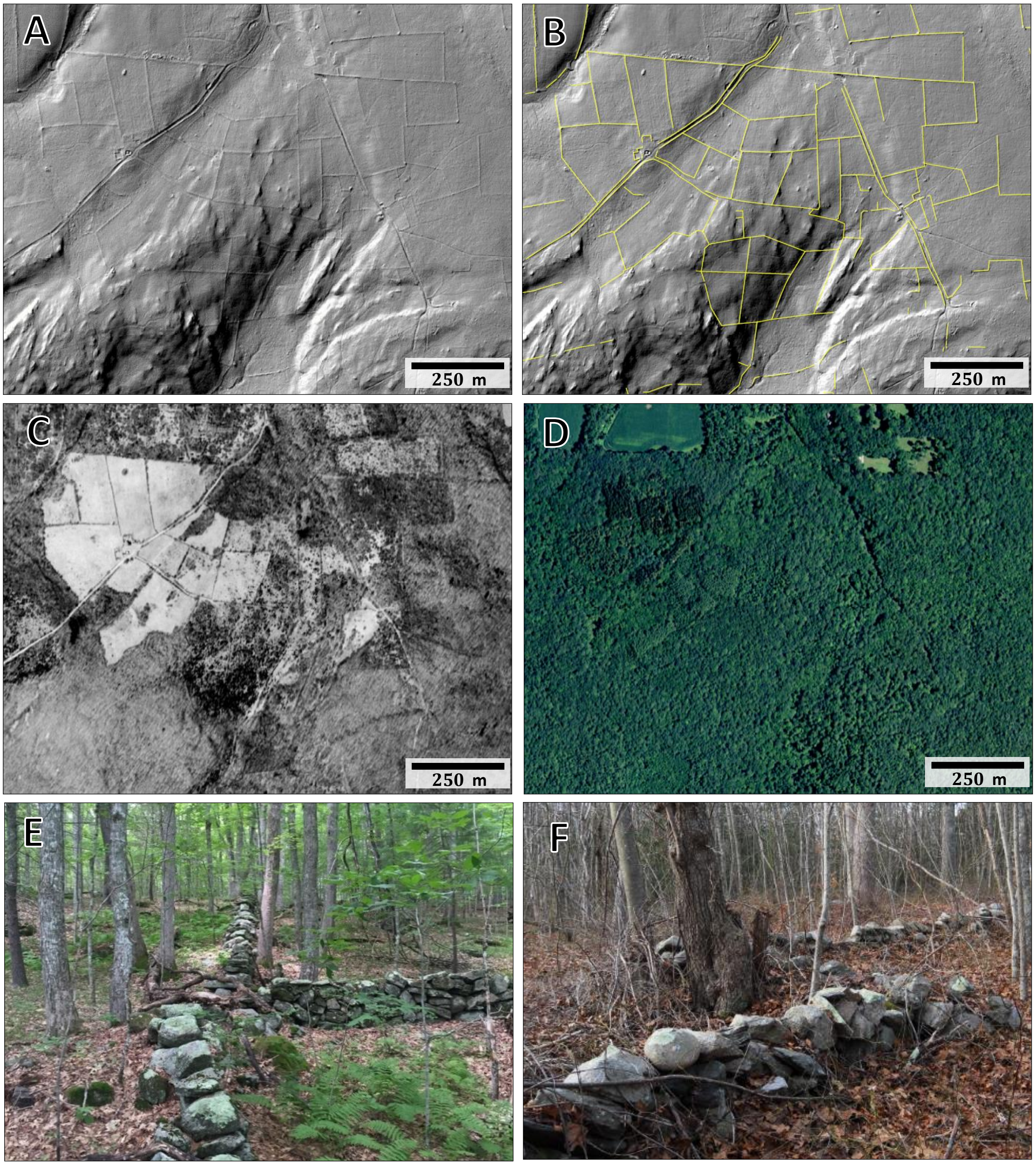


Figure 3

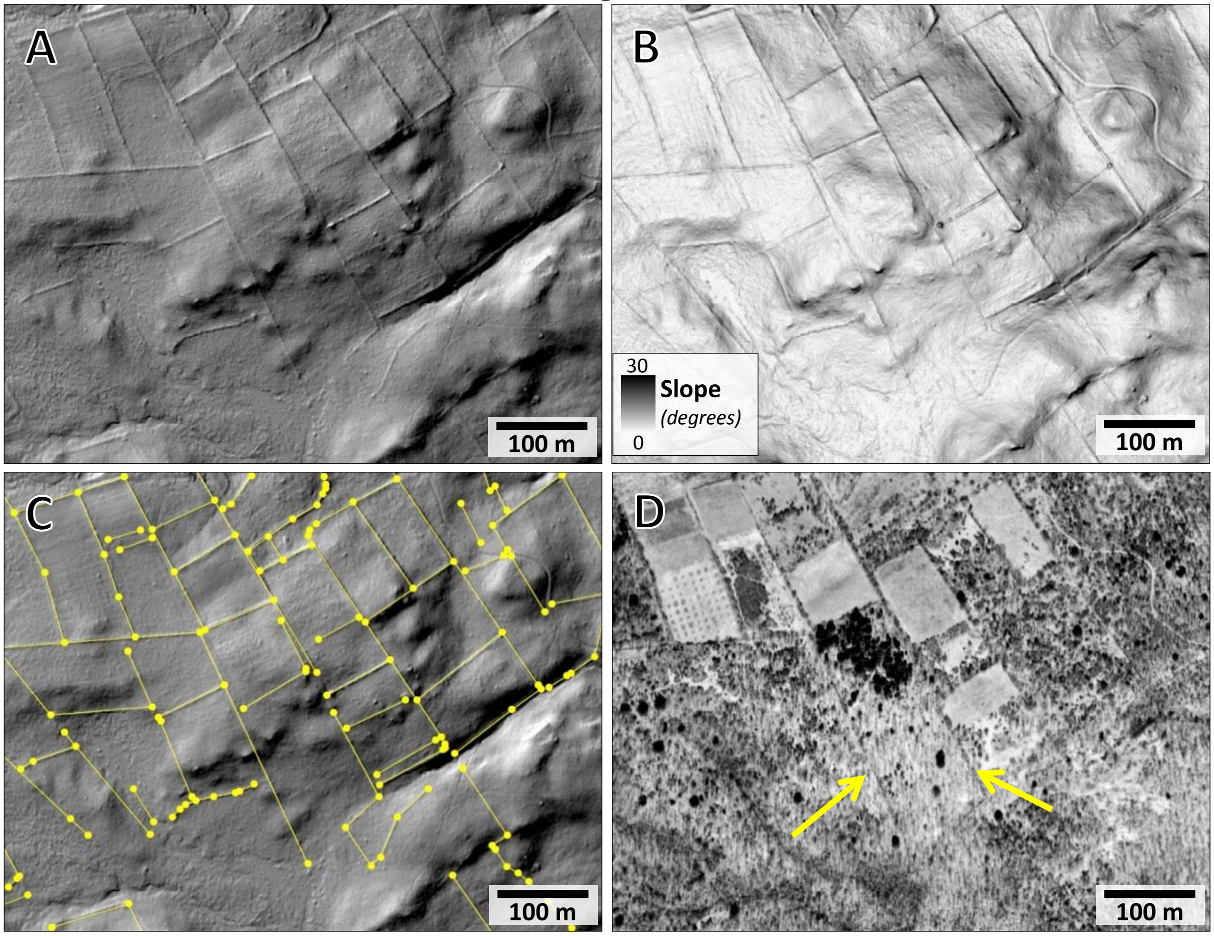


Figure 4

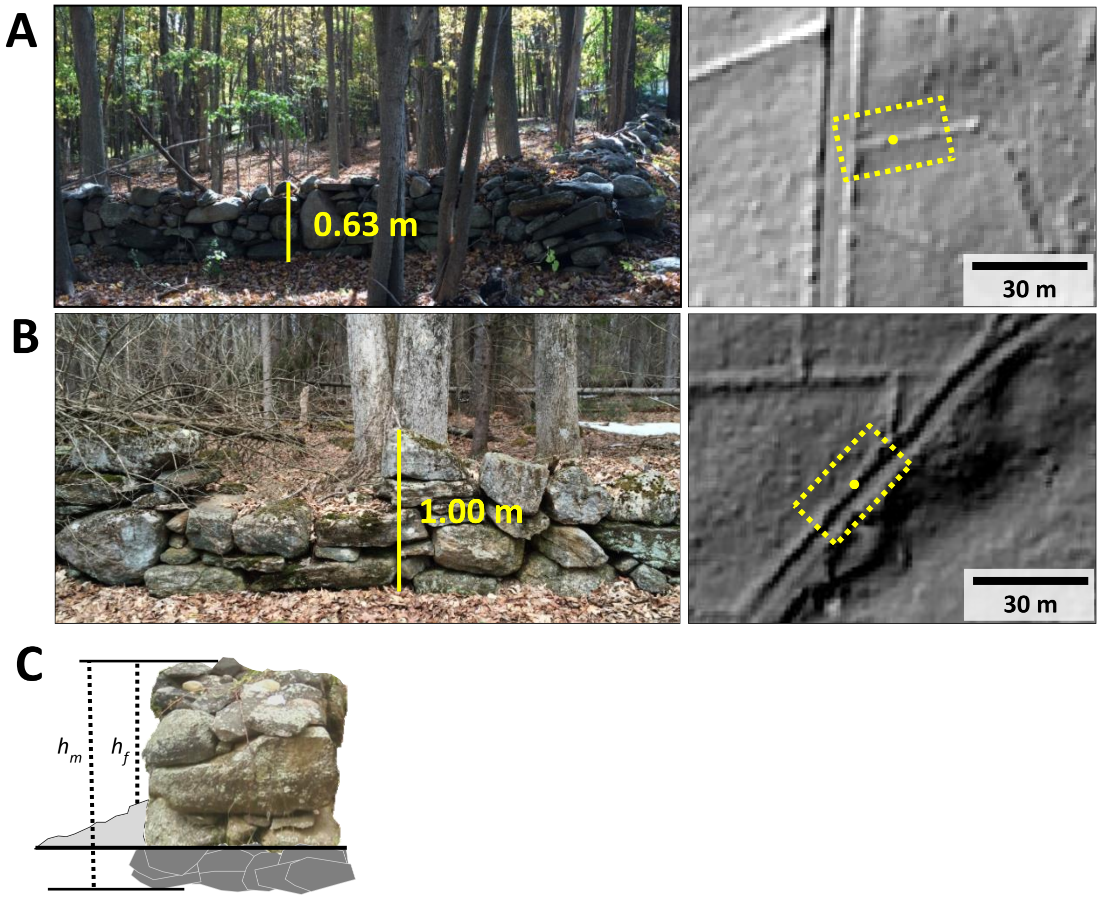


Figure 5

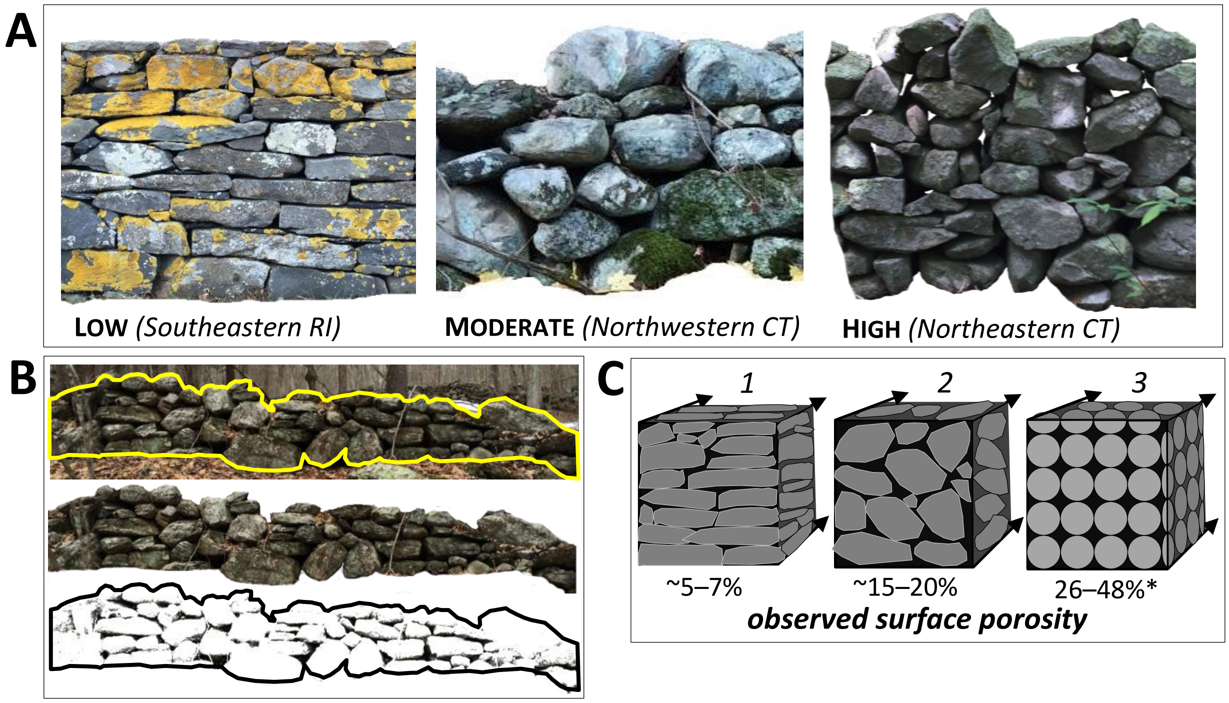
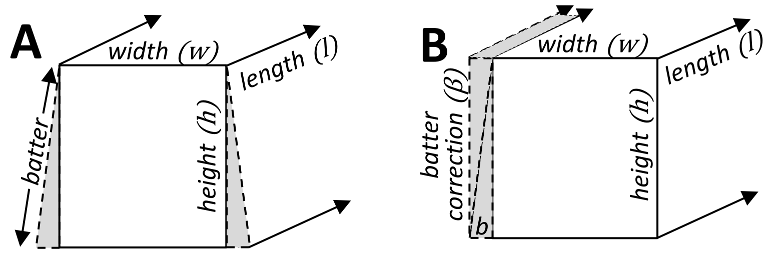
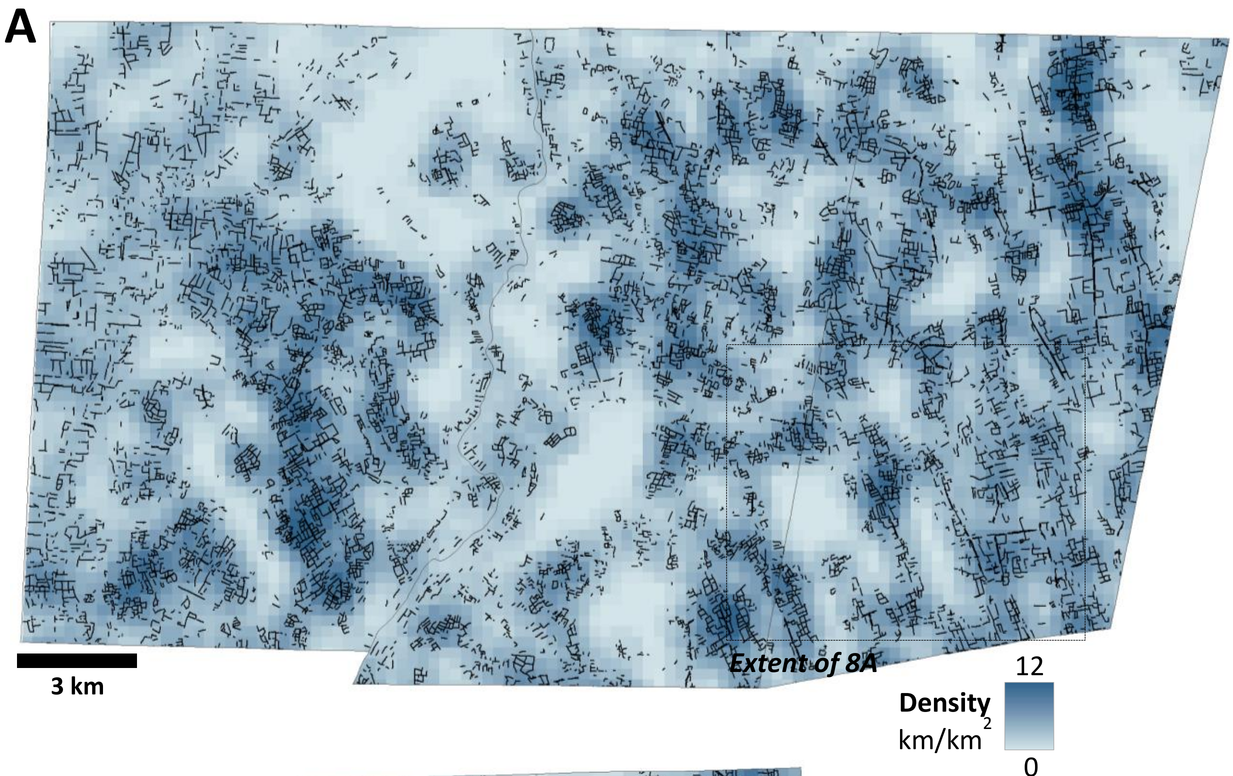

A
LOW (Southeastern RI)
MODERATE (Northwestern CT)
HIGH (Northeastern CT)
B
C
1
2
3
~5–7%
~15–20%
26–48%*
observed surface porosity

Figure 6



A
width (w)
length (l)
batter
height (h)
B
width (w)
length (l)
batter
correction (β)
b
height (h)

Figure 7


A
Extent of 8A
3 km
Density
km/km2
12
0

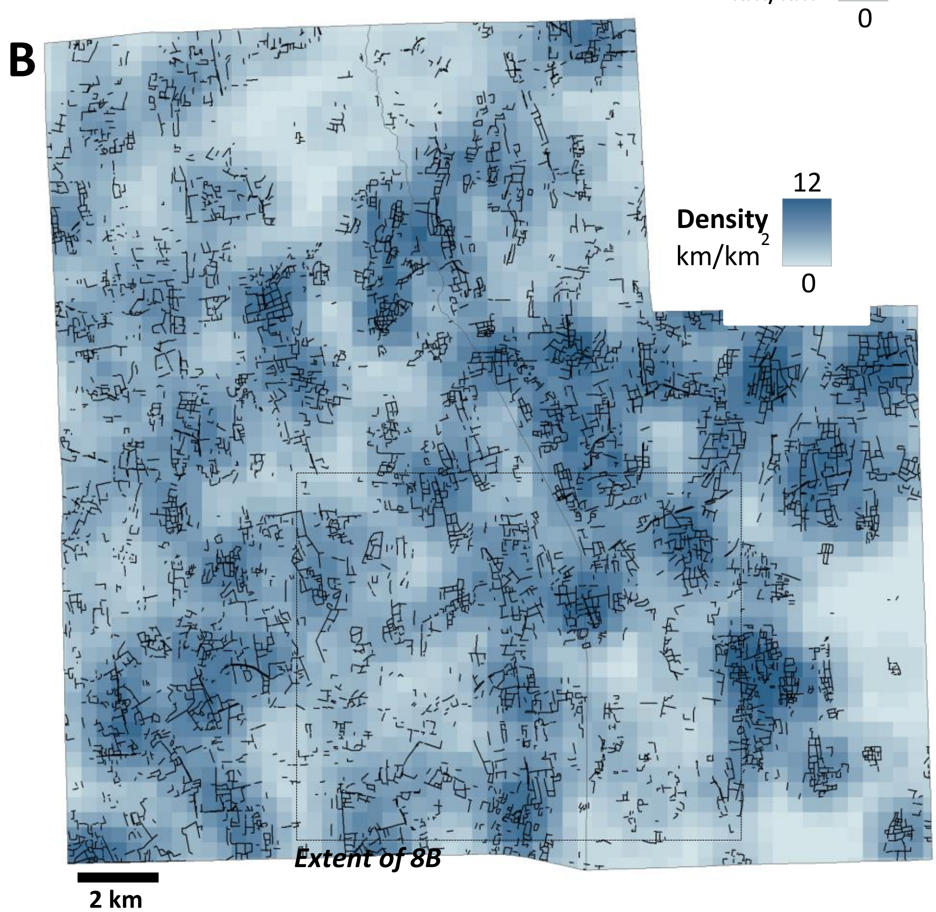

B
Density
km/km2
12
0
Extent of 8B
2 km

Figure 8

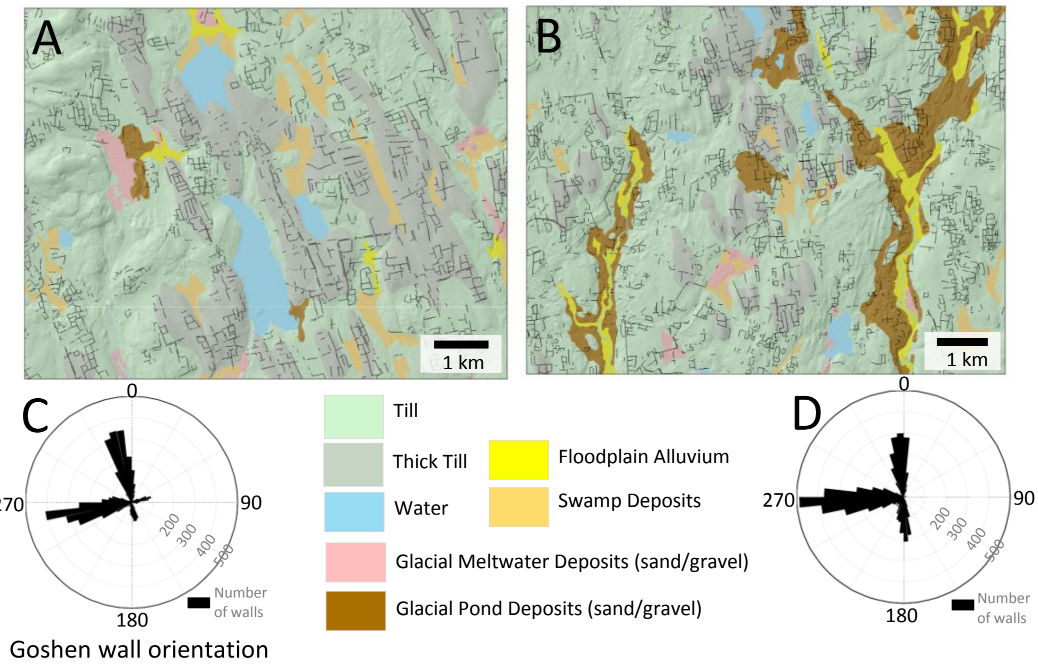

A
B
1 km
1 km
C
0
90
180
270
200
300
400
500
Number of walls
Goshen wall orientation
Till
Thick Till
Water
Floodplain Alluvium
Swamp Deposits
Glacial Meltwater Deposits (sand/gravel)
Glacial Pond Deposits (sand/gravel)
D
0
90
180
270
200
300
400
500
Number of walls

Figure 9

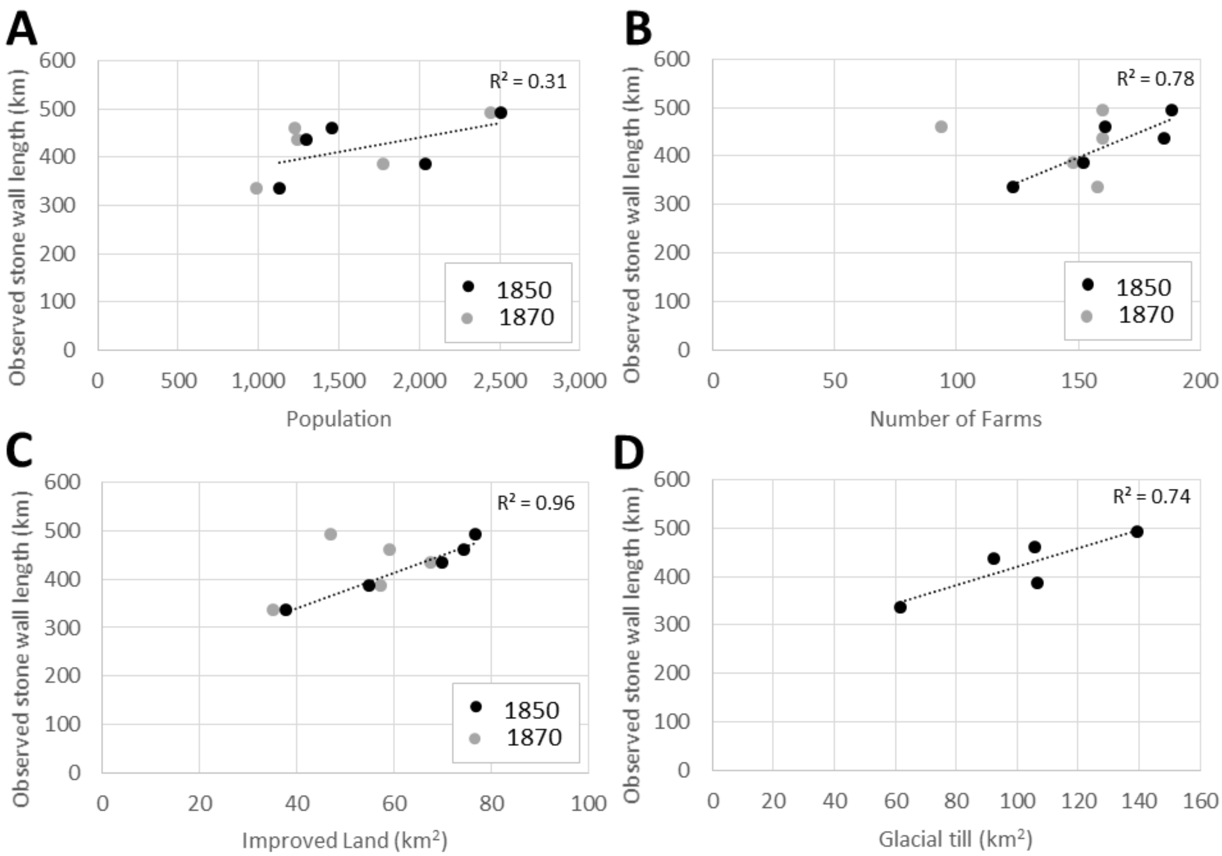

A
R² = 0.31
Observed stone wall length (km)
600
500
400
300
200
100
0
0
500
1,000
1,500
2,000
2,500
3,000
Population
1850
1870
B
R² = 0.78
Observed stone wall length (km)
600
500
400
300
200
100
0
0
50
100
150
200
Number of Farms
1850
1870
C
R² = 0.96
Observed stone wall length (km)
600
500
400
300
200
100
0
0
20
40
60
80
100
Improved Land (km²)
1850
1870
D
R² = 0.74
Observed stone wall length (km)
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
Glacial till (km²)

Figure 10

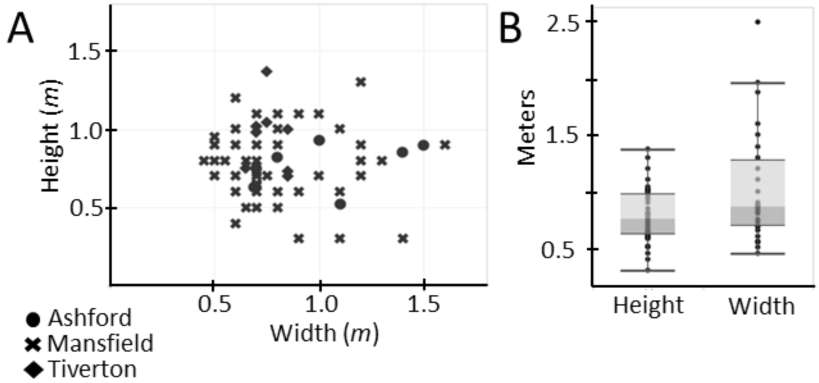

A
1.5
1.0
0.5
Height (m)
0.5
1.0
1.5
Width (m)
Ashford
Mansfield
Tiverton
B
2.5
1.5
0.5
Meters
Height
Width

Figure 11

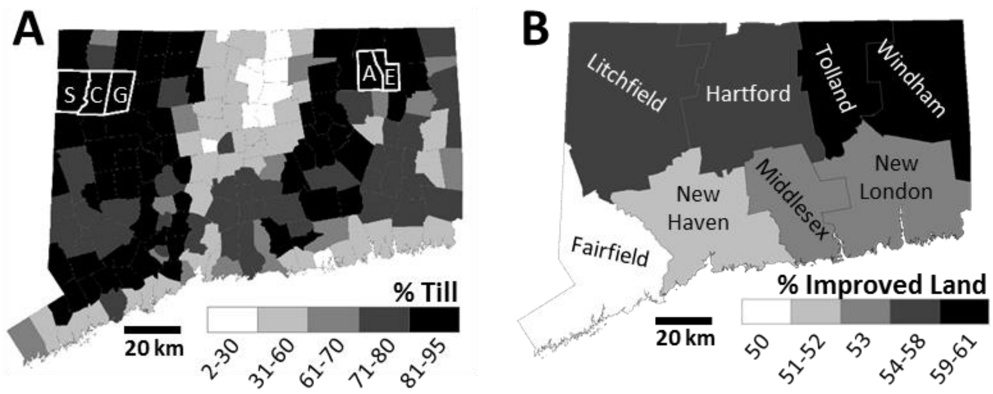

A
S
C
G
A
E
% Till
20 km
2-30
31-60
61-70
71-80
81-95
B
Litchfield
Hartford
Tolland
Windham
New Haven
Middlesex
New London
Fairfield
% Improved Land
20 km
50
51-52
53
54-58
59-61

Figure 12

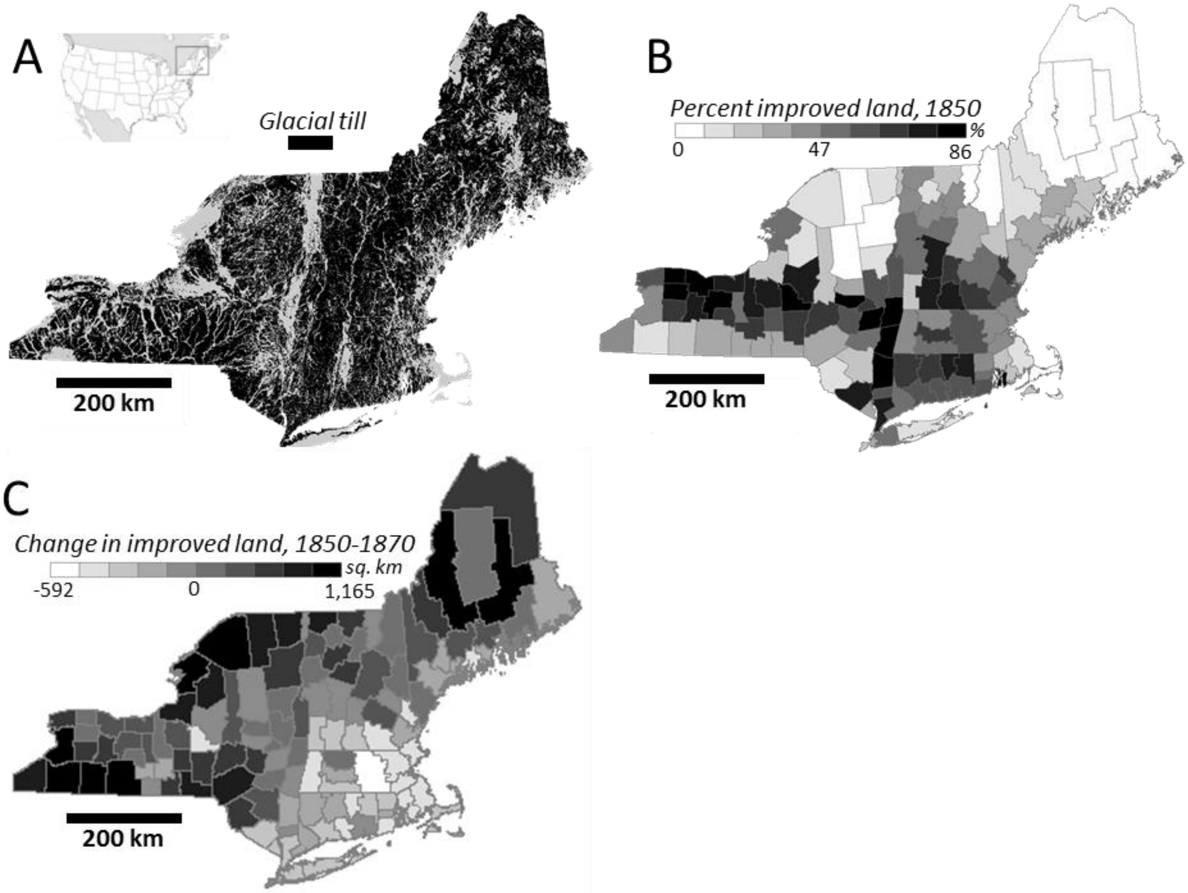

A
Glacial till
200 km
B
Percent improved land, 1850
%
0
47
86
200 km
C
Change in improved land, 1850-1870
sq. km
-592
0
1,165
200 km

Figure Captions

Figure 1. Study areas in Connecticut and Rhode Island with elevation (USGS National Elevation Dataset, 10m resolution) (A). Stone walls were fully digitized in Ashford, Cornwall, Eastford, Goshen, and Sharon. Towns where field measurements have been taken are Ashford, Mansfield, and Tiverton. (B) Distribution of developed and forested land in Connecticut (CLEAR, 2015) and Rhode Island (RIGIS, 2015) in 2010 and 2011, respectively. (C) Populations of towns discussed in this study. Population data compiled from the U.S. Census, CT Dept. of Economic and Community Development (CTDEC, 2015), and (Cross, 1888). *Note, Ashford and Eastford were both part of Ashford until 1847 when the towns split. They are shown with combined population totals here.

Figure 2. Example of land use changes in the northeastern United States. Hillshaded LiDAR DEMs in forested topography throughout the region reveal the extent of stone walls and implied historic land clearing that peaked in the mid-19th century (A and B). High resolution (0.3 m or better) aerial photographs from 1934 (C) and 2012 (D) show the progression of 20th century reforestation. (E) and (F) are examples of once-cleared, stone wall-lined fields, now reforested, in Ashford, CT and Tiverton, RI.

Figure 3. Using hillshade (A) and slope (B) rasters derived from 1m digital elevation models, stone walls were digitized by hand by placing vertices at stone wall intersections, ends, and abrupt turns (see examples in C). Stone walls were also sometimes visible in 1934 aerial imagery (D) which was used as a supplemental reference if needed.

Figure 4. Photographs of stone walls with associated measurements and depiction of measurement location in a hillshaded DEM. (A) shows a location in Mansfield, CT; and (B) in Ashford, CT. Factors that influence stone wall measurements include (C) possible foundations below ground surface and apron of soil and debris build-up adjacent to wall. Line h_m shows potential maximum height of the wall versus h_f, which shows the height as measured in the field.

Figure 5. (A) depicts examples of stone walls from the study areas ranging from angular tightly-stacked stones to loosely-stacked blocky stones; (B) shows a stone wall from Ashford, CT in an original field photograph, the same wall after being extracted from the background, and the dark pixels representing the observed surficial space between the stones after extraction; (C) depicts schematic diagrams showing the differences in porosity due to type and stacking-style of stones where *1* depicts a tightly-stacked wall of angular stones, *2* is a loosely-stacked blocky wall, and *3* is a schematic of actual measured porosity (*see Latham and Munjiza, 2004).

Figure 6. Walls were built with a slightly trapezoidal shape (A), called battering, which we take into account as a batter correction (B) in equations (1) and (2) when calculating the volume of stone in stone walls.

Figure 7. Digitized stone walls and calculated densities of stone wall length in km/km^2 in (A) Cornwall, Goshen, and Sharon, CT, and (B) Ashford and Eastford, CT showing spatial variation over each area of between 0 and 12 km of stone walls per km^2.

Figure 8. Digitized stone walls depicted on underlying 1:24,000 surficial geology in selected areas of (A) Goshen, CT and (B) Ashford and Eastford, CT. Rose diagram (C) shows azimuthal direction frequency of all walls in Goshen, CT and indicates a NW-SE trend with a strong cross-cutting component running SW-NE, while in Ashford (D) the trend is more toward the N–S and E–W directions.

Figure 9. Plots depicting the relationship between observed stone wall length in each study town and (A) population in 1850 and 1870; (B) the number of farms in 1850 and 1870; (C) the area of improved land in 1850 and 1870; and (d) glacial till.

Figure 10. Plots depicting (A) a subset of wall measurements from each study location and (B) the statistical distribution of wall height and width measurements. Note in the scatterplot that each study area has slightly different distributions.

Figure 11. Maps depicting (A) the percent glacial till by town in Connecticut; (B) the percent improved land in 1850 for each county in Connecticut.

Figure 12. Maps depicting (A) the distribution of glacial till in the northeastern United States (ESRI, 2016; MassGIS, 2015; NH GRANIT, 2015; NYSGIS, 2015; RIGIS, 2016; VCGI, 2015); (B) percent improved land in 1850 by county (Minnesota Population Center, 2015); and (C) the change in improved land (sq. km) between 1850 and 1870 in each county (Minnesota Population Center, 2015).

Tables

Table 1. Study towns and characteristics

	County, State	Year Incorporated	Average elevation[1]	"Woodland" 1870[2*]	Forest 2010/11
Ashford	Windham, CT	1714	203m	22%	81%[3]
Cornwall	Litchfield, CT	1740	327m	26%	83%[4]
Eastford	Windham, CT	1847	198m	18%	82%[3]
Goshen	Litchfield, CT	1739	394m	9%	75%[4]
Mansfield	Tolland, CT	1702	134m	17%	64%[4]
Sharon	Litchfield, CT	1739	299m	13%	70%[4]
Tiverton	Newport, RI	1694	44m	N/A	63%[5]

Sources: 1) 10m National Elevation Dataset (USGS, 2015); 2) Calculated by authors from United States Federal Non-Population Agricultural Schedule, 1870; 3) (Parent, Volin, and Civco 2015); 4) CLEAR, 2015; 5) RIGIS, 2015; incorporation dates from town websites.
*Woodland estimates are reported acreages in the 1870 U.S. Federal Census Non-Population Schedule for Agriculture and reflect woodland associated with farms. Estimates are likely minimums because larger proportions of each town may also have been forested at the time, not associated with farming, or not listed in the Census.

Table 2. Summary of digitized stone wall data

	Town Area (km^2)	Total wall length (km)	Length of stone walls per km^2: Min. (km)*	Max. (km)*	Overall Average (km)*	Improved land 1850 estimate*§	On glacial till (km)^	On other surficial materials (km)^	Number of wall segments	Average wall segment length (m)
Ashford	102.3	436.3	0.0	9.8	4.2±2.0	5.1±1.5	4.6	1.5	8,645	50±37
Cornwall	119.9	386.6	0.0	10.4	3.2±2.1	5.0±1.5	3.5	1.4	7,411	52±36
Eastford	75.8	336.8	0.0	12.0	4.3±2.6	5.9±1.8	4.9	2.4	6,009	56±41
Goshen	117.0	460.7	0.0	11.8	3.9±2.2	5.3±1.6	4.3	0.5	7,066	65±46
Sharon	154.2	493.6	0.0	11.4	3.2±2.1	5.0±1.5	3.4	1.7	9,028	54±43
Total	**569.2**	**2,113.9**	-	-	**3.7**±2.2†	**5.2**±1.6†	**3.9**†	**1.5**†	**38,159**	-

* Values based on raster statistics of density maps in Figure 7.
^ Values based on total stone wall length and total area of surficial materials in each town.
† Weighted averages based on town area.
§ >3 km/ km^2 (see text)

Table 3. Summary of surficial material extents, 1850 land census data, and observed total wall length in 5 study towns

	Area (km^2)	Glacial Till (km^2)	Other surficial material (km^2)	Improved land 1850 (km^2)	Unimproved land 1850 (km^2)	Observed wall length (km)
Ashford	102.3	92.4	9.9	69.9	28.9	436.3
Cornwall	119.9	106.7	13.2	54.8	33.6	386.6
Eastford	75.8	61.7	14.2	37.9	13.6	336.8
Goshen	117.0	105.8	11.3	74.5	19.2	460.7
Sharon	154.2	139.3	14.9	76.7	37.7	493.6
Total	**569.2**	**505.8**	**63.5**	**313.8**	**132.9**	**2,113.9**

Table 4. Historical estimates of stone wall length

Author	Year	Observer Location	Length (km)	Study area (km^2)	Length / km^2
Church[1]	1746	Little Compton, RI	221.1	54.1	4.1
Dodge[2]	1871	Connecticut	1.5	0.4	3.4
Myers[3]	1920	Upstate NY	2.0	0.7	2.8
Holcombe[4]	1950	Marlborough, CT	4.8	0.4	11.9
Teale[5]	1974	Hampton, CT	8.1	0.5	15.3
Foster and Aber[6]	2006	Petersham, MA	380.0	100.0	3.8
Thorson[7]	2002	New England	1.2	0.4	2.7

Note: Areas and lengths have been converted from their original estimates in acres & rods, or miles. 1. Thomas Church cited in (Allport 1990; Guillemette 2011; Wilbour 1970), 2. (Dodge, 1872); 3. (Bowles 1939; Myers 1920); 4. (Holcombe 1950); 5. (Teale 1974); 6. (Foster and Aber 2006) 7. (Thorson, 2002 p.248, footnote 5).

Table 5. Estimated volume of stone in stone walls for 5 study towns

	Estimated Stone Volume			
	Min. (m^3)	Avg. (m^3)	Max. (m^3)	Avg. moved per year (m^3)*
Ashford	85,006	281,758	591,606	1,878
Cornwall	75,315	249,638	524,164	1,664
Eastford	65,619	217,498	456,681	1,450
Goshen	89,748	297,476	624,609	1,983
Sharon	96,156	318,715	669,205	2,125
Total	**411,843**	**1,365,085**	**2,866,264**	**9,101**

*Assumes 150 year period of wall-building.

References

Allen, E., 2003. Cornwall, 1800 and 1801, in: Bickford, C.P. (Ed.), Voices of the New Republic, Connecticut Towns 1800–1832, Volume I: What They Said. Connecticut Academy of Arts and Sciences, New Haven, CT, pp. 93–108.

Allport, S., 1990. Sermons in Stone: The Stone Walls of New England and New York. W.W. Norton & Company, New York.

Bachofer, F., Queneherve, G., Marker, M., 2014. The Delineation of Paleo-Shorelines in the Lake Manyara Basin Using TerraSAR-X Data. Remote Sens. 6, 2195–2212.

Barnosky, A.D., Hadly, E.A., Bascompte, J., Berlow, E.L., Brown, J.H., Fortelius, M., Getz, W.M., Harte, J., Hastings, A., Marquet, P.A., Martinez, N.D., Mooers, A., Roopnarine, P., Vermeij, G., Williams, J.W., Gillespie, R., Kitzes, J., Marshall, C., Matzke, N., Mindell, D.P., Revilla, E., Smith, A.B., 2012. Approaching a state shift in Earth's biosphere. Nature 486, 52–58.

Bart, V., 2015. *Photo GPS Extract,* http://pge.bvsoft.be, Accessed 12 December 2015.

Bell, M.M., 1985. The Face of Connecticut. State Geological and Natural History Survey of Connecticut, Hartford.

Bell, M.M., 1989. Did New England Go Downhill? Geogr. Rev. 79, 450–466.

Bennett, R., Welham, K., Hill, R.A., Ford, A., 2012. A Comparison of Visualization Techniques for Models Created from Airborne Laser Scanned Data. Archaeol. Prospect. 19, 41–48.

Bescoby, D.J., 2006. Detecting Roman land boundaries in aerial photographs using Radon transforms. J. Archaeol. Sci. 33, 735–743.

Boisvert, R.A., 2012. The Paleoindian Period in New Hampshire, in: Chapdelaine, C. (Ed.), Late Pleistocene Archaeology and Ecology in the Far Northeast. Texas A&M University Press, College Station, TX, pp. 77–94.

Bonfield, L.A., 2004. The Work Journal of Albert Bickford, Mid-Nineteenth-Century Vermont Farmer, Cooper, and Carpenter. Vt. Hist. 72, 113–159.

Boulanger, M.T., Lyman, R.L., 2014. Northeastern North American Pleistocene megafauna chronologically overlapped minimally with Paleoindians. Quat. Sci. Rev. 85, 35–46.

Bowles, O., 1939. The Stone Industries. McGraw Hill Book Company, New York.

Braje, T.J., Erlandson, J.M., 2013. Human acceleration of animal and plant extinctions: A Late Pleistocene, Holocene, and Anthropocene continuum. Anthropocene 4, 14–23.

Brown, A., Toms, P., Carey, C., Rhodes, E., 2013. Geomorphology of the Anthropocene: Time-transgressive discontinuities of human-induced alluviation. Anthropocene 1, 3–13.

Certini, G., Scalenghe, R., 2011. Anthropogenic soils are the golden spikes for the Anthropocene. The Holocene 21, 1269–1274.

Chapdelaine, C. (Ed.), 2012. Late Pleistocene Archaeology and Ecology in the Far Northeast, First. ed. Texas A&M University Press.

Chase, A.F., Chase, D.Z., Fisher, C.T., Leisz, S.J., Weishampel, J.F., 2012. Geospatial revolution and remote sensing LiDAR in Mesoamerican archaeology. Proc. Natl. Acad. Sci. U. S. A. 109, 12916–21.

Chilton, E.S., 2002. "towns they have none": Diverse Subsistence and Settlement Strategies in Native New England, in: Hart, J.P., Rieth, C.B. (Eds.), Northeast Subsistence-Settlement Change: A.D. 1700–1300. New York State Museum, Albany, pp. 289–300.

Chin, A., Fu, R., Harbor, J., Taylor, M.P., Vanacker, V., 2013. Anthropocene: Human interactions with earth systems. Anthropocene 1, 1–2.

CLEAR, 2015. Center for Land Use Education and Research. Connecticut's Changing Landscape, http://clear.uconn.edu/projects/landscape/index.htm. Accessed September 2, 2015.

Collier, M.J., 2013. Field Boundary Stone Walls as Exemplars of "Novel" Ecosystems. Landsc. Res. 38, 141–150.

Cooper, A., Turney, C., Hughen, K.A., Brook, B.W., McDonald, H.G., Bradshaw, C.J.A., 2015. Abrupt warming events drove Late Pleistocene Holarctic megafaunal turnover. Science, doi:10.1126/science.aac4315
Cronon, W., 1983. Changes in the Land. Hill and Wang, New York.
Cross, S.H., 1888. Manual with Rules and Orders for the use of the General Assembly of the State of Rhode Island, 1888-1889. E.L. Freeman & Son. Providence, RI.
Crow, P., Benham, S., Devereux, B.J., Amable, G.S., 2007. Woodland vegetation and its implications for archaeological survey using LiDAR. Forestry 80, 241–252.
Crutzen, P.J., Stoermer, E.F., 1999. The "Anthropocene." IGBP Newsl. 4, 17–18.
CTDEC, 2015. Department of Economic and Community Development, Connecticut Population by Town. http://www.ct.gov/ecd/cwp/view.asp?a=1106&q=250670. Accessed December 18, 2015.
CTECO, 2015. Connecticut Environmental Conditions Online, National Aerial Imagery Program (NAIP). http://www.cteco.uconn.edu/help/info_orthos2012.htm. Accessed September 2, 2015.
Dathe, A., Eins, S., Niemeyer, J., Gerold, G., 2001. The surface fractal dimension of the soil-pore interface as measured by image analysis. Geoderma 103, 203–229.
DEEP, 2015. Connecticut Department of Energy and Environmental Protection, Connecticut Quaternary Geology and Surficial Materials. http://www.ct.gov/deep/cwp/view.asp?a=2698&q=322898&deepNav_GID=1707. Accessed December 13, 2015.
Delcourt, P.A., Delcourt, H.R., 1987. Late-Quaternary Dynamics of Temperate Forests: Applications of Paleoecology to Issues of Global Environmental Change. Quat. Sci. Rev. 6, 129–146.
Dewberry, 2011. Project Report for the U.S. Corps of Engineers High Resolution LiDAR Data Acquisition and Processing for portions of Connecticut. Prepared for USDA-NRCS, September 2011.
Dewberry, 2012. Project Report for the U.S. Corps of Engineers High Resolution LiDAR Data Acquisition and Processing for portions of Connecticut. Prepared for USDA-NRCS, August, 2012.
Dodge, J.R., 1872. Statistics of Fences in the United States, in: Dodge, J.R. (Ed.), Report of the Commissioner of Agriculture for the Year 1871. United States Department of Agriculture, Government Printing Office, Washington D.C., pp. 497–512.
Donahue, B., 2004. The Great Meadow: Farmers and the Land in Colonial Concord. Yale University Press, New Haven, CT.
Doneus, M., Briese, C., Fera, M., Janner, M., 2008. Archaeological prospection of forested areas using full-waveform airborne laser scanning. J. Archaeol. Sci. 35, 882–893.
Dotterweich, M., 2013. The history of human-induced soil erosion: Geomorphic legacies, early descriptions and research, and the development of soil conservation - a global synopsis. Geomorphology 201, 1–34.
Edwards, L.E., 2015. What Is the Anthropocene? Eos (Washington. DC). 95.
Erlandson, J.M., 2014. Shell middens and other anthropogenic soils as global stratigraphic signatures of the Anthropocene. Anthropocene 4, 24–32.
Erlandson, J.M., Braje, T.J., 2013. Archeology and the Anthropocene. Anthropocene 4, 1–7.
ESRI, 2016. World Countries and World Countries (Disputed Boundaries) dataset, ArcWorld Supplement.
Evans, D.H., Fletcher, R.J., Pottier, C., Chevance, J.-B., Soutif, D., Tan, B.S., Im, S., Ea, D., Tin, T., Kim, S., Cromarty, C., De Greef, S., Hanus, K., Bâty, P., Kuszinger, R., Shimoda, I., Boornazian, G., 2013. Uncovering archaeological landscapes at Angkor using lidar. Proc. Natl. Acad. Sci. 110, 12595–12600.
Foley, S.F., Gronenborn, D., Andreae, M.O., Kadereit, J.W., Esper, J., Scholz, D., Pöschl, U., Jacob, D.E., Schöne, B.R., Schreg, R., Vött, A., Jordan, D., Lelieveld, J., Weller, C.G., Alt, K.W., Gaudzinski-

Windheuser, S., Bruhn, K.-C., Tost, H., Sirocko, F., Crutzen, P.J., 2013. The Palaeoanthropocene – The beginnings of anthropogenic environmental change. Anthropocene 3, 83–88.
Forsythe, W., 2007. On the Edge of Improvement: Rathlin Island and the Modern World. Int. J. Hist. Archaeol. 11, 221–240.
Foster, D.R., 1992. Land-use history (1730-1990) and vegetation dynamics in Central New England, USA. J. Ecol. 80, 753–771.
Foster, D.R., 1999. Thoreau's Country: Journey through a Transformed Landscape. Harvard University Press, Cambridge, MA.
Foster, D. R., and J. D. Aber eds. 2006. Forests in Time: The Environmental Consequences of 1,000 Years of Change in New England. New Haven, CT: Yale University Press.
Foster, D.R., Donahue, B., Kittredge, D., Motzkin, G., Hall, B., Turner, B., Chilton, E., 2008. New England's forest landscape: ecological legacies and conservation patterns shaped by agrarian history, in: Redman, C.R., Foster, D.R. (Eds.), Agrarian Landscapes in Transition: Comparisons of Long-Term Ecological & Cultural Change. Oxford University Press, New York, pp. 44–88.
Francis, R.A., 2010. Wall ecology: A frontier for urban biodiversity and ecological engineering. Prog. Phys. Geogr. 31, 43–63.
Frank, D.H., Fish, D., Moy, F.H., 1998. Landscape features associated with lyme disease risk in a suburban residential environment. Landsc. Ecol. 13, 27–36.
Fraser, J.A., Leach, M., Fairhead, J., 2014. Anthropogenic Dark Earths in the Landscapes of Upper Guinea, West Africa: Intentional or Inevitable? Ann. Assoc. Am. Geogr. 104, 1222–1238.
Gallagher, J.M., Josephs, R.L., 2008. Using LiDAR to Detect Cultural Resources in a Forested Environment: an Example from Isle Royale National Park, Michigan, USA. Archaeol. Prospect. 15, 187–206.
Ginsberg, C.A., 1988. Estimates and Correlates of Enumeration Completeness: Censuses and Maps in Nineteenth-Century Massachusetts. Soc. Sci. Hist. 12, 71–86.
Given, M., 2002. Maps, Fields, and Boundary Cairns: Demarcation and Resistance in Colonial Cyprus. Int. J. Hist. Archaeol. 6, 1–22.
Given, M., 2004. The Archaeology of the Colonized. Routledge, London.
Gordon, R.B., 2001. A Landscape Transformed: The Ironmaking District of Salisbury, Connecticut. Oxford University Press, New York.
Gordon, R.B., Raber, M., 2000. Industrial Heritage in Northwest Connecticut. Connecticut Academy of Arts and Sciences, New Haven, CT.
Greven, P.J., 1970. Four Generations: Population, Land, and Family in Colonial Andover, Massachusetts. Cornell University Press, Ithaca.
Guillemette, R., 2011. Painting a Picture with Walls. Past Times Newsl. Little Compt. Hist. Soc. Spring, 3,7.
Hall, B., Motzkin, G., Foster, D.R., Syfert, M., Burk, J., 2002. Three hundred years of forest and land-use change in Massachusetts, USA. J. Biogeogr. 29, 1319–1335.
Hamre, L.N., Domaas, S.T., Austad, I., Rydgren, K., 2007. Land-cover and structural changes in a western Norwegian cultural landscape since 1865, based on an old cadastral map and a field survey. Landsc. Ecol. 22, 1563–1574.
Hasho, S.L., 2012. Bound in stone: a landscape and architectural analysis of the Eastern Pequot Tribal Nation Reservation, Connecticut. MA Thesis, University of Massachusetts Boston, Andrew Fiske Memorial Center for Archaeological Research.
Hewes, L., Jung, C.L., 1981. Early Fencing on the Middle Western Prairie. Ann. Assoc. Am. Geogr. 71, 177–201.
Hill, M.M., Ouimet, W.B., 2015. Gullies as Markers of Holocene and Anthropocene Environmental Change in Southern New England. Paper presented at the *Association of American Geographers* meeting, April 2015, Chicago, IL.

Hoard, R.J., Prawl, T.M., 1998. The Origins and Evolution Rock Fences in Missouri. Mater. Cult. 30, 1–22.
Holcombe, H.G., 1950. Stone Walls in Eastern Connecticut. Antiq. 2, 24–31.
Holland, P.G., 1972. The Pattern of Species Density of Old Stone Walls in Western Ireland. J. Ecol. 60, 799–805.
Hooke, R.L., 1994. On the efficacy of humans as geomorphic agents. GSA Today 4, 217, 224–225.
Hooke, R.L., 2000. On the history of humans as geomorphic agents. Geology 28, 843–846.
Hooke, R.L., Martin-Duque, J.F., Pedraza, J., 2012. Land transformation by humans: A review. GSA Today 22, 4–10.
Humme, A., Lindenbergh, R., Sueur, C., 2006. Revealing Celtic fields from lidar data using kriging based filtering, in: Proceedings of the ISPRS Commission V Symposium. Dresden.
Hutson, S.R., 2015. Adapting LiDAR data for regional variation in the tropics: A case study from the Northern Maya Lowlands. J. Archaeol. Sci. Reports 4, 252–263.
Ives, T.H., 2013. Remembering Stone Piles in New England. Northeast Anthropol. 79–80, 37–80.
Ives, T.H., 2015. Cairnfields in New England's Forgotten Pastures. Archaeol. East. North Am. 43, 119–132.
James, P.E., 1929. The Blackstone Valley: a study in chorography in southern New England. Ann. Assoc. Am. Geogr. 19, 67–109.
Jefferson, A.J., Wegmann, K.W., Chin, A., 2013. Geomorphology of the Anthropocene: Understanding the surficial legacy of past and present human activities. Anthropocene 2, 1–3.
Jim, C.Y., 1998. Old stone walls as an ecological habitat for urban trees in Hong Kong. Landsc. Urban Plan. 42, 29–43.
Johnson, K.M., Ouimet, W.B., 2014. Rediscovering the lost archaeological landscape of southern New England using airborne Light Detection and Ranging (LiDAR). J. Archaeol. Sci. 43, 9–20.
Johnson, K.M., Ouimet, W.B., 2015. Impacts of Terrain Roughness on 18th–20th Century Land Use Distribution and Sediment Mass Transfer in Southern New England. Paper presented at the Geological Society of America annual meeting, Baltimore, MD. November 2015. *GSA Abstracts with Programs* 47(7): 239.
Johnson, K.M., Ouimet, W.B., and Raslan, Z. 2015. "Geospatial and LiDAR-based analysis of 18th to early 20th century timber harvesting and charcoal production in southern New England," Paper presented at the Geological Society of America Northeastern Section meeting, Bretton Woods, New Hampshire. March 2015. *GSA Abstracts with Programs* 47(3): 65.
Jones, B.D., Forrest, D.T., 2003. Life in a postglacial landscape: settlement-subsistence change during the Pleistocene-Holocene transition in Southern New England, in: Clements, D.L., Hart, J.P. (Eds.), Geoarchaeology of Landscapes in the Glaciated Northeast. University of the State of New York and State Education Department, Albany, pp. 75–90.
Krech, S., 1999. The Ecological Indian: Myth and History. W.W. Norton & Company, New York.
Land Use Consultants, AC Archaeology, 2007. Defining stone walls of historic and landscape importance. Report for the Department of Environment, Food, and Rural Affairs. Bristol, UK.
Langevin, T.N., 2011. Sedimentary Records of Rural Land Use Change at Church Farm in Ashford, Connecticut. Willimantic, CT.
Larned, E.D., 1874. History of Windham County, Connecticut, First. ed. Charles Hamilton, Worcester, MA.
Latham, J.P., Munjiza, A., 2004. The modelling of particle systems with real shapes. Philos. Trans. A. Math. Phys. Eng. Sci. 362, 1953–1972.
Lewis, M. (Ed.), 2007. American Wilderness: a New History. Oxford University Press, Oxford.
Lewis, Q., 2013. An Archaeology of Improvement in Rural New England: Capitalism, Landscape Change, and Rural Life in the Early 19th Century. PhD Dissertation, University of Massachusetts Amherst.

Lightfoot, K.G., Panich, L.M., Schneider, T.D., Gonzalez, S.L., 2013. European colonialism and the Anthropocene: A view from the Pacific Coast of North America. Anthropocene 4, 101–115.
Little, E.A., 2010. Limestone, Shell, and the Archaeological Visibility of Maize and Beans in New England: A Fertilizer Hypothesis, in: Chilton, E.S., Rainey, M.L. (Eds.), Nantucket and Other Places: The Legacy of Elizabeth Alden Little. SUNY Press, Albany, pp. 181–200.
Lothrop, J.C., Newby, P.E., Spiess, A.E., Bradley, J.W., 2011. Paleoindians and the Younger Dryas in the New England-Maritimes Region. Quat. Int. 242, 546–569.
Lundholm, J.T., Richardson, P.J., 2010. Habitat analogues for reconciliation ecology in urban and industrial environments. J. Appl. Ecol. 47, 966–975.
Ma, L., Konter, J., Herndon, E., Jin, L., Steinhoefel, G., Sanchez, D., Brantley, S., 2014. Quantifying an early signature of the industrial revolution from lead concentrations and isotopes in soils of Pennsylvania, USA. Anthropocene 7, 16–29.
MAGIC, 2015. Map and Geographic Information Center at University of Connecticut Libraries. Connecticut Historical Aerial Photography, http://magic.lib.uconn.edu/mash_up/aerial_index.html. Accessed September 2, 2015.
Manenti, R., 2014. Dry stone walls favour biodiversity: a case-study from the Appennines. Biodivers. Conserv. 23, 1879–1893.
MassGIS, 2015. Massachusetts Geographic Information System. Surficial Geology. http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/sg.html. Accessed December 13, 2015.
Merchant, C., 1989. Ecological Revolutions: Nature, Gender, and Science in New England. University of North Carolina Press, Chapel Hill.
Merritts, D., Walter, R., Rahnis, M., Hartranft, J., Cox, S., Gellis, A., Potter, N., Hilgartner, W., Langland, M., Manion, L., Lippincott, C., Siddiqui, S., Rehman, Z., Scheid, C., Kratz, L., Shilling, A., Jenschke, M., Datin, K., Cranmer, E., Reed, A., Matuszewski, D., Voli, M., Ohlson, E., Neugebauer, A., Ahamed, A., Neal, C., Winter, A., Becker, S., 2011. Anthropocene streams and base-level controls from historic dams in the unglaciated mid-Atlantic region, USA. Philos. Trans. R. Soc. 369, 976–1009.
Minnesota Population Center, 2015. National Historical Geographic Information System: Version 2.0 Minneapolis, MN: University of Minnesota 2011. http://www.nhgis.org, Accessed December 13, 2015.
Morse, N.B., Pellissier, P.A., Cianciola, E.N., Brereton, R.L., Sullivan, M.M., Shonka, N.K., Wheeler, T.B., McDowell, W.H., 2014. Novel ecosystems in the Anthropocene: A revision of the novel ecosystem concept for pragmatic applications. Ecol. Soc. 19(2), 12.
Mrozowski, S.A., 1994. The Discovery of a Native American Cornfield on Cape Cod. Archaeol. East. North Am. 22, 47–62.
Murray-Wooley, C., Raitz, K., 1992. Rock Fences of the Bluegrass. University Press of Kentucky, Lexington.
Myers, W.I., 1920. An Economic Study of Farm Layout. Cornell University.
National Archives, 2016. Nonpopulation Census Records. http://www.archives.gov/research/census/nonpopulation/#intro. Accessed April 13, 2016.
NH GRANIT, 2015. New Hampshire Statewide GIS Clearinghouse, Aquifers: Transmissivity. http://www.granit.unh.edu. Accessed December 13, 2015.
Norton, L.M., 2003. Goshen, 1812, in: Bickford, C.P. (Ed.), Voices of the New Republic, Connecticut Towns 1800-1832, Volume I: What They Said. Connecticut Academy of Arts and Sciences, New Haven, CT, pp. 113–120.
NYSGIS, 2015. New York State Geographic Information System. Surficial Geology. http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=667. Accessed December 13, 2015.
Opitz, R.S., Ryzewski, K., Cherry, J.F., Moloney, B., 2015. Using Airborne LiDAR Survey to explore Historic-era archaeological landscapes of Montserrat in the Eastern Caribbean. J. F. Archaeol. 40, 523–541.

Pagoulatos, P., 1990. Late Woodland and Contact Period Land-Use Patterns in Rhode Island: Continuity and Change. Bull. Massachusetts Archaeol. Soc. 51, 69–82.
Parent, J.R., Volin, J.C., Civco, D.L., 2015. A fully-automated approach to land cover mapping with airborne LiDAR and high resolution multispectral imagery in a forested suburban landscape. ISPRS J. Photogramm. Remote Sens. 104, 18–29.
Passoni, S., Pires, L.F., Cooper, M., 2014. Software ImageJ to Study Soil Pore Distribution. Ciência e Agrotecnologia 32, 122–128.
Perroy, R.L., Bookhagen, B., Chadwick, O.A., Howarth, J.T., 2012. Holocene and Anthropocene Landscape Change: Arroyo Formation on Santa Cruz Island, California. Ann. Assoc. Am. Geogr. 102, 1229–1250.
Petersen, J.B., Cowie, E.R., 2002. From Hunter-Gatherer Camp to Horticultural Village: Late Prehistoric Indigenous Subsistence and Settlement, in: Hart, J.P., Rieth, C.B. (Eds.), Northeast Subsistence-Settlement Change: A.D. 1700–1300. New York State Museum, Albany, pp. 265–288.
Prufer, K.M., Thompson, A.E., Kennett, D.J., 2015. Evaluating Airborne LiDAR for Detecting Settlements and Modified Landscapes in Disturbed Tropical Environments at Uxbenká, Belize. J. Archaeol. Sci. 57, 1–13.
Randall, A.R., 2014. LiDAR-aided reconnaissance and reconstruction of lost landscapes: An example of freshwater shell mounds (ca. 7500–500 cal B.P.) in northeastern Florida. J. F. Archaeol. 39, 162–179.
RIGIS, 2015. Rhode Island Geographic Information System, Land Cover & Land Use–2011, http://www.edc.uri.edu/rigis/data. Accessed September 2, 2015.
RIGIS, 2016. Rhode Island Geographic Information System, Glacial Deposits. http://www.edc.uri.edu/rigis/data. Accessed April 22, 2016.
Ruddiman, W.F., Ellis, E.C., Kaplan, J.O., Fuller, D.Q., 2015. Defining the epoch we live in. Science (80-.). 348, 38–39.
Silverman, D.J., 2003. "We Chuse to Be Bounded": Native American Animal Husbandry in Colonial New England. William Mary Q. 60, 511–548.
Silverman, D.J., 2005. Faith and Boundaries: Colonists, Christianity, and Community among the Wampanoag Indians of Martha's Vineyard, 1600-1871. Cambridge University Press, Cambridge.
Sinclair, N.R., Getz, L.L., Bock, F.S., 1967. Influence of stone walls on the local distribution of small mammals. Univ. Connect. Occas. Pap. Biol. Sci. Ser. 1, 43–62.
Sluyter, A., 2001. Colonialism and Landscape in the Americas: Material/Conceptual Transformations and Continuing Consequences. Ann. Assoc. Am. Geogr. 91, 410–429.
Smith, B.D., Zeder, M. a., 2013. The onset of the Anthropocene. Anthropocene 4, 8–13.
Steckel, R.H., 1991. The Quality of Census Data for Historical Inquiry: A Research Agenda. Soc. Sci. Hist. 15, 579–599.
Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., Ludwig, C., 2015. The trajectory of the Anthropocene: The Great Acceleration. Anthr. Rev. 2, 81–98.
Stone, J.R., Schafer, J.P., London, E.H., DiGiacomo-Cohen, M.L., Lewis, R.S., Thompson, W.B., 2005. Quaternary Geologic Map of Connecticut and Long Island Sound Basin. Scientific Investigations Map 2784.
Streeter, R., Dugmore, A. J., Lawson, I.T., Erlendsson, E., Edwards, K.J., 2015. The onset of the palaeoanthropocene in Iceland: Changes in complex natural systems. The Holocene.
Štular, B., Kokalj, Ž., Oštir, K., Nuninger, L., 2012. Visualization of lidar-derived relief models for detection of archaeological features. J. Archaeol. Sci. 39, 3354–3360.
Teale, E.W., 1974. A Naturalist Buys an Old Farm. Dodd, Mead & Co., New York.
Thorson, R.M., 2002. Stone by stone: the magnificent history in New England's stone walls. Walker & Company, New York.

Thorson, R.M., 2005. Exploring Stone Walls: A Field Guide to New England's Stone Walls. Walker & Company, New York.
Thorson, R.M., Harris, A.G., Harris, S.L., Gradie, R.I., Lefor, M.W., 1998. Colonial Impacts to Wetlands in Lebanon. Rev. Eng. Geol. 12, 23–42.
Thorson, R.M., Harris, S.L., 1991. How "Natural" Are Inland Wetlands? An Example From the Trail Wood Audubon Sanctuary in Connecticut, USA. Environ. Manage. 15, 675–687.
United States Census Bureau, 1850a. Seventh Census of the United States. Ancestry.com. Accessed September 2, 2015.
United States Census Bureau, 1850b. Seventh Census of the United States. Accessed at the Connecticut State Library, microfilm 317.46 fC76c 7a.
United States Census Bureau, 1870. Ninth Census of the United States. Ancestry.com. Accessed September 2, 2015.
United States Census Bureau, n.d. Agricultural Schedules 1850–1900. http://www.census.gov/history/pdf/agcensusschedules.pdf. Accessed September 2, 2015.
United States Department of Transportation, 2016. First American Macadam Road. http://www.fhwa.dot.gov/rakeman/1823.htm. Accessed September 2, 2015.
United States Geological Survey (USGS). 2015. National Elevation Dataset. http://nationalmap.gov/elevation.html. Accessed September 2, 2015.
VCGI, 2015. Vermont Center for Geographic Information, Surficial Geology Data (1:62,500). http://vcgi.vermont.gov/opendata. Accessed December 13, 2015.
Vogel, H.J., Kretzschmar, A., 1996. Topological characterization of pore space in soil—sample preparation and digital image-processing. Geoderma 73, 23–38.
Warren, G., 1914. Farm Management, Third. ed. The MacMillan Co., New York.
Waters, C.N., Zalasiewicz, J., Summerhayes, C., Barnosky, A.D., Poirier, C., Ga, A., Cearreta, A., Edgeworth, M., Ellis, E.C., Ellis, M., Jeandel, C., Leinfelder, R., Mcneill, J.R., Richter, D., Steffen, W., Syvitski, J., Vidas, D., Wagreich, M., Williams, M., Zhisheng, A., Grinevald, J., Odada, E., Oreskes, N., Wolfe, A.P., 2016. The Anthropocene is functionally and stratigraphically distinct from the Holocene. Science 351(6269), doi: 10.1126/science.aad2622
Wessels, T., 2010. Forest Forensics: A Field Guide to Reading the Forested Landscape. The Countryman Press, Woodstock, VT.
Westport Town Records, 2016. Dates referenced here range from 1787-1924. Available online from the Westport, Massachusetts Historical Society. http://wpthistory.org/research/. Accessed April 16, 2016.
Wilbour, B.F., 1970. Notes on Little Compton. Little Compton Historical Society, Little Compton, RI.
Zakšek, K., Oštir, K., Kokalj, Ž., 2011. Sky-View Factor as a Relief Visualization Technique. Remote Sens. 3, 398–415.

CHAPTER 5

Anthropocene landscape change and land use dynamics in post-17th century southern New England[4]

1. Introduction

Multiple studies have demonstrated that historic land use practices drastically alter landscapes in terms of forest structure and ecology (Bellemare et al., 2002; Delcourt and Delcourt, 1987; Foster, 1992; Hall et al., 2002; McDonald et al., 2008) as well as geomorphology (Brown et al., 2013; Dotterweich, 2013; Dotterweich et al., 2015; Jefferson et al., 2013; Merritts et al., 2011). The magnitude, timing, and extent of these processes are integral in considering the proposed geologic epoch termed the "Anthropocene" (Chin et al., 2013; Crutzen and Stoermer, 1999; Waters et al., 2016), or the conceptual "anthropocene" (Edwards, 2015; Ruddiman et al., 2015), both of which encapsulate the view that the landscape and environment have been measurably impacted by humans. Two major contributing factors of the Anthropocene that have been widely discussed, and that have occurred on a global scale over the past 10,000 years, are deforestation and the spread of agriculture (Barnosky et al., 2012; Ruddiman et al., 2015; Waters et al., 2016).

In southern New England, the imposition of English-style agriculture on the landscape in the 17th-19th centuries initiated widespread deforestation for pasture and tillage land resulting in erosion, changes in the transport and deposition of sediment in fluvial systems, and variation in the ecological distribution of species in the region (Cronon, 1983; Foster, 1992; Thorson and Harris, 1991; Thorson et al., 1998; Walter and Merritts, 2008). This classic story of historic land use change in New England often includes aspects of English-style husbandry such as cultivation, pasture, meadows, and woodlots (Bell, 1989; Cronon, 1983; Donahue, 2004; Foster et al., 1998; Harrison and Judd, 2011; Thorson, 2002), however, a majority of these studies fail to address two

[4] Johnson, K.M. and Ouimet, W.B. in preparation to be submitted to the *Annals of the American Association of Geographers.*

important factors associated with the dramatic changes introduced to this landscape by Europeans. First, though these studies do examine the percentage or area of land cover such as forest, tillage, or meadow within standard political boundaries such as parcel, town, county, or state, the current literature lacks rigorous geospatial analysis of the observed regional distribution of relict land use features and associated cumulative results of deforestation and intensive land use over time. Additionally, while focusing exhaustively on the transformative forces of agriculture and husbandry, there is almost no mention of charcoal production, a form of land use introduced by Europeans in the 17th century that was also responsible for widespread deforestation and associated effects that have been correlated with erosion, alteration of soil properties, and ecological change (Gordon, 2001; Ignatiadis et al., 2016; Johnson et al., 2015; Knowles and Healey, 2006; Knowles, 2013; Mikan and Abrams, 1996, 1995).

Following European settlement of the northeastern United States in the 17th century, iron production began on an industrial scale in eastern Massachusetts primarily using bog ore (NPS, 2016a) and became a major manufacture in other eastern states such as Pennsylvania and New Jersey by the 18th century (Kury, 1993; NPS, 2016b). Iron working on smaller scales in nearby Rhode Island made use of Cumberlandite, an ore native to the area and high in titanium, in addition to bog ore which was used elsewhere in the region. During European settlement of western portions of New England during the 1730s, limonite and goethite iron ore was discovered, mined, and this resulted in the first forges by the 1730s, and first blast furnaces in that area as early as 1762 (Gordon and Raber, 2000; Gordon, 2001; Kirby, 2011, 1998). The growing industry in western New England precipitated the settlement of numerous small towns in the northwestern part of Connecticut in what is now Litchfield County, an area that eventually became known as the "Salisbury Iron District" (Gordon, 2001; Harris, 1885; Knowles, 2013).

The regional-scale production of iron necessitated equally widespread production of charcoal to fuel blast furnaces, foundries, forges, and other iron-related manufactures. Charcoaling

alone would have contributed to widespread deforestation, yet coupled with historic agriculture the results were likely far more dramatic than recent research has presented. Charcoal was produced by piling logs on top of a flat earthen platform, and covering them with earth, leaves, and bark so that the wood would smolder slowly instead of fully burning (Barger, 2013; Svedelius and Anderson, 1875). Since the 19th century, this type of feature has been variably referred to as a *meiler*, coal pit, log pit, charcoal mound, charcoal hearth, charcoal kiln or charcoal burning platform (Barger, 2013; Brown, 1894; Deforce et al., 2013; Harris, 1885; Hesse, 2013; Lesley, 1859; Potter et al., 2013; Raab et al., 2015; Rolando, 1992; Samuelson, 1883; Svedelius and Anderson, 1875) (**Figure 1**). Typically in the United States, charcoal kiln or retort is used to refer to structures built from metal or brick that gradually replaced charcoaling by hand in the late 19th and early 20th centuries (MACRIS, 2016a; MACRIS, 2016b; Rolando, 1992). These allowed for more efficient production with predictable outcomes, and also marketable byproducts such as wood vinegar (Samuelson, 1883). Charcoaling occurred at regional scales in western New England and along the Appalachians to Georgia during the 18th to early 20th centuries to support the burgeoning iron industry in the United States (Gordon, 2001; Knowles, 2013; Potter et al., 2013), and also occurred at local scales as individual farmers also produced it for sale or their own use (Barger, 2013). We hereafter refer to these features as relict charcoal hearths (RCHs).

High resolution airborne Light Detection and Ranging (LiDAR) data has enabled identification and analysis at a regional scale for stone walls, dams, and other historic land use features under southern New England's dense forest canopy (Johnson and Ouimet, 2014), and recently for >20,000 RCHs in the northwestern and northeastern parts of Connecticut (Johnson et al., 2015). Airborne LiDAR has become a frequently used instrument in historical and archaeological landscape studies, especially in forested regions, because of its ability to map topographic relief through vegetation at extremely fine scales (e.g., Chase et al., 2012; Devereux et al., 2005; Fernández-Lozano et al., 2015; Opitz et al., 2015; Rosenswig et al., 2013). Despite the wide

range of studies across Europe that have used airborne LiDAR to locate and analyze RCHs (Bollandsås et al., 2012; Crow et al., 2007; Crutchley and Crow, 2009; Fruchart et al., 2011; Hesse, 2013; Mlekuz, 2013a; Raab et al., 2015; Risbøl et al., 2013; Trier and Pilø, 2012), few published studies in the United States have done so to date (Potter et al., 2013) (**Figure 2**).

This study uses high resolution LiDAR data coupled with historical records and surficial geology data to examine the spatial distribution of RCHs relative to stone walls, and demonstrates that the distribution and location of these relict land use features can be used as a reliable indicator for the distribution of past land use. Previous work has shown a high correlation (r^2 = 0.96) between the total length of stone walls mapped using LiDAR and the area of cleared, improved farmland in the 19th century (Johnson and Ouimet, 2016). In examining the distribution of and controls on historic land use, this study provides an integral piece often omitted from the classic story of southern New England's land use history, and demonstrates the ability of LiDAR coupled with historic records to reconstruct the spatial distribution of historic land use and historic forest extents across the landscape. The study also demonstrates the drastic extent to which humans altered this landscape following European settlement through analysis of two major relict land use features, thus providing critical evidence in interpreting human-land use dynamics and the Anthropocene in this region.

2. Study areas

The study area here includes several towns in Litchfield County which comprise a large portion of the historic Salisbury Iron District of northwestern Connecticut (Gordon, 2001), as well as two comparative towns in eastern Connecticut where charcoaling also occurred, but on a much smaller scale (**Figure 3, Table 1**). Towns for which both stone walls and RCHs have been digitized are Ashford, Cornwall, Eastford, Goshen, and Sharon, while RCHs have been digitized in all others. The town of Canaan was divided into Canaan and North Canaan in 1858; for the purposes of this

study the area encompassing both modern towns will be referred to as Canaan so as to consider pre-1858 sources within their proper political boundaries.

Topography in northwestern Connecticut is comprised of rugged, hilly uplands with northern hardwood and mixed deciduous-coniferous forest (Foster, 1992; Foster et al., 2008; Parent and Volin, 2014). Average elevation in this area is ~330m above sea level but reaches >700m in Salisbury. The area is bisected by the Housatonic River, whose many tributaries were used for early industry in the area (Cooper, 2003; Gordon, 2001). The area, like all of New England, was glaciated until ~17–18,000 years ago (Stone et al., 2005; Thorson, 2002). Glacial processes drastically shaped the land surface in this region in terms of differential till deposition and fluvial processes, and the resulting topography influenced subsequent land use by both Native American and later European groups following deglaciation (Bell, 1985; Donahue, 2004; Thorson, 2002).

This portion of the state, along with adjacent New York and Massachusetts, provided an ideal location for iron production as a result of its geology and topography (Kirby, 1998). The bedrock here is a product of the Taconic orogeny (~550–440 ma) which resulted in the uplift of coastal carbonate sea-floor sediments, later becoming valuable industrial marble and limestone deposits stretching from northern Vermont down through New York (Bell, 1985). Limestone was frequently used for flux in blast furnaces (Gordon, 2001; Kirby, 1998), and well-known limonite and goethite ore deposits exist along contacts of resulting calcite and dolomite marble and fine-grained schist. In addition to the bedrock geology, the forested hillslopes were noted as being too steep for agriculture, so were being used for charcoal production (Slosson, 2003). The location of the Housatonic, and proximity to the Hudson allowed for easy transport of iron to New York's markets (Secretary of the Treasury, 1833).

This hillier inland portion of New England was settled by Europeans much later than areas near the coast or major rivers. It was during this period of westward migration, due to population pressure and an increasing lack of farmland for third and fourth generation colonists (Greven,

1970), that iron ore was discovered in northwestern Connecticut. Towns in Litchfield County were first surveyed by European settlers in the early 18th century, and those in the study area were incorporated between 1739 and 1786, becoming heavily settled in later years as a result of the discovery of iron ore during early surveys and iron working (see **Table 1**). Despite the strong Native American presence recorded in this part of Connecticut (and elsewhere) during the 18th century (Norton, 2003; Slosson, 2003; Smith, 2003), and associated ecological impacts from thousands of years of hunting, gathering, and agricultural strategies (Cronon, 1983; Dincauze, 1987; Lothrop et al., 2011; McWeeny, 1994; Nicholas, 2000), the magnitude and extent of European land use that began during this time period was unparalleled (Cronon, 1983).

Historical accounts that discuss land use types in this area often compared land qualitatively with regard to its capability to support agriculture, and suggest that certain topography was more or less suitable for different land use types. More specifically, steep or rough hilly lands were often described as better for growing or harvesting wood, while flatter areas were better for agriculture, and lower, marshy areas were best for mowing or even grazing (see Warren, 1914). For example, in 1812 it was noted that the soil in Goshen was "better adapted to grazing than to ploughing" with lower, moist lands "unfit for ploughing" and better suited for "mowing and grazing"(Norton, 2003). Similar sentiments were expressed in nearby Kent during the same time period regarding the "proportion of land unfit for cultivation," and which was already being put to use producing charcoal for furnaces and forges (Slosson, 2003). In Sharon in 1807, it was noted that the eastern side of the town had "so much broken ground favorable to the growth of trees, and at the same time wholly unfit for cultivation" that residents could expect fuel wood for future generations (Smith, 2003).

The spatial distribution or absence of relict land use features visible in LiDAR provide a means to examine the differences described by historical sources between lands better suited for agriculture, and better suited for woodlots or lumbering. The combination of agriculture and

charcoal production during the 18th and 19th centuries would have resulted in extensive deforestation in this portion of Connecticut, possibly more so than elsewhere in southern New England. This likely also led to widespread erosion and sediment mobilization as has been documented in the Mid-Atlantic (Merritts et al., 2011). By the last half of the 19th century and early 20th century, widespread farm abandonment coupled with the cessation of iron working and associated charcoal production led to the drastic reforestation of these areas (see **Figure 2**) (Bell, 1989). Today, the towns presented in this study are >77% forest on average, with low levels of residential development, and a high proportion of relict land use features in protected municipal, state, or federal lands.

3. Methods

3.1 LiDAR processing & feature digitization

Two airborne LiDAR datasets were acquired through Connecticut Environmental Conditions Online (CTECO, 2016) in the form of .LAS tiles. The data were collected in December 2011 by Dewberry, Inc. for the USDA-NRCS in a 1,703 km^2 portion of northwestern Connecticut (Dewberry, 2011) and in November and December 2010 in a 4,589 km^2 area of eastern Connecticut. There is a point spacing of ~0.7m to ~1.0m throughout the study areas for 2-Ground classified points. After downloading the data, digital elevation models (DEMs) with a 1m pixel resolution were then created from points classified as “2-Ground” using the “LAS Dataset to Raster” function in ArcGIS 10.2.2. (ESRI, 2016).

Historic land use features were digitized by hand by examining both slope and hillshade rasters which were derived from the DEMs. RCHs were digitized by placing a point in the center of each circular feature, and stone walls were digitized by placing a vertex at endpoints, at abrupt changes in direction, or intersections with other walls. Automatic detection algorithms have been developed in Europe for RCHs (Schneider et al., 2015; Trier and Pilø, 2012; Trier et al., 2009) and

elsewhere for linear features (Bachofer et al., 2014; Humme et al., 2006). While the terrain in southern New England has made similar efforts difficult, it is our hope that these can be applied and used in future for the datasets in the region (see **Figure 3**).

3.2 Geospatial analysis

Several different analyses were performed using ArcGIS 10.2.2 and the R packages *spatstat. shapefiles*, and *maptools* to determine the spatial distribution of RCHs and stone walls in the study area, characterize their relationship to topography, and potential impacts on historic deforestation (Baddeley and Turner, 2005; ESRI, 2016; R Core Team, 2014; Stabler, 2013). The extent of clustering at regional and local scales was determined for RCHs using nearest neighbor ratios (NNR) and associated nearest neighbor distances. The density of RCHs per km^2 was calculated using the Point Density tool in ArcGIS 10.2.2, and the length of stone walls per km^2 was calculated using the Line Statistics tool. Both were calculated with a circular neighborhood containing a radius of 564.19 m to account for a search distance of 1 km, and an output cell size of 250m. Output raster data was clipped and reclassified for each study town to determine intensively improved or used areas where the number of RCHs per km^2 exceeded 15 hearths, and where the length of walls per km^2 exceeded 2,000 km.

It has been estimated that each RCH may have required 1–2 acres of forest each time it was in use (Straka, 2014). Thiessen polygons were calculated for each RCH in the study area to examine the area of forest that might have been impacted by each RCH. Additionally, buffers were calculated for each RCH with a radius of 50.76 m to account for an area equivalent to the estimated 2 acres (~8,094 m^2) (Straka, 2014). Because many RCHs occurred on steep hillslopes adjacent to wetlands, Thiessen polygons were clipped to the outer extent of the density kernel, which approximates the outer edges of RCH intensive land use.

3.2.1 Characterizing topographic relief and slope

In the study region the relief or roughness of the terrain varies in terms of its scale, and ranges from areas with blocky, glacially-deposited boulders which would have influenced land use decisions at human-perceived scales, to the first-order influences of geologic landforms on much broader scales. To characterize these differences a 1m LiDAR DEM was used where each pixel contained the interpolated average of all LiDAR ground-classified elevation point returns within it. Focal statistics were calculated in ArcGIS 10.2.2 with rectangular window sizes of 3m, 5m, 10m, 25m, 50m, 100m, 250m, 500m, 1000m, and 5000m to determine the range in elevation values over various sampling distances (**Figure 4**). This concept was also examined using the LiDAR point cloud by assigning the range in minimum and maximum elevation values from points to a pixel cell based on sampling distance size. Using this method, the resolution of the raster increased with each sampling distance size, thus focal statistics is preferable because it allows for increased sampling distance of elevation values while maintaining a 1m pixel resolution.

Pixel statistics were extracted to 2m-wide buffers that were generated 4m away from each stone wall centerline and to 2m buffers that were 8m away from each RCH so as not to include the topographic signature of each feature in results. To further characterize the terrain in areas where only specific land use types occur, polygons were generated to encompass areas where we observe only RCHs, only stone walls, or areas where there were no discernable relict historic land use types. Over 100,000 random points were generated within these zones and values from each of the relief rasters were extracted to these points.

Slope statistics for each feature type were also calculated in a similar manner. Minimum, maximum, and average slope for the area around each feature was extracted using 2m buffers that were 4m and 8m from stone walls and RCHs respectively (**Figure 5**). To assess the significance of observed slope values for RCHs, the same number of points with 2m-wide buffers was generated 30 times in random locations within the study area, and statistics for those values were also extracted.

3.3 Archival documents and maps

Historic maps and archaeological records for the state of Connecticut were examined to determine locations of features associated with the iron industry in Litchfield County, CT (MAGIC, 2016; OSA, 2014). The approximate locations of blast furnaces, foundries, forges, ore beds, mining operations, and other associated features were digitized from Hopkins' 1854 Litchfield County map (MAGIC, 2016). Precise furnace locations, names, and dates of operation were derived from well-known secondary sources (Gordon and Raber, 2000), 19th century publications by the American Iron Association (Lesley, 1859), historic aerial imagery (MAGIC, 2016b) and LiDAR data. Annual input and output materials and quantities (e.g., bushels of charcoal, tons of ore) for blast furnaces, forges, charcoal producers, and other associated manufactures were acquired and tabulated at the town level from the 1850 U.S. Federal Census Non-Population Schedule for Manufacturing (United States Census Bureau, 1850a). For area related to agriculture, improved land and unimproved land, as well as the number of farms at the town level were acquired and tabulated from the 1850 U.S. Federal Census Non-Population Schedule for Agriculture (United States Census Bureau, 1850b).

4. Results and Discussion

The results of this analysis demonstrate that there is a strong relationship between the distribution of relict land use features in this region of Connecticut with regard to topographic relief and slope, as well as with historical reported estimates for specific land use types related to manufacturing and agriculture. Furthermore, we find that the distribution and magnitude of these land use features can be used in conjunction with historical data to examine or understand the spatial extent and amount of historic deforestation in these areas. Overall, these results support historical sources that discuss the merits of various topography for specific land use types, but provide novel insights into the spatial distribution of relict land use features using LiDAR and

provide further analysis of human-land use dynamics in Connecticut with implications for elsewhere in southern New England.

4.1 Spatial distribution of land use features and topography

The widespread distribution of RCHs and stone walls combined that are visible using LiDAR data reveals not only spatial variation in distribution and clustering, but also the degree to which historic land use impacted to the landscape in this region. High resolution airborne LiDAR data has revealed >20,000 RCHs in northwestern Connecticut and >15,000 stone walls totaling 1,340 km in Cornwall, Goshen, and Sharon where both types of features are digitized completely. The densities of each type of feature vary across the landscape; the length of stone walls in some locations exceeds 11 km/km^2 while RCHs can reach as high as $186/km^2$ in others (**Figure 6, Table 2**). RCHs exhibit clustering at regional scales (Nearest Neighbor Ratio = 0.43), which is likely a result of topographic controls and the prevalence of steep terrain in the area. At finer scales, however, RCHs are regularly spaced and even dispersed (NNR = 1.36) (Clark and Evans, 1954). This suggests that while the overall regional distribution of RCHs is influenced by first-order trends such as topography, their regular or dispersed placement at finer scales is likely a result of individual decision-making processes by colliers or woodcutters and related to forest characteristics such as the location of old growth or specific tree species types, as well as the number of times or length of time each RCH may have been used.

There is a clear inverse relationship between the distribution of RCHs and the distribution of stone walls in study areas where both features are digitized, suggesting that specific areas would have been amenable to each land use type as advocated in historical accounts. In some locations, there is an overlap between areas where RCHs > $15/km^2$ and where stone walls > $2km/km^2$ (**Figure 6C, Table 2**), suggesting that some areas were not used exclusively for these land use types. While features are not evenly dispersed throughout these overlapping areas, and maintain

discrete dispersal, in some instances we do observe RCHs that appear within the bounds of stone wall-lined fields (see **Figure 2**). It has been documented that abandoned agricultural fields were sometimes purchased by iron companies so that second-growth forest stands could be harvested and converted to charcoal (Thomas J. Dodd Research Center, 2016). These areas of overlap also likely occur on more moderate slopes and areas of topographic relief, which could have been amenable to both land use types to a certain degree. There is a noticeable difference in the amount of overlap in towns where charcoal production occurred heavily (**Table 2**), and those towns where little to no charcoal production took place. This suggests that in towns where charcoaling occurred, land that might have been amenable to plowing may have been used for charcoal production, or for charcoal production subsequent to agriculture.

4.1.1 Influence of topographic relief and slope

Many historic sources note the rough topography of the northwestern part of Connecticut (Allen, 2003; Slosson, 2003; Smith, 2003). Historic documents that discuss agricultural practice during this time period advocate using specific types of land for specific husbandry practices, and especially so under the guise of land "improvement" (Cooke, 2003; Forsythe, 2007; Izard, 2003; Lewis, 2013). Specifically, these sources advocate using steeper slopes for pasture or woodlots rather than tillage, because steep tilled slopes exacerbated erosion and caused already-marginal soils to deplete at high rates (Foster, 1999; Johnson et al., 2015; Warren, 1914). Topography was often considered a major factor in determining whether land was amenable to certain types of use, and the topic often appears in county and town histories, as well as agricultural journals (Allen, 2003; Cronon, 1983; Foster, 1999; Slosson, 2003; Warren, 1914).

Despite numerous historical accounts discussing topography as related to historic land use, topography has rarely been used alone as an indicator of the spatial distribution of historic land use and its implications for the modern landscape (Benjamin et al., 2005; Donahue, 2004; Eberhardt et

al., 2003; Hall et al., 2002, 1995; Iverson, 1988). Topographic relief and slope are common metrics used to examine the land surface, and have been calculated in a variety of ways often to characterize the relationship between biological and physical factors of the landscape (Benjamin et al., 2005; Black et al., 2003; Grohmann et al., 2009; Kreslavsky et al., 2013; Sappington et al., 2007; Shepard et al., 2001). Topography has often been coupled with land use to examine a wide range of other environmental variables such as pollutants, wildfire, water quality, plant species diversity, forest composition, and farmland abandonment (Benjamin et al., 2005; Eberhardt et al., 2003; Hall et al., 2002). In New England prior to this study, topographic characteristics such as slope and roughness were used as one of many metrics to examine the relationship between historic land use and the current forest cover (Cogbill et al., 2002; Foster et al., 1998), but sparingly in examining the distribution of historic land use alone (Eberhardt et al., 2003).

Our results demonstrate that topographic relief and slope have significantly influenced the distribution of both stone walls, which are representative of agricultural land, and RCHs which are representative of timber harvesting and charcoal production (**Figure 7**). These results expand upon the suggestion by historical accounts that cultivated land was more likely to have occurred on flat, even terrain, while steep and rocky areas were best left for woodland. We find that there are also areas with no evidence of relict land use features at all, suggesting that these areas were not amenable to either type of land use.

RCHs occur on slopes that average 10.1 degrees. This is significantly ($p=0.032$) steeper than either stone walls (7.6 degrees) or the maximum values obtained after running 30 random simulations of >20,000 points (9.0 degrees). Despite the small overlap between the datasets, the distributions are different which indicates a slight preference for building stone walls on lower slopes and RCHs on more moderate or steep slopes. Both of these diverge from the distribution for randomly placed points throughout the region, suggesting that though the landscape in this area has steeper average slopes, relict land use features appear differentially within specific ranges

(**Figure 7A**). Raster values representative of overlapping land use types have a mean slope of 10 degrees, which confirms that both walls and RCHs can occur in similar topographic locations despite their general distributions. While there are few other studies that have examined slope with regard to the distribution of historic land use in this region, (Eberhardt et al., 2003) also found a significant (p=0.004) difference between slopes for plowed land (2.3), open land (9.3), and woodland (6.5) amongst 19th century land use types on Cape Cod, Massachusetts.

Topographic relief, like slope, appears to have influenced the distribution of stone walls and RCHs in this area (**Figure 7B**). At all of the focal windows, we find differences between topographic relief for stone walls, RCHs, and areas where no relict land use features are observed. These differences are most pronounced at focal windows of 50 to 1000, suggesting that broader topography across the landscape influence the observed spatial distribution of these features more than scales of individual perception, ranging from 3m to 10m (**Figure 7C**). At a focal window size of 100m stone walls occur in areas with a mean topographic relief of 12m, RCHs occur in areas with a mean topographic relief of 27m, and areas where neither occur have a mean of 41m, though have a maximum of 121m. The bimodal distribution of areas where neither feature occurs suggests that areas of lower relief in this category are marshy, wet areas while higher relief areas are likely bedrock outcroppings or steep, rocky areas which were not amenable to either type of land use.

4.2 Implications for historic land use and deforestation

The spatial distribution of both stone walls and RCHs suggests that towns where both occurred were extensively deforested during the 18th and 19th centuries, and especially in ~1850, which is widely considered to be the peak of agricultural deforestation in southern New England, and which is also the peak of iron furnace operation and thus likely charcoal production in the area (Foster et al., 2008; Gordon, 2001; Merchant, 1989; Ouimet et al., 2015) (**Figure 8**). While we do not observe RCHs so densely clustered in towns outside of the Salisbury Iron District, it is likely that managed woodlots and lumber-harvesting activities occurred on portions of the landscape with

similar topographic properties. Harvested lumber would have been used for fencing, house building, fuel, exported as boards or shingles, or in other manufacturing (Allen, 2003). Archival data from the U.S. Federal Census Non-Population Schedules for Agriculture and Manufacturing provides a supplemental source in examining the spatial dynamics associated with historical land use.

4.2.1 Historic land use dynamics and agriculture

The agricultural census categorized the area of each farm in each town as either improved or unimproved acres, with the total of the two comprising the total amount of farmland (United States Census Bureau, n.d.). Improved land was defined as "cleared and used for grazing, grass, or tillage, or which is now fallow" while unimproved land was defined as "a wood lot or other land at some distance but owned in connection with the farm, the timber or range of which is used for farm purposes" (United States Census Bureau, n.d.). The total amount of reported farmland rarely equals the area of the town. Unreported areas have occurred in other documentary records for Connecticut (Waggoner, 2003), and indicate regions that may have been water bodies, unsurveyed or uninhabited by European settlers, another type of land use, or generally a source of error (Ginsberg, 1988; Steckel, 1991) (**Table 3**). Additionally, the 1850 schedule excluded any farms that made < $100 in profit during that year, so it is likely that farms of smaller acreages may have also been excluded from these estimates (United States Census Bureau, n.d).

There is a strong correlation between improved land area in 1850 and areas where the length of stone walls is >2 (R^2 = 0.97) or >3 km/km^2 (R^2 = 0.98) which is derived from the spatial analysis presented in section 4.1 (**Figure 9A**). Despite the strong correlation, more land was cleared per town in total than predicted by 1850 improved land alone. This is likely a result of cumulative deforestation for agriculture over time, to the point where over 80% of the entire town was cleared solely for agriculture at some point (Johnson and Ouimet, 2016). So while there is a strong relationship, the distribution of stone walls is more a reliable indicator that specific areas of

land were cleared for agriculture at some point in time and is therefore a more reliable marker of the spatial distribution of historic agricultural practice.

Conversely, areas that were listed as unimproved during 1850 have a strong correlation ($R^2 = 0.92$) with areas of towns where RCHs occur >15/km^2 and where woodlots, and not tillage land, would have been more common (**Figure 9B**). Foster and colleagues (Foster et al., 1998) found similar results in adjacent areas of Massachusetts, where there was strong correlation between area that had been mapped as woodland in 1830 and lands deemed “unimprovable” in the 1830 state census records. This indicates that areas mapped as forest in 1830 were comprised of “wooded areas, cut-over and re-growing forest, and wooded wetlands and rocky areas unsuitable for agriculture…” (Foster et al., 1998). Thus in towns where charcoaling did not occur, it is probable that the land would have been used for managed woodlots and likely not harvested at industrial-level scales.

4.2.2 Charcoal production and forest use

Towns where RCHs occur most frequently and are most widely distributed appear to have had much more area related to charcoaling than expected in 1850, suggesting that charcoaling may have been more widespread in later years, or a cumulative deforestation process over time (see **Figure 9B**). Despite this reported widespread deforestation for charcoal production, data from the 1850 U.S. Federal Census Non-Population Schedule for Manufacturing shows a small amount of charcoal produced in the study area in proportion to the amount consumed (**Table 3**). Because small operations that made < $500 in 1850 were excluded from the Census, this suggests that the production of charcoal in 1850 was undertaken by various smaller companies or individuals, so that it may not have been reported in the Census (National Archives, 2016; United States Census Bureau, 1850a). It is also possible that charcoal was being imported from nearby towns; both Mount Washington and Egremont, adjacent towns in Massachusetts, reported >190,000 bushels of

charcoal produced in 1850 combined. The overall low area and low production rates in 1850 suggest that charcoal may have been produced locally for furnaces either prior to that time, after that time, or cumulatively over the course of the period of iron production. For example, while the 1880 census does not provide the quantity of bushels, it does provide lists of manufactures and associated labor. For the same study towns, it shows that both Cornwall and Sharon employed 67 individuals producing charcoal during that time period, whereas they had not been included in 1850 records (United States Census Bureau, 1880). This suggests that charcoal production in those two towns may have exceeded 1850 regional levels, or that the process had condensed into larger, more controlled industrial operations.

Charcoal consumption in 1850 alone for 8 towns in Litchfield County comprised ~14 km^2 of forest, if using accepted conversion rates of 38 bushels of charcoal per 1 cord of wood, and 30 cords of wood per acre (Straka, 2014)(**Figure 10A**). Over 4 million bushels of charcoal were used in 74 manufacturing processes related to iron in only 8 of the towns in Litchfield County (**Table 3**), with blast furnaces using an average of ~240,000 bushels each, and 2.6 million bushels total (**Figure 10B**). In 1812, Barzillai Slosson wrote of Kent that "The proportion of land unfit for cultivation is so great that were wood employed for no other use than for fuel, there would probably never be a scarcity. Yet within a few years the consumption by means of the forges for making iron has been so great, that should it continue for some time longer, the scarcity will be great" (Slosson, 2003). The 1850 Schedule of Manufacturing also documents that iron companies harvested wood in the region to produce lumber as well. Hunts, Lyman & Co. and Barnum, Richardson & Co as well as several other well-known companies reported >7,000 logs harvested for lumber alone in Canaan and Salisbury. It was common for companies to own large tracts of woodland, and in 1890, Barnum & Richardson owned over 100 acres of surveyed land used solely for proprietary wood lots (Thomas J. Dodd Research Center, 2016).

The amount of forest area used associated with charcoal production would have depended on the tree species available, the age of the timber, the skill of the collier, and the size of the hearth (Straka, 2014). Thus the conversion rates of bushels, cords, and acres associated with estimating the area of forest needed to produce one bushel of charcoal are variable. The most commonly used historical measure for charcoal was one bushel, equivalent to ~0.035 m^3. Published estimates range from 30–40 bushels produced in an RCH per cord of wood (Straka, 2014). We find an average of 37 bushels of charcoal produced per cord of wood with a range of 24–53 bushels using the 1850 U.S. Federal Census Non-Population Schedule for Manufacturing for several towns in northwestern Connecticut and adjacent Massachusetts (**Table 3**). Eastern woodlands in the 19th century were primarily second-growth, and are estimated to have allowed for ~30 cords of wood per 1 acre (Straka, 2014), though this likely varied depending on the tree species, year of growth, or size (see below for further discussion).

One charcoal hearth is estimated to have used 25–35 cords of wood (associated with ~1–2 acres of cleared forest) and was able to produce 900–1,200 bushels of charcoal (Straka, 2014). These conversions suggest that for the study towns where historic manufacturing data is summarized, between ~2,900 and ~4,100 would have been needed to supply the reported iron manufacturing businesses for that one year (**Table 3**). This number represents only ~24% of the number of RCHs we observe in these towns combined, ranging from 6% of those observed in Sharon to >40% of those observed in Canaan, Salisbury, and Warren.

The spatial extent of forest clearing can be estimated using both Thiessen polygons or buffering approaches. In areas where charcoaling occurred, RCHs are densely packed, and 89% of RCHs occur in areas where densities are >15/km^2. The average acreage of the Thiessen polygon ranges from 1–1.5 acres on finer scales where RCHs are densely clustered, to 4.8 acres for polygons that have their centroid within areas demarcated by the density kernel (**Figure 11**). In locations near wetlands or low, swampy areas, peripheral polygons are larger as clustering dissipates

(**Figure 11A**). Buffers with a radius of 50.76m approximate an area of 2 acres around each hearth, and there is a clear variation in some cases between the area of a buffer and area of a Thiessen polygon. This suggests that the size of Thiessen polygon represents the extent to which a collier traveled to get an acceptable amount of wood for the hearth. Forest area closest to the hearth could have been softwood, so the collier would have had to collect more, or go further to obtain hardwood, to produce quality charcoal (Straka, 2014). This would have also occurred if the area was comprised of relatively recent tree growth which would have required more trees than old growth (Baldwin, 1942; Straka, 2014). Additionally, the area of Thiessen polygon could also be related to the number of times each hearth was used. Recent work has shown that hearths were frequently used more than once though the amount of time between use has not been confirmed (Ignatiadis et al., 2016). It is possible that larger Thiessen polygons represent hearths where the 2 closest acres were harvested and made into charcoal, and subsequent further acreages were then harvested and made into charcoal shortly thereafter (**Figure 11**).

5. Implications and Conclusions

Overall, this study has demonstrated that LiDAR prevails as a revolutionary tool in identifying and analyzing relict land use features in this densely forested region of the northeastern United States. The spatial distribution of those features with regard to topography is a reliable indicator of past land use practices, and that the human-land use dynamics of southern New England becomes a much more nuanced process when including the widespread deforestation of the landscape for charcoal production into typical land use histories.

Geospatial analysis of relict land use features derived from LiDAR also allows for interpretations of historic land use dynamics that are not possible using traditional archival research and historical data, especially with regard to the cumulative use of land over multiple decades. Our results have shown that the relationship of relict land use features is related to the

dichotomy of improved vs. unimproved land in northwestern CT well, due to the location of charcoal hearths, while in other locations the lack of hearths suggests that land might have been used solely for woodlots, or other uses.

Overall, these features demonstrate a lasting human impact on the landscape in this region, and suggest that further studies are necessary to utilize the regional extent of LiDAR coupled with other data to ascertain the extent of a range of impacts ranging from erosion and sediment transport, to alteration of soil properties, and changes in the distribution of various plant and animal species (Foster, 1992; Merritts et al., 2011; Mikan and Abrams, 1995). Coupled with intensive agriculture, charcoal production in support of the iron industry likely had a significant impact on the landscape in this region, as it did with other regions that experienced large-scale iron production in the United States such as the Mid-Atlantic, and even the southeast (Lesley, 1859; Merritts et al., 2011; Potter et al., 2013).These various impacts resulting from historic land use differ drastically from natural disturbance processes that are inherent to any landscape (Foster et al., 1998), and the use of LiDAR coupled with other regional data allows for regional examination of the drastic land use change following European colonization of this region in the 17th century.

Figures

Figure 1

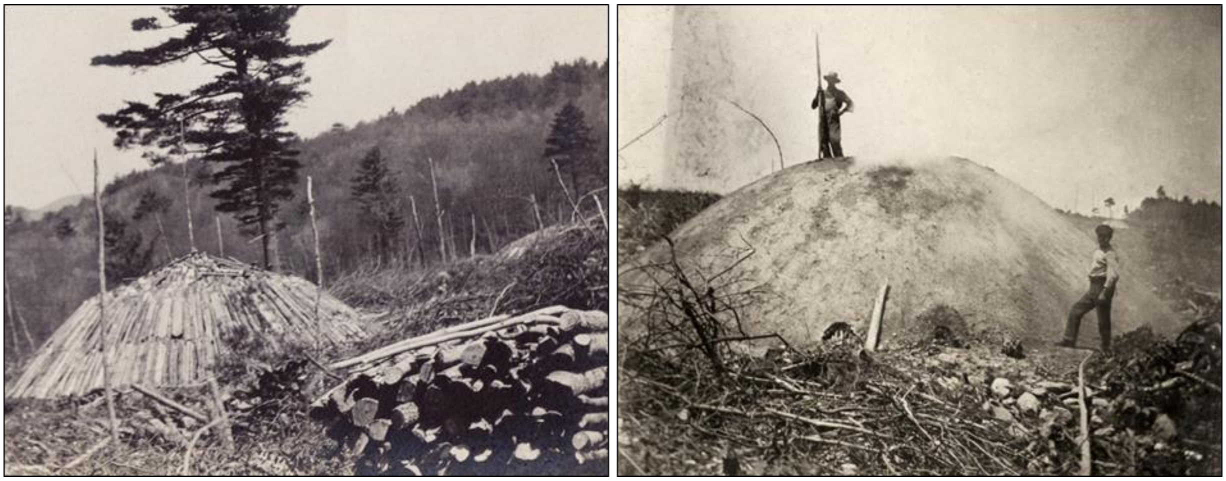


Figure 2

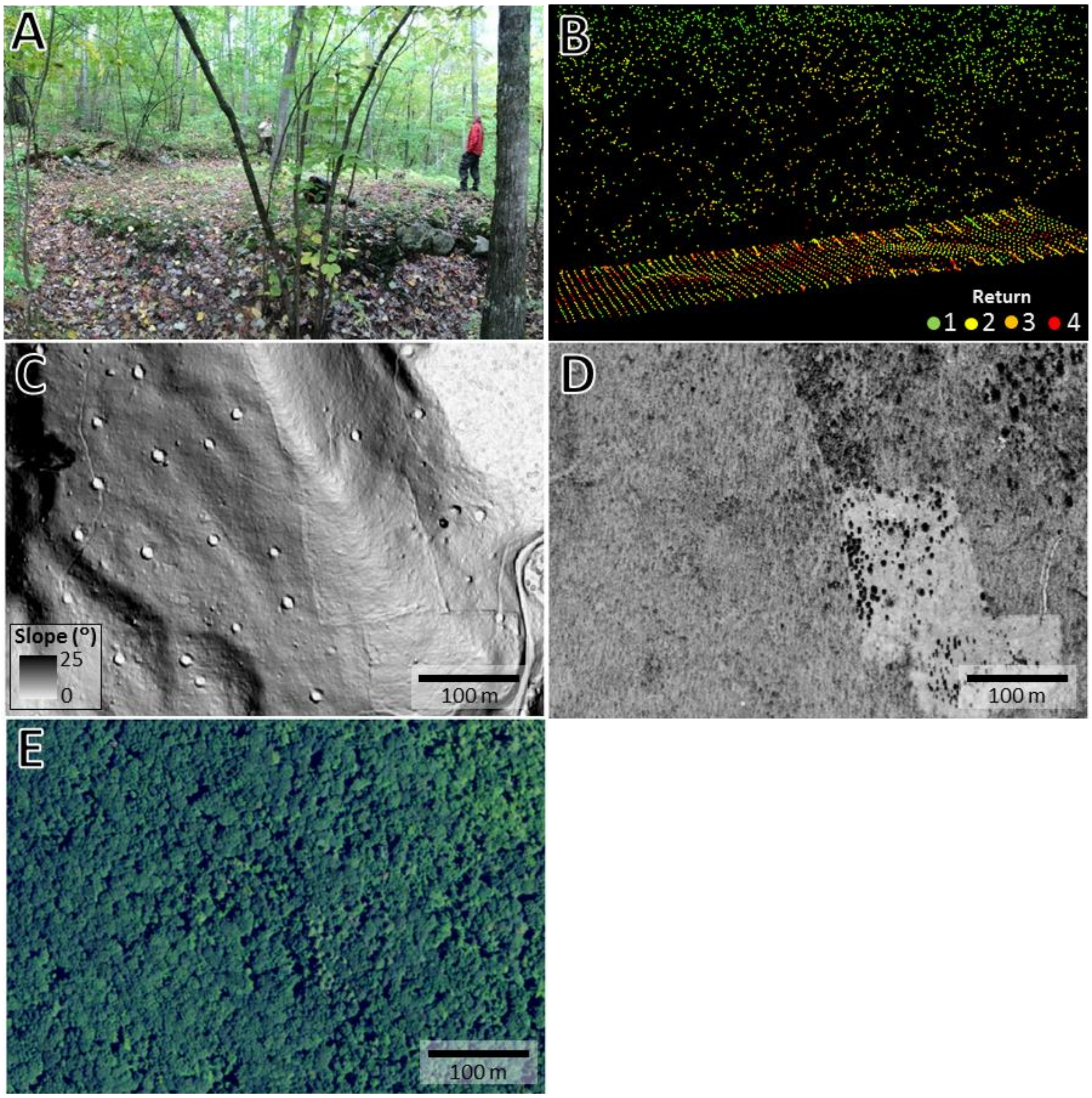


Figure 3

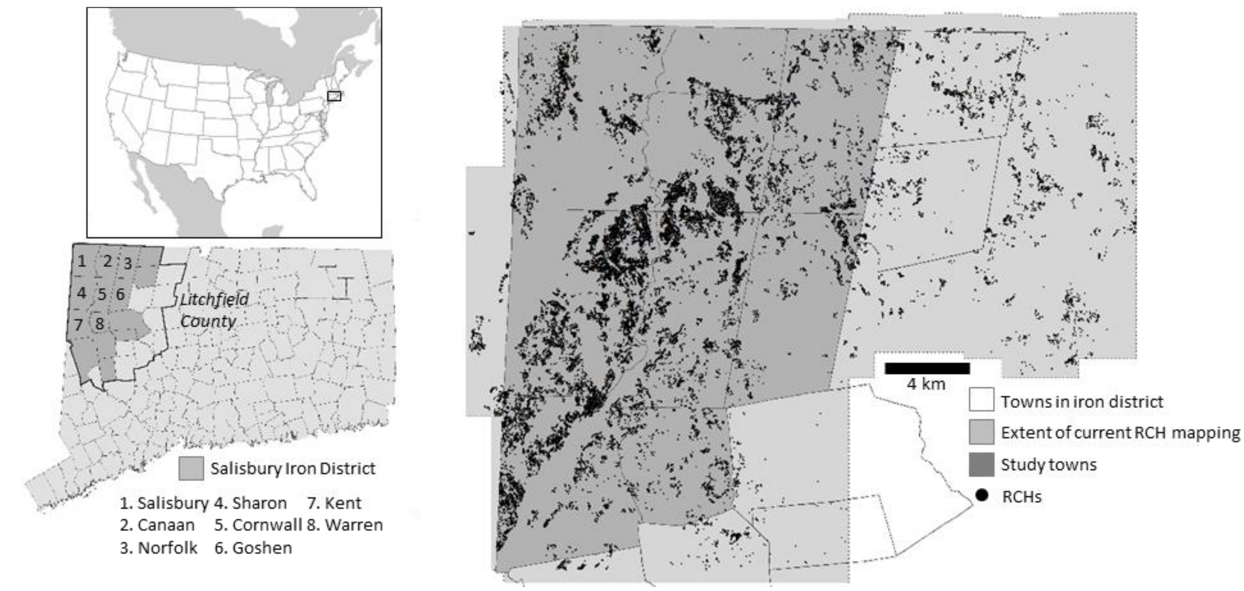

1
2
3
4
5
6
7
8
Litchfield County
Salisbury Iron District
1. Salisbury
2. Canaan
3. Norfolk
4. Sharon
5. Cornwall
6. Goshen
7. Kent
8. Warren
4 km
Towns in iron district
Extent of current RCH mapping
Study towns
RCHs

Figure 4

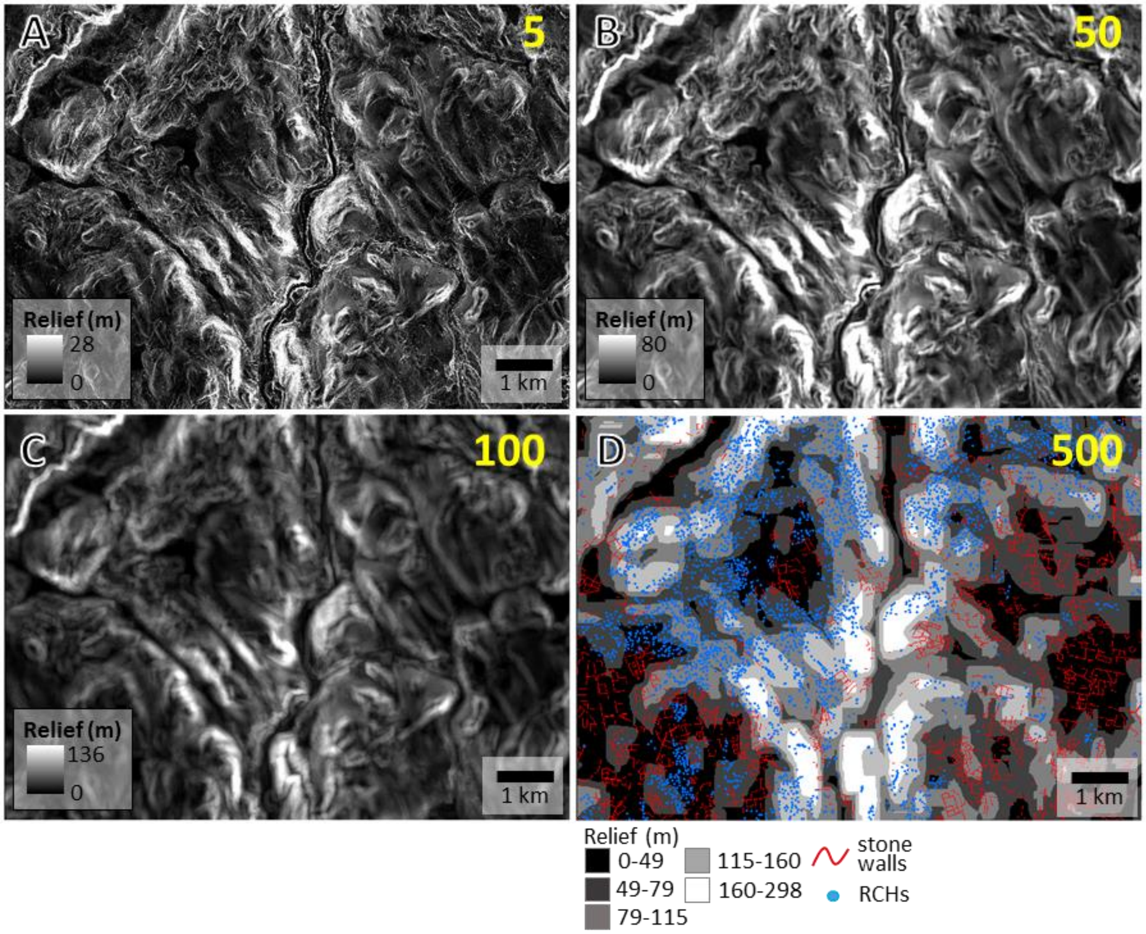
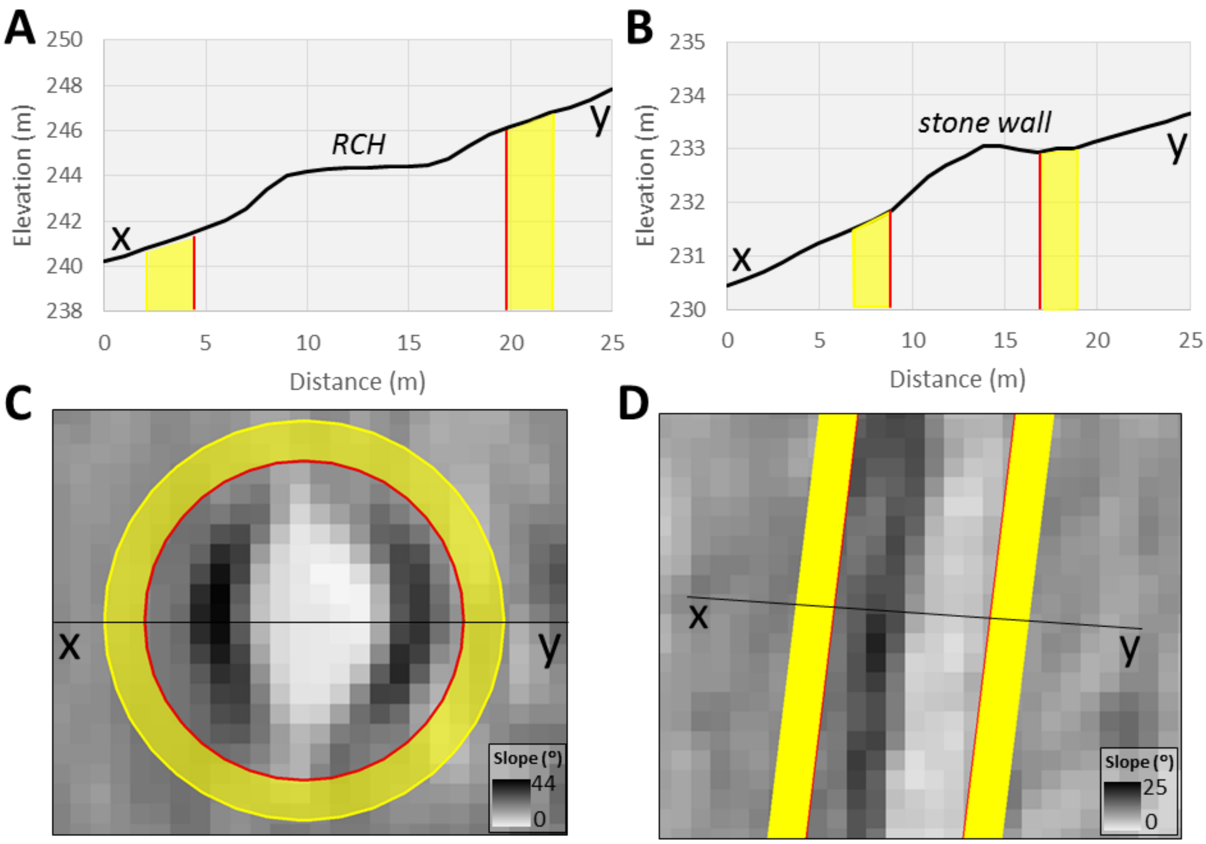

A
5
Relief (m)
28
0
1 km
B
50
Relief (m)
80
0
C
100
Relief (m)
136
0
1 km
D
500
1 km
Relief (m)
0-49
49-79
79-115
115-160
160-298
stone walls
RCHs

Figure 5



A
Elevation (m)
250
248
246
244
242
240
238
0
5
10
15
20
25
Distance (m)
RCH
x
y
B
Elevation (m)
235
234
233
232
231
230
0
5
10
15
20
25
Distance (m)
stone wall
x
y
C
x
y
Slope (°)
44
0
D
x
y
Slope (°)
25
0

Figure 6

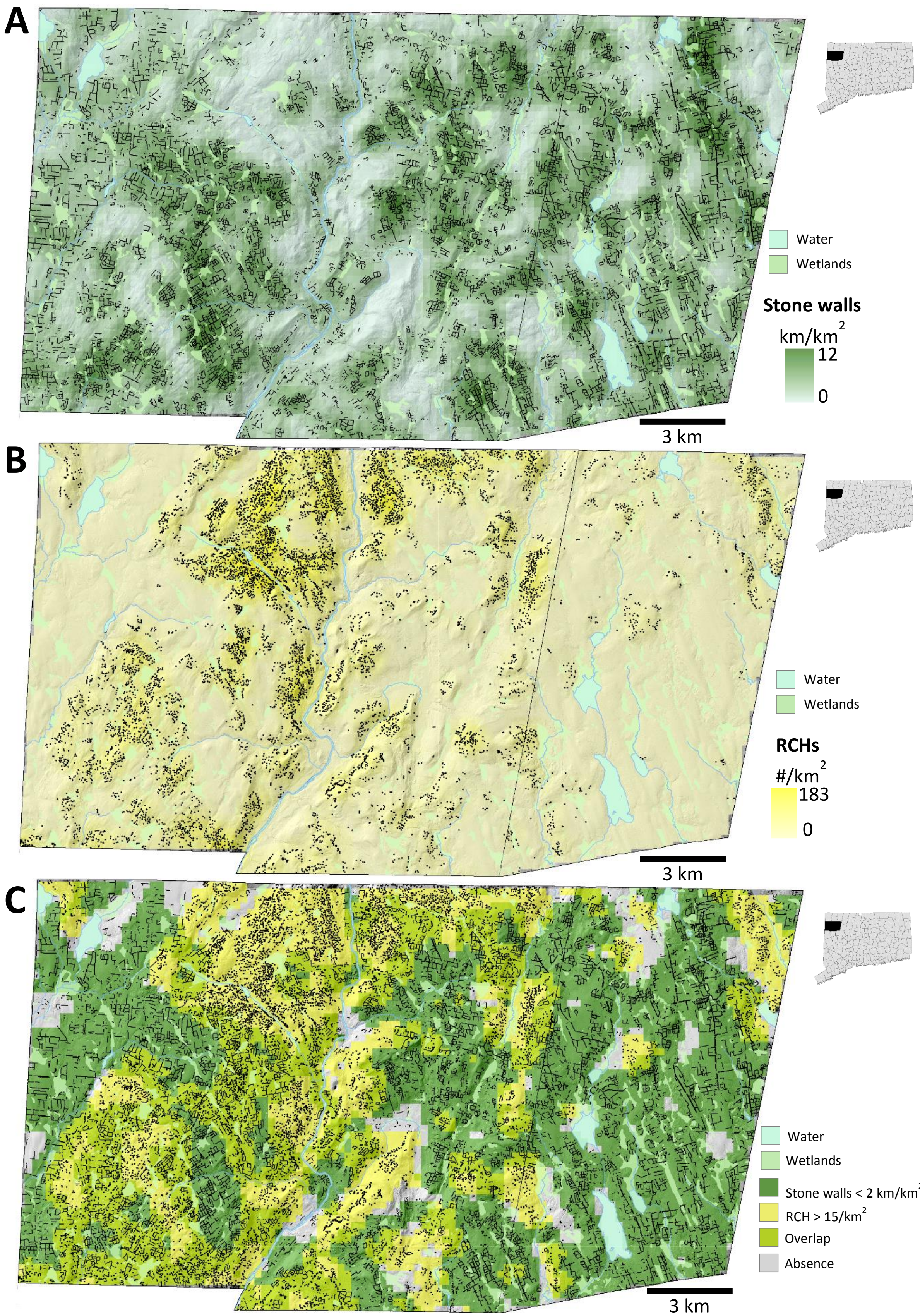

A
Water
Wetlands
Stone walls
km/km²
12
0
3 km
B
Water
Wetlands
RCHs
#/km²
183
0
3 km
C
Water
Wetlands
Stone walls < 2 km/km²
RCH > 15/km²
Overlap
Absence
3 km

Figure 7

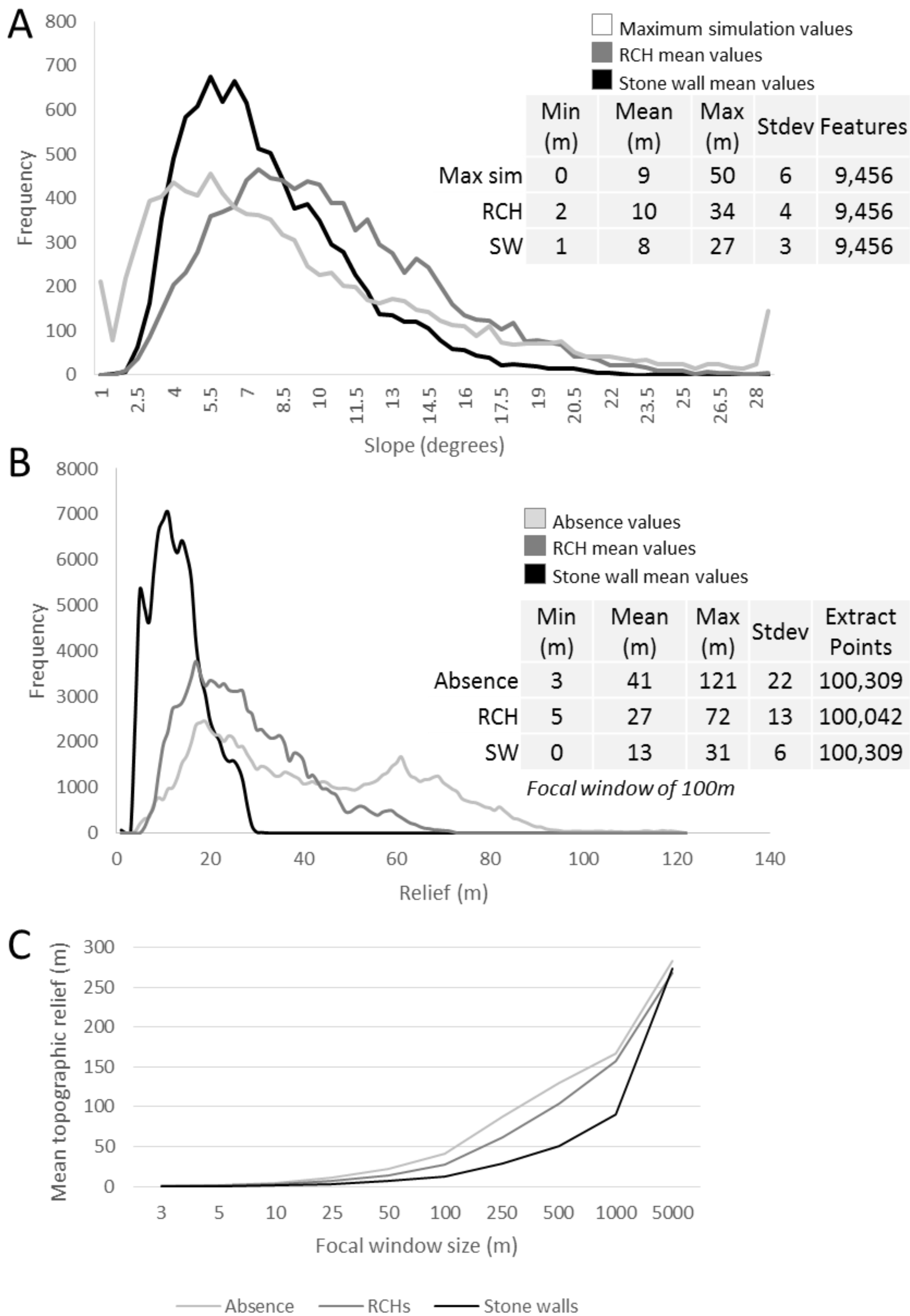

A
Maximum simulation values
RCH mean values
Stone wall mean values
Min (m) | Mean (m) | Max (m) | Stdev | Features
Max sim | 0 | 9 | 50 | 6 | 9,456
RCH | 2 | 10 | 34 | 4 | 9,456
SW | 1 | 8 | 27 | 3 | 9,456
Frequency
Slope (degrees)
B
Absence values
RCH mean values
Stone wall mean values
Min (m) | Mean (m) | Max (m) | Stdev | Extract Points
Absence | 3 | 41 | 121 | 22 | 100,309
RCH | 5 | 27 | 72 | 13 | 100,042
SW | 0 | 13 | 31 | 6 | 100,309
Focal window of 100m
Frequency
Relief (m)
C
Mean topographic relief (m)
Focal window size (m)
Absence
RCHs
Stone walls

Figure 8

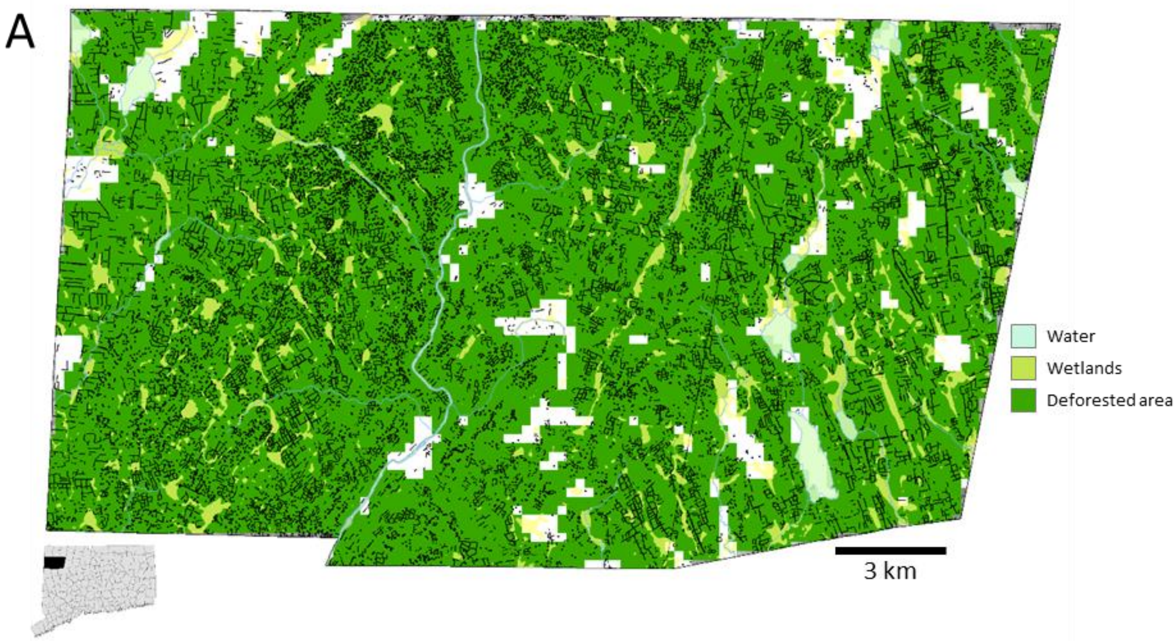


Figure 9

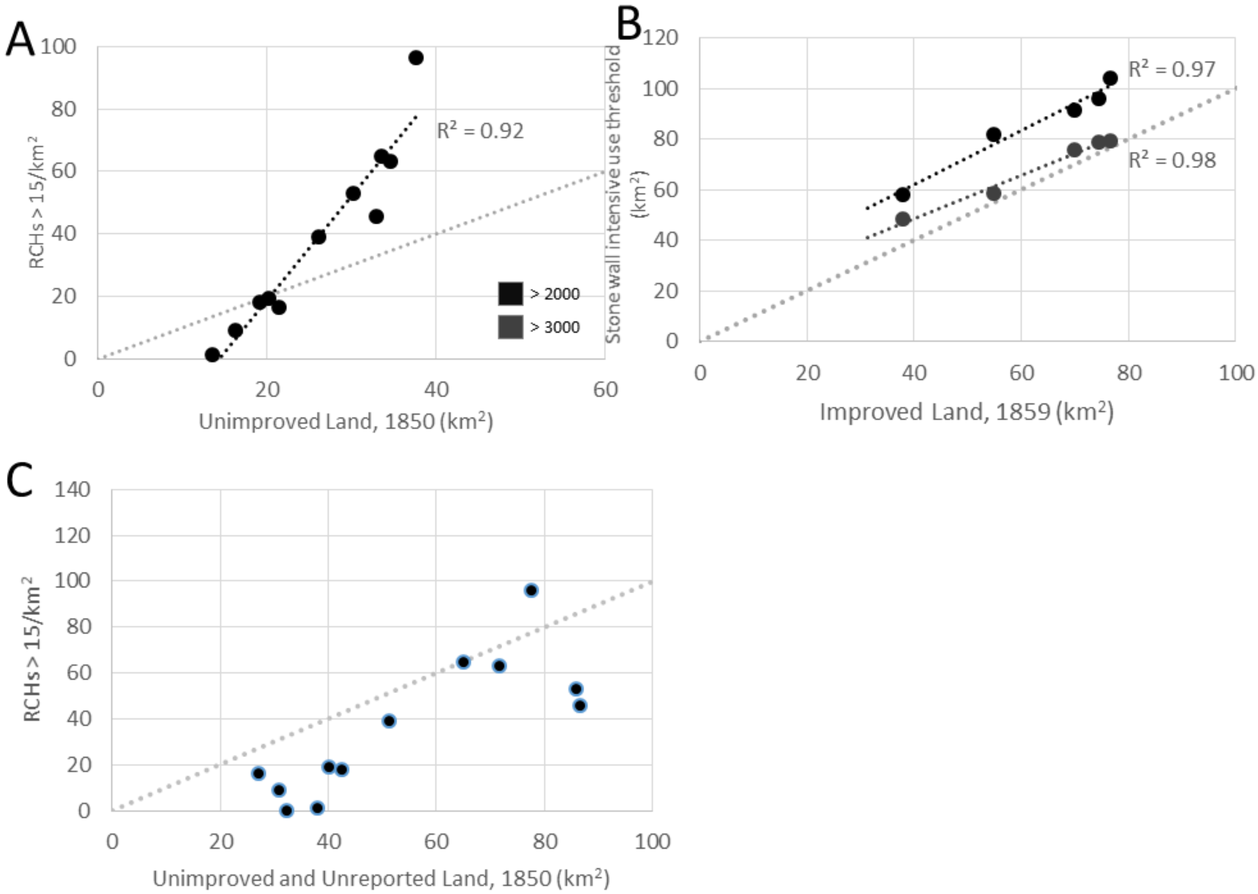

A
100
80
60
40
20
0
RCHs > 15/km²
R² = 0.92
> 2000
> 3000
0
20
40
60
Unimproved Land, 1850 (km²)
B
120
100
80
60
40
20
0
Stone wall intensive use threshold (km²)
R² = 0.97
R² = 0.98
0
20
40
60
80
100
Improved Land, 1859 (km²)
C
140
120
100
80
60
40
20
0
RCHs > 15/km²
0
20
40
60
80
100
Unimproved and Unreported Land, 1850 (km²)

Figure 10

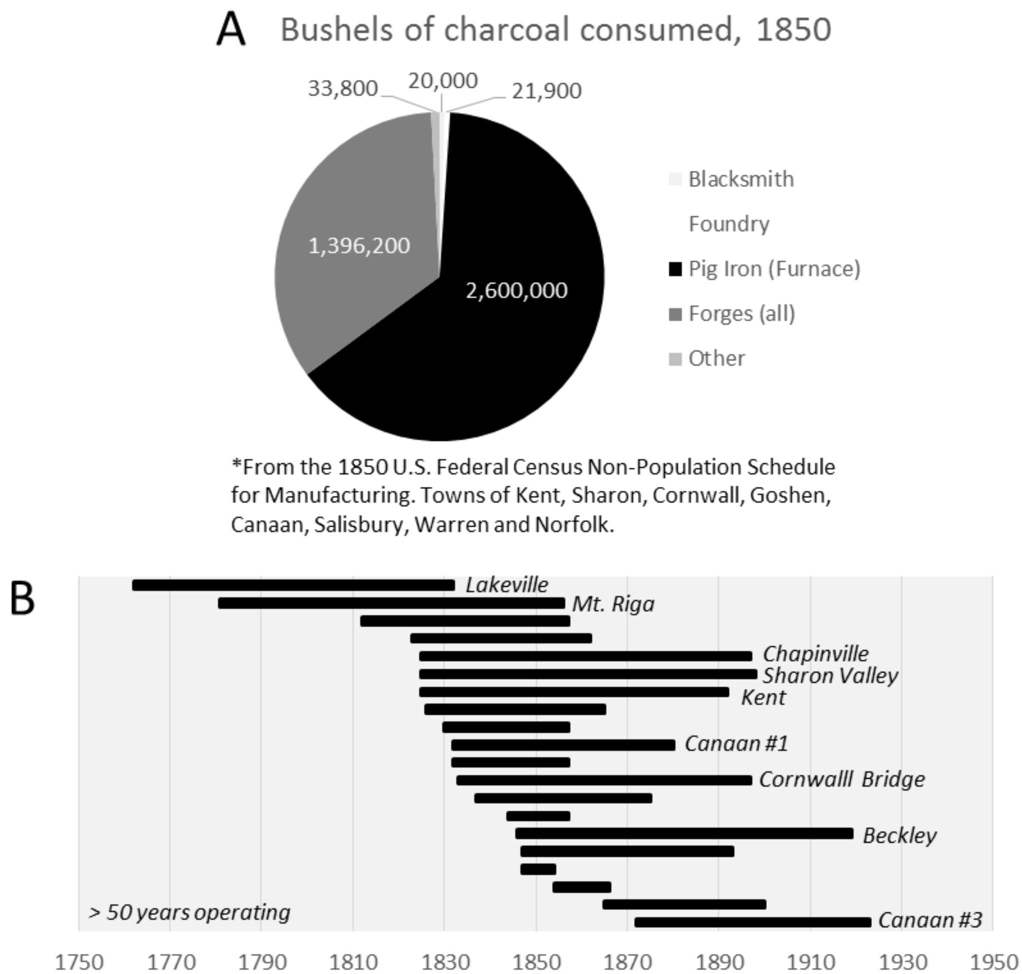

A
Bushels of charcoal consumed, 1850
33,800
20,000
21,900
1,396,200
2,600,000
Blacksmith
Foundry
Pig Iron (Furnace)
Forges (all)
Other
*From the 1850 U.S. Federal Census Non-Population Schedule for Manufacturing. Towns of Kent, Sharon, Cornwall, Goshen, Canaan, Salisbury, Warren and Norfolk.
B
Lakeville
Mt. Riga
Chapinville
Sharon Valley
Kent
Canaan #1
Cornwalll Bridge
Beckley
Canaan #3
> 50 years operating
1750
1770
1790
1810
1830
1850
1870
1890
1910
1930
1950

Figure 11

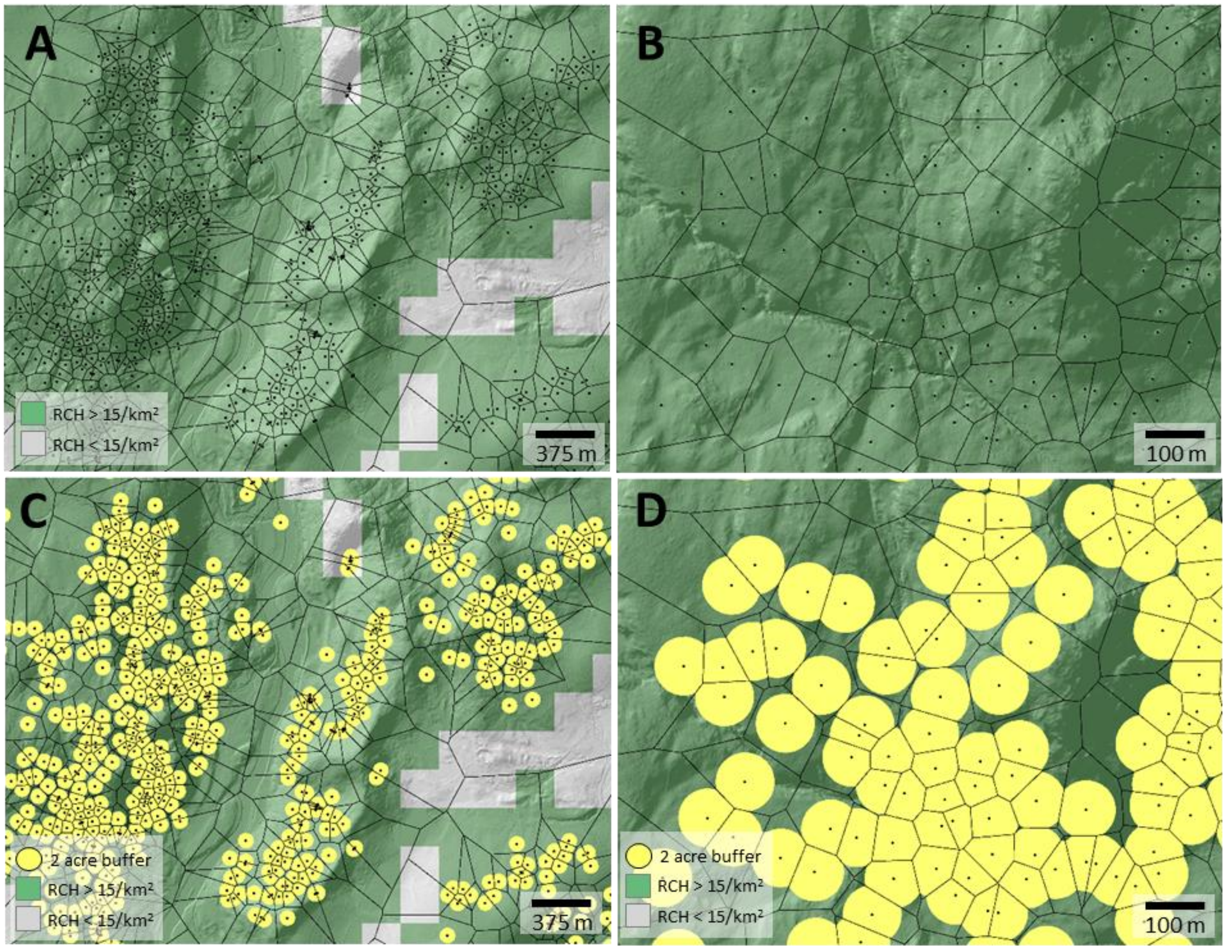

A
RCH > 15/km²
RCH < 15/km²
375 m
B
100 m
C
2 acre buffer
RCH > 15/km²
RCH < 15/km²
375 m
D
2 acre buffer
RCH > 15/km²
RCH < 15/km²
100 m

Figure Captions

Figure 1. Historic photographs from Cornwall, CT show: (A) wood stacked and ready to be turned into charcoal in a hearth in fore and background; and (B) a hearth while smoldering, and monitored by two colliers. Photographs courtesy of the Cornwall Historical Society.

Figure 2. RCHs are visible in the field (A) as flat earthen platforms and similarly in LiDAR point cloud data (B) and derivative slope maps (C). Historic aerial photography from 1934 (D) shows that much of the area that had originally been cleared for charcoal production was reforested by that time, with the exception of an abandoned agricultural field, all of which was reforested by 2012 (E).

Figure 3. Study areas and towns in the context of the Salisbury Iron District as well as comparative towns that exhibit lower levels of charcoal production in eastern Connecticut.

Figure 4. Topographic relief over a variety of window sizes was calculated; examples of relief for a small sample area in northwestern CT show (A) relief over a 5m window; (B) relief over a 50m window; (C) relief over a 100m window; and (D) classified relief values over a 500m window with digitized features, exemplifying the difference in distribution with regard to relief.

Figure 5. Because RCHs (A) and stone walls (B) have their own geomorphic signatures at a resolution of 1m, buffers with a width of 2m were calculated at 8 and 4 meters distant from (C) charcoal hearth center points and (D) wall polylines respectively to obtain zonal statistical average pizel values for the slope on which the feature was constructed.

Figure 6. Spatial distribution of areas (A) stone wall length per km2; (B) number of RCHs per km2; and (C) digitized features with areas, and areas of overlap or where features exist below that threshold, or do not exist.

Figure 7. (A) Comparison of mean slope values for stone walls, RCHs, and maximum slope values obtained from random simulations; (B) comparison of relief values for stone walls, RCHs, and areas where no features exist for a focal window of 100m; (C) comparison of mean relief values across the range of focal windows indicating differences in types of features and relief.

Figure 8. Extent of deforestation occurring in Cornwall, Goshen, and Sharon in northwestern CT by combining intensive use areas for stone walls and RCHs.

Figure 9. Plots showing (A) the relationship between reported unimproved land and areas of intensive RCH density; (B) areas of reported improved land areas where stone wall length is >2 km/km2 and >3 km/km2; and (C) areas of reported unimproved and unreported land combined relative to areas of intensive RCH density.

Figure 10. (A) Bushels of charcoal used per industry type in several towns in the Salisbury Iron District of northwestern Connecticut; and (B) years of operation and duration for blast furnaces in the Salisbury Iron District.

Figure 11. (A) Distribution of RCHs with associated Thiessen polygons at broader landscape scales showing relationship to topography and (B) at larger scales; and comparison of Thiessen polygons to 2-acre buffers at (C) broader landscape scales and (D) larger scales which shows the difference in clustering and dispersion patterns.

Tables

Table 1. Study towns overview

	Year Incorporated*	Average elevation (m)^	Town Area (km²)†	Features digitized
Ashford	1712**	203	102.3	RCH, SW
Canaan	1739	299	136.5	RCH
Cornwall	1740	328	119.9	RCH, SW
Eastford	1712**	198	75.8	RCH, SW
Goshen	1739	394	117.0	RCH, SW
Kent	1739	260	128.4	RCH
Norfolk	1758	422	120.2	RCH
Salisbury	1741	305	155.5	RCH
Sharon	1739	299	154.2	RCH, SW
Warren	1786	350	71.3	RCH

* Lewis, 1881
^ National Elevation Dataset, 2016 10m data
† Connecticut Towns shapefile, MAGIC 2016
** Eastford was part of the town of Ashford until 1847 and reincorporated then.

Table 2. Summary of geospatial data for towns with charcoal production

	Town Area (km²)	Number of RCHs	*Density of RCHs per km²**			*Intensive land use area (km²)**		
			Min.	Mean	Max.	RCH density > 15/km²	Wall length > 2 km / km²	Overlap (km²)
Ashford	102.3	9	0	0	5	0	91.7	-10.6
Canaan	136.5	2,717	0	20	165	52.9	-	-
Cornwall	119.9	3,019	0	25	165	64.8	82.0	26.9
Eastford	75.8	97	0	1	32	1.2	58.3	-16.3
Goshen	117.0	795	0	7	70	18.0	96.1	-2.9
Kent	128.4	3,431	0	26	197	63.2	-	-
Norfolk	120.2	1,409	0	11	73	33.0	-	-
Salisbury	155.5	2,225	0	14	119	45.8	-	-
Sharon	154.2	5,648	0	36	183	96.2	104.3	46.4
Warren	71.3	777	0	11	56	19.2	-	-
Total	1,003.1	20,282	-	-	-	399.1	282.5	-

* Values based on raster statistics of density maps in Figure 7

Table 3. Summary of historical agricultural data, 1850

	Town Area (km²)	Improved Land, 1850 (km²)	Unimproved Land, 1850 (km²)	Farmland, 1850 (km²)	Unrecorded Land, 1850 (km²)
Ashford	102.3	69.9	28.9	98.8	3.5
Canaan	136.5	50.7	30.3	81.0	55.5
Colebrook	85.2	58.2	21.5	79.6	5.6
Cornwall	119.9	54.8	33.6	88.4	31.5
Eastford	75.8	37.9	13.6	51.4	24.4
Goshen	117.0	74.5	19.2	93.7	23.3
Kent	128.4	56.9	34.7	91.5	36.9
Norfolk	120.2	69.0	26.2	95.2	25.1
Salisbury	155.5	68.9	33.0	101.9	53.6
Sharon	154.2	76.7	37.7	114.3	39.8
Warren	71.3	31.3	20.2	51.5	19.8
Winchester	87.6	56.7	16.3	73.0	14.6

Table 4. Summary of historical iron manufacturing data, 1850

	Number of iron-related manufactures in 1850	Reported charcoal produced (bushels)	Reported charcoal consumed (bushels)	Estimated wood used (cords)*	Estimated area of forest used (km²)^	RCHs, 35 cords/ bushel *^	RCHs, 25 cords/ bushel *^
Canaan	16	0	1,073,300	29,008	3.9	829	1,160
Cornwall	5	0	552,700	14,938	2.0	427	598
Goshen	9	40,300	0	1,090†	0.2	38	54
Kent	8	0	424,200	11,465	1.5	328	459
Norfolk	4	0	32,500	878	0.1	25	35
Salisbury	23	0	1,006,000	27,189	3.7	777	1,088
Sharon	6	0	303,400	8,200	1.1	234	328
Warren	3	0	359,500	9,716	1.3	278	389
Total	**74**	**40,300**	**4,071,900**	**102,738**	**13.9**	**2,935**	**4,110**

* Assuming avg. 37 bushels per cord of wood (U.S. Federal Census, 1850a; Straka, 2014).
^ Assuming 30 acres per cord; acres converted to km² (Straka, 2014).
† Actual value from 1850 census.

References

Allen, E., 2003. Cornwall, 1800 and 1801, in: Bickford, C.P. (Ed.), Voices of the New Republic, Connecticut Towns 1800–1832, Volume I: What They Said. Connecticut Academy of Arts and Sciences, New Haven, CT, pp. 93–108.

Bachofer, F., Queneherve, G., Marker, M., 2014. The Delineation of Paleo-Shorelines in the Lake Manyara Basin Using TerraSAR-X Data. Remote Sens. 6, 2195–2212.

Baldwin, H.I., 1942. Forestry in New England. Boston, Massachusetts.

Barger, L.C., 2013. Life on a Rocky Farm: Rural Life near New York City in the Late Nineteenth Century. University of New York Press, Albany.

Barnosky, A.D., Hadly, E.A., Bascompte, J., Berlow, E.L., Brown, J.H., Fortelius, M., Getz, W.M., Harte, J., Hastings, A., Marquet, P.A., Martinez, N.D., Mooers, A., Roopnarine, P., Vermeij, G., Williams, J.W., Gillespie, R., Kitzes, J., Marshall, C., Matzke, N., Mindell, D.P., Revilla, E., Smith, A.B., 2012. Approaching a state shift in Earth's biosphere. Nature 486, 52–58.

Bell, M.M., 1985. The Face of Connecticut. State Geological and Natural History Survey of Connecticut, Hartford.

Bell, M.M., 1989. Did New England Go Downhill? Geogr. Rev. 79, 450–466.

Bellemare, J., Motzkin, G., Foster, D.R., Forest, H., 2002. Legacies of the agricultural past in the forested present: an assessment of historical land-use effects on rich mesic forests. J. Biogeogr. 29, 1401–1420.

Benjamin, K., Domon, G., Bouchard, A., 2005. Vegetation Composition and Succession of Abandoned Farmland: Effects of Ecological, Historical and Spatial Factors. Landsc. Ecol. 20, 627–647.

Black, A.E., Morgan, P., Hessburg, P.F., 2003. Social and biophysical correlates of change in forest landscapes in the interior Columbia Basin, USA. Ecol. Appl. 13, 51–67.

Bollandsås, O.M., Risbøl, O., Ene, L.T., Nesbakken, A., Gobakken, T., Næsset, E., 2012. Using airborne small-footprint laser scanner data for detection of cultural remains in forests: an experimental study of the effects of pulse density and DTM smoothing. J. Archaeol. Sci. 39, 2733–2743.

Brown, A., Toms, P., Carey, C., Rhodes, E., 2013. Geomorphology of the Anthropocene: Time-transgressive discontinuities of human-induced alluviation. Anthropocene 1, 3–13.

Brown, I.B., 1894. Report of the Bureau of Industrial Statistics. Harrisburg, PA.

Chase, A.F., Chase, D.Z., Fisher, C.T., Leisz, S.J., Weishampel, J.F., 2012. Geospatial revolution and remote sensing LiDAR in Mesoamerican archaeology. Proc. Natl. Acad. Sci. U. S. A. 109, 12916–23921.

Chin, A., Fu, R., Harbor, J., Taylor, M.P., Vanacker, V., 2013. Anthropocene: Human interactions with earth systems. Anthropocene 1, 1–2.

Clark, P.J., Evans, F.C., 1954. Distances to Nearest Neighbor as a Measure of Spatial Relationships in Populations. Ecology 35, 445–453.

Cogbill, C. V, Burk, J., Motzkin, G., 2002. The forests of presettlement New England, USA: spatial and compositional patterns based on town proprietor surveys. J. Biogeogr. 29, 1279–1304.

Cooke, K.J., 2003. Art and Science in Crop and Livestock Improvement: The Connecticut Towns Survey and Agricultural Change Around 1800, in: Lamar, H.R., Cooper, C.C. (Eds.), Voices of the New Republic, Connecticut Towns 1800-1832, Volume II: What We Think. Connecticut Academy of Arts and Sciences, New Haven, CT, pp. 37–43.

Cooper, C.C., 2003. Technology in Transition: Connecticut Industries 1800-1832, in: Lamar, H.R., Cooper, C.C. (Eds.), Voices of the New Republic, Connecticut Towns 1800-1832, Volume II: What We Think. Connecticut Academy of Arts and Sciences, New Haven, CT, pp. 149–170.

Cronon, W., 1983. Changes in the Land. Hill and Wang, New York.

Crow, P., Benham, S., Devereux, B.J., Amable, G.S., 2007. Woodland vegetation and its implications for archaeological survey using LiDAR. Forestry 80, 241–252.

Crutchley, S.P., Crow, P., 2009. The Light Fantastic: Using airborne LiDAR in archaeological survey. Swindon.
Crutzen, P.J., Stoermer, E.F., 1999. The "Anthropocene." IGBP Newsl. 4, 17–18.
Deforce, K., Boeren, I., Adriaenssens, S., Bastiaens, J., De Keersmaeker, L., Haneca, K., Tys, D., Vandekerkhove, K., 2013. Selective woodland exploitation for charcoal production. A detailed analysis of charcoal kiln remains (ca. 1300-1900 AD) from Zoersel (northern Belgium). J. Archaeol. Sci. 40, 681–689.
Delcourt, P.A., Delcourt, H.R., 1987. Late-Quaternary Dynamics of Temperate Forests: Applications of Paleoecology to Issues of Global Environmental Change. Quat. Sci. Rev. 6, 129–146.
Devereux, B.J., Amable, G.S., Crow, P., Cliff, A.D., 2005. The potential of airborne lidar for detection of archaeological features under woodland canopies. Antiquity 78, 648–660.
Dincauze, D.F., 1987. Strategies for Paleoenvironmental Reconstruction in Archaeology. Adv. Archaeol. Method Theory 11, 255–336.
Donahue, B., 2004. The Great Meadow: Farmers and the Land in Colonial Concord. Yale University Press, New Haven, CT.
Dotterweich, M., 2013. The history of human-induced soil erosion: Geomorphic legacies, early descriptions and research, and the development of soil conservation—a global synopsis. Geomorphology 201, 1–34.
Dotterweich, M., Ivester, A.H., Hanson, P.R., Larsen, D., Dye, D.H., 2015. Natural and human induced prehistoric and historical soil erosion and landscape development in southwestern Tennessee, USA. Anthropocene, 1–19.
Eberhardt, R.W., Foster, D.R., Motzkin, G., Hall, B., 2003. Conservation of Changing Landscapes: Vegetation and Land-Use History of Cape Cod National Seashore. Ecol. Appl. 13, 68–84.
Edwards, L.E., 2015. What Is the Anthropocene? Eos (Washington. DC). 95.
Fernández-Lozano, J., Gutiérrez-Alonso, G., Fernández-Morán, M.Á., 2015. Using airborne LiDAR sensing technology and aerial orthoimages to unravel roman water supply systems and gold works in NW Spain (Eria valley, León). J. Archaeol. Sci. 53, 356–373.
Forsythe, W., 2007. On the Edge of Improvement: Rathlin Island and the Modern World. Int. J. Hist. Archaeol. 11, 221–240.
Foster, D.R., 1992. Land-use history (1730–1990) and vegetation dynamics in Central New England, USA. J. Ecol. 80, 753–771.
Foster, D.R., 1999. Thoreau's Country: Journey through a Transformed Landscape. Harvard University Press, Cambridge, MA.
Foster, D.R., Donahue, B., Kittredge, D., Motzkin, G., Hall, B., Turner, B., Chilton, E., 2008. New England's forest landscape: ecological legacies and conservation patterns shaped by agrarian history, in: Redman, C.R., Foster, D.R. (Eds.), Agrarian Landscapes in Transition: Comparisons of Long-Term Ecological & Cultural Change. Oxford University Press, New York, pp. 44–88.
Foster, D.R., Motzkin, G., Slater, B., 1998. Land-Use History as Long-Term Broad-Scale Disturbance: Regional Forest Dynamics in Central New England. Ecosystems 1, 96–119.
Fruchart, C., Laplaige, C., Opitz, R.S., Nuninger, L., 2011. The LIEPPEC Project: using lidar for the study of long term landscape change [WWW Document]. Antiq. Proj. Gall. URL http://www.antiquity.ac.uk/projgall/opitz327/
Ginsberg, C.A., 1988. Estimates and Correlates of Enumeration Completeness: Censuses and Maps in Nineteenth-Century Massachusetts. Soc. Sci. Hist. 12, 71–86.
Gordon, R.B., 2001. A Landscape Transformed: The Ironmaking District of Salisbury, Connecticut. Oxford University Press, New York.
Gordon, R.B., Raber, M., 2000. Industrial Heritage in Northwest Connecticut. Connecticut Academy of Arts and Sciences, New Haven, CT.
Greven, P.J.J., 1970. Four Generations: Population, Land, and Family in Colonial Andover, Massachusetts. Cornell University Press, Ithaca.

Grohmann, C.H., Smith, M.J., Riccomini, C., 2009. Surface Roughness of Topography : A Multi-Scale Analysis of Landform Elements in Midland Valley, Scotland, in: Purves, R., Gruber, S., Straumann, R. (Eds.), Proceedings of Geomorphometry. Zurich, pp. 140–148.
Hall, B., Motzkin, G., Foster, D.R., Syfert, M., Burk, J., 2002. Three hundred years of forest and land-use change in Massachusetts, USA. J. Biogeogr. 29, 1319–1335.
Hall, C.A.S., Tian, H., Qi, Y., Pontius, G., Cornell, J., 1995. Modelling Spatial and Temporal Patterns of Tropical Land Use Change. J. Biogeogr. 22, 753–757.
Harris, H.P., 1885. Charcoal Manufacture in the Salisbury Iron Region. J. United States Assoc. Charcoal Iron Work. 6, 49–53.
Harrison, B., Judd, R.W. (Eds.), 2011. A Landscape History of New England. The MIT Press, Cambridge, MA.
Hesse, R., 2013. Charcoal burning platforms in the southern Black Forest: from LIDAR point cloud to spatial patterns of resource use, in: Socio-Environmental Dynamics over the Last 12,000 Years: The Creation of Landscapes III.
Humme, A., Lindenbergh, R., Sueur, C., 2006. Revealing Celtic fields from lidar data using kriging based filtering, in: Proceedings of the ISPRS Commission V Symposium. Dresden.
Ignatiadis, M.E., Ouimet, W.B., Johnson, K.M., Dethier, D.P., 2016. Charcoal remains in Litchfield County Connecticut record widespread hillslope disturbance in the iron corridor from mid-18th to early 20th centuries and present day carbon storage. Geol. Soc. Am. Abstr. with Programs 48.
Iverson, L.R., 1988. Land-use changes in Illinois, ASA: The influence of landscape attributes on current and historic land use. Landsc. Ecol. 2, 45–61.
Izard, H. V., 2003. The State of Connecticut Agriculture in 1800, in: Lamar, H.R., Cooper, C.C. (Eds.), Voices of the New Republic, Connecticut Towns 1800-1832, Volume II: What We Think. Connecticut Academy of Arts and Sciences, New Haven, CT, pp. 59–74.
Jefferson, A.J., Wegmann, K.W., Chin, A., 2013. Geomorphology of the Anthropocene: Understanding the surficial legacy of past and present human activities. Anthropocene 2, 1–3.
Johnson, K.M., Ouimet, W.B., 2014. Rediscovering the lost archaeological landscape of southern New England using airborne Light Detection and Ranging (LiDAR). J. Archaeol. Sci. 43, 9–20.
Johnson, K.M., Ouimet, W.B., Raslan, Z., 2015. Geospatial and LiDAR-based analysis of 18th to early 20th century timber harvesting and charcoal production in southern New England. Geol. Soc. Am. Abstr. with Programs 47, 65.
Kirby, E., 1998. Echoes of Iron in Connecticut's Northwest Corner. Sharon Historical Society, Sharon, CT.
Kirby, E., 2011. Salisbury Iron Forged Early Industry [WWW Document]. ConnecticutHistory.org. URL http://connecticuthistory.org/salisbury-iron-forged-early-industry/ (accessed 5.12.16).
Knowles, A.K., 2013. Mastering Iron: The Struggle to Modernize an American Industry, 1800–1868. University of Chicago Press, Chicago.
Knowles, A.K., Healey, R.G., 2006. Geography, Timing, and Technology: A GIS-Based Analysis of Pennsylvania's Iron Industry, 1825-1875. J. Econ. Hist. 66, 608–634.
Kreslavsky, M.A., Head, J.W., Neumann, G.A., Rosenburg, M.A., Aharonson, O., Smith, D.E., Zuber, M.T., 2013. Lunar topographic roughness maps from Lunar Orbiter Laser Altimeter (LOLA) data: Scale dependence and correlation with geologic features and units. Icarus 226, 52–66.
Kury, T.W., 1993. Labor and the Charcoal Iron Industry: The New Jersey-New York Experience. Mater. Cult. 25, 19–33.
Lesley, J.P., 1859. The Iron Manufacturer's Guide to the Furnaces, Forges and Rolling Mills of the United Sates. John Wiley, New York.
Lewis, Q., 2013. An Archaeology of Improvement in Rural New England: Capitalism, Landscape Change, and Rural Life in the Early 19th Century. University of Massachusetts Amherst.
Lothrop, J.C., Newby, P.E., Spiess, A.E., Bradley, J.W., 2011. Paleoindians and the Younger Dryas in the New England-Maritimes Region. Quat. Int. 242, 546–569.

McDonald, R.I., Motzkin, G., Foster, D.R., 2008. Assessing the influence of historical factors, contemporary processes, and environmental conditions on the distribution of invasive species. J. Torrey Bot. Soc. 135, 260–271.
McWeeny, L.J., 1994. Archaeological Settlement Patterns and Vegetation Dynamics in Southern New England in the Late Quaternary. Yale University.
Merchant, C., 1989. Ecological Revolutions: Nature, Gender, and Science in New England. University of North Carolina Press, Chapel Hill.
Merritts, D., Walter, R., Rahnis, M., Hartranft, J., Cox, S., Gellis, A., Potter, N., Hilgartner, W., Langland, M., Manion, L., Lippincott, C., Siddiqui, S., Rehman, Z., Scheid, C., Kratz, L., Shilling, A., Jenschke, M., Datin, K., Cranmer, E., Reed, A., Matuszewski, D., Voli, M., Ohlson, E., Neugebauer, A., Ahamed, A., Neal, C., Winter, A., Becker, S., 2011. Anthropocene streams and base-level controls from historic dams in the unglaciated mid-Atlantic region, USA. Philos. Trans. R. Soc. 369, 976–1009.
Mikan, C.J., Abrams, M.D., 1995. Altered forest composition and soil properties of historic charcoal hearths in southeastern Pennsylvania. Can. J. For. Res. 25, 687–696.
Mikan, C.J., Abrams, M.D., 1996. Mechanisms inhibiting the forest development of historic charcoal hearths in southeastern Pennsylvania. Can. J. For. Res. 26, 1893–1898.
Mlekuz, D., 2013. Messy landscapes: lidar and the practices of landscaping, in: Opitz, R.S., Cowley, D.C. (Eds.), Interpreting Archaeological Topography: Airborne Laser Scanning, 3D Data and Ground Observation. Oxbow Books, Oxford, pp. 88–100.
Nicholas, G.P., 2000. A Light but Lasting Footprint: Human Influences on the Northeastern Landscape, in: Levine, M.A., Sassaman, K.E., Nassaney, M.S. (Eds.), The Archaeological Northeast. Bergin & Garvey, Westport, CT, pp. 25–38.
Norton, L.M., 2003. Goshen, 1812, in: Bickford, C.P. (Ed.), Voices of the New Republic, Connecticut Towns 1800–1832, Volume I: What They Said. Connecticut Academy of Arts and Sciences, New Haven, CT, pp. 113–120.
Opitz, R.S., Ryzewski, K., Cherry, J.F., Moloney, B., 2015. Using Airborne LiDAR Survey to explore Historic-era archaeological landscapes of Montserrat in the Eastern Caribbean. J. F. Archaeol. 40, 523–541.
Ouimet, W.B., Dethier, D.P., Johnson, K.M., Kotikian, M., Wicherski, W., 2015. Quantifying 18th to early 20th century human impacts on hillslopes and sediment mobilization in southern New England and Colorado Front Range. GSA Abstr. with Programs 47, 240.
Parent, J.R., Volin, J.C., 2014. Assessing the potential for leaf-off LiDAR data to model canopy closure in temperate deciduous forests. ISPRS J. Photogramm. Remote Sens. 95, 134–145.
Potter, N.J., Brubaker, K., Delano, H., 2013. LiDAR Reveals Thousands of 18th and 19th Century Charcoal Hearths on South Mountain, South-Central Pennsylvania. GSA Abstr. with Programs 45, 99.
Raab, A., Takla, M., Raab, T., Nicolay, A., Schneider, A., Rösler, H., Heußner, K.-U., Bönisch, E., 2015. Pre-industrial charcoal production in Lower Lusatia (Brandenburg, Germany): Detection and evaluation of a large charcoal-burning field by combining archaeological studies, GIS-based analyses of shaded-relief maps and dendrochronological age determination. Quat. Int. 367, 111–122.
Risbøl, O., Bollandsås, O.M., Nesbakken, A., Ørka, H.O., Næsset, E., Gobakken, T., 2013. Interpreting cultural remains in airborne laser scanning generated digital terrain models: effects of size and shape on detection success rates. J. Archaeol. Sci. 40, 4688–4700.
Rolando, V.R., 1992. 200 Years of Soot and Sweat: The History and Archaeology of Vermont's Iron, Charcoal, and Lime Industries. Vermont Archaeological Society, Burlington.
Rosenswig, R.M., López-Torrijos, R., Antonelli, C.E., Mendelsohn, R.R., 2013. Lidar mapping and surface survey of the Izapa state on the tropical piedmont of Chiapas, Mexico. J. Archaeol. Sci. 40, 1493–1507.

Ruddiman, W.F., Ellis, E.C., Kaplan, J.O., Fuller, D.Q., 2015. Defining the epoch we live in. Science 348, 38–39.
Samuelson, B., 1883. The Iron and Steel Industries of Foreign Countries: America - United States. J. Iron Steel Inst. 2, 724–775.
Sappington, J.M., Longshore, K.M., Thompson, D.B., 2007. Quantifying Landscape Ruggedness for Animal Habitat Analysis: A Case Study Using Bighorn Sheep in the Mojave Desert. J. Wildl. Manage. 71, 1419–1426.
Schneider, A., Takla, M., Nicolay, A., Raab, A., Raab, T., 2015. A Template-matching Approach Combining Morphometric Variables for Automated Mapping of Charcoal Kiln Sites. Archaeol. Prospect. 22, 45–62.
Secretary of the Treasury, 1833. Documents relative to the manufactures in the United States: Volume I. Duff Green, Washington D.C.
Shepard, M.K., Campbell, B.A., Bulmer, M.H., Farr, T.G., Gaddis, L.R., Plaut, J.J., 2001. The roughness of natural terrain: a planetary and remote sensing perspective. J. Geophys. Res. 106, 32777–32795.
Slosson, B., 2003. Kent, 1812, in: Bickford, C.P. (Ed.), Voices of the New Republic, Connecticut Towns 1800–1832, Volume I: What They Said. Connecticut Academy of Arts and Sciences, New Haven, CT, pp. 123–126.
Smith, J.C., 2003. Sharon, 1807, in: Bickford, C.P. (Ed.), Voices of the New Republic, Connecticut Towns 1800–1832, Volume I: What They Said. Connecticut Academy of Arts and Sciences, New Haven, CT, pp. 145–149.
Steckel, R.H., 1991. The Quality of Census Data for Historical Inquiry: A Research Agenda. Soc. Sci. Hist. 15, 579–599.
Stone, J.R., Schafer, J.P., London, E.H., DiGiacomo-Cohen, M.L., Lewis, R.S., Thompson, W.B., 2005. Quaternary Geologic Map of Connecticut and Long Island Sound Basin. Scientific Investigations Map 2784.
Straka, T.J., 2014. Historic Charcoal Production in the US and Forest Depletion: Development of Production Parameters. Adv. Hist. Stud. 3, 104–114.
Svedelius, G., Anderson, R.B., 1875. Handbook for Charcoal Burners. John Wiley & Son, New York.
Thorson, R.M., 2002. Stone by stone: the magnificent history in New England's stone walls. Walker & Company, New York.
Thorson, R.M., Harris, A.G., Harris, S.L., Gradie, R.I., Lefor, M.W., 1998. Colonial Impacts to Wetlands in Lebanon. Rev. Eng. Geol. 12, 23–42.
Thorson, R.M., Harris, S.L., 1991. How "Natural" Are Inland Wetlands? An Example from the Trail Wood Audubon Sanctuary in Connecticut, USA. Environ. Manage. 15, 675–687.
Trier, Ø.D., Larsen, S.O., Solberg, R., 2009. Automatic Detection of Circular Structures in High-resolution Satellite Images of Agricultural Land. Archaeol. Prospect. 16, 1–15.
Trier, Ø.D., Pilø, L.H., 2012. Automatic Detection of Pit Structures in Airborne Laser Scanning Data. Archaeol. Prospect. 19, 103–121.
Waggoner, P.E., 2003. Fertile Farms among the Stones, in: Lamar, H.R., Cooper, C.C. (Eds.), Voices of the New Republic, Connecticut Towns 1800–1832, Volume II: What We Think. Connecticut Academy of Arts and Sciences, New Haven, CT, pp. 45–57.
Walter, R.C., Merritts, D.J., 2008. Natural streams and the legacy of water-powered mills. Science 319, 299–304.
Warren, G., 1914. Farm Management, Third. ed. The MacMillan Co., New York.
Waters, C.N., Zalasiewicz, J., Summerhayes, C., Barnosky, A.D., Poirier, C., Ga, A., Cearreta, A., Edgeworth, M., Ellis, E.C., Ellis, M., Jeandel, C., Leinfelder, R., Mcneill, J.R., Richter, D., Steffen, W., Syvitski, J., Vidas, D., Wagreich, M., Williams, M., Zhisheng, A., Grinevald, J., Odada, E., Oreskes, N., Wolfe, A.P., 2016. The Anthropocene is functionally and stratigraphically distinct from the Holocene. Science (80). 351, aad2622–1–aad2622–10.

CHAPTER 6

Conclusions and Future Work

This study has demonstrated that (LiDAR) is a revolutionary tool for examining relict land use features at the landscape and regional scale in densely forested areas. LiDAR has proven to be integral in developing datasets whose spatial distributions can be analyzed at broad scales to infer impacts associated with past land use. While a powerful tool by itself, LiDAR is most successfully used to examine these processes when combined with other data such as field measurements, historic maps, census data, or aerial photographs, and interpreted within broader theoretical frameworks that closely examine the production and representation of landscapes (see Randall 2014; Crutchley 2006; Gallagher and Josephs 2008).

The distribution of stone walls and relict charcoal hearths was highly influenced by surficial geology, slope, and relief measured over ~100 m. As suggested in historic documents, in towns where only farming occurred, steep areas with thin topsoil were used for woodlots and very rarely were used for plowland. Historic accounts suggest that sometimes steep areas might have supported grazing livestock as well (Allen, 2003). In towns where iron manufacturing and charcoal production occurred, steeper areas were instead deforested, and the wood used for the production of charcoal (Gordon, 2001). Stone walls were built in areas of relatively low topographic relief and slope, and there was a preference for building on the thick till of glacial landforms such as drumlins, with avoidance of low marshy areas, or steep, rocky areas. This is exemplified by the orientation of walls in towns with variable topography, such as in the northwestern portion of Connecticut, where walls align closely with the NW–SE orientation of drumlins, left by the most recent glaciation which ended ~17 ka.

Combining geospatial datasets for historic features with land use data from agricultural and manufacturing census records, as well as historic maps and aerial photographs, shows that the presence of both stone walls and relict charcoal hearths is a reliable predictor of areas of intensive

land use and deforestation. Both the length of stone walls per town, as well as the areas where their length exceeds certain thresholds, have high correlations ($R^2 > 0.97$) with the amount of reported improved farmland in 1850, suggesting that this was likely the height of farm improvement in southern New England as well as the height of wall building. Conversely, areas where the number of relict charcoal hearths exceeds 15/km^2, suggesting intensive use, have a strong correlation ($R^2=0.92$) with areas of unimproved land in each town, suggesting these areas of woodland that would not otherwise have been actively-used plowland were in fact being using for charcoaling over certain periods of time.

Overall, the datasets presented reveal the unprecedented extent to which historic land use has impacted the landscape in southern New England. Tens of thousands of relict land use features—stone walls, building foundations, dams, relict charcoal hearths, roads—now hidden in high resolution aerial photography by a dense forest canopy, attest to the magnitude of land use changes following European colonization of the region in the 17th century, and subsequent intensive land use in the centuries to come (Donahue, 2004; Foster, 1992; Thorson, 2002). In southern New England, the drastic changes have been studied and discussed, however very few studies have addressed the eventual impacts perpetuated by historic land use.

More research is needed to understand the full range of impacts produced by the types of land use discussed here, including erosion, alteration of soil properties, changes in fluvial systems, or changes in ecology and biodiversity (Foster, 1992; Ouimet et al., 2015; Sinclair et al., 1967; Thorson et al., 1998; Yellen et al., 2014). Future research that builds upon this work might evaluate the impacts of past land use from an interdisciplinary standpoint by examining geospatial, physical, and archival data. Automated or semi-automated feature extraction, of which research has been ongoing, should also be pursued so that regional datasets can be created more efficiently to further enhance the scale and magnitude of the questions presented here. A variety of visualization techniques have also been developed to extract and better identify cultural landscape features as

well, and these could also be built upon in this region (Bennett et al., 2012; Hesse, 2010; Štular et al., 2012). Intensive field sampling of areas impacted by land use features such as stone walls, which are indicative of plowed and fertilized land, and relict charcoal hearths, which are indicative of charcoal production would yield information regarding alteration of soil properties as it has elsewhere (Mikan and Abrams, 1996, 1995). Further research of supplemental data from archival sources such as historic census records, agricultural journals, historic aerial photographs, and historic maps will also provide contextual information through which to interpret LiDAR and derivative geospatial data. Combined, these resources provide a means to examine and quantify the extent and magnitude of Anthropocene land use change in southern New England and its broader impacts in the northeast and globally in areas that were similarly impacted by the English agricultural and colonial sphere.

References

Allen, E., 2003. Cornwall, 1800 and 1801, in: Bickford, C.P. (Ed.), Voices of the New Republic, Connecticut Towns 1800–1832, Volume I: What They Said. Connecticut Academy of Arts and Sciences, New Haven, CT, pp. 93–108.

Bennett, R., Welham, K., Hill, R.A., Ford, A., 2012. A Comparison of Visualization Techniques for Models Created from Airborne Laser Scanned Data. Archaeol. Prospect. 19, 41–48.

Crutchley, S., 2006. Light Detection and Ranging (lidar) in the Witham Valley, Lincolnshire: an Assessment of New Remote Sensing Techniques. Archaeol. Prospect. 13, 251–257.

Donahue, B., 2004. The Great Meadow: Farmers and the Land in Colonial Concord. Yale University Press, New Haven, CT.

Foster, D.R., 1992. Land-use history (1730–1990) and vegetation dynamics in Central New England, USA. J. Ecol. 80, 753–771.

Gallagher, J.M., Josephs, R.L., 2008. Using LiDAR to Detect Cultural Resources in a Forested Environment: an Example from Isle Royale National Park, Michigan, USA. Archaeol. Prospect. 15, 187–206.

Gordon, R.B., 2001. A Landscape Transformed: The Ironmaking District of Salisbury, Connecticut. Oxford University Press, New York.

Hesse, R., 2010. LiDAR-derived Local Relief Models - a new tool for archaeological prospection. Archaeol. Prospect. 17, 67–72.

Mikan, C.J., Abrams, M.D., 1995. Altered forest composition and soil properties of historic charcoal hearths in southeastern Pennsylvania. Can. J. For. Res. 25, 687–696.

Mikan, C.J., Abrams, M.D., 1996. Mechanisms inhibiting the forest development of historic charcoal hearths in southeastern Pennsylvania. Can. J. For. Res. 26, 1893–1898.

Ouimet, W.B., Dethier, D.P., Johnson, K.M., Kotikian, M., Wicherski, W., 2015. Quantifying 18th to early 20th century human impacts on hillslopes and sediment mobilization in southern New England and Colorado Front Range. GSA Abstr. with Programs 47, 240.

Randall, A.R., 2014. LiDAR-aided reconnaissance and reconstruction of lost landscapes: An example of freshwater shell mounds (ca. 7500–500 cal B.P.) in northeastern Florida. J. F. Archaeol. 39, 162–179.

Sinclair, N.R., Getz, L.L., Bock, F.S., 1967. Influence of stone walls on the local distribution of small mammals. Univ. Connect. Occas. Pap. Biol. Sci. Ser. 1, 43–62.

Štular, B., Kokalj, Ž., Oštir, K., Nuninger, L., 2012. Visualization of lidar-derived relief models for detection of archaeological features. J. Archaeol. Sci. 39, 3354–3360.

Thorson, R.M., 2002. Stone by stone: the magnificent history in New England's stone walls. Walker & Company, New York.

Thorson, R.M., Harris, A.G., Harris, S.L., Gradie, R.I., Lefor, M.W., 1998. Colonial Impacts to Wetlands in Lebanon. Rev. Eng. Geol. 12, 23–42.

Yellen, B., Woodruff, J.D., Kratz, L.N., Mabee, S.B., Morrison, J., Martini, A. M., 2014. Source, conveyance and fate of suspended sediments following Hurricane Irene. New England, USA. Geomorphology 226, 124–134.