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Rediscovering the lost archaeological landscape of southern New England using airborne light detection and ranging (LiDAR)

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ABSTRACT

Recently, light detection and ranging (LiDAR) data has been made publicly available for the states of Connecticut, Massachusetts, and Rhode Island in New England, a geographic region in the northeastern United States. Despite the wide range of archaeological studies that have been undertaken with LiDAR on a global scale, few published studies exist in the United States, and no published studies exist for the northeastern US, which has a unique historical and geomorphological landscape. This landscape is densely forested, and archaeological studies in this region highlighting how humans have historically shaped the New England landscape can benefit greatly from the use of LiDAR. This paper contributes to the growing international dialogue regarding the use of LiDAR for archaeological studies by providing examples of features that have been discovered in this region, how these features can be interpreted in conjunction with historical documents and used for reconnaissance surveys, and how these interpretations can contribute to theoretical anthropological perspectives regarding how humans divide and use the landscape. Our analysis has positively identified numerous archaeological sites that have not been previously recorded by archaeological studies.

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; Cowley, 2011; Crutchley, 2009; Crutchley and Crow, 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 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

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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 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) (Fig. 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

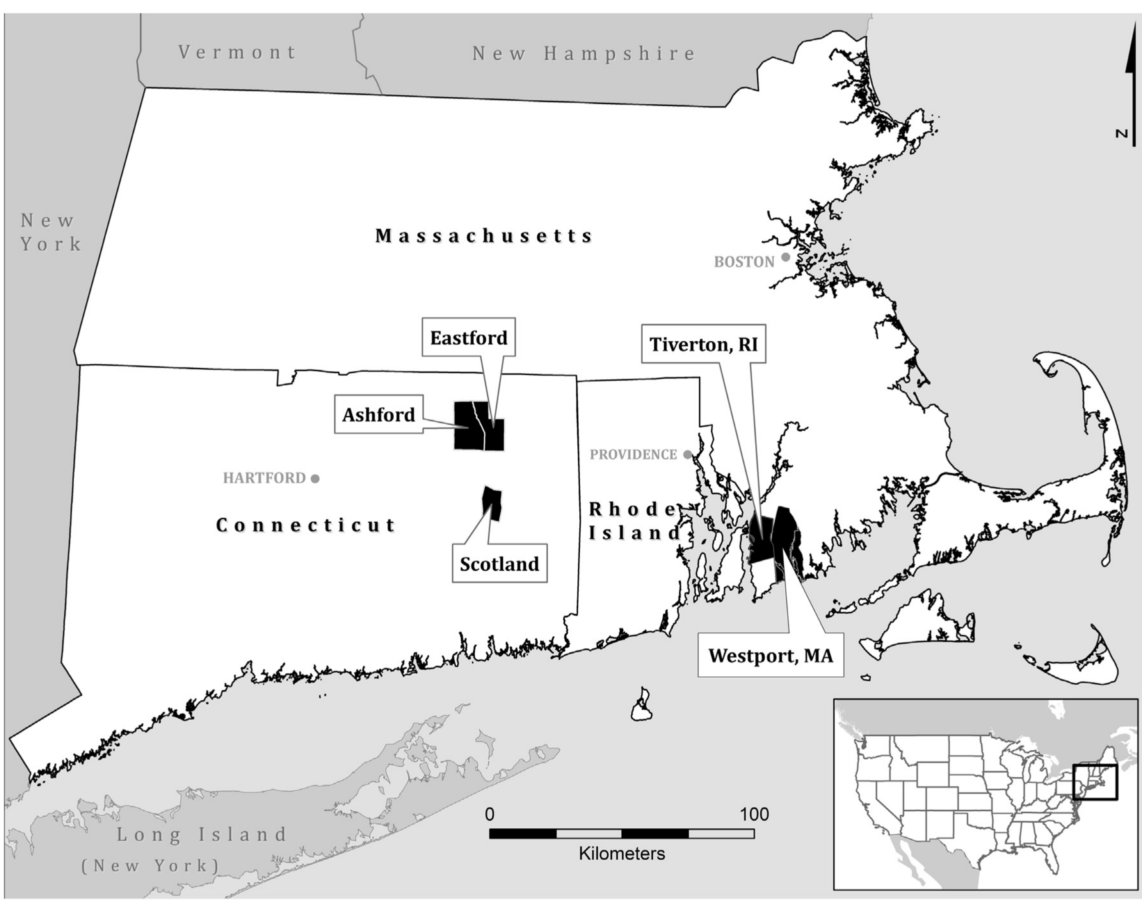

Fig. 1. Study area with focus areas indicated.

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 (see Johnson and Beranek, 2010).

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 2225 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 6.73 people per square km. In 2010, Ashford alone had 4317 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 km 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 is 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 1 m or better due to their size or shape. For example, many stone walls in this area are not much wider than 1 m 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 m (e.g., Fig. 2). Prior to LiDAR data being acquired and distributed for portions of these states, these were the highest resolutions available.

The LiDAR DEMs used in our study were derived from the original three-dimensional point cloud acquired and processed by the vendor subcontractors associated with each LIDAR flight. After acquisition and spatial processing for horizontal (latitude, longitude) and vertical (elevation) locations, all data points in the raw point cloud are classified in order to isolate the ground points in the dataset (e.g., Dewberry, 2011). Classified .las point clouds are the standard deliverable in LiDAR datasets. The classification scheme used is fairly common and involves classifying only actual ground points as "ground," while excluding other objects such as cars, buildings, bridges, and vegetation (see Meng et al., 2010; Zhang et al., 2003). Thus, the DEMs reflect an interpolated bare earth surface created using ground-classified points only and are directly tied to the average point spacing of the data acquisition (MassGIS, 2013). State agencies can provide the LiDAR bare earth DEMs for the user, such as the case with LiDAR DEM tiles used here from MassGIS (MassGIS, 2012) and Rhode Island GIS (RIGIS, 2012) for the towns of Westport, MA and Tiverton, RI, or LiDAR DEMs can be created by the user using classified .las datasets and the capabilities in ArcGIS 10.1 (ESRI, 2013), which include a LiDAR toolbar. This latter approach was used for the LiDAR DEM tiles we discuss from Ashford, CT. In general, we find good agreement between vendor provided, state agency provided, and user created LiDAR DEMs, owing in large part the fact that all three originate from the same classification scheme. We refer the reader to Zhang et al. (2003) and Meng et al. (2010) for the details of the algorithms employed in typical classification schemes.

In ArcGIS 10.1 (ESRI, 2013), individual LiDAR DEM tiles were mosaicked as necessary and hillshade maps were made using default settings (azimuth: 315, altitude: 45). Hillshade maps are common, easy to generate, retain the same resolution as the original LIDAR DEMs and are the primary visualization used in this study (see Figs. 2–7). 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 (Fig. 3), and relief rasters (not shown) were also created to more comprehensively understand the topographic relief and measurements of the landscape. Though other studies have been done to test which visualization methods work best (Bennett et al., 2012; Challis et al., 2011; 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. We anticipate that future work in this region would benefit greatly from the visualization techniques cited above, and also through automatic feature extraction, a technique that is already popular in remote sensing, but has also recently begun to be applied to LiDAR data and extraction of archaeological features (Cowley, 2012; Trier and Pilu, 2012).

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

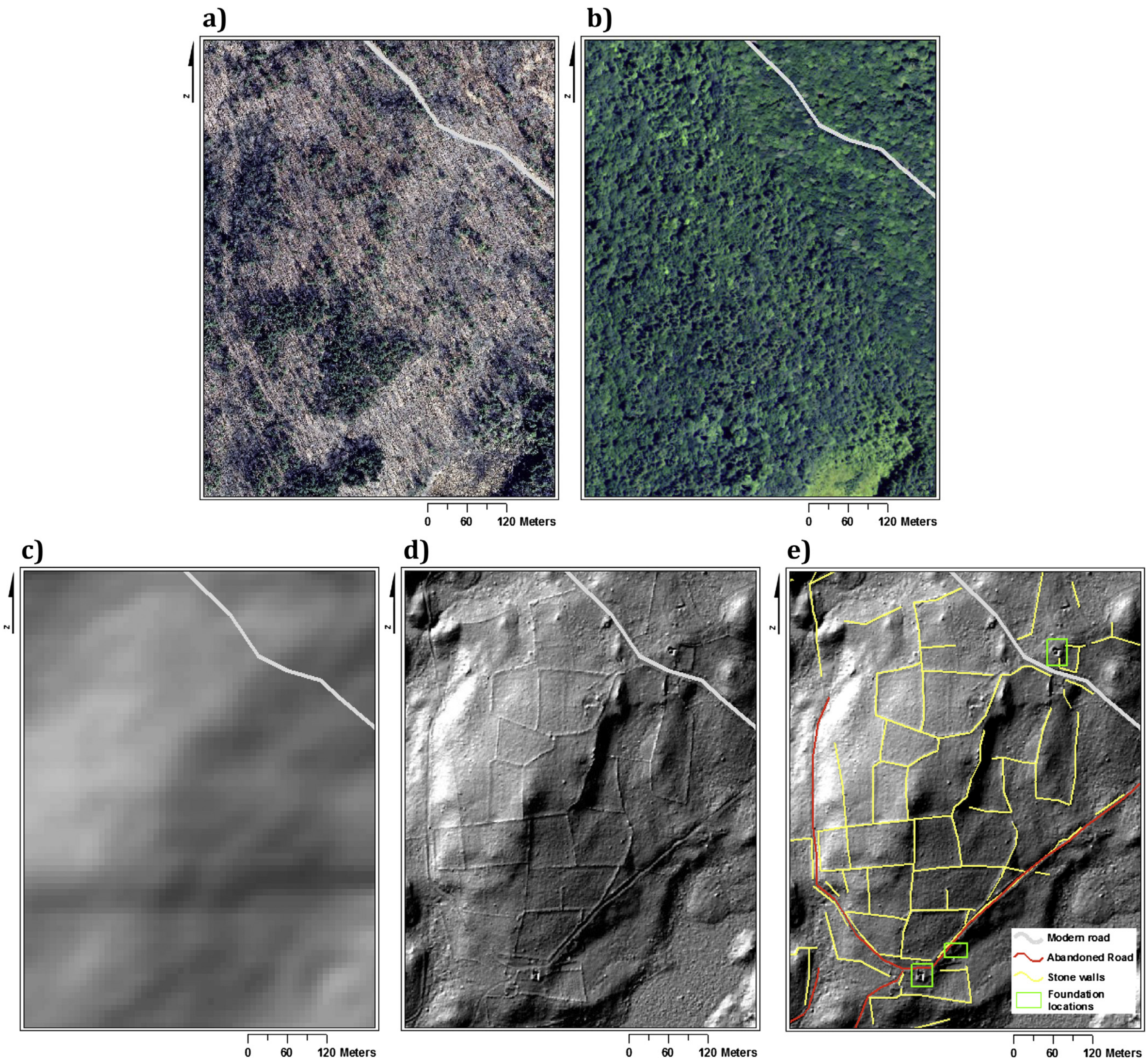

Fig. 2. This figure illustrates the advantage of LiDAR data with a point spacing of 1 m or better over traditional map views of the landscape for archaeological purposes. (a) and (b) show leaf-off and leaf-on aerial photographs with a modern road superimposed through the northeast corner of the image for reference (National Agricultural Imagery Program [NAIP], 2012). (c) shows a hillshaded DEM derived from the 10 m 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 1 m resolution (d) depicts many features quite clearly and they can then be digitized (e). In (e), stone walls are yellow, abandoned roads are red, and building foundations are outlined by green squares. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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 (Figs. 2e and 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 in the LiDAR DEM hillshades (e.g., Fig. 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 historical archaeological features, stone wall networks, building foundations, old roads and pathways. These features of the “lost” New England landscape,

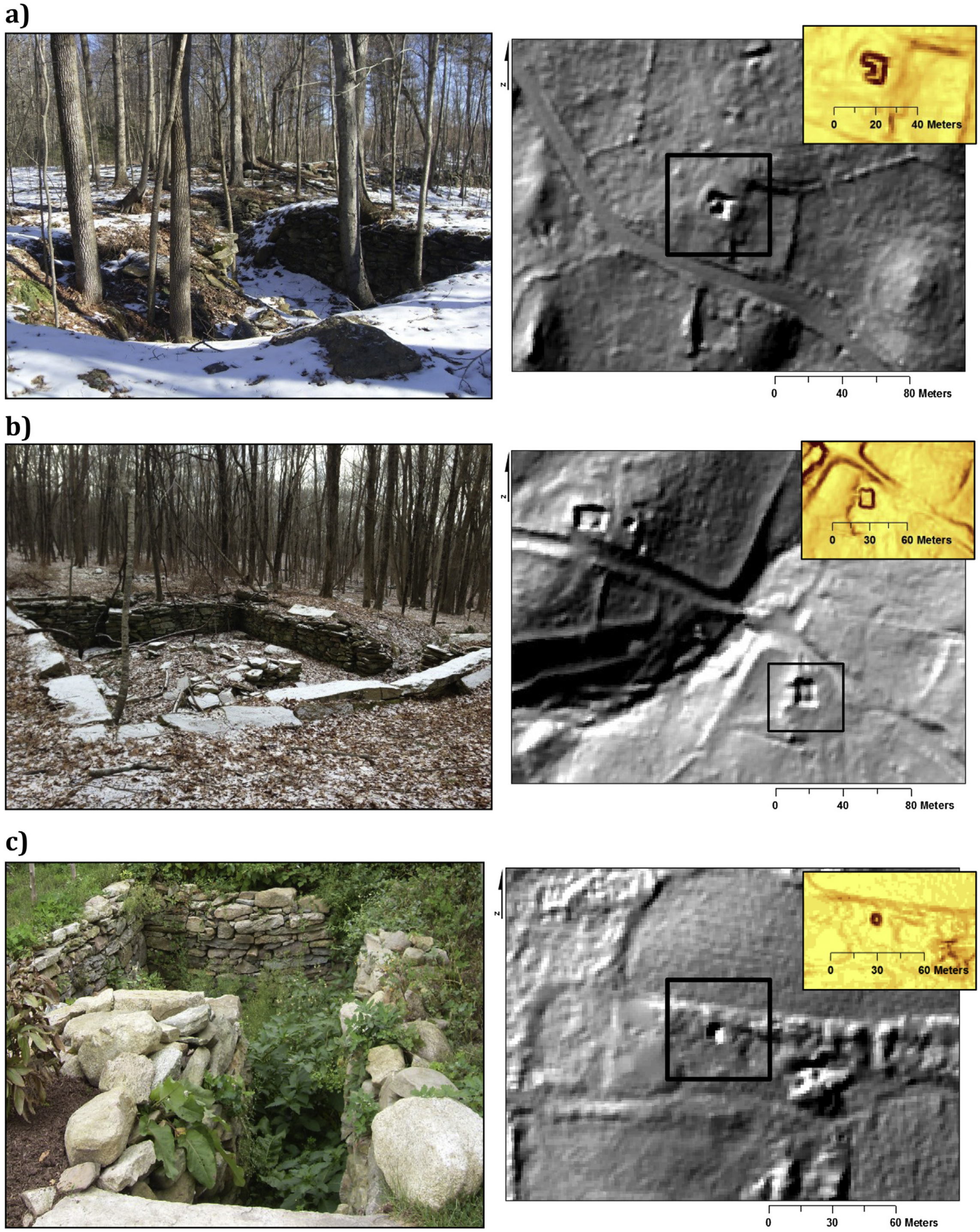

Fig. 3. (a) and (b) show building foundations found using the Connecticut LiDAR, which has a higher point density per square meter (0.7 m point spacing) than that for Massachusetts (1 m point spacing), an example of which is seen in (c). All three examples also have slope rasters, which are better in 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 (c) is somewhat smaller, and this coupled with a lower point density seems to impact its visibility.

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 (Fig. 3), which are also visible in both slope and relief rasters. Dimensions derived using 3D Analyst and LAS Dataset 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

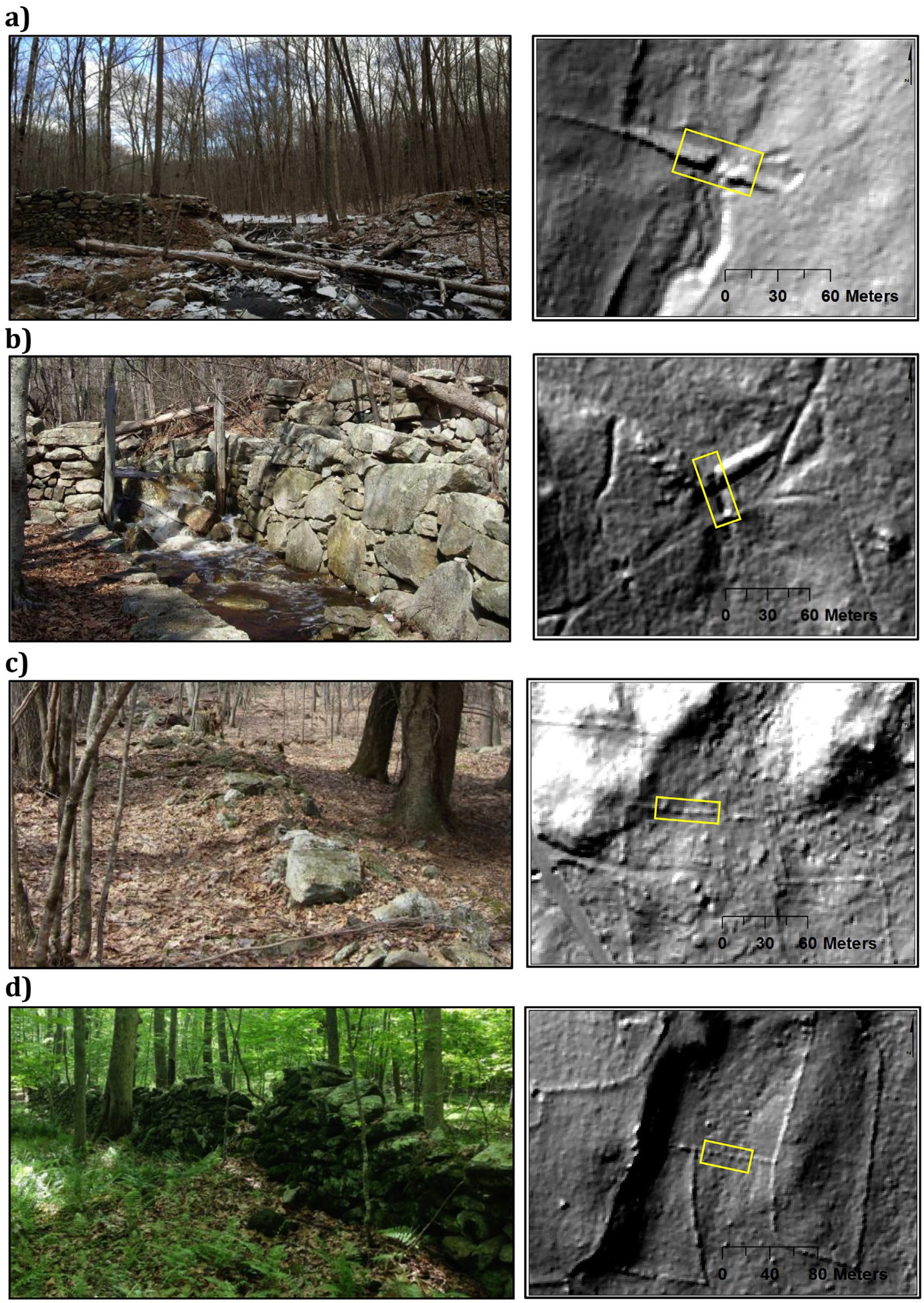

Fig. 4. In addition to building foundations, LiDAR allows us to see other archaeological features such as dams, mills, stone walls and old roads. (a) shows a dam and walls in Ashford, CT that were once part of a mill complex; (b) shows a race for an 18th century sawmill in Tiverton, RI; (c) and (d) show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

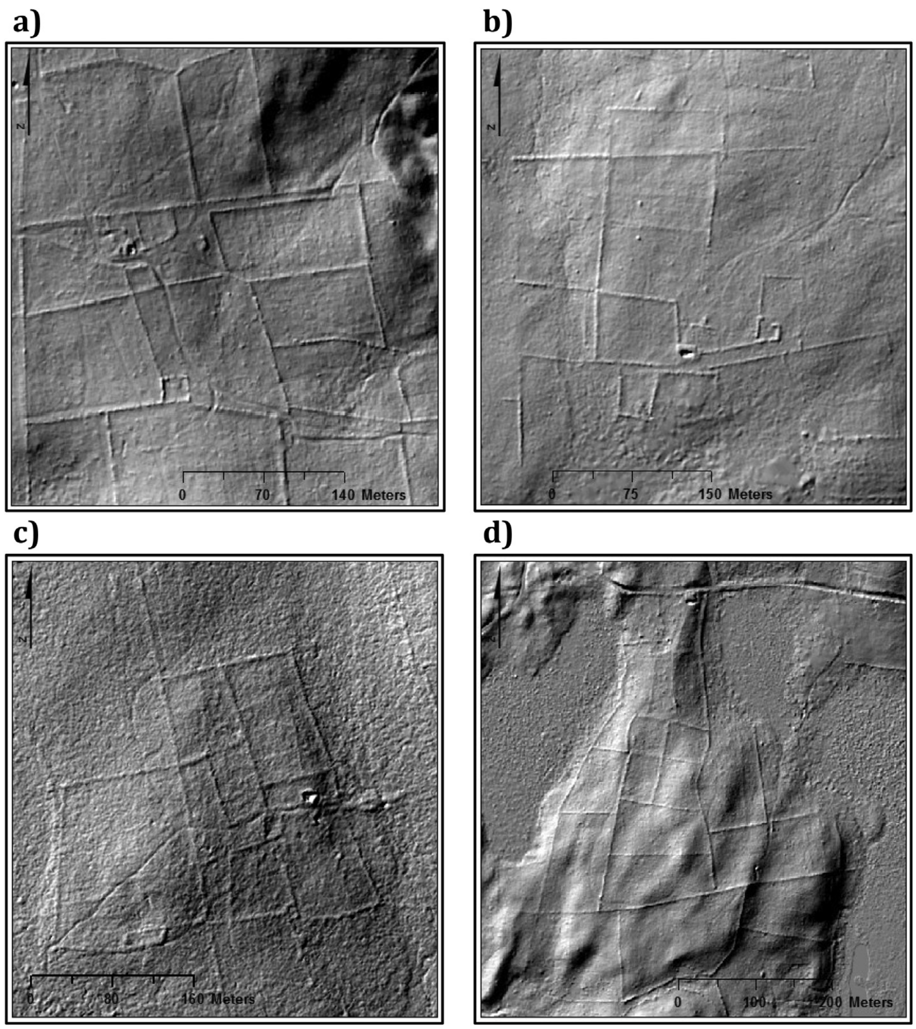

Fig. 5. LiDAR has also shown to be vital in understanding the spatial layout of historical farmsteads. Most historical research yields only a small point on a map for reference; LiDAR reveals not only the foundation where that point was, but the surrounding fields and enclosures that create irregular 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.

type of structure. 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 (Fig. 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 1–1.5 m thick, or 1.5 m tall; others are no more than the width and height of individual boulders (ranging in diameter from 0.2 to 0.4 m) and only subtly visible on the ground surface (see Fig. 4c). Despite the range of construction techniques or preservation states, these walls are clearly visible by using LiDAR data with at least 1 m point spacing, in large part because they stick out above neighboring topography and the shading in hillshade maps accentuate sharp increases in local elevation. 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 (Fig. 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

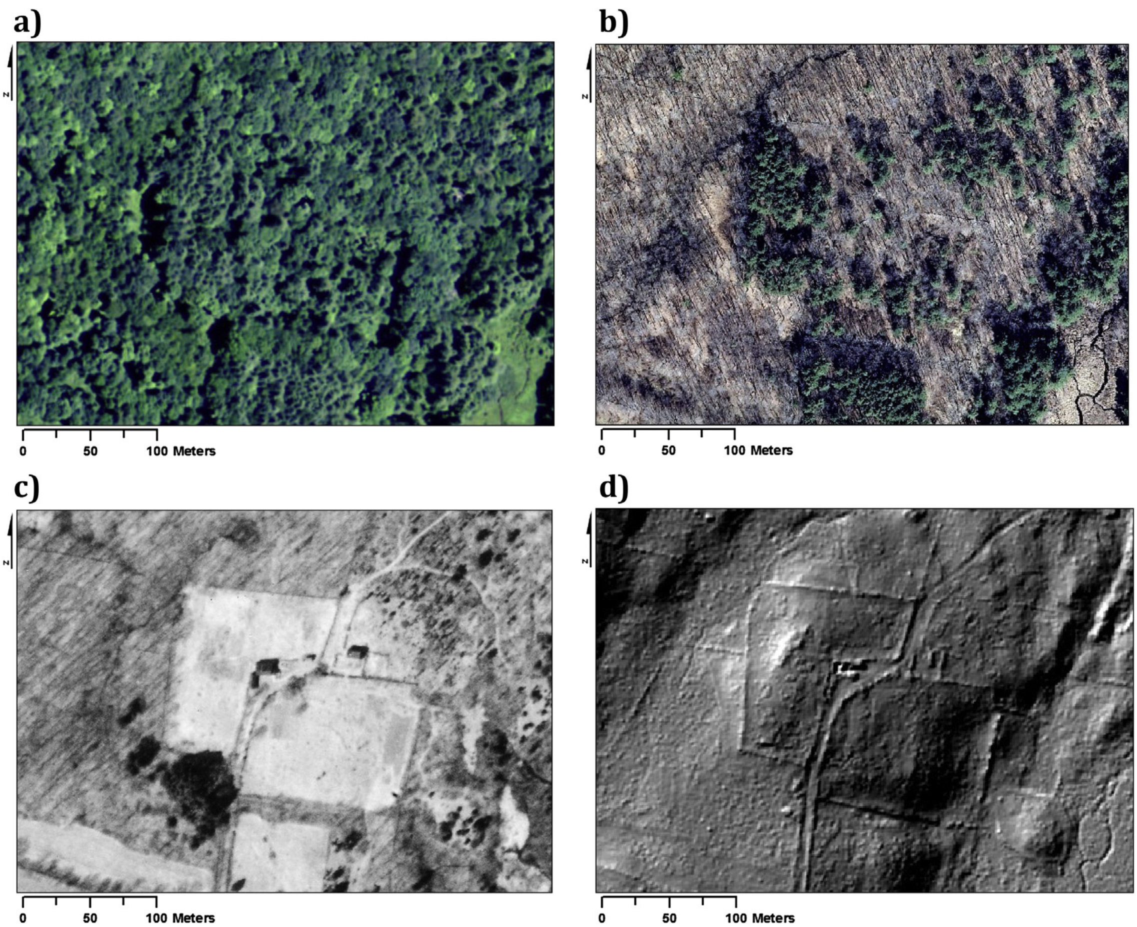

Fig. 6. LiDAR can be used in conjunction with historical documents to more thoroughly understand the history of landscape change as well. 1934 aerial photography (c) shows that this area was a working farm with a house, barn, outbuildings, and cleared fields at that time. 2012 leaf-on and leaf-off aerial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

be useful to assess how farms were actually arranged versus how agricultural literature suggested they should be (see also McMurray, 1988).

Fig. 5c depicts a building foundation (center) surrounded by networks of stone wall enclosures and an old road or pathway in Westport MA. The DEM and resultant hillshaded image for this area exhibit small-scale topographic variation of less than 10–15 cm, giving the hillshaded image a rough, unsmooth look. We interpret this to be because of the high density of vegetation such as low shrubs and brush covering the ground surface, particularly in swampy or marshy areas. Doneus et al. (2008) 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 (Doneus et al., 2008:886–887, see also Crow et al., 2007). The stone walls that we have identified in the field in relation to this study are typically between 0.3 and 1.2 m in height, consistent with published studies (Thorson, 2002). We continue to build a dataset of wall heights, but we expect that this range is characteristic of all stone walls in New England that are likely to be identified by interpreting LiDAR data. This suggests that the small-scale topographic variation seen in datasets such as Westport, MA in association with vegetation do not affect the ability to identify stone walls in the landscape. It is possible that diminutive or deteriorated walls that may exist in swampy or marshy areas with thick, short vegetation may be more difficult to resolve without different classification techniques or further processing, such as those suggested by Doneus et al. (2008). However, because walls are linear features cutting across a landscape, we find that even though they might have a subtle topographic expression, their linearity stands out among the roughness spread throughout bare earth topography (Figs. 4c and 5c). In a similar fashion, we find that foundations are typically deep enough (>0.5 m) and large enough such that the roughness associated with the vegetation also does not affect their identification using the LiDAR data.

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

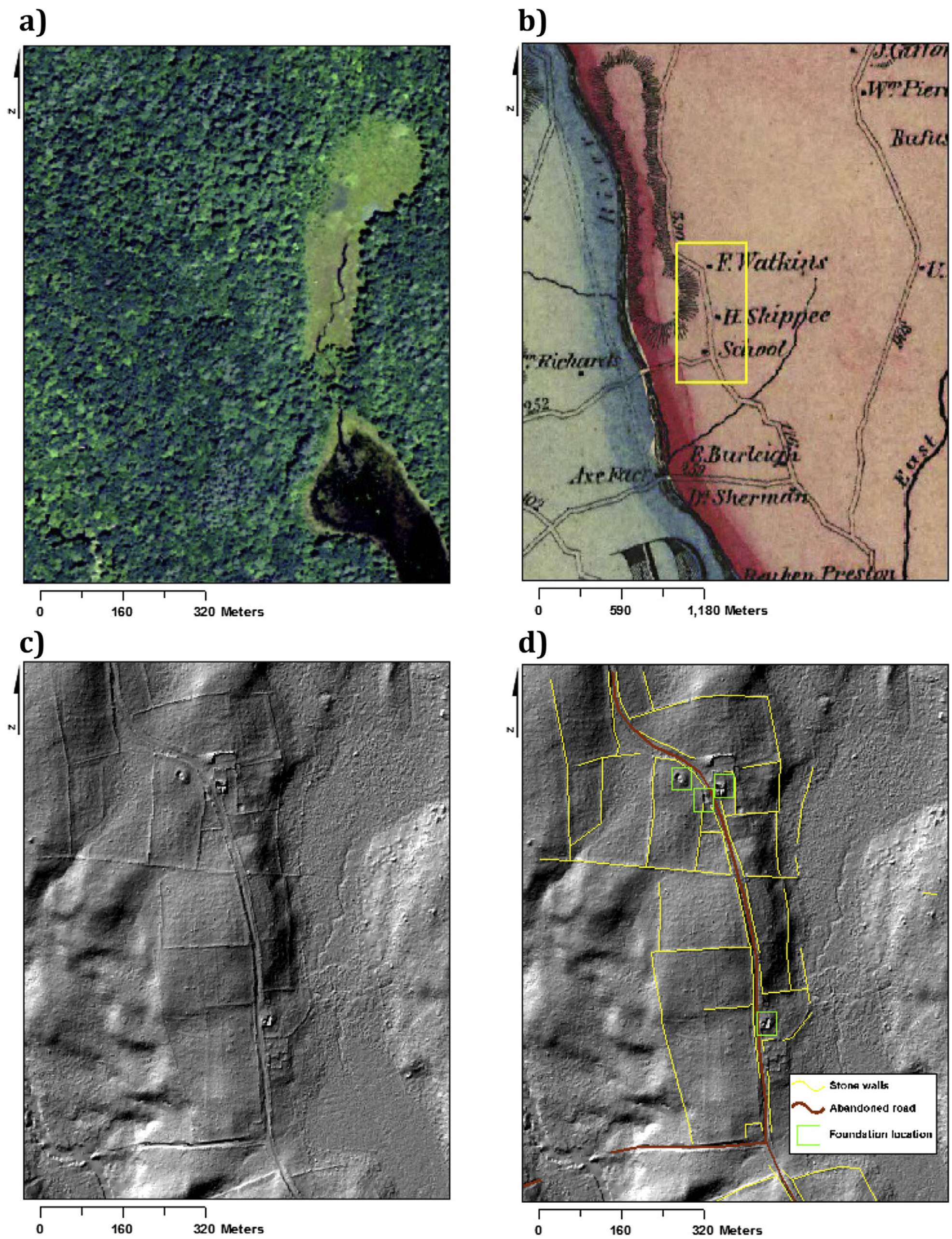

Fig. 7. LiDAR is a powerful tool by itself, but also when used in conjunction with historical documents. This area of Ashford, CT is now densely forested as shown in the 2012 aerial photograph (a) (NAIP, 2012). However, this historical map from 1858 (c) shows that the area once had a road running through it with several homesteads and even a school (MAGIC, 2012). 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. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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. LiDAR provides an efficient means to document many of these sites remotely, whereas it might otherwise be impossible to visit them in the field or analyze them.

Through examination of the hillshaded LiDAR data, the authors of this paper were successful in locating twelve new historic archaeological sites in a 9 km^2 subset of our study area in Westport (just over 5% of the town's total area) that have not been previously recorded in the archaeological records of the Massachusetts Historical Commission. There are currently only three sites recorded in that area. We were also successful in identifying forty-eight new sites that were not recorded with the Office of the State Archaeologist in Connecticut for a 4065 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, Fig. 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 Fig. 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.

Fig. 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. 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 (Fig. 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

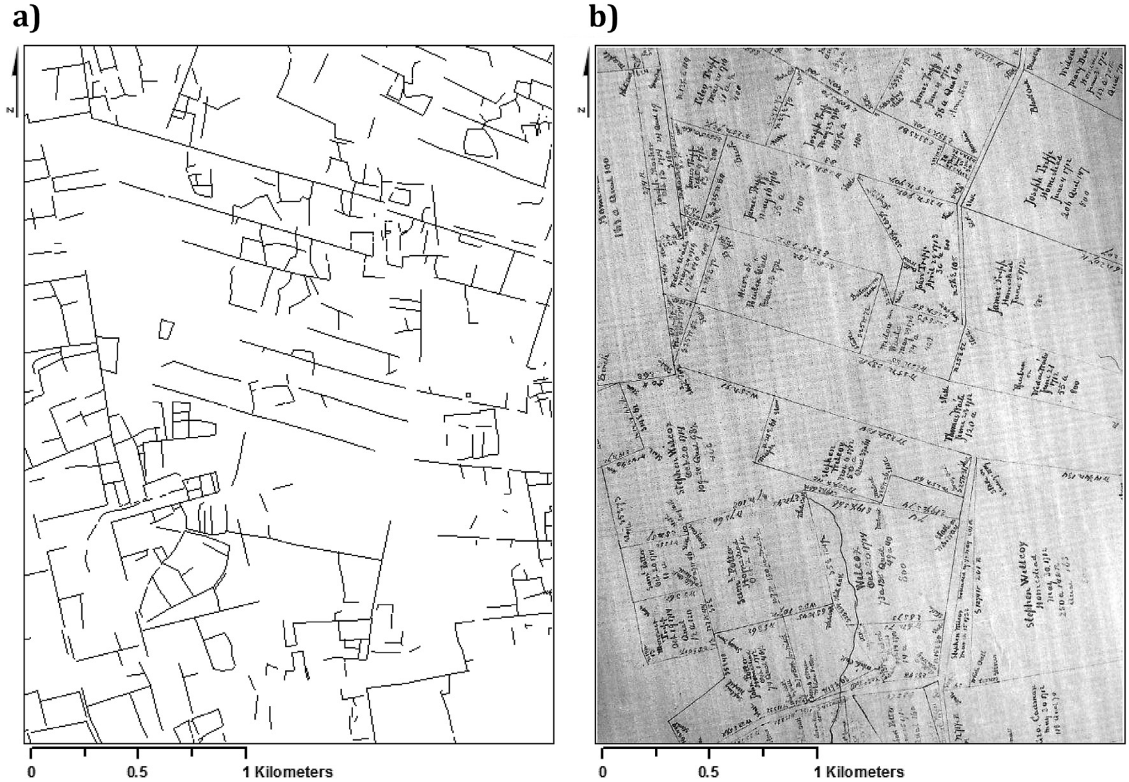

Fig. 8. By using LiDAR data, we can compare stone walls with historical property boundaries and land divisions. In this example from Westport, MA, many stone walls that have been digitized from LiDAR data (a) correspond to property boundaries shown on this map from 1712 (b) (New Bedford Public Library, 2009). 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.

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 (see Fig. 8). 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. A good example provided here in our current research is that shown in Fig. 8. The LiDAR data shows that stone walls currently visible on the landscape correspond not only to modern property boundaries, but also to property boundaries visible on a 1712 map of the town of Westport, MA. This indicates that the walls were built at that time or (more likely) prior to that year, and shows that land divisions created in the 18th century have persisted up through the present, and continue to influence how modern people divide, perceive, and use the landscape.

As evidenced by the results of various 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.

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