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

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ABSTRACT

High resolution airborne Light Detection and Ranging (LiDAR) has become a commonly used resource on a global scale to study landscapes and associated cultural features, especially in areas covered by dense forest. While LiDAR allows for unprecedented views of the terrain beneath the forest canopy, and of landscapes at broad scales generally, few studies have provided an examination of features within theoretical frameworks used to describe landscapes, or have acknowledged LiDAR data as a palimpsest. Any derivative imagery from LiDAR data depicts a moment in time of a contemporary landscape with topographic traces of cultural and physical elements from a range of time periods within and beyond human history. In order to effectively interpret the landscape as represented through LiDAR, it is critical to supplement this data with multiple contextual sources and a more robust theoretical geographic framework. While the concept of landscape as a palimpsest is well known, for the first time in hyper-realistic form we can see and physically interpret that palimpsest, along with the traces of data processing and visualization that we ourselves add to the digital landscape palimpsest in an effort to interpret it. This study provides a critical examination of the LiDAR landscape as a palimpsest, summarizes studies that have used a combination of LiDAR and supplementary resources, and provides observational examples from the northeastern United States, thus providing a practice-based observational and theoretical framework from which other landscapes and associated cultural features can be studied using LiDAR.

1. Introduction

Light detection and ranging (LiDAR) datasets have been used over the course of more than a decade in examining cultural landscape features (Risbøl, 2013; Sittler, 2001), with an increasing popularity during the last several years (Doneus & Kühteiber, 2013; Opitz, 2013; Tarolli, 2014). LiDAR has become widely used in heavily forested areas internationally in Europe (Bewley, Crutchley, & Shell, 2005; Devereux, Amable, Crow, & Cliff, 2005; Doneus, Briese, Fera, & Janner, 2008; Lasaponara, Coluzzi, & Masini, 2011; Risbøl, 2013; Schindling & Gibbes, 2014; Sittler, 2001; Tarolli, Preti, & Romano, 2014), Asia (Evans et al., 2013), and North and Central America (Chase et al., 2011; Gallagher & Josephs, 2008; Johnson & Ouimet, 2014; Millard, Burke, Stiff, & Redden, 2009; Opitz, Ryzewski, Cherry, & Moloney, 2015; Pluckhahn & Thompson, 2012; Randall, 2014; Rosenswig, López-Torrijos, Antonelli, & Mendelsohn, 2013). Despite exciting new applications and an overwhelming number of recent case studies, any imagery derived from LiDAR data portrays the landscape and associated long-term processes occurring at varying temporal rates at the single point in time (or a short series of points in time (Nordström, 2017)) that the data were collected; not truly as they appeared during historical time periods that many of these studies examine (Harmon, Leone, Prince, & Snyder, 2006). The concept of landscape as a palimpsest or as an accumulation of physically-expressed events provides a theoretical framework based in human and physical geography, as well as anthropology (Harrison et al., 2004), through which to interpret LiDAR data and associated derivative raster data such as commonly-used hillshaded digital elevation models (DEMs), slope, relief, or a variety of other visualization types (e.g., Bennett, Welham, Hill, & Ford, 2012; Challis, Forlin, & Kincey, 2011). By processing and interpreting the LiDAR data, we provide an additional layer to the landscape palimpsest, creating a new digital LiDAR landscape palimpsest that must be further interpreted with processing techniques, interpretation biases, and supplementary datasets in mind.

Landscapes have often been likened to palimpsests due to the rich history of physical and cultural events expressed on or below the surface (Anschuetz, Wilshusen, & Scheick, 2001; Brierley, 2010; Harmon et al., 2006; Holtorf & Williams, 2006; Hritz, 2014; Johnson, 2007;

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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). Humans have altered their environments and landscapes for thousands of years (Foley et al., 2013; Smith & Zeder, 2013), indeed it has been argued that the concept of "place" is a "historically contingent process" (Pred, 1984) or that "the cultural landscape" contains a "series of sedimentary layers of social accretion, each cultural stratum reflecting particular ideological origins, intentions, and contexts" (Schein, 1997). It is thus critical to recognize the temporal range and possible cultural affiliations of features that might be observed or interpreted through examining data derived from high-resolution LiDAR.

Because LiDAR allows for such high resolution imaging of the ground surface, it often provides an overwhelming amount of data to interpret. 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 & Lucas, 2010), or a "temporal collage" (Holtorf & Williams, 2006). The current landscape is the continuously-changing cumulative result of complex processes involving coupled human-environment systems and feedbacks, and not necessarily always "scraped clean" like a true palimpsest (McDonagh & Daniels, 2012). 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 & Williams, 2006; Ingold, 1993), power dynamics (Given, 2004; Spencer-Wood & Baugher, 2010), as well as human settlements or activity sites that lack widespread or localized surficial topographic signatures. This makes it difficult or impossible to discern these processes using LiDAR, though recent studies have shown that in some cases microtopographic cultural features are in fact visible (Howey, Sullivan, Tallant, Kopple, & Palace, 2016), and that motion and contemporary movement through the landscape can be captured using laser scanning (Nordström, 2017).

The overwhelming number of remaining topographic features expressed as a collection on the land surface often make it difficult to interpret surface or elevation models derived from LiDAR data and locate or identify specific features of interest without supplementary information – in a sense, there is almost too much information to interpret without context. While also acknowledging that our own histories and worldviews influence our interpretations of landscapes (Holtorf & Williams, 2006), many limitations to landscape interpretation and the burden of excess information can be partially overcome for more recent time periods by using supplementary data such as sequential satellite or aerial photography, other remote sensing techniques, historical maps, oral histories, field validation studies, archival data, or other physical or environmental data for a broader range of time periods (e.g., Challis, Kokalj, Kincey, Moscrop, & Howard, 2008; Pluckhahn & Thompson, 2012).

While a number of studies have used these methods (primarily historical maps and aerial photography) with LiDAR (Crutchley, 2006; Gheyle et al., 2018; Harmon et al., 2006; McNeary, 2014; Millard et al., 2009; Randall, 2014; Stichelbaut et al., 2016; Werbrouck, van Eetvelde, Antrop, & de Maeyer, 2009), very few employ, but 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). Those studies that have used both LiDAR and supplementary sources generally have shown new (re)interpretations about the landscapes they were studying; for example, reinterpretations of feature ages, microtopographic features, landscape development, or previously-unknown features (McNeary, 2014; Millard et al., 2009; Randall, 2014; Werbrouck et al., 2009).

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 & 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 & Luman, 2012; Shilts, Berg, Luman, & McKay, 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, Fu, Harbor, Taylor, & Vanacker, 2013; Crutzen & Stoermer, 1999; Harden, 2014; Hooke, 1994, 2000; Hooke, Martin-Duque, & Pedraza, 2012; Tarolli & Sofia, 2016).

2. Contextualizing the landscape palimpsest and airborne LiDAR

Though the studies that emphasize various visualization techniques are numerous (Bennett et al., 2012; Challis, Forlin et al., 2011; Doneus, 2013; Hesse, 2010; Kokalj, Zaksek, & Ostir, 2011; McCoy, Asner, & Graves, 2011; Štular, Kokalj, Oštir, & Nuninger, 2012), few provide critiques of LiDAR landscapes as palimpsests 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. 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 or in regions where field conditions are challenging. It may seem relatively straightforward to identify certain features of interest on the landscape using LiDAR, but it is difficult to interpret the derivative imagery objectively, or even at all, without the proper context (Cowley, 2012; Crutchley, 2006; Doneus & Kühteiber, 2013; Harmon et al., 2006).

2.1. 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 & Viles, 2010; Hunt & 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 & Davis, 2013; Mlekuz, 2013a, 2013b). A palimpsest is 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, 2017). 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 & Lucas, 2010; Bailey, 2007; Lucas, 2008; McDonagh & Daniels, 2012).

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). Dynamics of colonization, power, and human perception 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 & Williams, 2006; Spencer-Wood & Baugher, 2010; Tuan, 1977). Over centuries these landscapes often become "messy" (Mlekuz, 2013a) in that they become an assemblage of various events and processes both topographically expressed, and not (Aldred & 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 expressions of resistance and dominance in the context of colonialism (Given, 2002, 2004; Lightfoot, Panich, Schneider, & Gonzalez, 2013; Massey, 2005; McIntyre-Tamwoy & Harrison, 2004), climate change (Barnosky et al., 2012; Dugmore et al., 2012; Yellen et al., 2014), or changes in land use decisions (Bellemare, Motzkin, Foster, & Forest, 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.

2.2. LiDAR and a new type of landscape palimpsest

LiDAR provides us with a completely new view of the landscape palimpsest and many of its contributing elements. While it is indeed well-known that the landscape is a palimpsest, we can now *see* that it is as well, and begin to interpret and study that in a more quantifiable, tangible way at spatial scales and resolutions that were never possible before. LiDAR allows for a hyper-observation of the landscape and its accumulation of cultural features; an accumulation that continues to increase as point density resolutions of LiDAR datasets do so. In observing LiDAR data, we are also experiencing the landscape from a new perspective as well, one that is not necessarily from the point of view that human-environment interaction occurred (see Ingold, 2011).

LiDAR instruments collect the data as a three-dimensional (3D) cloud of points, representing the moment when the laser beam interacts with an object on the ground surface on the order of thousands of times a second (Jensen, 2007). In order to accurately interpret these features of the landscape, we as users (or often the data vendor) are responsible for then processing that 3D point cloud, a representative digital landscape, into something interpretable and quantifiable. Point cloud or digital elevation model (DEM) processing choices, such as classification, interpolation, pixel size, and visualization type impact to very high degrees what the resulting LiDAR landscape looks like. For example, after the data is collected, the point cloud is classified using various (often proprietary) algorithms to separate vegetation, water, ground, and a variety of other object classes from one another (Dewberry, 2011). This process, often done prior to distribution of the LiDAR data in its final .las file form, dictates what future processing and interpolation will allow the user to display and quantify – for example, points classified as “ground” might not always be truly ground but low or dense vegetation instead (Doneus et al., 2008). In making specific processing decisions, we may slightly alter the data, affect the interpreted outcomes of what constitutes a feature and what does not, and add to the digital landscape artifacts of our own LiDAR processing and interpretation (for example, see Figs. 29–34 in Crutchley & Crow, 2009).

Previous in-depth descriptions of palimpsest typology related to cultural features have dealt primarily with specific archaeological sites, describing different activities and levels of preservation that comprise a wide ranging typology (Bailey, 2007). We propose here a new category within the typology of palimpsests, that of the digital LiDAR palimpsest, containing not only a digital representation of a cumulative landscape from a short period of time but also containing the fingerprint of our own (and others') processing and interpretive assertions about the features on that landscape. Because of this, it is imperative to use supplementary data sources to interpret LiDAR data. While these resources may vary by region, simply processing and examining the data is not enough to gain a full understanding of the nature of the LiDAR landscape though it may provide a groundbreaking starting point.

Recent studies with visualization techniques, manual digitization, and automated extraction have all attempted to identify and interpret cultural landscape features (Witharana et al., in review; Cowley, 2012; Luo et al., 2014; Schneider, Takla, Nicolay, Raab, & Raab, 2015; Sofia, Fontana, & Tarolli, 2014, Sofia, Bailly, Chehata, Tarolli, & Levavasseur 2016, Sofia, Marinello, & Tarolli 2016; Trier, Larsen, & Solberg, 2009; Witharana et al., in review). While all of these are certainly useful to identify and capture features of interest, there are often false positives or features that are missed, demonstrating that interpreting the LiDAR landscape palimpsest is indeed challenging without validating interpretations properly (Quintus, Day, & Smith, 2017). Recent publications have assessed the efficacy of local relief models (Hesse, 2010), sky-view factor (Kokalj et al., 2011; Zakšek, Oštir, & Kokalj, 2011), principal components analysis (PCA) (Devereux et al., 2005), slope contrast (McCoy et al., 2011), intensity of returns (Challis, Carey, Kincey, & Howard, 2011), openness (Doneus, 2013; Yokoyama, Shlrasawa, & Pike, 2002), global/direct radiation (Challis, Forlin et al., 2011), and other specific metrics (Sofia & Tarolli, 2016; Sofia, Marinello, et al., 2016) for locating cultural landscape features. Many have compared these techniques with one another (and others) to discern best practices (Bennett et al., 2012; Challis, Forlin et al., 2011; Štular et al., 2012). 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, Zaksek, & Oštir, 2013), or when examining features on different types of terrain (Sofia, Marinello, & Tarolli, 2014; Štular et al., 2012). Despite the wide range of visualization techniques that are becoming available, all of them are constrained by knowledge of the interpreter as to the types of cultural features may exist on the landscape and their context.

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 & Crow, 2009; Daukantas, 2014; Mlekuz, 2013b). Difficulties in interpretation or identification have arisen not only from a complexity or persistence of land use but also as a result of the resolution of LiDAR data (Anderson, Thompson, Crouse, & Austin, 2006), or vegetation type and density (Prufer, Thompson, & Kennett, 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. Several studies have performed field validation research to discern detection rates between human interpretation of LiDAR-derived raster data and the actual ground surface (Gallagher & Josephs, 2008; McNeary, 2014; Quintus et al., 2017; Risbøl et al., 2013; Rosenswig et al., 2013). Many 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 (Coluzzi, Lanorte, & Lasaponara, 2010; New Forest, 2017).

3. Case study: LiDAR and the landscape palimpsest in southern New England

3.1. Overview and study area

The availability of LiDAR for southern New England has made it possible to visualize the landscape beneath the dense forest canopy that is common throughout much of the region (Fig. 1). The landscape is a product of the underlying bedrock geology (Bell, 1985; Stone et al., 2005), widespread glacial processes ending approximately 20,000 years ago, and subsequent land use impacts made by humans, whose land use decisions were generally constrained or heavily impacted by the glacial and geologic history (Cronon, 1983; Thorson, 2002). 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. Once mostly cleared for agriculture, over half of the New England landscape is currently forested, the result of

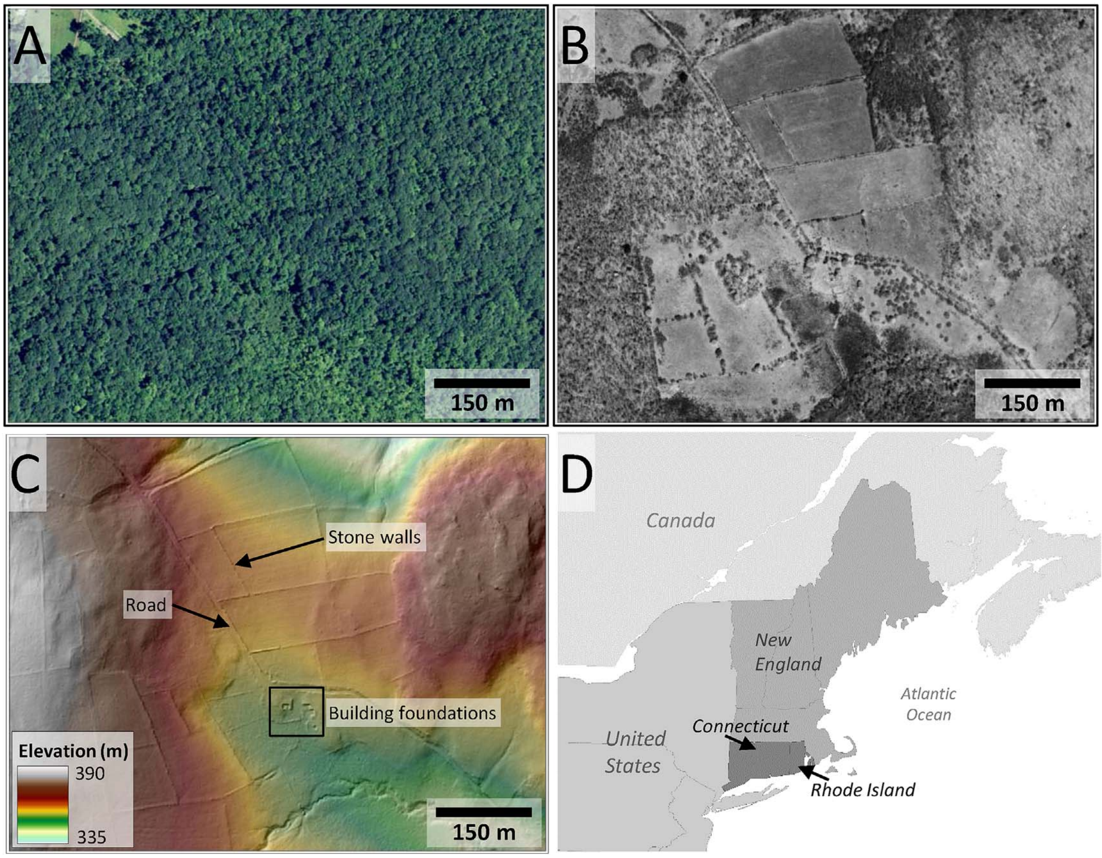

Fig. 1. Example of reforested area in Connecticut showing (A) a 30 cm aerial photograph from 2012 (CTECO, 207a), (B) aerial photograph from 1934 with cleared fields and active farm (MAGIC, 2017), (C) hillshaded LiDAR image showing some features of interest, including stone walls, abandoned road, and building foundations. (D) depicts the general location of the study area for this manuscript.

widespread farm abandonment during the industrialization and westward movement of the late 19th century in this region (Bell, 1989; Hall, Motzkin, Foster, Syfert, & Burk, 2002).

As with all landscapes, there is a rich land use history that is expressed on and below the surface. There are thousands of archaeological sites in this region dating to between 12ka up to the colonization of the region by Europeans in the 17th century that remain unexpressed topographically, or have such subtle topographic variation that it may be difficult or impossible to see with even high resolution LiDAR data. We 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 display a record of post-17th century land use (Johnson & Ouimet, 2014, 2016). This of course does not preclude the possibility of pre-17th century Native American sites and 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 & Williams, 2006; Pauls, 2006).

Nevertheless, LiDAR has proven critical in understanding the post-17th century cultural landscape in this region in addition to forest structure (Weishampel, Drake, Cooper, Blair, & Hofton, 2007) and geomorphology (Snyder, 2009), and has revealed thousands of features of post-17th century 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 & 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 impacts related to the proposed geologic epoch "Anthropocene". The fine scale of the features in this region makes high-resolution LiDAR data coupled with contextual resources and an interpretive framework critical in identifying and interpreting them. As an example, the complexities of feature interpretation in LiDAR-derived DEMs can be seen in New England when attempting to visually identify 17th to 20th century building foundations that in some cases bear striking resemblance to modern in-ground swimming pools even in DEMs with pixel resolutions of as fine as 1 m (Fig. 2).

3.2. Data and processing

LiDAR datasets are available in southern New England for the entirety of Connecticut, Rhode Island, and Massachusetts. Multiple surveys have been flown since the early 2000s, but the most recent surveys between 2010 and 2016 have provided the data with the highest point densities to date (CTECO, 2017b). The examples in this manuscript draw upon two different datasets in Connecticut and Rhode Island, both with an average point spacing of ~ 2 points/m^2. 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, 2017a). This dataset was collected in April and May of 2011 when there are typically no leaves on the trees of the predominantly deciduous forests. However, because Rhode Island is a coastal location, these forests contain dense shrubs and briars in addition to both American holly and mountain laurel which both remain green all winter. 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 collected in November and December of 2010 for the USDA Natural Resource Conservation Service and covers an area of approximately

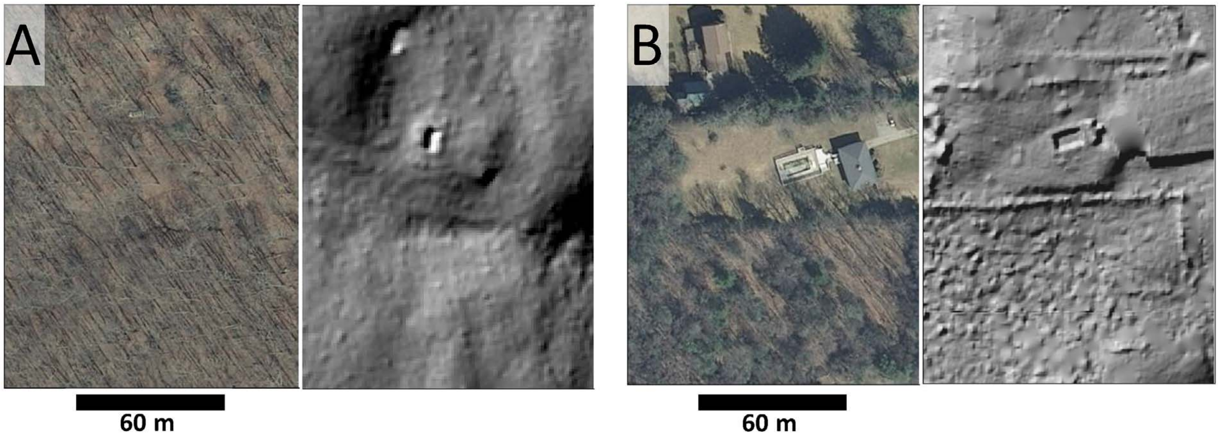

Fig. 2. Without contextual information, building foundations found in densely forested areas (A) could potentially be mistaken for modern in-ground swimming pools (B). Use of aerial photographs and an understanding of adjacent topographic context are vital in interpreting these features to avoid misinterpretation.

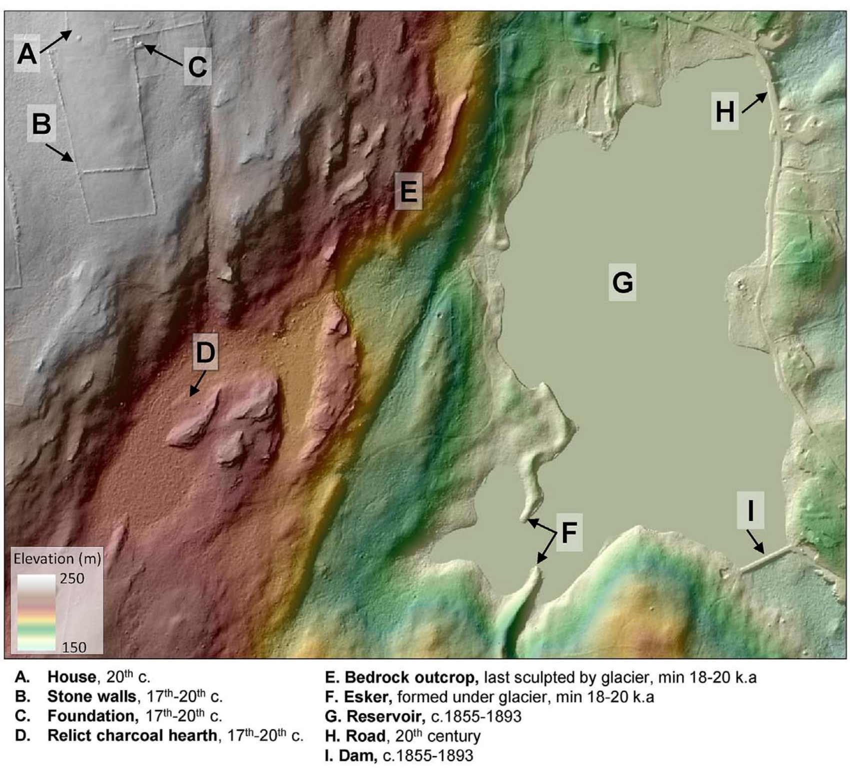

Fig. 3. A range of features spanning geologic, glacial, and partial human history in the region. Dates for G and I interpreted from historic maps.

2851 km^2 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 3D point cloud data were processed in ArcGIS 10.2 as LAS Datasets to create DEMs with a 1m pixel resolution from points pre-classified as 2-Ground. Derivative hillshade rasters were then created from the DEMs using the default settings in ArcGIS (azimuth: 315, altitude: 45). This tends to be the most commonly used visualization technique, and we find that it allows for a clear initial overview of the data in our region prior to any further image processing. Our study used hillshaded DEMs in addition to slope to identify features. Historic maps (Library of Congress, 2017) and aerial photographs (MAGIC, 2017; RIGIS, 2017b) 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 exemplify the human and landscape dynamics that have historically defined the region since the 17th century. New England's landscape typifies the several types of archaeological palimpsests that have been discussed by Bailey (2007), as well as the LiDAR landscape palimpsest we've described above 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 (Fig. 3). Each object is a part of the greater landscape, but also exists within a changing timeline of its own. Bailey's example of an archaeological "temporal palimpsest ("an assemblage of materials and objects that form part of the same deposit but are of different ages and 'life' spans" (Bailey, 2007:207)) can be seen here on a landscape scale, though the original

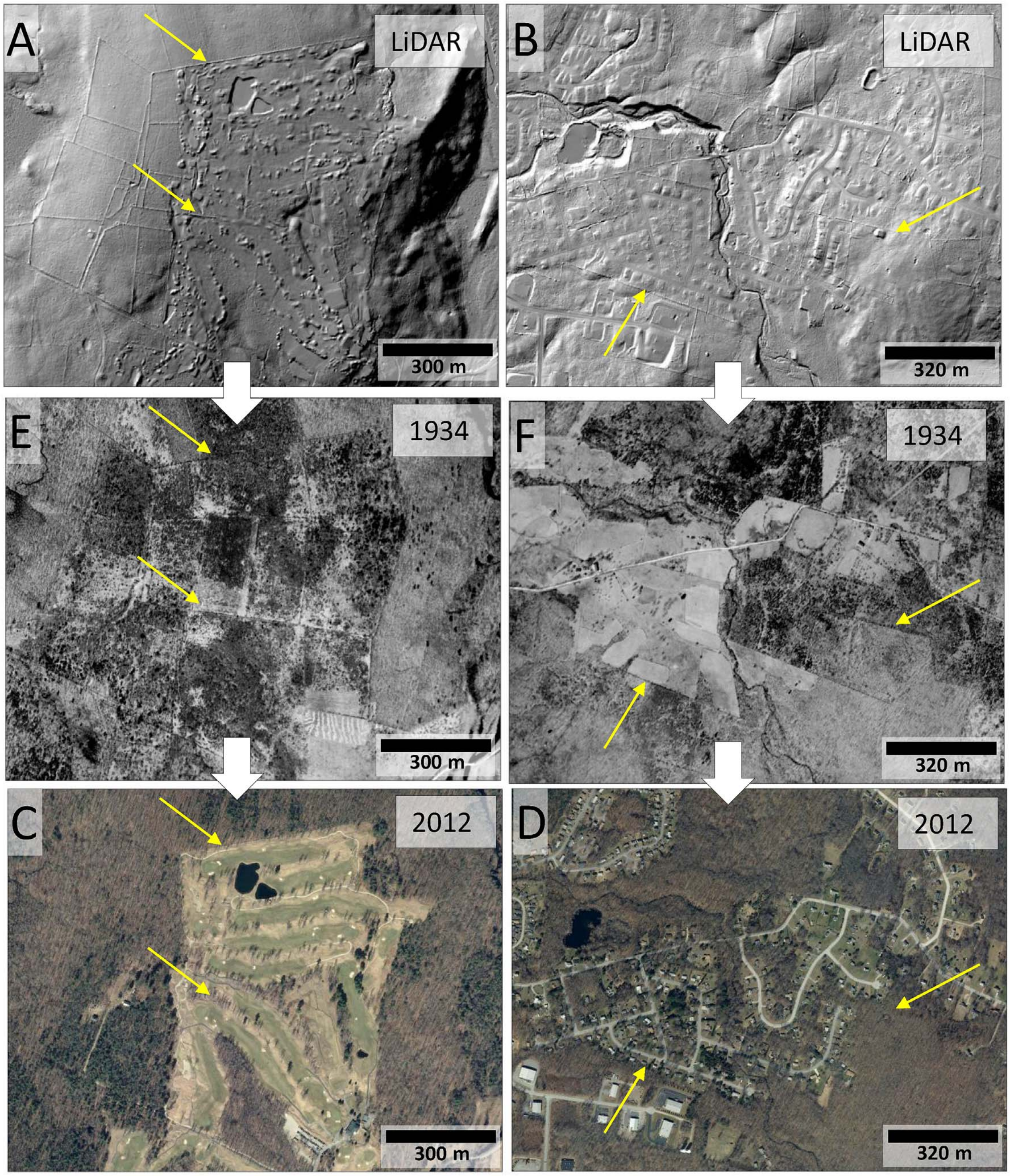

Fig. 4. A golf course (A,C,E) was built in the 1990s and has re-appropriated historic stone wall-lined field boundaries as its own, visible in the hillshaded LiDAR data (arrows depict examples) (A) and depicted as reforested fields by 1934 (E) (MAGIC, 2017). Stone walls once belonging to agricultural fields have also been re-appropriated in this suburban neighborhood in Plainfield, CT (arrows depict examples) (B,D,F).

definition was never meant to address a complex, digital, landscape. In this case, the assemblage is the surficial topography as captured by LiDAR; the materials, features, processing artifacts, and interpretations are the objects (both seen and unseen) that comprise the land surface and the digital LiDAR landscape palimpsest. As a singular image, the conflation of time (and space (Massey, 2006)) is evident in most LiDAR-derived imagery for this area in the outcroppings of constantly-weathering bedrock next to glacial landforms, 17th - 19th century stone walls, and modern subdivisions and highways.

The hillshaded DEM depicts the land surface and associated processes as apparent in 2010, and allows us to see a myriad of objects at various points in their own histories depending on the processing techniques and knowledge base that we use for interpretation. The underlying Devonian (360–410 mya) bedrock is overlain by glacially deposited till and meltwater deposits (21-17 kya) as evidenced by the esker that is partially submerged in a man-made reservoir, built sometime after 1854 and prior to 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 19th century (or earlier) delineate once-farmed fields. While they likely exist below the surface in this image, 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. Exceptions are larger landscape features that may have been part of oral histories or the production of memory, as well as portions of the landscape that are now mapped at higher resolutions so that fine-resolution predictive modeling can be undertaken (see

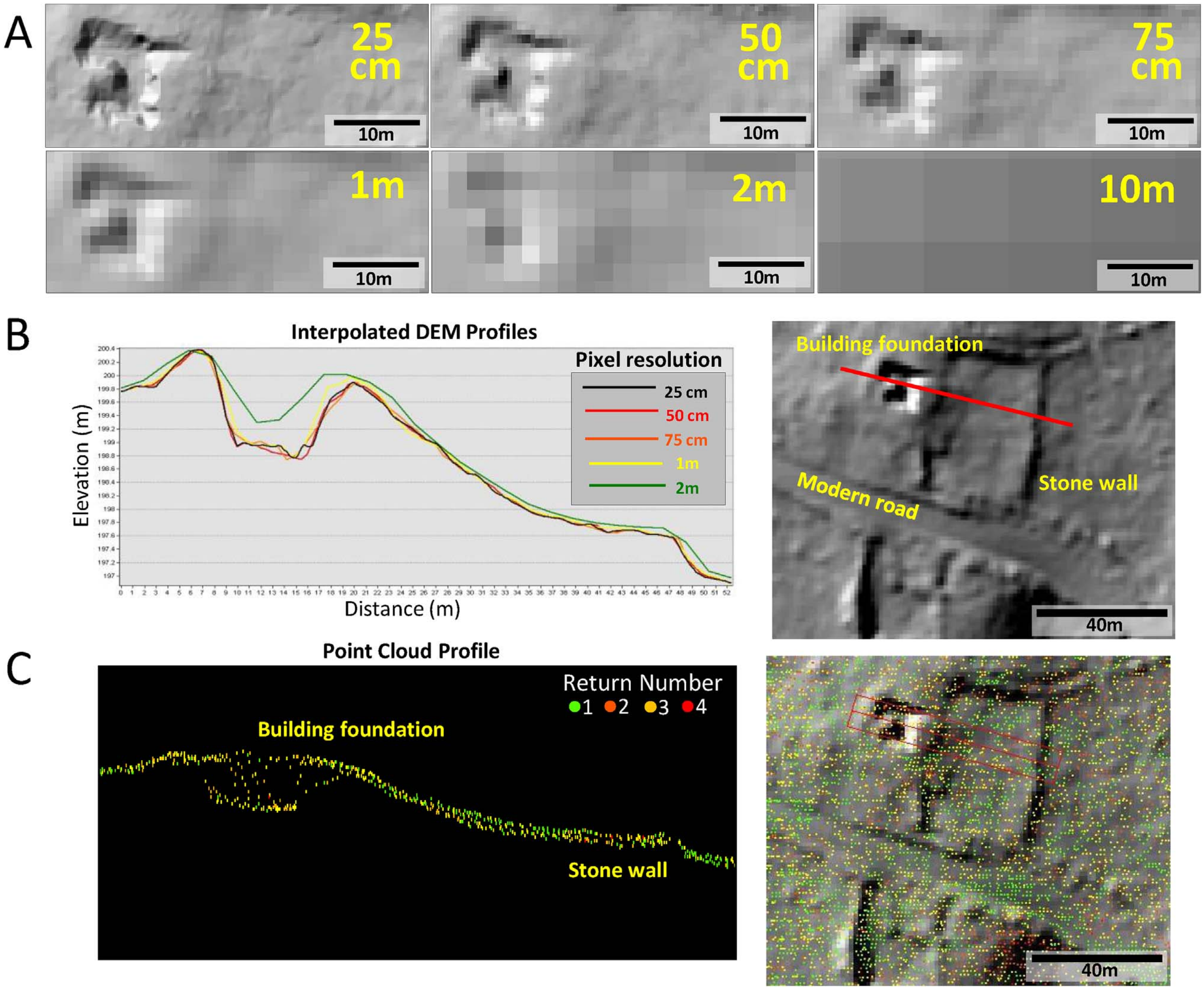

Fig. 5. Interploated pixel resolution in derivative DEMs is of great importance in identifying and analyzing cultural features. In (A), a historical house foundation is of varying quality as pixel resolutions increase from 25 cm to 10 m. (B) depicts how the resolution of the foundation and a nearby stone wall profile vary depending on pixel processing size; and (C) depicts how those features appear prior to processing and interpolation in the LiDAR point cloud itself.

Verhagen & Drăguţ, 2012). There is differential preservation of other, later, cultural features such as 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-19th and early 20th century; these are now found in forested areas that are preserved (see Fig. 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 becoming part of a new land use entirely (Fig. 4).

3.3.1. Processing and interpreting the LiDAR landscape palimpsest

The landscape we interpret post-processing is not necessarily the landscape that was there when the data was collected. Size, shape, and location of features coupled with pre-processing LiDAR point density, interpolation process, and subsequent pixel size are extremely important in identifying features on any landscape, as it is with that in southern New England (Fig. 5). Current publicly-available LiDAR datasets for southern New England have average point densities of ~2 points/m^2 – though this varies based on vegetation, and some areas have higher densities and others have lower. Other studies using LiDAR where the data was specifically collected have yielded datasets of ground-classified returns also at 2 or 4–5 points/m^2 (Bernardini et al., 2013; Evans et al., 2013) up to 20–22 points/m^2, though the number of ground-classified returns varies based on vegetation (Chase et al., 2011; Hutson, 2015). While we feel confident that many of the types of features we have been studying (and looking for) in southern New England are visible using these lower resolutions (~2 points/m^2 with a resulting 1 m DEM pixel resolution), it is highly likely that in this region more objects on the landscape would be visible and thus interpretable with higher point densities. Thus this higher resolution and existence of more interpretable features on the landscape would alter the digital LiDAR palimpsest we see.

Various visualization methods have helped identify and analyze features on the landscape in this region (Fig. 6). These visualization techniques can influence the interpretations that we make about specific landscapes and the presence or absence of associated objects. Many studies have addressed best practices for identifying specific types of features, or cultural landscape features generally (Bennett et al., 2012; Challis, Forlin et al., 2011; Risbøl et al., 2013; Sofia, Marinello et al., 2014), though it seems that final interpretation relies heavily on some background knowledge of the landscape and the types of features that a researcher might expect to encounter. In our forested landscape we expect to see building foundations, stone walls, abandoned roads, and other readily-visible historic cultural features; but how do we begin to interpret objects or landscapes we haven't seen before or those we're

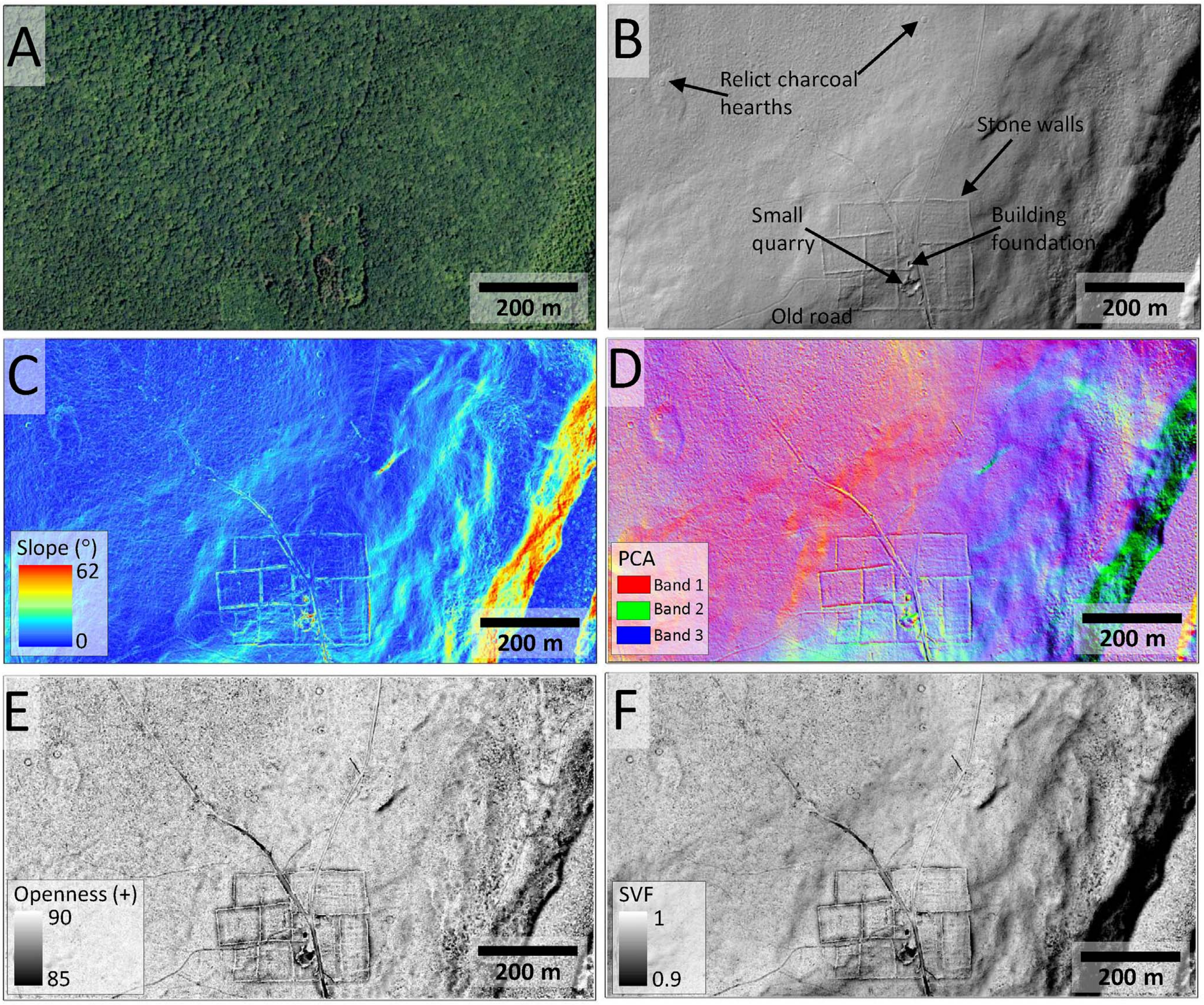

Fig. 6. Multiple visualization techniques provide different methods to view cultural features on the landscape; often it is preferred to use several methods. Aerial photography from 2012 (A) (CTECO, 2017b) depicts the current highest resolution view of the landscape without LiDAR, which is shown as hillshade (B), slope (C), RGB composite PCA of 16 hillshade directions (D), positive openness (E), and sky-view factor (SVF) (F). We used the Relief Visualization Toolbox (RVT) to generate D-F; available https://iaps.zrc-sazu.si/en/rvt#v (Kokalj et al., 2011; Zakšek et al., 2011). ArcGIS was used to generate B and C. See (Doneus, 2013; Yokoyama et al., 2002) for more information about openness.

unsure of?

3.3.2. *Interpreting the landscape palimpsest with supplementary datasets*

Interpretation of LiDAR data in southern New England has best been done using a combination of historical aerial photographs, maps, visualization techniques, and field validation (Ignatiadis, Ouimet, Johnson, & Dethier, 2016; Johnson & Ouimet, 2014, 2016; Raab et al., 2017). Successive land use in one location resulting from various processes can result in a blurring of individual events or loss of resolution (see 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. Both of the examples provided here 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.

In southern New England, the continuation of agricultural practices, though they have 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, and were thus expanded (Barger, 2013; 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 & 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 (Fig. 7). These microtopographic features are similar to findings

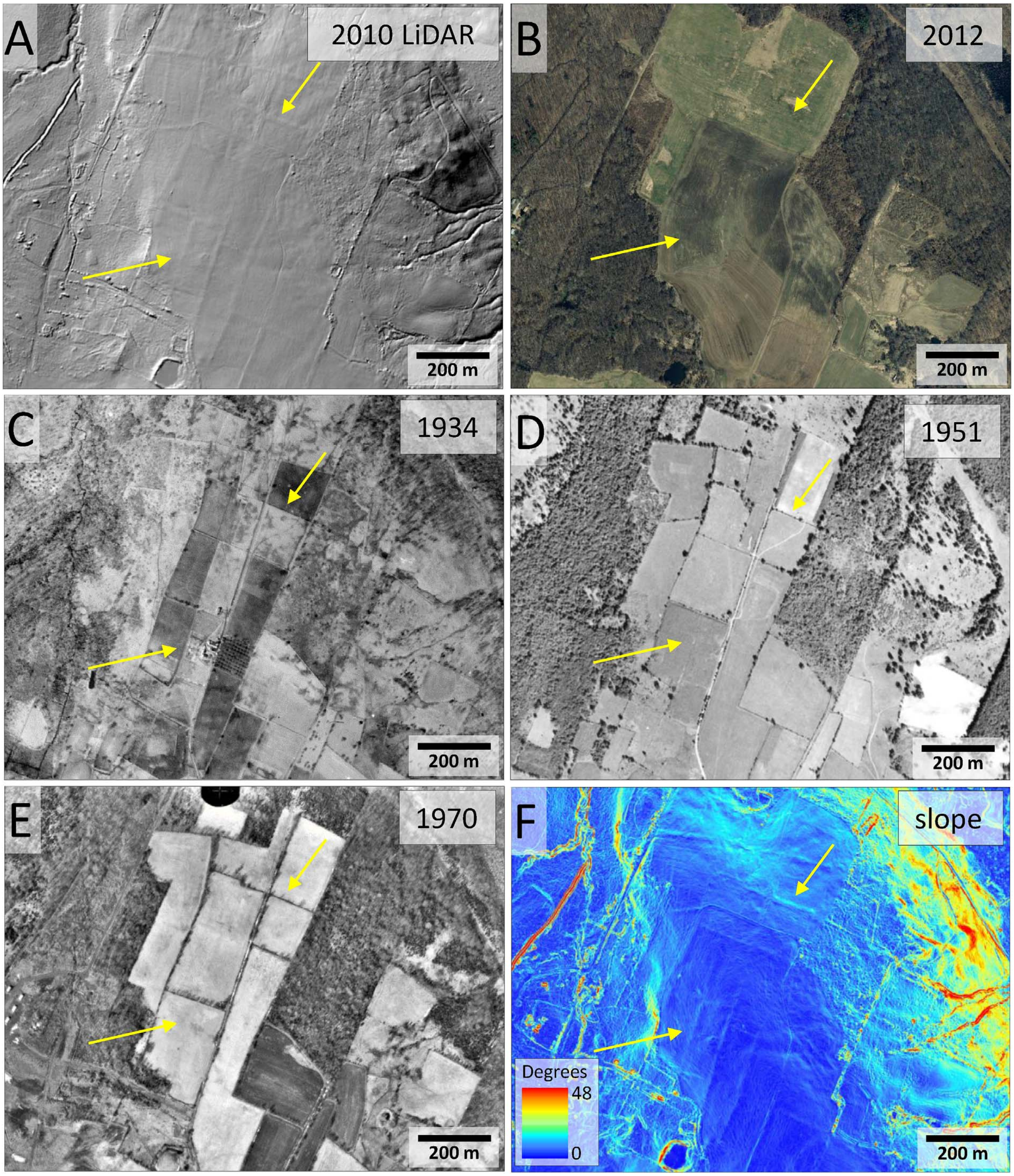

Fig. 7. Use of time-series historical aerial photos to examine field expansion in eastern Connecticut. Between 1934 (B) and 1951 (D) an entire farmstead disappears from the center of the image, the foundation plowed in and the surface smoothed; though some traces do remain in the topography on the surface. (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.

reported in England and Ireland where subtle topographic variations indicative of earthworks or field boundaries were 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 & Davis, 2013). In Connecticut, the subtle traces of old walls and field boundaries visible in LiDAR data can be retraced by comparison with historical aerial photographs over a period of time so that the process of gradual field expansion and boundary change can be better interpreted and understood.

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. Middletown, Rhode Island was the site of 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 (Fig. 8). 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

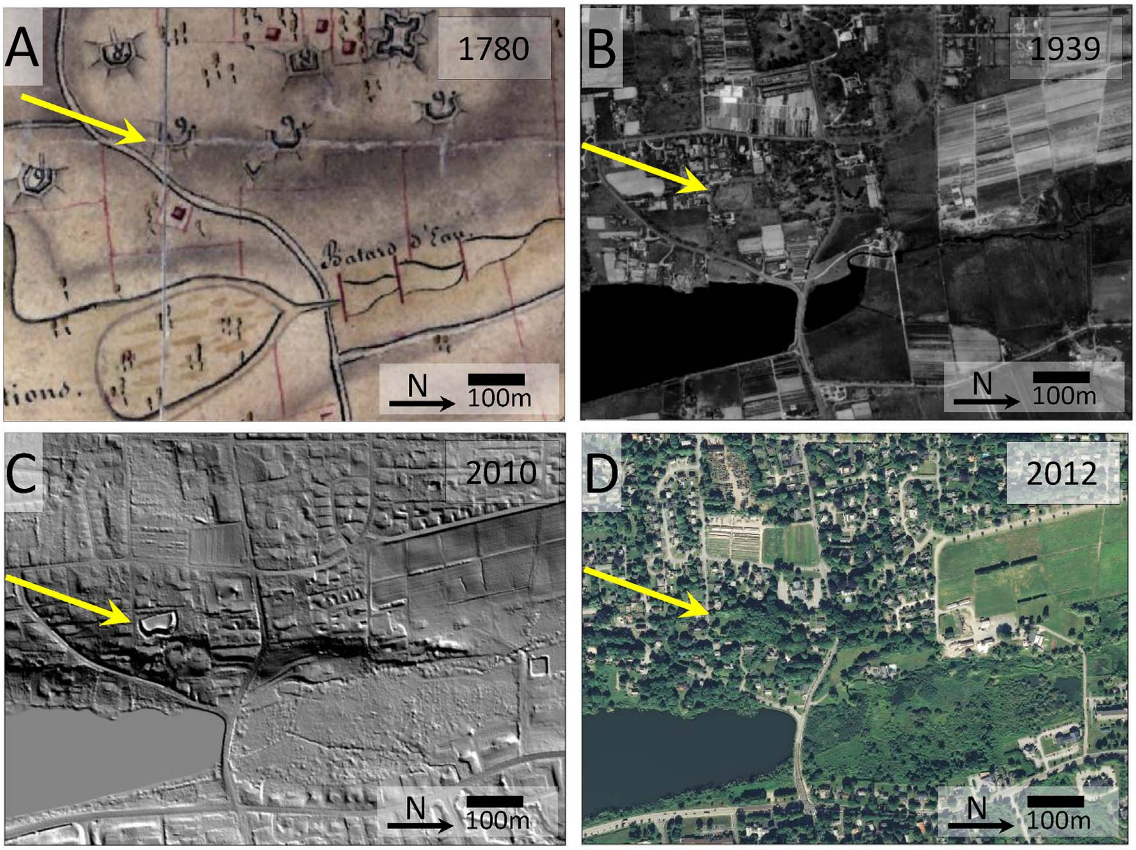

Fig. 8. Examination of historical sources for this area in southeastern Rhode Island reveals a dense post-WWII suburban landscape, though trace elements of the 18th century landscape remain and are visible in a historic map from 1780 (A) (Library of Congress, 2017) as well as LiDAR data (C) and historic aerial photography from 1939 (B) (RIGIS, 2017b).

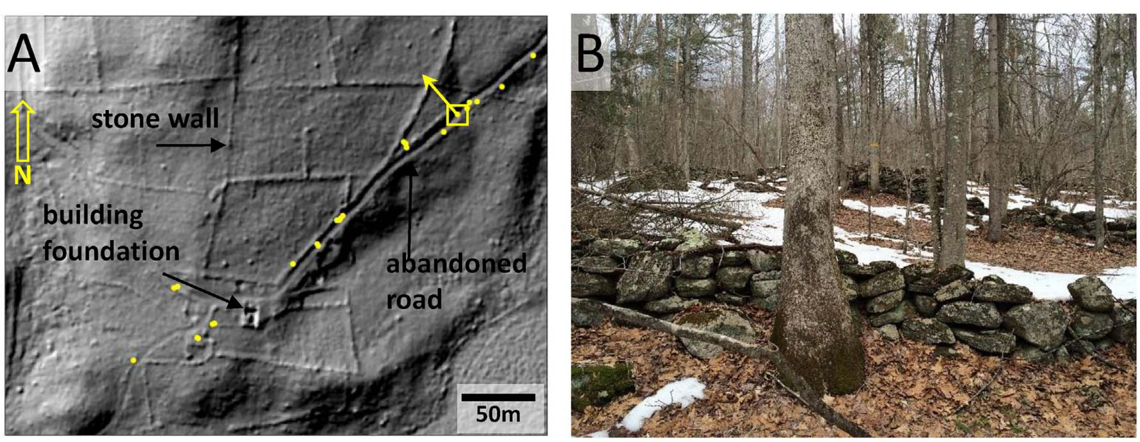

Fig. 9. Exchangeable image file (EXIF) data extracted from mobile phone photographs has allowed us to map field validation survey routes on LiDAR while capturing the point at which a photo was taken (dot with square), the direction, and elevation, while also allowing us to enter other information and notes (A). This photo (B) was taken facing northwest toward the stone walls lining the abandoned road shown in the hillshaded LiDAR data.

used strategically by first American, and then British forces, is still extant (see RIMAP, 2017). 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 (Fig. 8A) 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-WWII suburban patterned development on the outskirts of Newport. This and other maps and accounts help reconstruct the complex layer of conflict that is part of this landscape as in other regions being studied with LiDAR and supplementary sources (Gheyle et al., 2018; Stichelbaut et al., 2016).

In areas where we are able to interpret LiDAR data in what we believe to be a straightforward manner, there are still gaps in our knowledge about the surface features we see (or don't see) that can only be filled with field observations. For example, while interpreting the spatial density of stone walls on a regional scale is best done with brute-force digitization methods and geospatial analysis based on LiDAR data, understanding the complexities of stone wall construction, material, and archaeology is a supplementary field task after LiDAR has assisted us in identifying the wall (Fig. 9).

4. Discussion and conclusions

Conceptualizing the landscape seen through LiDAR as a palimpsest helps us understand and account for as many objects, processes, and events as possible that have occurred on the landscapes we are studying. And not only those which we see and interpret as being the physical landscape, but those that we ourselves impose upon it through our interpretation and processing efforts. Processing artifacts, low point densities, dense year-round low vegetation, interpolation method, pixel size; all of these factors and more contribute to how we create and eventually interpret the digital landscapes and their associated features from LiDAR data. Recognizing our own impacts and limitations is extremely important in then being able to accurately and comprehensively interpret the data in a meaningful way using supplementary source material.

There are a wide range of limitations in our interpretations of this digital landscape. Foremost, there are obvious additional limitations for areas or time periods where contextual information is scarce or unavailable and there are certainly study regions where field observations are difficult to obtain. Thus it might not always be the case that supplementary sources are readily available, though multple visualization techniques and processing biases can always be used and recognized. Ultimately, any supplemental source is important to use, as 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 examples presented above show features that have been partially or fully erased topographically, though it is likely that they have a substantial archaeological record which is not visible using LiDAR. LiDAR primarily allows for landscape interpretations topographically, though it also provides associated intensity data, which has been used infrequently for examining cultural landscape features (Challis, Carey et al., 2011; Coren, Visintini, Prearo, & Sterzai, 2005) though there is great potential. Our interpretation of the topography is also heavily influenced by processing techniques, vegetation, differential preservation of features on the landscape, visualization technique, viewing scale, resolution, feature size, and a variety of other factors that can vary greatly.

There are also temporal limitations with LiDAR, and 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 archival data 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, environmental, or field data. These examples reveal a wide temporal variation of features that appear in one layer of the derivative LiDAR data; interpretation with supplementary historical data is integral to fully understanding these landscapes and the features from which they are comprised.

In conclusion, the landscape palimpsest we interpret with LiDAR data is a representation of the physical landscape, with additional layers added to that landscape through our own efforts to interpret it. In order to comprehensively understand as many of those layers as possible, contextual supplementary information in some form is absolutely necessary. And while LiDAR has become an important and irreplaceable tool in studying cultural landscape features over the past decade, we may never truly be able to fully interpret the range of meaning, events, and features that the landscape palimpsest holds.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.apgeog.2017.12.018.

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