

Identifying Landscape Modification using Open Data and Tools: The Charcoal Hearths of the Blue
Mountain, Pennsylvania

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ABSTRACT

In this technical brief I demonstrate two methodological points broadly relevant to historical archaeologists. While LiDAR airborne laser scanning (Light Detection and Ranging; a.k.a. airborne laser scanning or ALS) has been widely used to identify prehistoric archaeological sites, its use in historical archaeology could be expanded. LiDAR data is particularly valuable because it is frequently open access. By coupling open LiDAR data with open source software, one can quickly, easily and inexpensively identify historic landscape modification. I present an illustrative example, the identification of charcoal hearths in Pennsylvania, along with tools and techniques used to carry out the research. This method has allowed us to identify 758 charcoal hearths within the 74 km² research area along the Blue Mountain of northeastern Pennsylvania.

Introduction

Analysis and interpretation of the physical landscape is a significant component of historical archaeology. In this technical brief, I demonstrate, through the case of charcoal hearths from the Blue Mountain in Pennsylvania, the value of open LiDAR data and of using open source software to process the data. The project has facilitated the identification of charcoal production sites (hearths) along the slopes of the Blue Mountain, revealing an extensive industrial landscape within the “wilds” of State Game Lands #217. Although not presented here, this newly revealed historic landscape creates an opportunity to better understand a poorly documented segment of 19th century society- the people, known as colliers, who produced the charcoal. In order to provide these richer interpretations, however, we need evidence upon which they can be built. Below, I discuss four important aspects of this project. First, I provide historical context for the project. Second, I discuss the ethical and practical advantages of open data and open source software along with the specific data and software used herein. Third, I present the analysis, which, though specific to this study, promotes both the reproducibility of this research and the use of these tools for other research projects in historical archaeology. Fourth, I present a very brief discussion of the results, though not the interpretation, of the methods discussed herein.

Charcoal Production

During the 19th century charcoal was widely used as a fuel for smelting iron (Birkinbine 1879; Kemper 1941; Straka 2014). Charcoal was ideal because it introduced few contaminants into the iron smelting process (McVarish 2008:268). In the Americas, vast tracts of “unoccupied” forests made charcoal an even more attractive fuel. Even once methods were devised to use coal for iron smelting, replacement of charcoal by coal was a slow process that took approximately 100 years (Schallenberg 1981).

Between 1828 and 1878, two charcoal furnaces (Lehigh and East Penn furnaces) and one charcoal forge (East Penn Forge, a.k.a. Pennsville) were constructed in northern Lehigh County and southern Carbon County, Pennsylvania, along at the northern edge of the Lehigh Valley (Figure 1) (Mathews and Hungerford 1884; Swank 1892; Brenckman 1913). At the time the only large tracts of standing forest remaining in the Lehigh Valley were along the Blue Mountain, a long (approximately 150 miles) ridge that acts as the boundary between Lehigh and Carbon/ Schuylkill counties. Bernard Fernow, who managed the tract from 1879 to 1887 and would become the third chief of forestry of the USDA, labeled the mountainous tract, “waste land” because it had little use beyond charcoal production (Fernow 1883). Between 6000-15000 acres along the Blue Mountain were owned and harvested by the owners of these furnaces (Straka and Ramer 2010).

The making charcoal involves steps that ensure the production careful and efficient conversion of wood to charcoal. Wood was cut into four-foot lengths by wood cutters, who were frequently farmers, or colliers, working in the winter “off season.” To begin, a flat, level, compact circle of earth between 8-14 meters in diameter was constructed. On slopes, this involved the removal of upslope earth that was placed downslope to create a circular or oval terrace. Wood was then piled vertically in three tiers around a central “chimney” placed in the center of the circle. Gaps left by stacking larger “billets” (4-7 inches in diameter) were filled with “lap-wood” (1-4 inches in diameter). The entire pile was covered with a layer of leaves and other detritus, which was then coated with a layer of earth and charcoal dust (Figure 2). Colliers then ignited the wood through the chimney, which they then sealed. During the first 24 hours or so, the collier carefully monitored and controlled air vents in order to ensure the spread of the charring while avoiding burning the wood. Once the collier was sure that the smoldering had spread throughout the hearth, they did not need to remain at the hearth, instead returning periodically for monitoring and managing throughout the next seven days. After completion, the hot hearth was raked out to separate the charcoal from the soil (Figure 3), which was then transported to its destination

via carts along forest paths and roads (Kemper 1941; Walker 1966; Wigginton 1979; Zeier 1987; Wettstead 2003, Hart et al. 2008; Strachan et al. 2013; Johnson and Ouimet 2014; Straka 2014).

We know little about how the forests were managed or about the lives of the colliers who, through skill and sleepless nights, produced the fuel to power the furnaces. This brief describes the LiDAR-based methodology employed that will allow us to begin shedding light on the lives of the colliers.

LiDAR

LiDAR, or Light Detection and Ranging (a.k.a., Airborne Laser Scanning or ALS), has revolutionized archaeology in forested regions. In recent years, archaeologists have used LiDAR to dramatically rewrite our understanding of settlement patterns and farming practices in the Maya area, Hawaii, Mexico and Cambodia (Chase et al. 2011; McCoy et al. 2011; Chase et al. 2012; Evans et al. 2013; Fisher et al. 2017). Historic landscapes have also been investigated using LiDAR (Devereux et al. 2005; Harmon et al. 2006; Opitz et al. 2015; Johnson and Ouimet 2018). Charcoal hearths and their associated industry have been investigated in northeastern United States and in Europe (Raab et al. 2015; Schneider et al. 2015; Hirsch et al. 2017; Raab et al. 2017).

In essence, LiDAR is a relatively simple technology (for detailed description see Fernandez-Diaz et al. 2014). A laser pulse is shot at a surface, bounces off the surface, and that is the reflected signal that returns to the source, or “return,” is detected. The time traveled is recorded and the distance calculated (at the speed of light through a medium, typically air) measuring the relative location of the surface compared to the laser. Highly sensitive equipment and powerful computing is required as thousands of pulses are shot and recorded per second from an airplane. The geolocation of the airborne laser is measured through the use of high precision GNSS (Global Navigation Satellite System; GPS in the US)

units and inertial measurement units (IMU). The first measures absolute location and the second records relative movement. Between the two, airplane location can be measured with great accuracy and precision. From the airplane, lasers are scanned across the surface in a swath covering the study area.

After post-processing, the resultant data is a point cloud, a series of points recorded with longitude, latitude and altitude coordinates. Points are computationally classified (Table 1). Archaeologists are primarily concerned with ground points, which are relatively easy to identify because they are the “last return,” that is the pulses that took the longest to return to the detector. Since laser pulses cannot penetrate the ground, “last returns” represent the surface. LiDAR data for much of the United States is available through aggregators¹. For the ground return (class 2) data considered herein, an average of 6.25 LiDAR points were collected per 100 ft² (or approximately 1 point/ 1.5 m²).

Although the point cloud can be used as is, it is typically converted into a digital elevation model (DEM) (Werbrouck et al. 2011; Kokalj and Hesse 2017). A DEM is a raster that stores elevation in each grid unit, much as digital photographs store color in a grid of pixels. The difference is that DEM grids are located on the landscape. To convert the point cloud to a DEM, a triangular irregular network (or TIN) is one of the more common methods used to convert the point cloud into a solid surface by making contiguous triangles with three of the closest points as vertices (Fernandez-Diaz et al. 2014). This surface of triangles (Figure 4b) is then converted into the regularly gridded surface of a DEM. Once prepared the DEM can be visualized using hillshade, ruggedness, slope and slope aspect (Challis et al. 2011). For this analysis, each cell of the DEM is 1.3 m × 1.3 m (1.69 m²).

Why Open?

Only open data and open source software (or FOSS) were utilized for this analysis for practical and ethical reasons (e.g., Kansa et al. 2011; Ducke 2012; Wilson and Adams 2015).

The FOSS tools described herein save time. It is often believed that open source software can have a high adoption threshold and a lack of support (for example via a help line), thereby costing precious time. When true, open source software can be difficult to use. Therefore, the tools described herein are included because they are well-supported, stable, cross platform, flexible and, therefore, have relatively low adoption thresholds.

The FOSS tools described herein save money. Because they are freely available on the internet, costs are limited to a computer and access to the internet. Low cost reduces (though cannot eliminate) barriers for underfunded archaeologists. Open source software can be seen to grease the wheels of entrance into professional archaeology. This is particularly significant for populations poorly represented in archaeology.

The use of open data and open software eases archaeologists' ability to abide by our organizational ethics, including those of the Society for Historical Archaeology (2015), the Society for American Archaeology (1996) and the Register of Professional Archaeologists (2018) (Huggett 2015). These ethical statements encourage open praxis (Smith and Seward 2017); the process of working as openly as possible at all stages. Being open about the processes by which data is collected, modified, "cleaned" and transformed, is inherent in those ethical statements. The goal of all archaeological research is the responsible² sharing with other researchers and the public. The results of research, including the data, should be shared openly through publishing in open access journals and repositories. The data for this research are published through the *Journal of Open Archaeology Data* and in digital repositories, Open Context and Zenodo (Carter 2018a-f; Carter [2019]).

FOSS tools have additional benefits associated with the ethics statements above. First, because open source software is based upon open formats they encourage sharing of raw data. Most software can read open formats, while proprietary formats are restricted to proprietary software. Open formats encourage responsible archiving and curation because they allow out-of-date formats to be easily read. Second, the ease of sharing also promotes “clean” data- data clearly understood by people other than those who collected it. Third, if we can share data easily then we must be more mindful of how it is collected in the first place. That is, openness promotes careful attention to both the data and the method of data collection yielding benefits for the original collectors/ users and unintended users. Fourth, the code for open source software is available for inspection. While few archaeologists will delve into the code, this availability means that they, or a knowledgeable expert, can check that code. This means that there are no more proprietary black boxes. Fifth, future uses of data are never fully predictable; openness encourages experimentation and reuse. Sixth, using open source software with students promotes skills (easily transferred to commercial software) and flexibility and frees them from oppressive subscription fees when they graduate.

Open Data

This project was initiated because of open data. At one point, curiosity about odd features of the local landscape along the Appalachian Trail led me to the streaming, LiDAR-derived hillshade on the Pennsylvania Imagery Navigator website. This data allowed me to quickly and easily identify many odd features on the landscape that turned out to be the remnants of charcoal hearths.

The data used in this research is provided openly by PAMAP, a collaborative project of local, state and federal agencies, and the Pennsylvania Spatial Data Access program and website as well as via the

user-friendly Pennsylvania Imagery Navigator. LiDAR data was collected by PAMAP between 2006 and 2008 (Pennsylvania Department of Conservation and Natural Resources 2018a). Accuracy of the post-processed LiDAR points is much better than the standards (18.5 cm vertical and 5 ft. horizontal accuracy) with approximately 1 point per 1.4 meters (Pennsylvania Department of Conservation and Natural Resources 2018b). Data is provided as a hillshade derivative of a DEM via the Imagery Navigator website via streaming data for GIS software or data download. However, the DEM (and therefore the hillshade) is based upon subsample of the original data and, therefore has a much lower resolution than possible. Luckily, the original (though processed) LiDAR point cloud data can also be downloaded in the open LAS format (American Society for Photogrammetry and Remote Sensing 2013).

Open Tools

Two FOSS applications were used for this analysis, LASTools³ and QGIS⁴ (for additional FOSS GIS see Orengo 2015). LASTools is a lightweight collection of tools for viewing, modifying and managing LiDAR data in a GUI (graphical user interface) that can also be run via command line. The licensing, and therefore the openness, of the tools within the suite varies. Some, such as las2las (see below), are FOSS. Others, such as lasview are free, but not open source. Others, such as lastile and blast2dem, are free for educational uses but are not free to others nor are they open source. While ideally all of the tools used herein would be open source, LASTools are the most efficient and widely used tools for working with LiDAR. LASTools can be used as standalone applications or within the QGIS (or ArcGIS) environment. The output of LASTools is typically a digital elevation model (DEM) for viewing and analysis within GIS software.

QGIS is a cross-platform (Windows, Mac and Linux) open source GIS application. There is no need to repeat the many comparisons of QGIS with commercial GIS applications, especially since software packages and subscriptions change constantly (e.g., Orengo 2015). Generally speaking, the differences tend to be at the edges of GIS use- for most purposes, QGIS is equivalent to commercial packages. “Bleeding edge” uses are more variable. QGIS contains a plethora of native analysis tools that can be expanded with plugins. QGIS support is extensive and includes tutorials, videos and a very active user community. Commercial support for QGIS can be purchased relatively inexpensively.

Method

In order to understand the landscape of charcoal production within the research area along the Blue Mountains (Carter 2018a), a wide variety of maps and other resources were consulted. Initially, using the online hillshade model provided by Pennsylvania Imagery Navigator, I was able to identify charcoal hearths along the mountain because they are visible along the flanks of the mountain as flat, level and round areas distinct from the slope (Figure 4). To record the charcoal hearths, the hillshade derived from the LiDAR was brought into QGIS via streaming WMS (Web Mapping Service)⁵. WMS makes it easy to quickly view large data sets over the internet, but you can also download the rather-large tiles from PASDA. Using only this data, we were able to identify 298 potential charcoal hearths within the study area (Figure 4b).

However, the hillshade provided by PASDA was derived from a subsample of the original point cloud. Only class 8 points (Table 1) were used, reducing the resolution of the data and limiting the visibility of many charcoal hearths (Pennsylvania Department of Conservation and Natural Resources 2018b) (Figure 4b). Happily, the Pennsylvania Imagery Navigator website provides the original LiDAR data openly via download.

Using LASTools, I converted the downloaded LiDAR data into a DEM. I used las2las to separate the ground points, including class 2 points and 8 points (Table 1), from the other points. Using lastile, these larger files were broken into smaller 1 km by 1 km tiles, which makes the work more efficient and gets around some of the licensing restrictions (without breaking the license). This is converted to a DEM using blast2dem then stitched back together using the Merge function in QGIS (Carter 2018b).

However, DEMs are difficult to use. One of the most common methods of visualizing DEMs is a hillshade (Carter 2018c), which is algorithmic construction of the landscape based upon illuminating the DEM with a “sun” in a particular position (Kokalj and Hesse 2017). This makes it much easier to understand the topography (Figure 4b and c). Visibility of features is dependent upon the direction of the sun, however. Therefore, a charcoal hearth it may be more or less visible in a hillshade depending upon its location (Figure 4c). An alternative was needed. Because many of the charcoal hearths are located on the slopes of the mountain, we can use the differing slope of the mountain versus the level charcoal hearth to better visualize the hearths (Kokalj and Hesse 2017). Using the slope analysis (Carter 2018e) we were able to identify 758 charcoal hearths within the research area (Figure 5) (Carter 2018d). Note that this includes only hearths visible in the slope analysis. Flat hearths on flat land would not be visible in the slope analysis or the hillshade. We are currently working on methods to identify these hearths.

Results

The increased ability to identify charcoal hearths can be seen in Figure 4. Figure 4a shows an aerial photo of a portion of the slope of the Blue Mountain. Figure 4b shows the streaming hillshade (based on class 8 points) provided by PASDA; only one charcoal hearth is visible. Figure 4c shows the

hillshade constructed from the LiDAR data selected using the tools above (Class 8 and 2). Figure 4d shows the slope analysis of the Class 2 and 8 data. Note that, with each additional step, the visibility of the charcoal hearths increases. In the original streaming hillshade, we were able to identify 298 charcoal hearths within the research area. The transformation of the LiDAR data described herein increased this number by 460 (154%) for a total of 758 charcoal hearths (Figure 5). To date, eighty-two of these hearths have been ground truthed – two false positives and one false negative have been recognized. Ground truthing involved visiting the location and examining the feature for characteristic features including: a flat, level area 10-15 meters in diameter; a distinct rim; dense charcoal near the surface at the edges and; on slopes, a dramatically steeper slope uphill and downhill from the removal of dirt uphill and placing it downhill. The reanalysis expanded our ability to discern charcoal hearths mainly in areas of lower slopes and more variable topography. Slopes of greater than 20% contain very few charcoal hearths, but these are highly visible. Charcoal hearths between 15-25% slope are extremely common and are now easy to identify. Charcoal hearths at <15% slope are more difficult to identify, but presumably, since it would have been easier to harvest and move timber on flatter land, more numerous. We are currently working on pedestrian surveys to help increase our ability to recognize charcoal hearths on relatively flat (i.e., <10%) areas including, the top of the mountain and the lower slopes.

Conclusion

The work discussed herein is a presentation of a particular research project, but it is intended to stress two important components of this research that are broadly applicable. First, the essential importance of ALS/ LiDAR in historical archaeology, especially in the recognition of historic landscapes. Second, the benefits of using open data and open tools. In this case, this former is only possible because of the latter. Open LiDAR data is particularly important for historical archaeologists because it facilitates the

recognition of activities that changes the landscape. Of particular note are mining and industrial activities, especially those that have been long abandoned and, therefore, are buried in forests. However, the recognition of activities with less significant impacts, such as historic trails and paths or agriculture, is also possible with LiDAR.

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References

American Society for Photogrammetry and Remote Sensing

2013 LAS Specification Version 1.4- R13. <https://www.asprs.org/wp-content/uploads/2010/12/LAS_1_4_r13.pdf>. Accessed 6 March 2018.

Birkinbine, John

1879 The Production of Charcoal for Iron Works. *Transactions of the American Institute of Mining Engineers* 7:149–158.

Brenckman, Frederick Charles

1913 *History of Carbon County, Pennsylvania: Also Containing a Separate Account of the Several Boroughs and Townships in the County, with Biographical Sketches*. J. J. Nungesser, Harrisburg, Pa.

Carter, Benjamin P.

2018a Blue Mountain Charcoal Project Research Area (Version 0.1.0) [Data set]. Zenodo. <<http://doi.org/10.5281/zenodo.1252418>>

Carter, Benjamin P.

2018b Digital Elevation Model for Blue Mountain Charcoal Research Project (Version 0.1.0) [Data set]. Zenodo. <<http://doi.org/10.5281/zenodo.1252441>>

Carter, Benjamin P.

2018c Hillshade Analysis of "Digital Elevation Model for Blue Mountain Charcoal Research Project" (Version 0.1.0) [Data set]. Zenodo. <<http://doi.org/10.5281/zenodo.1252520>>

Carter, Benjamin P.

2018d Identified Charcoal Hearths from "Slope Analysis of 'Digital Elevation Model for Blue Mountain Charcoal Research Project'" (Version 0.1.0) [Data set]. Zenodo.

<http://doi.org/10.5281/zenodo.1252985>

Carter, Benjamin P.

2018e Slope Analysis of "Digital Elevation Model for Blue Mountain Charcoal Research Project" (Version 0.1.0) [Data set]. Zenodo. <http://doi.org/10.5281/zenodo.1252977>

Carter, Benjamin P.

2018f Charcoal Hearths along the Blue Mountain of Pennsylvania. Released: 2018-11-23. Open Context. <https://doi.org/10.6078/M7DV1GZF>

Carter, Benjamin P.

[2019a] Data for Identifying Landscape Modification using Open Data and Tools: The Charcoal Hearths of the Blue Mountain, Pennsylvania. *Journal of Open Archaeology Data*.

Challis, Keith, Paolo Forlin, and Mark Kincey

2011 A Generic Toolkit for the Visualization of Archaeological Features on Airborne LiDAR Elevation Data. *Archaeological Prospection* 18(4):279–289.

Chase, A.F., D.Z. Chase, J.F. Weishampel, J.B. Drake, R.L. Shrestha, K.C. Slatton, J.J. Awe, and W.E.

Carter

2011 Airborne LiDAR, Archaeology, and the Ancient Maya Landscape at Caracol, Belize. *Journal of Archaeological Science* 38(2):387–398.

Chase, Arlen F., Diane Z. Chase, Christopher T. Fisher, Stephen J. Leisz, and John F. Weishampel
2012 Geospatial Revolution and Remote Sensing LiDAR in Mesoamerican Archaeology. *Proceedings of the National Academy of Sciences* 109(32):12916–12921.

Devereux, B. J., G. S. Amable, P. Crow, and A. D. Cliff
2005 The Potential of Airborne Lidar for Detection of Archaeological Features under Woodland Canopies. *Antiquity* 79(305):648–660.

Ducke, Benjamin
2012 Natives of a Connected World: Free and Open Source Software in Archaeology. *World Archaeology* 44(4):571–579.

Wilson, Andrew T., and Ben Edwards
2015 Open Source Archaeology, Ethics and Practice. Sciendo, Berlin.
<https://www.degruyter.com/view/product/460080>.

Evans, Damian H., Roland J. Fletcher, Christophe Pottier, Jean-Baptiste Chevance, Dominique Soutif, Boun Suy Tan, Sokrithy Im, Darith Ea, Tina Tin, Samnang Kim, Christopher Cromarty, Stéphane De Greef, Kasper Hanus, Pierre Bâty, Robert Kuszinger, Ichita Shimoda, and Glenn Boornazian
2013 Uncovering Archaeological Landscapes at Angkor Using Lidar. *Proceedings of the National Academy of Sciences* 110(31):12595–12600.

Fernandez-Diaz, Juan Carlos, William E. Carter, Ramesh L. Shrestha, and Craig L. Glennie
2014 Now You See It... Now You Don't: Understanding Airborne Mapping LiDAR Collection and

Data Product Generation for Archaeological Research in Mesoamerica. *Remote Sensing* 6(10):9951–10001.

Fernow, Bernhard E.

1883 Planting in Waste Places. *The American Journal of Forestry*. 153–155.

Fisher, Christopher T., Anna S. Cohen, Juan Carlos Fernández-Díaz, and Stephen J. Leisz

2017 The Application of Airborne Mapping LiDAR for the Documentation of Ancient Cities and Regions in Tropical Regions. *Quaternary International*. 448:129–138.

Harmon, James M., Mark P. Leone, Stephen D. Prince, and Marcia Snyder

2006 Lidar for Archaeological Landscape Analysis: A Case Study of Two Eighteenth-Century Maryland Plantation Sites. *American Antiquity* 71(4):649–670.

Hart, Justin L., Saskia L. van de Gevel, David F. Mann, and Wayne K. Clatterbuck

2008 Legacy of Charcoaling in a Western Highland Rim Forest in Tennessee. *The American Midland Naturalist* 159(1):238–250. <http://www.jstor.org/stable/20491325>.

Hirsch, Florian, Thomas Raab, William Ouimet, David Dethier, Anna Schneider, and Alexandra Raab

2017 Soils on Historic Charcoal Hearths: Terminology and Chemical Properties. *Soil Science Society of America Journal* 81(6):1427–1435.

Huggett, Jeremy

2015 Digital Haystacks: Open Data and the Transformation of Archaeological Knowledge. In *Open Source Archaeology: Ethics and Practice*, Andrew T. Wilson and Ben Edwards, editors, pp. 6–29. De Gruyter Open. <http://www.degruyter.com/view/product/460080>.

Johnson, Katharine M., and William B. Ouimet

2014 Rediscovering the Lost Archaeological Landscape of Southern New England Using Airborne Light Detection and Ranging (LiDAR). *Journal of Archaeological Science* 43:9–20.

2018 An Observational and Theoretical Framework for Interpreting the Landscape Palimpsest through Airborne LiDAR. *Applied Geography* 91:32–44.

Kokalj, Ziga, and Ralf Hesse

2017 *Airborne Laser Scanning Raster Data Visualization: A Guide to Good Practice*. Založba ZRC, Ljubljana.

Kemper, Jackson

1941 American Charcoal Making in the Era of the Cold-Blast Furnace. History 14. U.S. Department of the Interior; National Park Service, Washington, D.C.

<https://www.nps.gov/parkhistory/online_books/popular/14/index.htm> Accessed 2 March 2018.

Mathews, Alfred, and Austin N Hungerford

1884 *History of the Counties of Lehigh and Carbon, in the Commonwealth of Pennsylvania*. Everts & Richards, Philadelphia.

McCoy, Mark D., Gregory P. Asner, and Michael W. Graves

2011 Airborne Lidar Survey of Irrigated Agricultural Landscapes: An Application of the Slope Contrast Method. *Journal of Archaeological Science* 38(9):2141–2154.

McVarish, Douglas C.

2008 *American Industrial Archaeology: A Field Guide*. Left Coast Press, Inc., Walnut Creek, Calif.

Opitz, Rachel S., Krysta Ryzewski, John F. Cherry, and Brenna Moloney

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.

Orengo, Hector

2015 Open Source GIS and Geospatial Software in Archaeology: Towards Their Integration into Everyday Archaeological Practice. In *Open Source Archaeology Ethics and Practice*, Andrew T. Wilson and Ben Edwards, editors, pp. 64–82. Walter de Gruyter GmbH & Co KG.

Pennsylvania Department of Conservation and Natural Resources

2018a PAMAP. Pennsylvania Department of Conservation and Natural Resources.

<<http://www.dcnr.pa.gov/Geology/PAMAP/Pages/default.aspx>>. Accessed 6 March 2018.

2018b PAMAP Lidar Elevation Data. PA DCNR - Geology - PAMAP LiDAR.

<<http://www.docs.dcnr.pa.gov/topogeo/pamap/lidar/index.htm>>. Accessed 6 March 2018.

Raab, A., M. Takla, T. Raab, A. Nicolay, A. Schneider, H. Rösler, K. -U. Heußner, and E. Bönisch

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. *Quaternary International* 367:111–122.

Raab, Thomas, Florian Hirsch, William Ouimet, Katharine M. Johnson, David Dethier, and Alexandra Raab

2017 Architecture of Relict Charcoal Hearths in Northwestern Connecticut, USA. *Geoarchaeology* 32(4). July 1:502–510.

Register of Professional Archaeologists

2018 Code of Conduct- The Register of Professional Archaeologists. April 10.

<https://cdn.ymaws.com/rpanet.site-ym.com/resource/resmgr/Register_Code_of_Conduct_10_.pdf>.

Accessed 22 May 2018.

Schallenberg, Richard H.

1981 Charcoal Iron: The Coal Mines of the Forest. In *Material Culture of the Wooden Age*, Brooke Hindle, editor, pp. 271–299. Tarrytown, NY, Sleepy Hollow Press.

Schneider, Anna, Melanie Takla, Alexander Nicolay, Alexandra Raab, and Thomas Raab

2015 A Template-Matching Approach Combining Morphometric Variables for Automated Mapping of Charcoal Kiln Sites. *Archaeological Prospection* 22(1):45–62.

Smith, Matthew Longshore, and Ruhiya Seward

2017 Openness as Social Praxis. *First Monday* 22(4).

<<https://firstmonday.org/ojs/index.php/fm/article/view/7073>>. Accessed 22 May 2018.

Society for American Archaeology

1996 Principles of Archaeological Ethics.

<<http://www.saa.org/AbouttheSociety/PrinciplesofArchaeologicalEthics/tabid/203/Default.aspx>>.

Accessed 22 May 2018.

Society for Historical Archaeology

2015 SHA Ethics Principles. <<https://sha.org/about-us/ethics-statement/>>. Accessed 22 May 2018.

Strachan, Scotty, Franco Biondi, Susan G. Lindström, Robert McQueen, and Peter E. Wigand

2013 Application of Dendrochronology to Historical Charcoal-Production Sites in the Great Basin,

United States. *Historical Archaeology* 47(4):103–119. <https://doi.org/10.1007/BF03377126>.

Straka, Thomas J.

2014 Historic Charcoal Production in the US and Forest Depletion: Development of Production

Parameters. *Advances in Historical Studies* 03(02):104–114.

Straka, Thomas J., and Wayne C. Ramer

2010 History on the Road: Hopewell Furnace National Historic Site. *Forest History Today*

Spring/Fall:58–62.

Swank, James Moore

1892 *History of the Manufacture of Iron in All Ages: And Particularly in the United States from*

Colonial Time to 1891, 2nd edition. American Iron and Steel Association, Philadelphia.

Walker, Joseph E.

1966 *Hopewell Village; a Social and Economic History of an Iron-Making Community*. Univ. of Pennsylvania Press, Philadelphia.

Werbrouck, I., M. Antrop, V. Van Eetvelde, C. Stal, Ph. De Maeyer, M. Bats, J. Bourgeois, M. Court-Picon, Ph. Crombé, J. De Reu, Ph. De Smedt, P. A. Finke, M. Van Meirvenne, J. Verniers, and A. Zwertvaegher

2011 Digital Elevation Model Generation for Historical Landscape Analysis Based on LiDAR Data, a Case Study in Flanders (Belgium). *Expert Systems with Applications* 38(7):8178–8185.

Wettstaed, James R.

2003 Cutting It Back and Burning It Black: Archaeological Investigations of Charcoal Production in the Missouri Ozarks. *The Journal of the Society for Industrial Archeology* 29(2):29–46.

<http://www.jstor.org/stable/40968627>.

Wigginton, Eliot (editor)

1979 Ironmaking and Blacksmithing. In *Foxfire* 5, pp. 77–207. Anchor Books, New York.

Zeier, Charles D.

1987 Historic Charcoal Production near Eureka, Nevada: An Archaeological Perspective. *Historical Archaeology* 21(1):81–101. <http://www.jstor.org/stable/25615614>.

Endnotes

¹ Aggregators include Open Topography (<http://www.opentopography.org/>) and United States Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>).

²It must be noted here that particular components of archaeological data need to be protected in order to steward the archaeological record. The location of sites can be particularly sensitive, but can also quite easily be generalized or obfuscated for sharing with the public.

³ LASTools (version used herein downloaded March 3, 2018). Available at <https://rapidlasso.com/lastools/>

⁴ QGIS (v. 2.18.17 used herein). Available at <https://www.qgis.org/en/site/>

⁵ Pennsylvania Imagery Navigator: <http://maps.psiee.psu.edu/ImageryNavigator/> Streaming hillshade-WMS:
http://imagery.pasda.psu.edu/arcgis/services/pasda/PAMAP_Hillshade/MapServer/WMSServer?SERVICE=WMS&request=getcapabilities or REST:
http://imagery.pasda.psu.edu/ArcGIS/rest/services/pasda/PAMAP_Hillshade/MapServer

Name and Address Block

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Tables

TABLE 1

DESCRIPTION OF LIDAR POINT CLASSES PER PAMAP (.)

| Class | Name | Description |
|-------|------------|--|
| 1 | Default | mixture of points remaining after the ground classification |
| 2 | Ground | points on the bare-earth surface |
| 8 | Model Key | thinned-out ground points used to generate digital elevation models and contours |
| 9 | Water | points inside hydrographic features |
| 12 | Non-ground | points identified as first or intermediate of many returns |
| 15 | Road Edges | points that fall within 1.5 feet of road breaklines |

Figure Captions

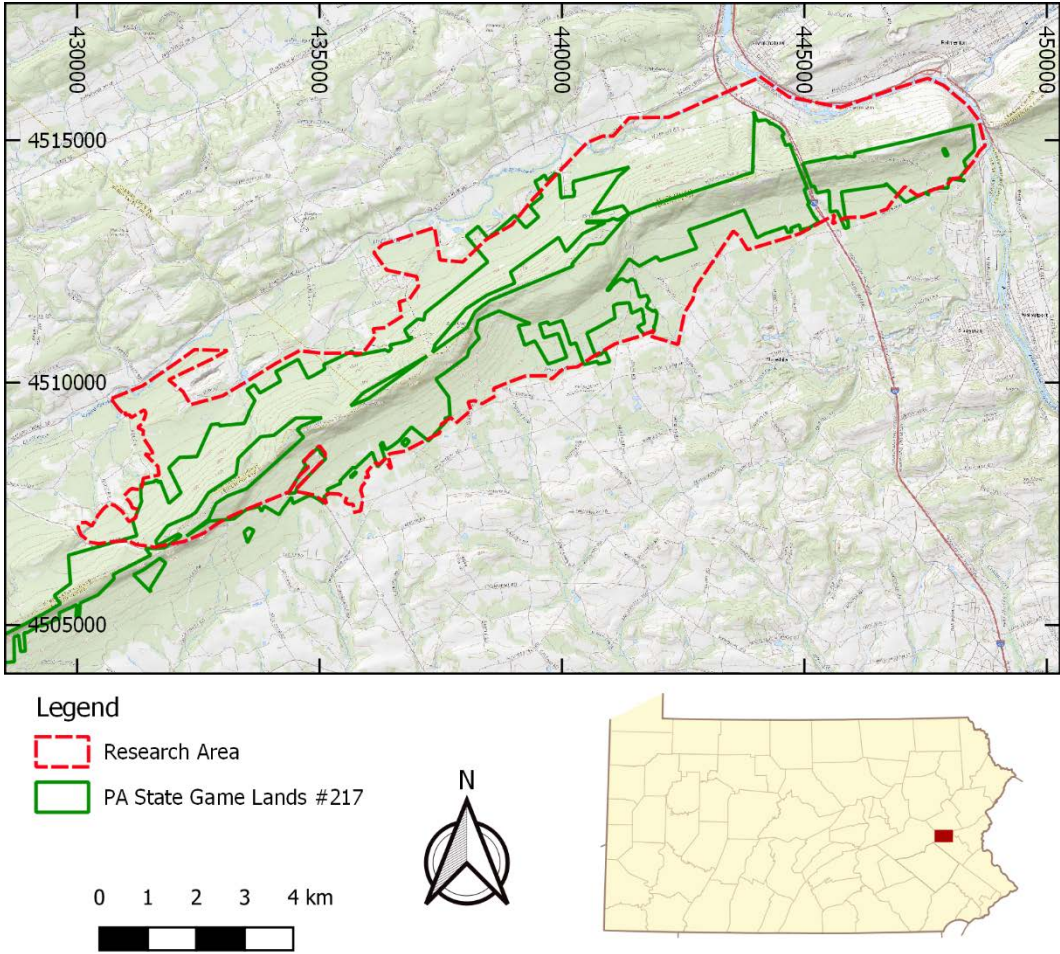


FIGURE 1. The research area, showing State Game Lands and the furnaces and forge associated with charcoal production in this area (Base map courtesy of USGS).



FIGURE 2. Collier covers the wood to be converted into charcoal with leaves and dirt. Wayne National Forest, May 1942 (National Archives #419981).



FIGURE 3. Colliers remove charcoal from the hearth. Wayne National Forest, May, 1942 (National Archives #419985).

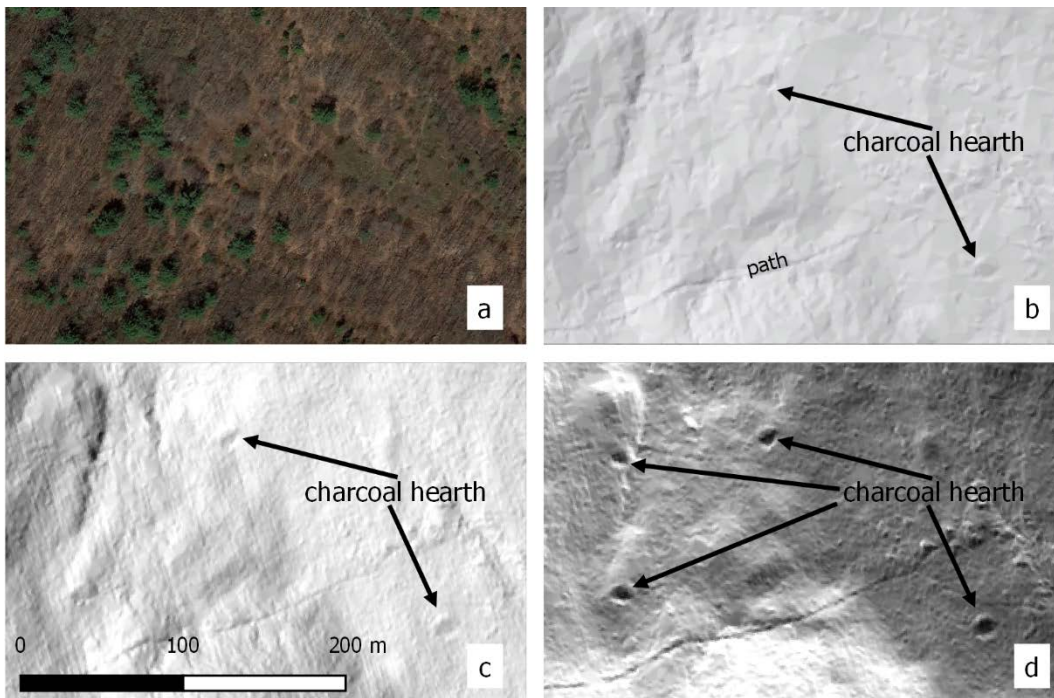
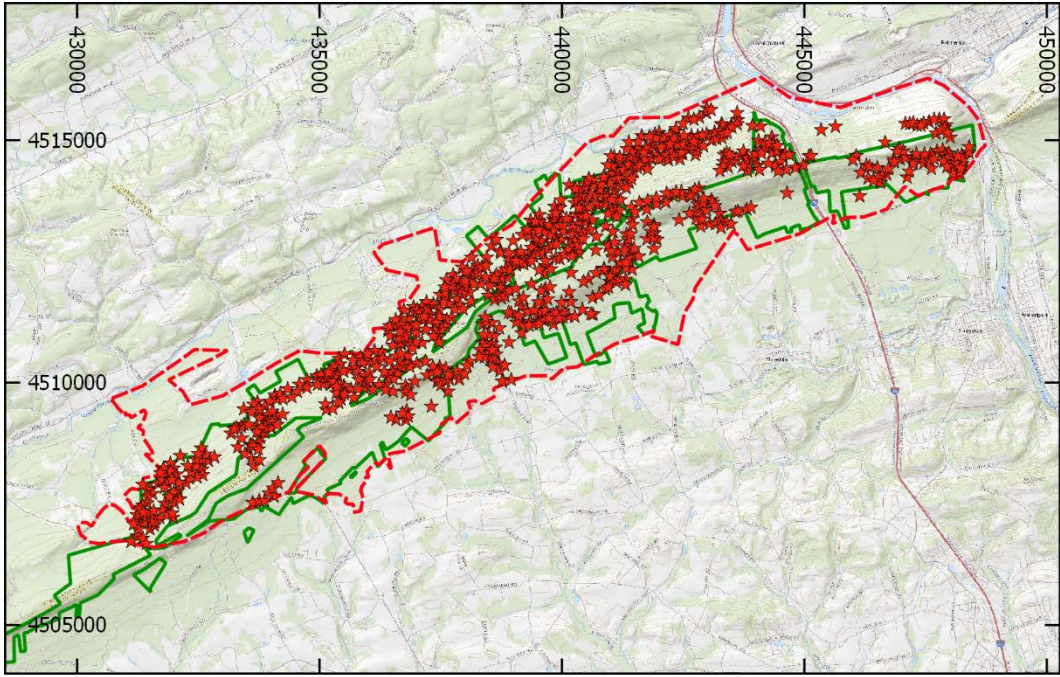


FIGURE 4. Views of the same location comparing aerial photos and different derivatives of the LiDAR/ ALS data: (a) aerial photograph (2017; courtesy of Google), (b) streaming hillshade (courtesy of PASDA) and (c) hillshade and (d) slope analysis produced by the process described herein.



Legend

- Red dashed line: Research Area
- Green solid line: PA State Game Lands #217

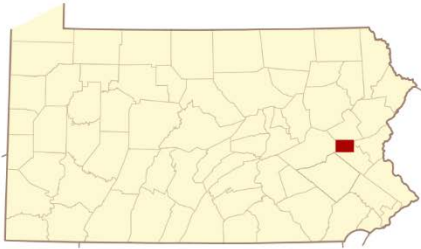
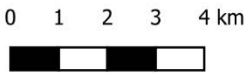


FIGURE 5. The research area showing identified charcoal hearths (Base map courtesy of USGS).