LiDAR Predictive Modeling of Pacific Northwest Mound Sites: A Study of Willamette Valley Kalapuya Mounds, Oregon (USA)

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A B S T R A C T

Archaeologists need new methods to survey large areas and overcome environmental and archaeological barriers to site discovery in heavily forested regions. LiDAR (light detection and ranging) technology is one possible solution to these challenges as LiDAR digitally clears away vegetation, facilitating large-scale remote sensing survey. The Calapooia Watershed, located in the southern Willamette Valley of Oregon, is an ideal area to utilize LiDAR. While valley lowlands are cleared for agriculture, riverine areas remain heavily wooded and are known to contain hundreds of low-lying earthwork features created by pre-colonial Kalapuyan people. To assess the potential application of LiDAR in this region, we developed and tested a mound detection predictive model using LiDAR and aerial imagery. Field testing of the model identified seven new Kalapuyan mounds and verified the location of several others. Our model was 44 percent successful in identifying cultural mounds and 100 percent successful in identifying *extant* previously identified mounds. The model is effective and can be used to identify and preserve mound features in the Pacific Northwest; the model can also be modified and used to identify earthwork features in other regions.

1. Introduction

Archaeologists grapple with the problematic nature of archaeological discovery. Human activities and associated archaeological sites are not uniformly distributed or easily discernable across a landscape. Sites are dispersed, clustered, low or high in visibility, fragmented or relatively complete. Archaeological survey recovery rates are highly variable depending on the shape of the survey (linear, elliptical, rectangular, etc.), the transect interval, the time spent in each transect, access to survey areas, local environment, and the nature of the archaeology itself (Sundstrom, 1993). In addition, the amount of unsurveyed land, the attention and ability of archaeological crewmembers, and budgetary constraints can limit the accuracy of site identification (Wandsnider and Camilli, 1992:169-170). Certain types of sites are difficult to see even in the best environmental conditions (e.g., low-density lithic scatters) and some environments are difficult to survey, such as jungles or dense temperate rain forests like those of the Pacific Northwest region of the U. S. These environments obstruct an archaeologists' ability to identify even the largest of sites, such as monumental structures or earthwork features. LiDAR (light detection and ranging) technology is one possible solution to these archaeological problems, as LiDAR digitally clears away swaths of vegetation and surveys the landscape (Crow et al., 2007; Devereux et al., 2005). LiDAR technology has the potential to change our approach to pedestrian survey in the Pacific Northwest, where dense forest growth, uneven terrain, and access are major obstacles to designing and carrying out survey. Analysis using LiDAR is effective over large areas and can be combined with other remote sensing data to create archaeological predictive models that identify likely site locations. These models can guide pedestrian survey design.

The southern Willamette Valley in Oregon is an ideal area to focus LiDAR's unique archaeological capabilities. The region is heavily wooded and known to contain hundreds of low-lying earthwork features or mounds. Local Indigenous communities, including the Confederated Tribes of the Grand Ronde and the Confederated Tribes of Siletz Indians, preserve knowledge of these low-lying mounds, which were constructed by Kalapuyan ancestors during the pre-colonial era. Euro-American naturalists and archaeologists learned of the Willamette Valley mounds in the 1800 s (Powers, 1886; Wright, 1922). However, the mounds have been the focus of only limited archaeological study. Land ownership, obscuring vegetation, and the expanse of the mounded landscape have impeded professional archaeological research. Out of the potentially hundreds of mounds in the Calapooia Watershed alone

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(Laughlin, 1941; Briece Edwards personal communication 2016) only 24 mounds are formally recorded with the Oregon State Historic Preservation Office (SHPO). The Grand Ronde Tribe and the Siletz Indians consider the Willamette Valley mound sites highly sensitive locations, due in part to the presence of burials at many mounds; furthermore, Bergman's (2016) research suggests that mounds and other places on the landscape are imbued with ideological power. Ethnographic accounts and limited archaeological work also indicate that some mounds are burial sites (Mackey, 1974; Laughlin, 1941, 1943; Roulette et al., 1996). Therefore, identifying and protecting mound sites is a priority, but pedestrian survey of the Calapooia watershed is impractical given that it encompasses roughly 234,000 acres and is 94 percent privately owned (Runyon et al.:1, 2004; Calapooia Watershed Council, 2016).

To address this problem, we collaborated with the Confederated Tribes of the Grand Ronde to develop and test a LiDAR and remote sensing predictive model to identify Kalapuyan mound sites in the Willamette Valley, Oregon (Fig. 1). Mound identification will lead to better protection and preservation of the region's mounds, and will also facilitate future research into the daily practices that created the sites. We developed a model appropriate for identifying mound features in the Willamette Valley and other similar regions, using an Automatic Feature Extraction method. This approach is relatively underutilized in the United States. Our work facilitates preservation of earthworks and additional archaeological research, if that is considered appropriate by descendant communities.

2. Background

2.1. Willamette Valley mounds

The Kalapuyan mounds are roughly ovoid earthworks; Oregon State Historic Preservation Office (SHPO) records indicate that recorded mounds in the Calapooia Watershed range from 22 m (m) to 120 m long, 15 m to 85 m wide, and less than 3 m in height (note that the Oregon

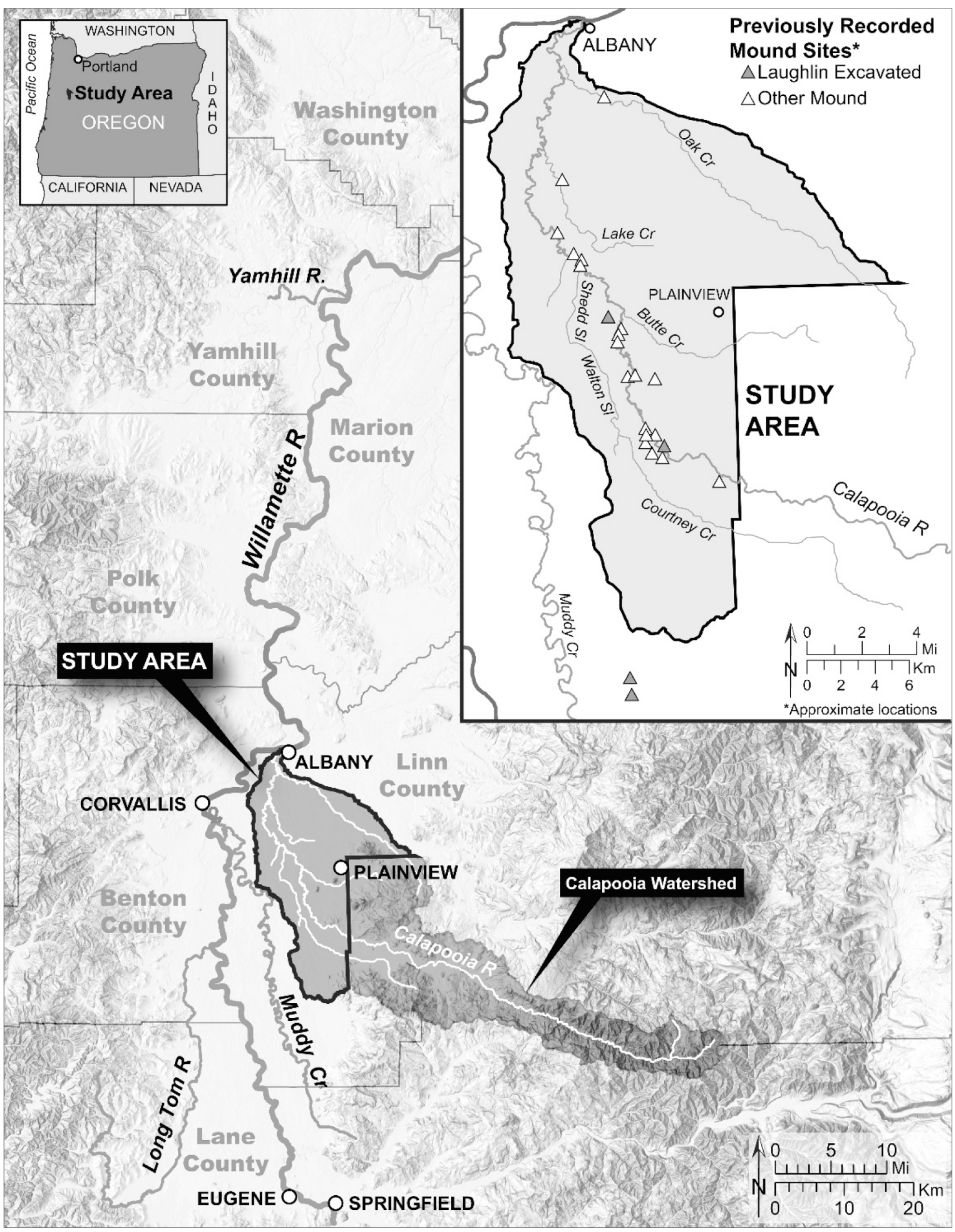

Fig. 1. Previously recorded mound sites in the Project area. Note that the locations of previously recorded mound sites are approximate. Figure by Johonna Shea.

SHPO records rarely include mound height information). Note that we use the Indigenous preference of "Kalapuyan" in reference to the Indigenous people of the region and "Calapooia" when referring specifically to the river. Dates obtained from several Willamette Valley mound sites indicate that mounded features were present as early as approximately 4200 cal BP (Cordell, 1967) and were occupied up to the late pre-colonial period in the 18th century (e.g. Cheatham, 1984; Collins, 1951; Roulette et al., 1996; White, 1979).

Ethnographic information about the mounds is limited, but it is widely understood that the mounds were created throughout the Willamette Valley by the Kalapuyan people who inhabited the region. The Kalapuya are now members of the Confederated Tribes of the Grand Ronde and the Confederated Tribes of Siletz Indians. The Kalapuyan people were a primarily inland group focused on terrestrial plant and animal resources common to the Willamette Valley (Beckham:48, 1977; Boag:21, 1988; Elder:10-11, 2010; Mackey:43, 1974; Teverbaugh, 2000). In the winter months large multi-family groups occupied permanent plank houses. In the summer, people split into smaller, transient groups that moved throughout the region tending resources (Beckham:45, 1977; Mackey:42, 1974; Teverbaugh, 2000; White:557, 1979; Zenk:548, 1990). It is unclear what cultural behaviors or processes formed the Kalapuyan mound sites, although the mounds have been the subject of archaeological interest since the late 1800 s (e.g. Powers, 1886).

Over the last 90 years collectors and early archaeologists excavated approximately 80 mounds in the Calapooia Watershed and along nearby Muddy Creek (Mackey, 1974:48, 51-56: see also Cheatham, 1984:11–12; Collins:58, 1951; Strong et al.:147, 1930). However, no detailed accounts, records, or artifacts from these investigations are available. The first major systematic archaeological work on the mounds was in the early 1940 s by Laughlin (1941), Laughlin (1943). Laughlin excavated six mound sites in the region and recovered Native American human remains and artifacts including a whale bone club, lithic tools, fire cracked rock (FCR), a shell necklace, groundstone, and camas root digging tools among other objects (Collins, 1951:70). Further investigations of mounds along the Long Tom River uncovered human remains and diverse artifact collections, as well as camas (*Camassia quamash)* bulbs and digging tools (Cheatham, 1984, 1988; Collins, 1951; Cordell, 1967; Miller, 1970, 1975). The last major excavation of a mound site occurred in 1996, in response to pipeline construction activities (Roulette et al., 1996). This investigation recovered human remains, faunal remains, hearth features, charred camas remains, and a variety of artifacts including flaked and ground stone tools. Several more minor investigations were undertaken related to cultural resource management (CRM) activities in the Calapooia Watershed. As shown, archaeologists have undertaken only limited systematic investigation of Kalapuyan mound sites and there is little agreement in the archaeological community about the age and nature of Willamette Valley mound sites. All of these efforts bring the total of archaeologically documented mounds in the watershed to 24, which we know to be a vast underestimate of the total number of mounds based on Indigenous oral histories and historic maps. Additional information about mound locations is needed in order to preserve these sensitive cultural sites; hence, our collaboration with the Confederated Tribes of the Grand Ronde to develop a predictive model that can be used to identify and protect mound sites in the future.

2.2. Archaeological applications of LiDAR in the U.S.

LiDAR and other remote sensing data can be used to identify mound sites, as remote sensing data provides archaeologists with a digital vantage point over the landscape. Archaeologists have used remote sensing techniques with increasing frequency since the 1960s, beginning with satellite imagery to identify sites and to guide on-the-ground survey all over the world; mound sites are one of the most prevalent site types identified by these projects (e.g. Challis et al., 2011; Giardino, 2011; Gren et al., 2011; Lasaponara et al., 2011a, 2011b; Lasaponara and Masini, 2011; Meredith-Williams et al., 2014; Rajani and Rajawat, 2011).

LiDAR technology was developed more recently than aerial and satellite imagery. LiDAR is an active rather than a passive sensor. Active sensors produce their own energy from which to create illumination, while passive sensors measure energy that is naturally available. LiDAR (airborne laser scanners) have been utilized since the 1960s, and were used to accurately measure the elevation of terrain in the 1970s (Price:25, 2012; Shepherd, 1965). Since the early 2000s, archaeologists have increasingly realized the potential of LiDAR and are using LiDAR for archaeological prospection (Challis et al., 2011; Holden et al., 2002). Use of LiDAR data to identify earthworks and other engineered landscapes has become common practice around the world, aiding in the discovery of ancient agricultural fields, deteriorated medieval structures, as well as Mayan ruins (e.g., Challis et al., 2011; Chase et al., 2011; Hesse, 2010; Lasaponara and Coluzzi et al. 2011; McCoy et al., 2011; Weishampel, 2012). Archaeologists manipulated LiDAR data, using local relief modeling to locate grave fields in Sweden (Doneus, 2011) and house mounds in Belize (Moyes et al., 2016). Researchers in Tonga used LiDAR and hydrological methods to identify both known and unknown low-lying mound sites in the Kingdom of Tonga (Freeland et al., 2016).

North American applications of LiDAR, however, are limited and are mostly restricted to states east of the Mississippi River (Gallagher and Josephs, 2008; Harmon et al., 2006; Johnson and Ouimet, 2014; Pluckhahn and Thompson, 2012; Riley, 2009, 2012; Rochelo et al., 2015). U.S. archaeologists have primarily applied LiDAR to the problem of identifying archaeological sites in densely vegetated environments (Gallagher and Josephs, 2008; Johnson and Ouimet, 2014). Some studies assessed whether LiDAR could detect the presence or absence of archaeological features on the landscape (Harmon et al., 2006; McCoy et al., 2011; Price, 2012; Randall, 2014; Riley and Tiffany, 2014). In other cases, the focus is on understanding how LiDAR can be used in conjunction with other geospatial techniques to create more accurate archaeological site maps (e.g. Pluckhahn and Thompson, 2012). Randall (2014) used LiDAR to highlight previously known freshwater shell mounds in Florida but did not perform any analysis beyond pairing LiDAR with topographic maps. Similarly, Davis et al. (2018) used LiDAR to identify new and previously recorded shell rings and mound sites in South Carolina. For the most part, U.S. archaeologists use LiDAR to locate previously known features, although new features are sometimes identified in a previously studied archaeological landscape. There are only two published U.S. studies that focus on automatically detecting new sites from LiDAR (Davis et al., 2018; Davis et al., 2019a, 2019b); there are other studies where researchers manually interpret LiDAR to identify new sites (e.g. Henry et al., 2019). Archaeological LiDAR applications are even more limited in the Pacific Northwest (although see Barrick, 2015). Archaeologists have not yet applied LiDAR to the identification of pre-colonial archaeological sites in this region.

Most archaeologists examine LiDAR data and identify potential features of archaeological interest to investigate further through field work or other remote sensing analysis. Only recently are archaeologists taking advantage of the analytical power of GIS by conducting more in-depth GIS analysis of LiDAR data to identify potential features of interest. Few archaeologists, particularly in the U.S., have used automatic feature extraction [AFE] methods available in GIS (Davis et al. 2018; Riley, 2009, 2012). AFE is the automatic detection of specific features using identified parameters or algorithms. AFE has exciting potential uses in the archaeological applications of GIS and LiDAR analysis as it effectively uses the computer, rather than the researcher, to survey the digital landscape for features within a set of modeler established parameters. The application of this method is rapidly growing as archaeologists recognize the potential of this approach (e.g. Davis, 2019; Guyot et al., 2018; Lambers et al., 2019; Traviglia and Torsello, 2017; Trier et al., 2019); other automated detection methods are also emerging (e.g. Trier et al., 2015; Menze and Ur, 2012;Verschoof-van der Vaart et al., 2019, 2020). This increases archaeological efficiency in LiDAR analysis as archaeologists no longer have to scroll through LiDAR data to identify sites; instead the computer identifies likely site locations. However, uses of AFE in identifying mound features in the U.S. is limited. Riley (2009), (2012) created an AFE model to identify mound sites in the Paleozoic Plateau, East-Central, and the South-Central Iowa Drift Plains of Iowa. Davis et al. (2018) use AFE to identify mound locations in South Carolina.

LiDAR usage in American archaeology is still in its infancy, with the full analytical capabilities of LiDAR yet to be fully realized by archaeologists. In this project we apply and expand on previous applications of LiDAR in U.S. archaeology to develop a tool useful for site identification. We explore the use of AFE in feature identification. Our model outcomes has important historic preservation implications in the Pacific Northwest and in other regions where dense vegetation and land access are challenges to archaeological work.

3. Materials and methods

Our primary question in developing our model was "Can the AFE procedure detect Kalapuyan mounds in LiDAR and other remote sensing data?" Although this is a simple question, it is a crucial one; the Kalapuyan mounds cannot be further understood, preserved, or protected without first identifying mound locations. We approached the project in three stages: 1) model development; 2) field survey to ground truth the model, and 3) analysis of lab and field data to assess the efficacy of the model.

3.1. Model development

We used ESRI's ArcMap 10.5.1 for our analysis. Hydrological methodology and zonal statistics were utilized to highlight and extract potential mounds from the LiDAR derived digital elevation model (DEM) dataset (DOGAMI, 2009; this is the only LiDAR currently available for the project area). Several additional spatial datasets were used to build the mound identification model (Table 1), which added to the robusticity of the LiDAR dataset and aided in analysis (See Fig. 2 for project workflow).

Table 1
Datasets used to construct the LiDAR model.

Dataset	Type of Dataset	Data Source
One-meter spatial resolution LiDAR DEM	Remotely Sensed Imagery	Oregon Department of Mineral Industries (DOGAMI) www.oregongeology.org/lidar (2009) (Portions supplied by the Grand RondeTribe)
Aerial Imagery	Remotely Sensed Imagery	ESRI ArcMap Basemap sourced from: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community (2018)
Oregon Cities and Towns Data	Vector Data	Acquired from the Oregon Spatial Data Library
Oregon Hydrography Data, including Calapooia Watershed boundary	Vector Data	National Hydrography Dataset from the United States Geological Survey
Oregon Public Transit Roadways Data	Vector Data	Acquired from the Oregon Spatial Data Library
Previously Identified Mound Sites	Township and Range, United States Geological Survey 1:24,000 map, UTM	OR SHPO site form location info

The DOGAMI LiDAR data came in "sets" that covered approximately 9 miles by 9 miles of the actual ground surface of the earth. A total of 19 LiDAR derived DEM datasets were downloaded and clipped to the Calapooia Watershed boundary. We then excluded the eastern portion of the Calapooia Watershed as it is dominated by the Cascade Mountain Range where there are no known mound sites and no terrain suitable for mound site construction. The final study area was comprised of nine LiDAR datasets. The LiDAR data had a linear spatial unit of a U.S. foot; we converted the linear spatial unit (1 square meter) to a meter to match recorded mound heights.

We used data on known mounds to build and inform the initial model; in other words, the previously identified mound site (PIMS) locations are used to teach the model what a mound looks like (Davis and DiNapoli et al. 2020; Freeland et al. 2016:66-67; Hanus and Evans 2015:91). We could not access the PIMS to collect new, highly accurate location data, because the sites are located on private land. Instead, we acquired *PIMS* information from the Oregon SHPO archaeological site database for the 20 previously recorded Calapooia Watershed mounds that are included in the database. Five of these 20 sites had Universal Transverse Mercator (UTM) easting and northing data; we digitized and uploaded the UTM information for these five sites into ArcMap as points. A total of 15 out of the 20 PIMS were recorded prior to modern GPS availability and the original recorders did not document UTM information; we digitized these site locations into points by converting their approximate mapped locations from the SHPO site database into UTM coordinates using the online program Geoplaner (Nathansen 2017). As a result, some of the *PIMS* locations could be approximations of actual mound location, due to potential error in how the sites were originally mapped in the SHPO database. Nevertheless, these are the only available data for the project area; thus, we used 20 PIMS to inform the initial model. After the initial model run we used the dimensions the model derived for these previously identified mound sites to further filter the model to identify other potential mound sites as we carried out subsequent geospatial analysis described below.

Although a one-meter spatial resolution dataset is fine-grained enough to identify mounds, it has so much detail it also identifies a fair amount of extraneous non-mound data points, e.g. local variation and "noise". To address this, we used the ArcMap 'Filter' tool to smooth the data and/or enable the enhancement of features that might have been missed originally (Arcgis.com, 2016a). We used the 'Low Pass Filter' five times initially to reduce extraneous elevation points (Arcgis.com, 2016a).

After constructing and filtering the initial model, we identified potential mound sites by inverting the LiDAR DEM dataset and applying hydrological GIS methods to the inverted dataset. To invert the dataset we used the formula (([dataset] – Z_Max)*-1) + Z_Min). We then utilized zonal statistics on the LiDAR DEM and derived slope layer. This approach was inspired by Freeland et al. (2016), who developed an iMound algorithm that inverted the landscape; a similar approach was also used for mound detection (Davis et al., 2019a, 2019b) and shipwreck detection (Davis et al., 2020a, 2020b). Freeland et al. (2016) identified mounds using a hydrological pit-filling algorithm similar to those used by by researchers Wang and Liu (2006). Freeland et al.'s (2016) method had an 85 percent positive identification rate when examining mound sites in the Kingdom of Tonga. At Greater Angkor in Cambodia, archaeologists also successfully identified household ponds by manipulating the 'Fill' tool in ArcMap (Hanus and Evans, 2016); rather than use the tool's intended function of filling pits/ponds, they manipulated the tool so that it would *identify* and *mark* ponds (Hanus and Evans, 2016:91). Inversion causes the Kalapuyan mound sites to act as sinks, which retain digital water (see Freeland et al., 2016). Sinks are defined as areas for which the direction of water flow from that area cannot be identified, or as areas of "internal drainage" (Arcgis.com, 2016b); the sinks trap digital water. These can be identified in ArcMap by applying the 'Flow Direction' tool to the dataset, using the D8 flow direction type (flow to the steepest downslope neighbor). The 'Flow

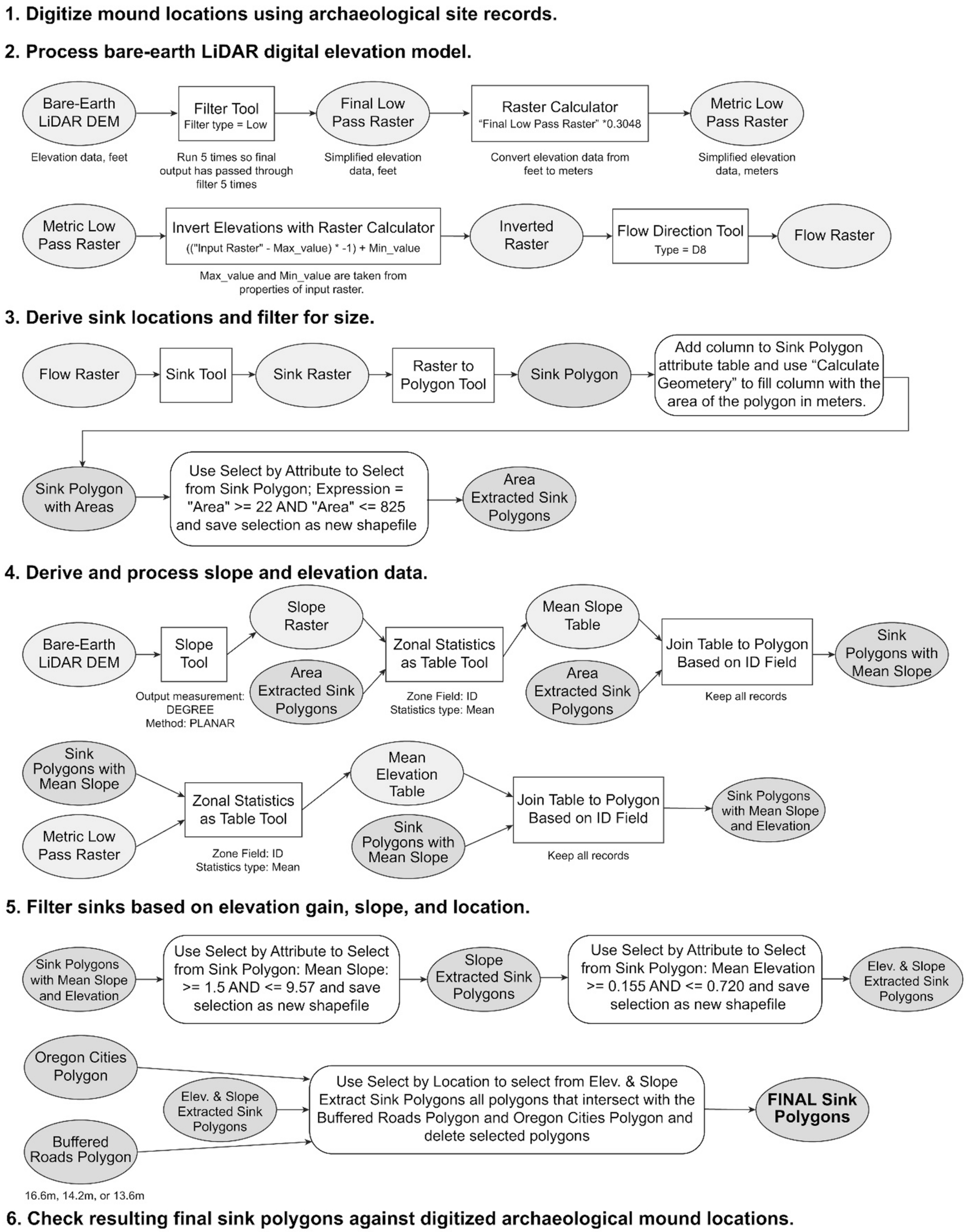

Fig. 2. Overview of project workflow. Figure by Johonna Shea.

Direction' tool assesses the direction that water would flow from each cell in the DEM raster dataset to its "steepest downslope neighbor" (Arcgis.com 2016c). We then applied the 'Sink' tool to extract the areas of "internal drainage," all of which are potential mound sites (Arcgis.com, 2016b). This process identified over 52,000 potential mound sites in the study area; clearly, not all of these were Kalapuyan mounds (Fig. 3).

Although this first stage of the model development was successful in identifying previously known mound sites, it identified far too many potential mounds to be useful. Therefore, additional reduction work was necessary. This involved the extraction of mound sites from the 'Flow Direction' and 'Sink' tool outputs. First, we converted the results of the 'Flow Direction' and 'Sink' tools from a raster dataset to a vector dataset, which created a polygon useful for further analysis. Using the vector

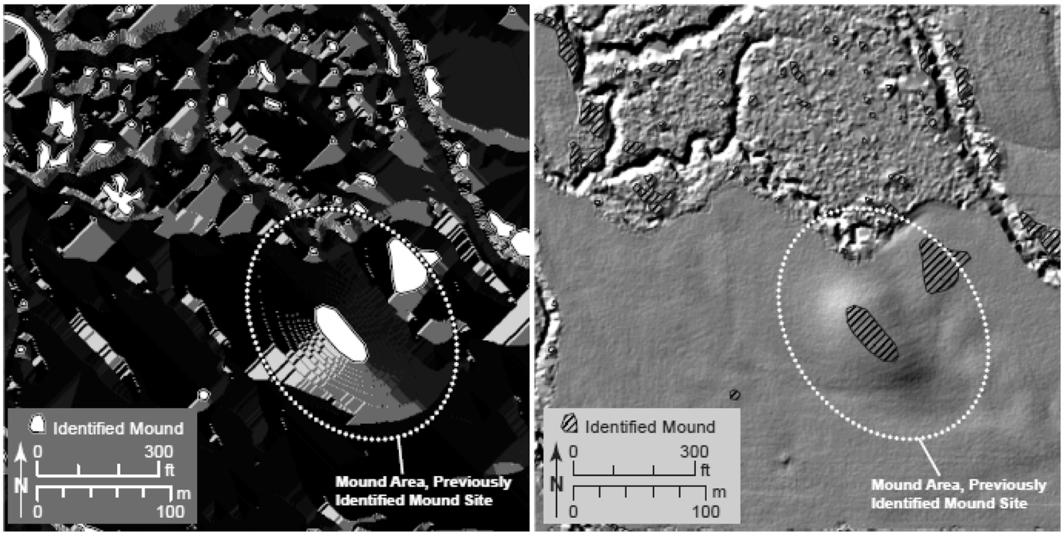

Fig. 3. (Left) Results of the "Flow Direction" and "Sink Tools" on one LiDAR grid. (Right) Model identification of the top most portion of a previously identified mound site. White dotted circle denotes the mound area. Other identified "mounds" are false positives. Figure by Johonna Shea.

data we could extract the potential mound (PM) sites by area. To do this, we examined the area values for each PIMS identified in the first stage; then, we queried those values ("Area" ≥ 22 AND "Area" ≤ 825). The area values of the previously identified mounds ranged from 22 square meters to 825 square meters. This query reduced the number of PM sites in the study area by roughly 46 percent as it eliminated those areas that we considered too big or too small to be mound sites.

Next we performed a slope extraction. To do this we uploaded a slope layer that was created from the LiDAR DEM and then, used the 'Zonal Statistics' Tool. The 'Zonal Statistics' tool calculates a range of statistics for a raster dataset (in this case, the slope dataset), based on the parameters set by another dataset (PM vector data model) (Arcgis.com 2016d). For the slope extraction, we chose to use the "mean" statistic because this gave us the average slope of each previously identified mound. The mean slopes from *PIMS* ranged from roughly 1.5° to 9.57°. We then queried all the mean slopes for each vector polygon that fell within the above range ("Mean" ≥ 1.5 AND "Mean" ≤ 9.57); this query reduced the number of potential mounds sites by roughly another 15 percent.

The final step was to perform an elevation extraction, in which we used the 'Zonal Statistics' tool as described above except on the LiDAR DEM. For this extraction, however, we chose to use the statistical range of elevation values for each vector polygon, as this would provide us with the heights of each mound within the defined mound polygon. As mentioned previously, the height values in this output do not necessarily indicate the true height of the mound; sometimes only the top most portion of the mound was identified by the "Sink" tool. The heights of each previously identified mound within each mound polygon fell within a range of 0.155 m to 0.720 m, with this maximum identified height almost two meters shorter than the max mound height reported in the previously identified site database. This discrepancy between reported and model measured height could be the result of several issues. The "Sink" tool does not necessarily identify the entirety of the mound on the ground, instead the tool often identifies only the top most portion of the mound (Fig. 3). It is also possible that the previously identified mound information was inaccurate, and/or that the mounds have deflated somewhat since they were originally reported. This has implications for the model further into the process, as the model measured PIMs heights that we used to filter our subsequent results may be excluding mounds taller than 0.720 m tall. We queried all the elevation ranges that fell within the above parameters for each potential mound site vector ("Range" ≥ 0.155 AND "Range" ≤ 0.720); this query reduced the number of potential mound sites by roughly another 2 percent. The result of 0.155 m for the height of a mound seemed relatively unusual, however it was retained in the analysis as it was thought to represent those potential mound sites that might have been affected by plowing or erosional forces.

After completing the above extractions, there were still extraneous potential mound site locations in the dataset primarily in roads, cities, and towns. We then used the polygonal data of urban areas (Oregon towns and cities) and road data (Oregon Public Transit Roadways) with a buffer (Table 2) to exclude potential mounds that intersect these areas. We chose the 'intersect' query option because it includes all those misidentified potential sites that overlap the boundary of a city/town/road at any point in its geometry. After querying, we removed those polygons that were highlighted by the program.

3.2. Field survey methods

After building and running the model in GIS, our goal was to visit potential mound sites identified by our model in order to assess its efficacy and to collect data for model improvement. Easily accessible publicly-owned land in the watershed is limited, with most of the federally-owned land is in the Cascades, which was excluded from our study (Fig. 4). The limited amount of public land made the use of a simple random or stratified random sampling strategy impossible. Our model identified 56 probable mounds and then we selected survey areas based on 1) the presence of probable mounds, and 2) our ability to access the property. Probable mounds were those mounds whose structure in the "Sink" identification dataset was similar to a *PIMS* shown in Fig. 4.

There was a single public land parcel (Fig. 4 Inset B) that had probable mounds and was also accessible. Permission to access private land was challenging. We contacted 17 landowners that had probable mounds on their property; three landowners granted permission for fieldwork (Fig. 4 Inset A-C). We undertook non-systematic survey on the parcels to which we had access; systematic survey was not possible due to time, budgetary constraints, and problematic field conditions (e.g. localized flooding). Our non-systematic survey consisted of walking directly to probable mound locations identified by the model. We also visited several landowner identified sites that were not previously recorded.

To assess whether or not a PM was in fact a mound, we visually assessed whether or not the area was higher than the local elevation. If there was dense vegetation, we tried to work our way as far into the vegetation as possible to determine whether or not the ground was sloping upward. Once we had determined that the identified point was

Table 2
Roadway dimensions used in the "roadway buffer" application. *

Road Type	Lane Width	Total Roadway Width (each direction)	Inside Shoulder Width	Outside Shoulder Width	Road Right-of-Way Buffer	Total Buffer Width Before Rounding Up
Highway	3.7 m	7.4 m	1.2 m	3.0 m	5.0 m (2.5 m either side)	16.6 m
Minor Highway/ Arterial	3.4 m	6.8 m	1.2 m	1.2 m	5.0 m (2.5 m either side)	14.2 m
All Other Roads	3.1 m	6.2 m	1.2 m	1.2 m	5.0 m (2.5 m either side)	13.6 m

* All roadway widths were acquired from Federal Highway Administration (FHWA 2014)

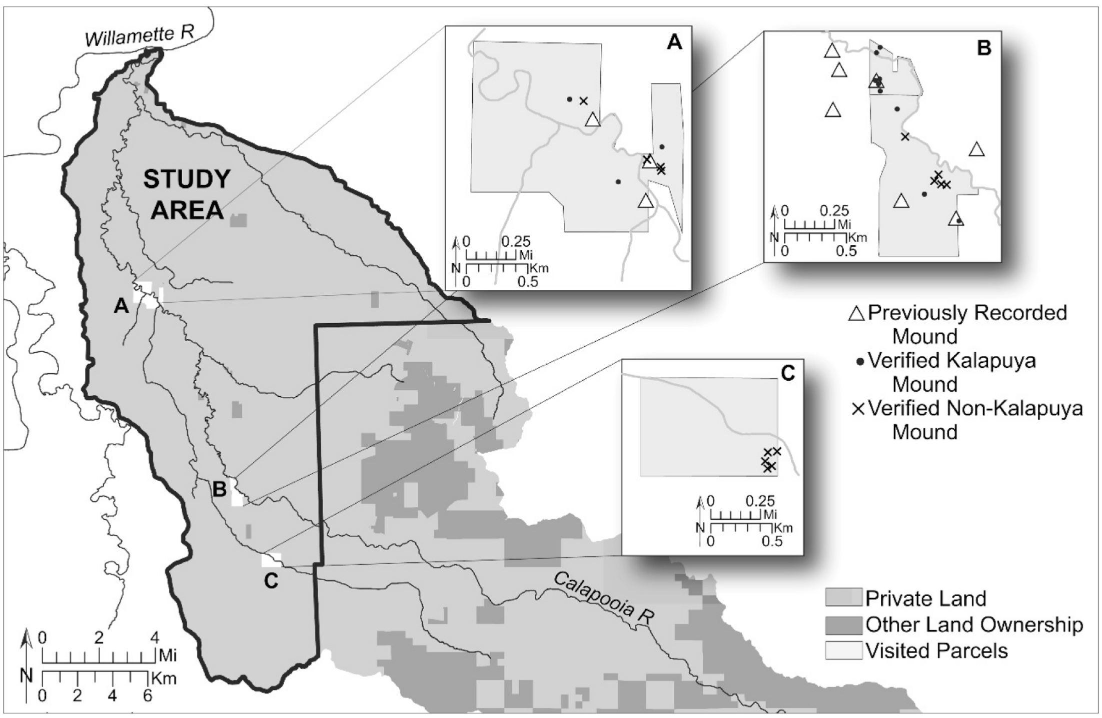

Fig. 4. Land management zones and field visited parcels in the Calapooia Watershed. Figure by Johonna Shea.

in fact mounded, we decided whether or not the identified mound was cultural or natural based on the presence of artifacts or exposed features. Finally, we determined which of the cultural model-identified mound sites were Kalapuyan by examining the mound for darker soils, FCR, lithic material, and possible human remains as these materials are indicative of Kalapuyan mound sites. If other cultural materials were present in or on a mounded area, such as Euro-American historic artifacts or refuse, the mound was determined cultural, but not considered a Kalapuyan mound. An Inadvertent Discovery Plan (IDP) developed in collaboration with our Indigenous project partners was in place in case human ancestral remains were identified during the fieldwork.

3.3. Methods for the assessment of model success

We used two metrics to assess the success of our model. The first metric for model success was a comparison in GIS of the number of *PIMS* in the SHPO database to a model identified mound point. A *PIMS* was considered positively identified by the model if its actual location was within 20 m or less of a model-identified mound point. A range of 20 m was chosen as it was considered a conservative estimate of the degree of location error inherent in the *PIMS* data. The second metric for model success was a comparison of the number of PM sites to the number that were field verified as cultural mounds. This metric for success was not as robust as originally desired given the minimal amount of land access acquired; only four properties were visited.

4. Results

4.1. Model results

After the identification and extraction methods were applied, including the removal of roads and cities, our model identified 13,708 potential mound sites in the study area (Table 3). In several instances, the model identified modern "mounds", such as pitching mounds in baseball fields and septic systems. Although these are not archaeological mounds, they serve as evidence that the model, in fact, identifies culturally mounded features. Field testing was imperative given that such a high number of potential mound sites were identified by the model and because some of these were *modern* cultural mounds. Data

Table 3
Results of mound identification and extraction for study area.

Method	Features Identified	Percent Decrease in Identified Features
Flow Direction & Sinks	51,333	—
Area Extraction	23,672	53.9%
Slope Extraction	15,753	69.4%
Elevation Extraction	15,001	70.8%
Road & City Extraction	13,708	73.3%

collected during fieldwork was also necessary to further refine our model and improve model output.

4.2. Field survey results

We visited one public land parcel and three privately owned parcels to assess the accuracy of our model and to collect data on positively identified mounds. Of 25 potential mounds (PMs) visited, seven were field verified as previously unidentified Kalapuyan mounds (Table 4 and Table 5). Three were cultural but not Kalapuyan, and 15 were non-cultural, of an unknown type, or not mounded.

Of the seven field verified Kalapuya Mounds, six exhibited the characteristics noted to belong to Kalapuyan Mounds (Fig. 5), e.g. darker soils, lithic material (Fig. 6), FCR, and/or camas growing on or near the mounds; PM25 did not have apparent Kalapuyan mound characteristics but was likely a Kalapuyan mound based on past landowner observations. Field verification of the remaining 18 PM identified them as a variety of non-Kalapuyan cultural and natural mound features, including heavily sedimented piles of wood (PM6), dense blackberry bushes, historic foundations (PM13), historic trash piles (PM17), historic burn piles (PM18), and low lying historical or recent structures. The latter were not removed during the city and town query of the model output. Other PM's were simply false positives and were neither mounded nor cultural. Additionally, we aimed to relocate and revisit six *PIMS*. Two of the six PIMS could be relocated; the remaining sites were either destroyed or the location information was poor enough that we could not relocate the mounds within our survey areas.

4.3. Model efficacy assessment

Out of the 20 *PIMS* incorporated into our model, four mounds were directly identified by the model (20 percent of the *PIMS*), four mounds were 20 m away from a PM site (20 percent), and 12 previously identified mounds were not identified by the model as potential mound sites (60 percent). The model was only 20 percent successful at directly identifying mounds. However, 15 of the 20 *PIMS* have an approximated location as their original data was recorded in the 1970s/1980s when locational data for archaeological sites were far less accurate. These were considered to have a possible location error of up to 20 m. When considering that four *PIMS* were within 20 m of a model-identified mound site and within our range of error, the model accuracy increases to 40 percent. One of the 12 *PIMS* that were not a model-

Table 4
Summary of potential mounds identified by the model, that were field verified.

Potential Mound (PM)	Is It Mounded	Is It Cultural	Kalapuyan Mound
PM1	Yes	Unknown	Unknown
PM2	Yes	Yes	Yes
PM3	Yes	Yes	Yes
PM4	Yes	Yes	Yes
PM5	No	No	No
PM6	No	No	No
PM7	Yes	Yes	Yes
PM8	No	No	No
PM9	No	No	No
PM10	No	No	No
PM12	Yes	Unknown	Unknown
PM13	No	Yes	No
PM14	No	No	No
PM17	No	Yes	No
PM18	Yes	Yes	No
PM19	Yes	Yes	Yes
PM20	No	No	No
PM21	No	No	No
PM22	No	No	No
PM23	Yes	Yes	Yes
PM24	Yes	No	No
PM25	Yes	Yes	Yes

Table 5
Summary of field verified and model identified Kalapuyan mound data.

Potential Mound (PM)	Mound Size	Cultural Material Present	Darker Soils Present
PM2	4 m L × 2.5 m W × 1.4 m H	FCR, lithic material (chert flakes)	Yes
PM3	~21.4 m L × ~ 10 m W × 30–50 cm H	FCR, lithic material (flakes and core)	Yes
PM4	~20.9 M L × ~ 16.2 m W × 50 cm H	FCR, lithic material (flakes), camas growing	Yes
PM7	~15.7 m L × ~ 6.8 m W	Lithic material (flakes, basalt core)	Unknown
PM19	42.1 m L × 36.7 m W × 2.4–3 m H	Lithic material (chert shatter), FCR, faunal bone – Landowner has mentioned lots of cultural material and human remains	Yes
PM23	23.8 m L × 22.3 m W × 80 cm H	Lithic material (projectile point, biface tip, flakes), FCR, faunal bone	Yes
PM25	31.8 m L × 21.8 M W × 30 cm H	None visible – Landowner has mentioned lithics and human remains	Unknown

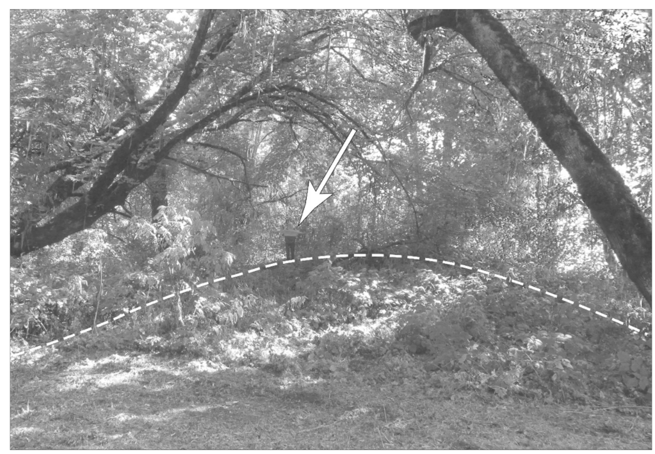

Fig. 5. PM19 located on private property. Author standing at the top of the mound. View to the Southeast.

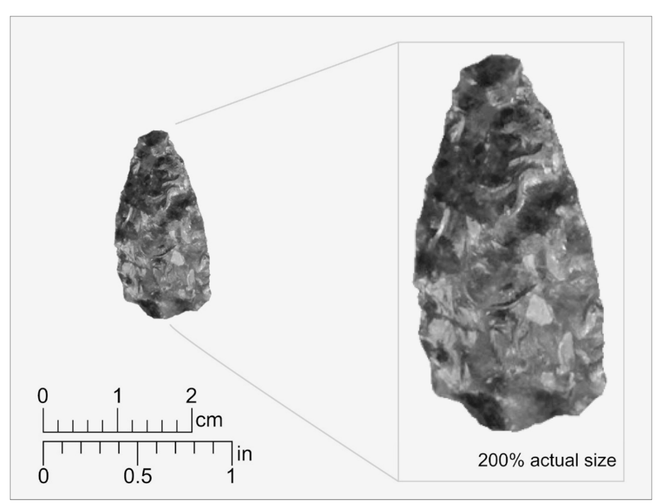

Fig. 6. Obsidian projectile point identified at PM4, a field verified mound site.

identified mound site was recorded in the middle of the farm and housing complex (35LIN57); field work verified that this site was destroyed. Another *PIMS* was noted as destroyed/deflated (35LIN806) upon its initial recording and therefore could not be identified by the model. If these two non-extant mounds are disregarded, the accuracy of our model increases to 44 percent. Of the remaining 10 *PIMS* that were not identified by the model, all except one are in active agricultural fields and are likely destroyed by plowing activities; however, their destruction was not able to be confirmed during fieldwork. Eroded, damaged, or destroyed mounds (non-extant) are difficult to identify within any model as they do not retain the identifiable structure of a relatively undisturbed mound (Magnini and Bettineschi 2019). Therefore, if the 10 probable non-extant *PIMS* are removed from the accuracy rating, the model identifies extant *PIMS* within 20 m of a PM site with 100 percent accuracy.

5. Discussion

Our primary goal for this project was to determine if a LiDAR model could identify where Kalapuyan mounds were located in the Calapooia Watershed. Knowing where the mounds are creates a foundation for any future research and for on-going preservation efforts. The current lack of information on these culturally significant mounds is a serious barrier to mound preservation. The results of this project indicate that modeling can identify cultural mounds in the Calapooia watershed. Our model was 44 percent successful in identifying cultural mounds and 100 percent successful in identifying extant *PIMS*. We also succeeded in locating seven previously unidentified mound sites through both lab and field work for this project. However, additional work is needed to address some of the problems we encountered over the course of our project and improve the efficacy of the model and its applicability to historic preservation issues.

Although we consider our model successful, false positives remain an issue; 13,708 PM sites in the study area. This is likely due to the model falsely identifying localities of dense low-lying vegetation as potential mound sites; the riverine areas of the Calapooia watershed are typified by dense vegetation (e.g. impenetrable blackberry bushes that can exceed 100 m^2 in area, and grow to over 10 m high). LiDAR is an excellent tool for digitally clearing away vegetation, although there are possible issues with extremely dense low-lying vegetation (e.g. low-lying blackberry bushes) preventing LiDAR pulses from hitting the ground surface and effectively create a false ground surface. This can affect archaeologists' understanding of how archaeology and the landscape intertwine and influence each other (Bater and Coops, 2009; Gould et al., 2013; Hodgson et al., 2005). Further fieldwork should be conducted in areas of dense, low-lying vegetation.

Additionally, the model identifies anthropogenic features that are not Kalapuya mound sites, such as historic foundations, trash piles, etc. This highlighted the unanticipated potential of identifying historical sites as mounds because they can be obscured and artificially mounded by vegetation overgrowth. Regardless, the model's ability to quickly identify probable mound locations will facilitate planning and carrying out future fieldwork in a more informed and directed manner. An additional consideration is that we utilized existing information about mounds to initially create and filter the model. If further fieldwork yields different spatial characteristics for mounds, the model should be adjusted; this is a standard part of the iterative modeling process (*sensu* Freeland et al.:66-67, 2016; Hanus and Evans, 2016:91). Therefore, future fieldwork should be directed at the collection of additional information (dimensions, contents, location) on Kalapuyan mounds in areas of the Calapooia watershed that we were not able to access for our initial study. Prior to additional fieldwork, model area parameters should be adjusted to reflect the new mound measurements acquired from fieldwork, given the problems with the precision and accuracy of the input data derived from SHPO archaeological records. This information will further inform the modeling process, facilitate model refinement, and likely result in fewer false positives.

It should also be noted that the mound dimension thresholds we used could be excluding mounds greater than the defined dimensions, which were based on the model measured size of existing mounds. For example, we used an upper threshold of 0.720 m for mound height based on model measured data for known mound sites. This information does not match the previously recorded mound information available via the Oregon SHPO database; the maximum reported mound height was 3 m, but we consider this an approximate height given the nature of pre-2000s data recording in the project area. However, it is possible that we excluded larger mounds by using these model measured parameters. This could be further explored in further iterations of the model and subsequent field testing. In the future, model thresholds should be rounded to the same accuracy as the laser itself, so as to yield more meaningful model thresholds.

The model could be used to further direct future fieldwork by creating a "buffer" around the rivers and then running the model in these buffered areas. The model indicated that 39 percent of all PM were located along major rivers and tributaries, as well as old river and tributary channels. By limiting the amount of area that the model has to assess, the model will produce fewer spurious points, and the problem of identifying homes, buildings, and roadways will likely be eliminated or greatly reduced. At the same time, fieldwork should also include systematic survey of non-riverine areas to address existing survey bias, to determine if agricultural activities have in fact been a factor in mound destruction, and to clarify whether or not the apparent association of mounds with riverways is real.

In tandem with ongoing field assessment of the model, archaeologists should work towards creating better relationships with the landowners in the Calapooia Watershed. These landowners have invaluable information regarding the mounds, and could aid in finding new ways of managing and protecting these significant cultural sites that suit the needs of all interested groups.

6. Conclusion

The use of LiDAR in archaeology has increased dramatically in recent years as archaeologists discover its capacity to aid archaeological discovery in environments that are prohibitive to survey and landscape level site analysis. Our study further establishes the efficacy of LiDAR in the archaeological realm. This project developed a method and a model appropriate for mound prospection in the Pacific Northwest, particularly in the Willamette Valley. Furthermore, the automatic extraction of mound sites offers a unique chance to fully utilize all that LiDAR and ArcGIS have to offer archaeologists. Our research shows that Willamette Valley mounds can be located using a LiDAR predictive model. This model serves as a guide that can focus archaeological fieldwork in the watershed and allow for greater efficiency in field surveys. Future work can focus on mound preservation and further research into why and how people created these mounds.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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