LiDAR Predictive Modeling of Kalapuya Mound Sites in the Calapooia Watershed, Oregon

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Archaeologists grapple with the problematic nature of archaeological discovery, as human activities and associated archaeological sites are not uniformly distributed or easily discernable across a landscape. Instead, sites are dispersed, clustered, low or high in visibility, fragmented or relatively complete. All of these factors affect the likelihood that archaeologists will find a site during pedestrian archaeological survey. Archaeological survey recovery rates are highly variable depending on the shape of the survey (linear, elliptical, rectangular, etc.), the transect interval, the time spent within each transect, access to survey areas, local environment, and the nature of the archaeology itself (Sundstrom 1993). Certain types of sites are difficult to see even in the best environmental conditions (e.g., low-density lithic scatters) and some environments are challenging to perform archaeological survey in, such as jungles or dense temperate rain forests like those of the Pacific Northwest. LiDAR (light detection and ranging) technology, a method for digitally clearing away swaths of vegetation and surveying the landscape, is one possible solution to some of these problems. 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 in designing and carrying out surveys. LiDAR modeling is effective over large areas and can be combined with other remote sensing data to create archaeological predictive models that identify likely site locations and guide pedestrian survey design.

The focus of my thesis research is to develop and test a LiDAR and remote sensing predictive model to identify mound sites in the Calapooia Watershed in the Willamette Valley, Oregon (Figure 1). The Grand Ronde Tribe considers the Willamette Valley mound sites highly sensitive locations, as ethnographic accounts and limited archaeological work suggest that some are burial sites (Mackey 1974; Laughlin 1941; Laughlin 1943; Roulette et al. 1996). According to Grand Ronde Tribal and written accounts, the watershed contains hundreds of unrecorded mounds extending from Albany to Eugene, Oregon (Laughlin 1941; Briece Edward personal communication 2016). Protecting mound sites is a priority but pedestrian survey of the watershed is impractical given that it covers roughly 234,000 acres.
and is 94 percent privately owned (Runyon et al. 2004:1; Calapooia Watershed Council 2016). I will use LiDAR data acquired by the Cultural Resources Department of the Confederated Tribes of the Grand Ronde from the Oregon Department of Geology and Mineral Industries (DOGAMI), as well as publicly available aerial photography, to develop a model that identifies probable mound locations in the watershed. I will test the model by carrying out a pedestrian survey. Finally, I will explore patterns in mound distribution and character in an effort to better understand the cultural and natural processes involved in mound formation; this analysis will inform future investigation of these enigmatic earthworks.

Use of LiDAR data to identify earthworks and other engineered landscapes is becoming common practice in other parts of the world (e.g., Challis et al. 2011; Chase et al. 2011; Hesse 2010; Lasaponara and Coluzzi et al. 2011; Weishampel 2012), but North American applications are rare. Archaeological LiDAR applications are even more limited in the Pacific Northwest and Oregon, although see Barrick 2015 for application to identification of historic gold mines. Archaeologists have not yet applied LiDAR to the identification of pre-Contact archaeological sites in this region. My work establishes a method and model appropriate for the Willamette Valley, which can also be modified for use in other regions of the Pacific Northwest and beyond. Furthermore, by identifying these mounds I lay the groundwork for future studies that may shed light on why and how people created these mounds, which will add valuable information to a poorly understood site type and cultural practice.
Figure 1 - Calapooia Watershed, cities, counties, other major river systems, and previously recorded mound sites. Note that the location of most previously recorded mound sites are approximate.

The Kalapuyan Mounds

Mound sites are somewhat of an archaeological enigma in the landscape of the Willamette Valley. The mounds are roughly ovoid earthworks; Oregon State Historic Preservation Office (SHPO) records indicate that recorded mounds in the Calapooia watershed range from 22 meters to 120 meters long, 15 meters to 85 meters wide, and less than 3 meters in height (Figure 2). Mounds are reported across northwest Oregon but are only minimally investigated (see Aikens et al. 2011; Roulette et al. 1996; White 1979; Wright 1922). Laughlin undertook several early excavations in Linn (Laughlin 1941).

There are multiple ways to refer to the mounds. The use of the word “Kalapuya” or “Kalapuyan” indicates a reference to the Kalapuyan peoples who lived within this region and constructed these mounds. The use of “Calapooia” indicates a reference to the actual watershed and the river.
and Yamhill Counties (Laughlin 1943). Laughlin recovered Native American remains and a variety of associated artifacts. Mackey mentions that over the last 90 years amateur archaeologists excavated approximately 80 mounds in the Calapooia Watershed (Mackey 1974:48, 51-56); no detailed accounts, records, or artifacts from these investigations are available. More recently, Archaeological Investigations Northwest, Inc. (AINW) excavated a mound site known as the Calapooia Midden Site (35LIN468) (Figure 1). This investigation recovered human remains, hearth features, charred camas (Camassia quamash) remains, and a variety of artifacts including flaked and ground stone tools. A total of 15 radiocarbon dates were obtained at 35LIN468, with ages ranging from 2880 +/- 80 calibrated years B.P. to 130 +/- 50 calibrated years B.P. (Roulette et al. 1996:8-73 – 8-74). The only other dated mounds in the region are the Spurland Mound, located in Linn County, which was indirectly dated to approximately 350 years ago during the late prehistoric/early historic (Kalapuyan) phase (White 1979:564). The other is 35LIN00050, which was recorded in 1970, and radiocarbon dated to 840 ± 110 years B.P. using charcoal found 60 – 80 cm below ground surface.

There is little to no consensus as to the nature of the mound sites and there are several hypotheses surrounding this question. A single ethnographic account (Laughlin 1941) mentions a Kalapuyan Tribal member and his son living at Halsey Mound, suggesting that the mounds may have been habitation sites in some cases. The theory that these mound sites could have been habitation sites has been a pervasive one (White 1975; Collins 1951; Cordell 1967). However ethnographic accounts (Mackey 1974; Collins 1951:40; Zenk 1990:548; White 1979:557) all indicate that the housing structures of the Kalapuya would have used posts as supports and permanent plank houses were used in the winter months. No excavated mound site to date has ever exhibited post holes or the remains of posts. Cordell’s initial goal of her master’s thesis was to identify post holes at a mound site in the Long Tom Watershed, however none were identified during field work (Cordell 1967). Materials recovered from mound excavations indicate that they were burial sites or were associated with camas (Camassia
processing and/or other food processing activities (Kaehler 2002; Roulette et al. 1996:8-58, 8-144; White 1975; Wilson 1993; Wilson 1997; Wilson personal communication 2017). Alternatively, mounds may have been multipurpose sites that encompassed some or all of the above activities.

Although the origin of mound sites is not well understood, it is well established that the Kalapuya mounds were created by the Kalapuyan people who inhabited this region and are now one of the Confederated Tribes of the Grand Ronde. The Kalapuyan band of peoples comprised the Tualatin at the far north of the Willamette Valley, the Yamhill, Ahantchuyuk, Luckiamute, Mary’s River, Santiam, Tsankupi, Tsan-chifin, Mohawk, Chemapho, Chelamera, Winnefelly, and the Youncalla at the far southern end of the Willamette Valley (Zenk 1990:548). The Santiam, Tsankupi, Tsan-chifin, and the Mohawk all traditionally lived around the Calapooia River. The Mary’s River people were located near the confluence of the Calapooia and the Willamette Rivers. Unfortunately, there are no available oral histories that describe how mounds were created and used by people in the past.

A total of 20 mound sites are recorded with the SHPO office in the Calapooia Watershed (Table 1). Four additional mounds were recorded in or near the watershed by Laughlin (1941). In addition, 134 possible mounds are noted in the SHPO database, but lack location data or any detailed information about the mounds (Table 1). Numerous mounds are also identified on a historic map of the region (Collins 1951) (Figure 3). The abundance of mound sites reported in the Calapooia Watershed make it an ideal location for LiDAR modeling and will facilitate a broader understanding of the archaeological landscape.

Table 1 – Previously recorded mound sites within the Calapooia Watershed.

<table>
<thead>
<tr>
<th>Site Number</th>
<th>Site Name</th>
<th>County</th>
<th>Site Type</th>
<th>Year Recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>35LIN00020</td>
<td>N/A</td>
<td>Linn</td>
<td>Heavily pot hunted mound, with lithics and human remains</td>
<td>1979</td>
</tr>
<tr>
<td>35LIN00041</td>
<td>N/A</td>
<td>Linn</td>
<td>A “mound-midden” site; located within a plowed field; several projectile points and glass scrapers (were collected)</td>
<td>1970</td>
</tr>
<tr>
<td>Site Code</td>
<td>County</td>
<td>Townships</td>
<td>Description</td>
<td>Date(s)</td>
</tr>
<tr>
<td>-----------</td>
<td>--------</td>
<td>------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>35LIN00042</td>
<td>N/A</td>
<td>Linn</td>
<td>A “mound-midden” site; potential for lithic material; surface collection noted</td>
<td>1970</td>
</tr>
<tr>
<td>35LIN00045</td>
<td>N/A</td>
<td>Linn</td>
<td>A “mound-midden”; noted as being excavated by amateurs; extensive lithic, decorative, and food processing artifacts found; burials were found in Feature 2, 3 bags of artifacts removed including points</td>
<td>1970</td>
</tr>
<tr>
<td>35LIN00046</td>
<td>N/A</td>
<td>Linn</td>
<td>Noted in 1970 to be a mound with points having been collected by landowner; Revisit in 2010 couldn’t find mound but stated it was possibly still present; small lithic scatter found</td>
<td>1970, 2010</td>
</tr>
<tr>
<td>35LIN00048</td>
<td>N/A</td>
<td>Linn</td>
<td>A “middlen” site; partially in plowed field partially naturally vegetated; small bag collected including a point</td>
<td>1970</td>
</tr>
<tr>
<td>35LIN00050</td>
<td>N/A</td>
<td>Linn</td>
<td>A “midden-mound” site; heavily vegetated; 11 bags of artifacts collected including points and C14 sample; one test pit; human remains found on surface</td>
<td>1970</td>
</tr>
<tr>
<td>35LIN00051</td>
<td>N/A</td>
<td>Linn</td>
<td>A “midden-mound” site; one surface bag collected with one point being noted</td>
<td>1970</td>
</tr>
<tr>
<td>35LIN00053</td>
<td>N/A</td>
<td>Linn</td>
<td>A “midden-mound” site; noted as being rather large; one surface collection bag, no lithics; exhibited evidence of potting</td>
<td>1970</td>
</tr>
<tr>
<td>35LIN00054</td>
<td>N/A</td>
<td>Linn</td>
<td>A “midden-mound” site; one “bag of chips” and a pestle fragment were collected</td>
<td>1970</td>
</tr>
<tr>
<td>35LIN00055</td>
<td>N/A</td>
<td>Linn</td>
<td>A “midden-mound” site; “chips” and bones were noted on the surface as well as bioturbation; one bag of “chips” collected</td>
<td>1970</td>
</tr>
<tr>
<td>35LIN00057</td>
<td>N/A</td>
<td>Linn</td>
<td>A “midden-mound” site; “chips” noted to be around mound; noted to have possibly been a burial that had been</td>
<td>1970</td>
</tr>
<tr>
<td>Code</td>
<td>Name</td>
<td>County</td>
<td>Description</td>
<td>Date</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------</td>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>35LIN00059</td>
<td>N/A</td>
<td>Linn</td>
<td>A “midden-mound” site; “chips” noted to be around the mound allowing for identification; surface collection</td>
<td>1970</td>
</tr>
<tr>
<td>35LIN00061</td>
<td>Foster Dam</td>
<td>Linn</td>
<td>A “mound-like area”; located very close to the water; several lithic artifacts collected</td>
<td>1973</td>
</tr>
<tr>
<td>35LIN00095</td>
<td>N/A</td>
<td>Linn</td>
<td>Mound site known to the land owner’s family for generations; large amounts of lithic artifacts and faunal remains; has been pothunted; surface collection of artifacts; has been partially plowed</td>
<td>1979</td>
</tr>
<tr>
<td>35LIN00291</td>
<td>N/A</td>
<td>Linn</td>
<td>Potentially a historic burial mound; prehistoric artifacts found in rodent backfill; historic artifacts present</td>
<td>No Date Given</td>
</tr>
<tr>
<td>35LIN00468</td>
<td>Calapooia Midden</td>
<td>Linn</td>
<td>Mound located on an old levee; lots of lithics, points, and FCR found on the surface; dense charcoal; evidence of pot hunting and cattle grazing</td>
<td>1991</td>
</tr>
<tr>
<td>35LIN00711</td>
<td>N/A</td>
<td>Linn</td>
<td>Large mound with lithic debitage and FCR; evidence of looting and collector piles</td>
<td>2007</td>
</tr>
<tr>
<td>35LIN00805</td>
<td>Mound Site</td>
<td>Linn</td>
<td>Mound adjacent to a lithic and FCR scatter; potentially a burial although it wasn’t examined</td>
<td>2013</td>
</tr>
<tr>
<td>35LIN00806</td>
<td></td>
<td>Linn</td>
<td>Potential midden with a historic structure built on top; hundreds of lithics, FCR, and pestles; some historic artifacts found</td>
<td>2013</td>
</tr>
<tr>
<td>Unknown</td>
<td>Spurland Mound</td>
<td>Unknown</td>
<td>Large trenched mound with six human skeletal remains, animal bone, extensive lithic artifacts, a copper necklace, preserved rawhide and leather, bone artifacts, and shell</td>
<td>1940-1941</td>
</tr>
<tr>
<td>Unknown</td>
<td>Miller Mound</td>
<td>Unknown</td>
<td>Mound without systematic excavation; three human</td>
<td>1936, 1940-1941</td>
</tr>
<tr>
<td>Site</td>
<td>Mound</td>
<td>Location</td>
<td>Notes</td>
<td>Date</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------</td>
<td>---------------------</td>
<td>----------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Unknown</td>
<td>Halsey Mound</td>
<td>Unknown</td>
<td>Large trenched mound; hearths, charcoal, and lots of lithic and bone material found; scattered human remains; mentions remains of two Native Americans who were allowed to live on the mound by the white landowner</td>
<td>1940-1941</td>
</tr>
<tr>
<td>Unknown</td>
<td>Shedd Mound</td>
<td>Unknown</td>
<td>Two plowed mounds of very poor condition; minimal lithic debris; skeleton, mortar and pestle, and well made lithic tools were removed and kept by the land owner</td>
<td>1940-1941</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>Unknown, potentially Linn and Benton Counties</td>
<td>Potentially 134 mound sites with undocumented information; most are digitized from old SHPO maps</td>
<td>Unknown</td>
</tr>
</tbody>
</table>
Figure 2 - Spurland Mound excavation schematic (Laughlin 1941:148).
Figure 3 – Map of mound sites along the Calapooia River and Muddy Creek (Collins 1951).
Application of LiDAR Modeling to Earthwork Identification

LiDAR and other remote sensing data are effective at identifying mounds and other earthworks. Archaeologists have used remote sensing techniques with increasing frequency since the development of satellite imagery in the 1960s, with one of the first applications being the archaeological analysis of NASA satellite imagery. This led to the discovery of previously unknown ancient canal systems in Arizona (Giardino 2011). Since then, archaeologists have used satellite imagery and multi-spectral imagery (imagery comprised of multiple wavelengths of light) all over the world to identify sites and guide on-the-ground survey; mound sites are one of the most prevalent site types identified through analysis of satellite imagery (e.g. Challis et al. 2011; Rajani and Rajawat 2011; Giardino 2011:2007; Gren et al. 2011; Lasponara and Masini 2011; Meredith-Williams 2014).

The use of LiDAR to accurately measure the elevation of terrain did not begin until the 1970s, from which point its use expanded throughout the sciences (Price 2012:25). Archaeological appreciation of LiDAR is more recent, with the first mention of its potential use in archaeology being in 2002 (Holden et al. 2002). Despite its relative newness as an archaeological method, it has proven to be extremely effective and is growing in popularity and use (Challis et al. 2011; Holden et al. 2002). For example, LiDAR was used to identify terraced agricultural fields in Hawaii (McCoy et al. 2011), low-lying earthen features in England (Challis et al. 2011), and deteriorated medieval structures in Italy (Lasponara et al. 2011). Archaeologists have also manipulated LiDAR data, using local relief modeling to locate grave fields in Sweden (Doneus 2013) and house mounds in Belize (Shane Montgomery personal communication 2017). Several recent studies, including those performed by Challis et al. (2011:287) note that slope calculations from a LiDAR derived elevation-based model are effective in analyzing archaeological earthwork features and in highlighting their uniqueness on the landscape by showing localized increases in slope. Methods for identifying low-lying features in LiDAR data include the use of analyzing satellite imagery to identify paleochannels in India (Rajani and Rajawat 2011) and the
manipulation of satellite imagery using such tools as a Principal Component Analysis to identify sites in Peru (Lasaponara and Masini et al. 2011). Researchers in Tonga used LiDAR and hydrological methods to successfully identify low-lying mound sites within the Kingdom of Tonga (Freeland et al. 2016). Their model was 85 percent successful in identifying earthwork features (Freeland et al. 2016:70). Some of these sites were previously unseen by archaeologists. Modeling of satellite, multi-spectral imagery, and LiDAR data are all viable methods for locating mound sites in the Calapooia Watershed.

Although LiDAR has been successful in a variety of archaeological settings, archaeologists have not widely adopted LiDAR modeling in the United States. One reason for this is that only 23 states, mostly eastern states, have complete LiDAR imagery (NOAA 2018). Completing LiDAR for an entire state and flying traditional LiDAR flights (e.g. not unmanned aerial vehicle [UAV] LiDAR) are extremely expensive to perform, restricting archaeologists’ ability to fully make use of LiDAR. The few archaeological uses of LiDAR within the United States are focused on visual interpretation of archaeological sites underneath densely vegetated environments (Gallagher and Josephs 2008; Johnson and Ouimet 2014), to visually assess 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), or to understand how LiDAR can be used in conjunction with other geospatial techniques to reanalyze archaeological sites (Pluckhahn and Thompson 2012).

U.S. archaeologists have used LiDAR in few cases to help identify mounds. If work is done on mounds, the main goal of the study usually is to use LiDAR to relocate previously identified mounds and to assess the viability of using LiDAR to identify mounds. To identify previously known mounds, it is necessary to use the process of automatic feature extraction [AFE] (the automatic detection of specific features based off of identified parameters or algorithms), which can be more efficient and cover greater areas than just an archaeologist examining the LiDAR data alone (Freeland et al. 2016:65). However, almost no work using AFE methods has been conducted on mound features within the United
States (see Riley 2009 for one U.S. example of AFE usage). No studies have used LiDAR solely to locate unidentified archaeological sites (Riley’s [2012] AME tool is a published tool within the Iowa SHPO and can be used by archaeologists to identify unknown archaeological sites). Archaeological LiDAR usage within the United States is still in its infancy, with its full analytical capabilities yet to be entirely understood or utilized. This project is an expansion of archaeological LiDAR methods and usage, as well as an exploration of the use of AFE in feature identification.

**Research Design and Methods**

There are three stages of my project: 1) model development, lab testing, and modification; 2) field survey, and 3) analysis of possible formation processes. The analysis of possible formation processes is ongoing.

**Model Development**

The first step in the creation of the model was an exploration of various methods that may be effective for identifying mounds through iterative modeling. I began this process by focusing first on the potential use of slope and vegetation data in identifying mound sites. From here I employed hydrological methodology and zonal statistics to highlight and extract potential mounds from the LiDAR dataset. I used several spatial datasets to build the mound identification model (Table 3), which added to the robusticity of the LiDAR dataset and aided in analysis. To build a functioning model that identifies mounds, several assumptions were made to inform the model. These assumptions were informed by my review of the literature regarding Willamette Valley mound sites. I assumed the following:

- Mound sites will be uniquely visible and relatively uniform in their dimensions.
- Mounds will be of a height and width that can be identified within the LiDAR data and aerial photography.
- Mounds will be relatively low lying and either circular or ovoid in shape.
- Mounds will express a slope change that is distinguishable and unique in comparison to the surrounding landscape.

In addition to the above assumptions, it was important to know the general dimensions of the mounds, as this helped guide the model in correctly distinguishing between mounds and large, natural landscape features. Therefore, mounds within the study area appear to have a certain set of dimensions (22 meters to 120 meters in length and 15 meters to 85 meters in width), which provide additional guidelines for mound identification.

Table 2 – Datasets used to construct model.

<table>
<thead>
<tr>
<th>Type of Dataset</th>
<th>Dataset</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remotely Sensed Imagery</td>
<td>LiDAR Digital Elevation Model (DEM)</td>
<td>Oregon Department of Mineral Industries (DOGAMI) – Supplied by the Grand Ronde Tribe</td>
</tr>
<tr>
<td>Remotely Sensed Imagery</td>
<td>Aerial Imagery</td>
<td>ESRI ArcMap Basemap sourced from: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community</td>
</tr>
<tr>
<td>Standard</td>
<td>Oregon Cities and Towns Data</td>
<td>Acquired from the Oregon Spatial Data Library</td>
</tr>
<tr>
<td>Standard</td>
<td>Oregon Hydrography Data</td>
<td>National Hydrography Dataset from the United States Geological Survey</td>
</tr>
<tr>
<td>Archaeological</td>
<td>Previously Recorded Mound Sites</td>
<td>SHPO site form location info</td>
</tr>
</tbody>
</table>

During the initial stages of modeling, I found that a slope layer was a useful tool for visually identifying sites. However, the slope layer is difficult to query (querying allows for selection of a subset of features or attributes within data). This method of mound identification required several complicated steps and multiple conversions of the slope dataset before I could use it to identify mounds; the resulting model was only 40 percent successful in identifying known mounds. This process has the potential to be refined, for instance, by adjusting the mound area query and finer resolution slope attributes. However, this particular slope layer method was likely to continue to be very complex, making it relatively inefficient.
I also experimented with the use of remotely sensed satellite imagery to identify vegetation differences and mounds, using National Agricultural Imagery Program (NAIP) imagery. Vegetation grows on archaeological sites, especially those that contain foreign organic material such as human or animal remains (Giardino 2011:2008; Grön 2011:2025). This differential vegetation growth can be detected in remotely sensed satellite imagery. I found, however, that this method does not provide consistent enough mound identification results to be useful within the model. The efficacy of satellite and infrared imagery may be improved through the analysis of an aggregation of satellite imagery over the years, which could allow the identification of differential vegetation growth on mound sites across time. However, I determined that this method was inefficient and unreliable for mound identification.

Next, I attempted a method that involved inverting the LiDAR dataset and then applying hydrological GIS methods to the inverted dataset. Then, I utilized zonal statistics on an elevation layer and a slope layer. All of this was conducted in the program ArcMap 10.5.1. This method was the most successful and efficient method of mound identification, for both new and previously recorded mounds. This approach was inspired by similar successful methods used by Freeland et al. (2016), who developed an iMound algorithm that inverted the landscape and then identified mounds by using a hydrological pit filling algorithm developed by researchers Wang and Liu (2006). Their method had an 85 percent positive identification rate when examining mound sites within the Kingdom of Tonga. At Greater Angkor in Cambodia, archaeological researchers also successfully identified household ponds by manipulating the ‘Fill’ tool in ArcMap; rather than use the tool’s intended function of filling pits/ponds, they manipulated it so that it would identify and mark ponds (Hanus and Evans 2015:91). The method used in my model comprises two stages; the first is the mound identification process and the second is the mound extraction process.

The first stage involves filtering the LiDAR DEM. Although a one-meter spatial resolution dataset is fine-grained enough to identify mounds, it also allows for extraneous non-mound data points, or
“noise.” To combat this excess of data I used the ArcMap ‘Filter’ tool, which removes excess data or enables the enhancement of features that might have been missed originally (Arcgis.com 2016a). The ‘Filter’ tool has two options, a ‘Low Pass Filter’ and a ‘High Pass Filter.’ I chose to use the ‘Low Pass Filter’ as it smooths the dataset by “reducing local variation and noise,” both of which are issues when analyzing one-meter spatial resolution LiDAR data, as mentioned above (Arcgis.com 2016a). I applied the ‘Low Pass Filter’ to the dataset several times until a large majority of extraneous elevation points were removed.

My second step in the process of mound identification was to invert my LiDAR DEM. The inversion effectively causes the Kalapuyan mound sites to act as sinks, which can retain digital water, as mentioned by 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). These sinks effectively trap digital water and allow for their identification within ArcMap. To identify the mound sinks using the inverted LiDAR DEM, it was necessary to apply the ‘Flow Direction’ tool to the dataset. The ‘Flow Direction’ tool assesses the direction that water would flow from each cell in the DEM raster dataset (a dataset on which each cell contains information) to its “steepest downslope neighbor” (Arcgis.com 2016c).

The third step toward mound identification was to apply the ‘Sink’ tool, which identified the sinks created by the application of the ‘Flow Direction’ tool to the dataset. The ‘Sink’ tool extracted the areas of “internal drainage,” all of which are potential mound sites (Arcgis.com 2016b). As shown in Figure 4, this process identifies over 20,000 “potential mound sites” within one LiDAR grid (covering roughly 81 square miles); however, it was successful in identifying previously known mounds.
Although the first stage of my model development was successful in identifying previously known mound sites, it produced far too many potential mound sites to be useful. Therefore, a second stage was necessary to further reduce the number of potential mound sites. The second stage of my model involved the extraction of mound sites from the ‘Flow Direction’ and ‘Sink’ tool outputs. First, I converted the results of the ‘Flow Direction’ and ‘Sink’ tools from a raster dataset to a vector dataset. By converting the potential mound sites into a vector data model, I was able to create a polygon for each potential mound site, calculate the area for each feature, and use it as a boundary for further statistical analysis.
analysis. Next, I extracted the identified potential mound sites by area. To do this, I examined the area values for each previously identified mound that was identified in the first stage; then, I queried those values. The area values of the previously identified mounds ranged from 22 square meters to 825 meters. This query reduced the number of potential mound sites in one LiDAR grid by roughly 55 percent.

The second step was to perform a slope extraction. To do this I uploaded a slope layer, which is produced from the LiDAR DEM using the ArcMap ‘Slope’ Tool, and then, using the ‘Zonal Statistics’ Tool, I extracted a range of statistics for the slope of each potential mound site. 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 (potential mound sites vector data model) (Arcgis.com 2016d). For the slope extraction, I chose to use the mean statistic because this gave me the average slope of each previously identified mound. The mean slopes from previously identified mound sites ranged from roughly 1.5° to 9.57°. I then queried all the mean slopes for each potential mound site vector that fell within the above range; this query reduced the number of potential mounds sites by roughly another 14 percent.

The final step was to perform an elevation extraction. To do this I uploaded the LiDAR DEM and then used the ‘Zonal Statistics’ tool in the same manner as described for the slope extraction. For this extraction, however, I chose to use the statistical range of elevation values for each previously identified mound site vector, as this would provide me with the heights of each mound from the ground surface. The heights of each previously identified mound fell within a range of 0.155 meters to 2.383 meters. I queried all the elevation ranges that fell within the above parameters for each potential mound site vector; this query reduced the number of potential mound sites by roughly another 4 percent.

Field Survey Methods
After building and running the model in GIS, my goal was to visit several potential mound sites identified by my model in order to assess its efficacy. Ideally, these survey areas would be randomly chosen using a simple random or stratified random sampling strategy. However, publicly owned land within the watershed is limited, and most of the federally owned land is in the Cascades, where mounds are unlikely to be located (Figure 5).

Figure 5 – Land management zones within the Calapooia Watershed.

Only two potential mound sites were identified on a small parcel of publicly owned land. I visited these two sites on March 23rd, 2018, accompanied by one crew member. Given the size of the parcel, as well as the extremely wet and water-logged conditions, the crew member and I walked directly to the probable locations and performed a small visual survey. Both locations were determined
to be mound sites, with one exhibiting a great deal of fire cracked rock, darker soils, and lithic materials (all indicative of mound sites [Table 2]).

All other potential mound sites are located on privately owned property. Through a written letter mailed on April 9th, 2018, I contacted a total of 17 landowners within the Calapooia Watershed, requesting permission to access their property to perform a field survey of potential mound sites. Seven landowners did not grant access, seven landowners have yet to respond, and three landowners granted permission. On May 7th, 2018, two field crew members and I visited a parcel of private property to assess both the previously identified mound sites and the potential mound sites located on that land. We conducted a random survey with no survey transects as we walked to each potential mound site location that had been identified by the model. During this survey, three new mound sites were verified, noting darker soils, lithic material (including and obsidian projectile point [Figure 6]), and an abundance of fire cracked rock. Two potential mound sites identified by the GIS model were, in fact, mounds, but we determined that they were not cultural in nature. Two previously recorded mound sites were relocated and verified. Unfortunately, acquiring land access in the Calapooia Watershed is extremely difficult, as landowners are uneasy about archaeological collaboration. Further field verification of the model is ongoing and will most likely continue for years to come.
Figure 6 - Obsidian projectile point identified at a field verified mound site.

Analysis of Mound Formation Processes

The model has shown to be successful in identification of mounds sites. Therefore, it is imperative that I conduct a deductive analysis of the identified mounds to determine any additional patterns in their physical characteristics and location, which could inform future investigations regarding their formation and use. For example, I will evaluate whether any patterning exists in the location of mound sites with respect to: 1) natural features, such as waterways, ecozones, or soil types, or 2) cultural features, such as other mound sites or other types of recorded sites. By analyzing the relationship between the location of the mounds and natural and/or cultural features, archaeologists can begin to understand whether these sites are related to significant activities, such as camas processing and the ritual burial of the dead (e.g. Luby and Gruber 1999), or these mounds acquire their
significance from their location near important features, such as major rivers. The analysis of formation processes is ongoing and has not yet been completed.

**Results and Discussion**

The model was able to identify previously recorded mound sites with roughly 70 percent accuracy. This accuracy accounts for the fact that many previously recorded mound sites no longer exist; as they were located in agricultural fields, they were most likely destroyed by plowing. Additionally, a large majority of previously recorded mound sites were recorded in the 1970s, when locational data for archaeological sites was far less accurate. The locations of these sites in ArcMap are approximations of the sites’ locations and may also account for a portion of the model’s inaccuracy. Even considering these issues, the model identified extant well-known mound sites with marked regularity.

In several instances, the model identified recently constructed mounds, such as pitching mounds in baseball fields and septic systems (Ronald and Karen Litwiller personal communication 2018). Although these are not archaeological mounds, they serve as evidence that the model, in fact, identifies mounded features. In addition, field verification of seven model-identified potential mound sites yielded five mound sites that could be recorded as cultural in nature. The other two potential mound sites were determined to be non-cultural in nature. In one case, the model identified a heavily sedimented pile of wood that had most likely been piled by the landowners. The pile was small and extremely low lying, so its identification as a potential mound site might be the result of too much remaining “noise” within the model. Field verification is ongoing and is limited by landowner permission rights, as well as time constraints.

After all identification and extraction methods were applied, my model identified 4,227 potential mound sites for one LiDAR grid (Table 3). Although this is an extremely high number of potential mound sites, several factors must be kept in mind. The first is that further filtering of the LiDAR
DEM is necessary, as there are still too many extraneous or “noisy” data points creating false positives. The number of potential mound sites will likely continue to drop with further filtering.

The second factor is that areas overlying roads, towns, or cities were not removed from the dataset, but caused excessive false positives. Several potential mound sites, when examined in aerial photography, were in fact portions of roads or houses within one of the many towns in the watershed. With the removal of these areas from the dataset, the number of potential mound sites will decrease.

The final factor is that it is unlikely that an archaeologist or an archaeological crew will survey the entire area covered by a LiDAR grid for an archaeological project. Given the nature of modern day Cultural Resource Management (CRM) archaeology, the areas surveyed will coincide with a small construction footprint. Therefore, archaeologists can run this model within their particular survey area, which will yield a far more manageable number of potential mound sites.

Table 3 - Results of mound identification and extraction.

<table>
<thead>
<tr>
<th>Method</th>
<th>Features Identified</th>
<th>Percent Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Direction &amp; Sinks</td>
<td>15,346</td>
<td>---</td>
</tr>
<tr>
<td>Area Extraction</td>
<td>6,953</td>
<td>54.7%</td>
</tr>
<tr>
<td>Slope Extraction</td>
<td>4,836</td>
<td>68.5%</td>
</tr>
<tr>
<td>Elevation Extraction</td>
<td>4,227</td>
<td>72.5%</td>
</tr>
</tbody>
</table>

The refinement of the model is ongoing; however, the model has already shown its incredible capability to aid archaeologists in their search for the Kalapuyan Mounds. This LiDAR model does not serve as a replacement for field archaeologists, as both my model and field results show. Rather, the results discussed above indicate that LiDAR is a viable and valuable tool to assist archaeologists in archaeological prospection for culturally sensitive sites.

Project Deliverables
The results of this project, as well as the model methodology itself, will be shared with the Grand Ronde Tribe to further facilitate their efforts in protecting these sites.

**Project Significance**

This project will assist the Grand Ronde in the identification and protection of Calapooia Watershed mound sites, which the tribe considers extremely sensitive. In addition, this project sheds light on the cultural processes that created these mounds and furthers our understanding of human modification of the landscape in northwest Oregon, since Pacific Northwest research on earthworks and landform engineering is limited (Grier 2014). My work also demonstrates how archaeologists can use LiDAR and other remote sensing tools to better identify archaeological sites that cannot be located by traditional archaeological survey methods. In addition, my methodological approach can be applied to other areas in northwest Oregon, as well as further afield, to identify similar types of sites. Archaeologists will be able to reach sites that they have never reached before by applying LiDAR data and the powerful analyzing capabilities of a GIS; these efforts will greatly expand the archeological record and broaden our collective understanding of the past.
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