*Archaeological Prospection*



RESEARCH ARTICLE OPEN ACCESS

# Bathymetric LiDAR and Semi-Automated Feature Extraction Assist Underwater Archaeological Surveys

Dylan S. Davis[1,2,3] | Jessica W. Cook Hale[4,5] | Nathan L. Hale[6] | Trevor Z. Johnston[7] | Matthew C. Sanger[8]

[1]Columbia Climate School, Columbia University, New York, New York, USA | [2]Division of Biology & Paleoenvironment, Lamont-Doherty Earth Observatory, Palisades, New York, USA | [3]Columbia Center for Archaeology, Columbia University, New York, New York, USA | [4]School of Archaeological and Forensic Sciences, University of Bradford, Bradford, UK | [5]Department of Geology, University of Georgia, Athens, Georgia, USA | [6]Aucilla Research Institute, Monticello, Florida, USA | [7]Department of Anthropology, Florida State University, Tallahassee, Florida, USA | [8]National Museum of Natural History, Smithsonian Institution, Washington, DC, USA

**Correspondence:** Jessica W. Cook Hale (j.cookhale@bradford.ac.uk)

**Received:** 30 November 2023 | **Revised:** 8 February 2024 | **Accepted:** 2 April 2024

**Funding:** This study was supported by the Directorate for Social, Behavioral and Economic Sciences and the UK Research and Innovation.

**Keywords:** bathymetric LiDAR | Florida | semi-automated image analysis | shell middens | underwater archaeology

## ABSTRACT

Critical data concerning key developments in global human history now lie submerged on continental shelves where investigations confront significant challenges. Whereas underwater excavations and surveys are expensive and weather dependent and require specialized training and equipment, remote sensing methods can improve chances for success offshore. A refinement in one method, a semi-automated analysis protocol that can help to identify Pleistocene and Holocene era archaeological deposits in bathymetric LiDAR datasets, is presented here. This method employs contour mapping to identify potential archaeological features in shallow water environments in Apalachee Bay, Florida. This method successfully re-identified multiple previously recorded archaeological sites in the study region and detected at least four previously undocumented archaeological sites. These results suggest that this procedure can expand on methods to identify and record submerged archaeological deposits in sediment-starved, shallow-water environments.

## 1 | Introduction

Around the world, coastlines typically offer an unparalleled richness and diversity of resources, many of which are available year-round, making these regions particularly attractive places to live for pre- or non-agricultural peoples (Compton 2011; Faulkner et al. 2021; Marean 2014; Thompson and Worth 2011). Along with food resources, coastlines and their associated riverways provide unique opportunities to utilize watercraft and engage in trade and large-scale movement of people, information and materials (Bailey et al. 2007; Erlandson and Fitzpatrick 2006; Fitzpatrick, Rick, and Erlandson 2015). For these reasons, among others, the study of coastal populations is critical in understanding how past peoples, particularly non-agricultural groups, adopted new settlement, mobility and subsistence strategies along with novel social configurations, economic networks and cultural manifestations (Kirch and Hunt 1997; Turck and Thompson 2016). Although the modern coastline is a central point in current research, the archaeological study of coastal peoples is significantly hampered by past and current rising sea levels that have submerged prior coastlines—particularly those predating the middle Holocene (Bailey 2014; Bailey and Flemming 2008; Bailey and Milner 2002; Bailey and Parkington 1988).

Underwater archaeology has made significant strides in documenting archaeological data, including from submerged sites that were formerly coastal occupations (e.g. Bailey, Harff, and Sakellariou 2017; Farr et al. 2017; Gaffney, Thomson, and Fitch 2007). Remote sensing technologies have been at the forefront of underwater archaeological investigation over the past several decades, with researchers making use of underwater robotics, ship-based acoustic methods and submersible vehicles, among others (e.g. Fernández-Montblanc et al. 2018; Janowski et al. 2021; Plets, Dix, and Bates 2013; Somma et al. 2016). Submerged site prospection also benefits from predictive modelling based on onshore site analogues and their proximity to foundational resources like freshwater and specific habitats (Benjamin 2010; Cook Hale and Garrison 2019; Cook Hale and Sanger 2020; Faught 2004a, 2004b).

Despite these advancements, it remains difficult to identify potential archaeological targets given the nature of submerged site formation processes, which subject archaeological deposits to subaerial and marine forces that often erode, bury, redistribute or otherwise destroy or obscure archaeological deposits (e.g. Quinn and Boland 2010). Likewise, the inundation of submerged sites greatly increases the labour, expertise and expense needed to survey for these deposits and to test them when detected (e.g. Faught and Flemming 2008; Flemming, Harff, and Moura 2017). Even some of the tools used to help mitigate the challenges associated with working in an offshore environment, such as the application of onshore analogues to predict the presence of now inundated sites, have limited applicability as archaeologists are unsure whether earlier coastal adaptations may differ substantially from anything extant in the current archaeological record (Ford and Halligan 2010).

Until recently, one of the most powerful remote sensing technologies used in terrestrial environments has been unavailable for underwater research, but advancements in Light Detection and Ranging (LiDAR) have created an opportunity to use this technology in shallow submerged contexts (Doneus et al. 2013, 2020; Lobb 2016; Tian-Yuan Shih, Chen, and Chen 2014). With the availability of bathymetric LiDAR, underwater archaeologists are faced with a similar challenge as their colleagues working on dry land—a wealth of data that hold critical information but are also vast and beyond human capacity to analyse. Given the unique taphonomic conditions in underwater contexts, new tools are needed to effectively analyse bathymetric datasets and accurately locate areas of archaeological interest. We provide and test such a tool within this paper by using a type of object-based image analysis (OBIA) known as inverse depression analysis (IDA). We test the feasibility of this approach by using it to identify archaeological deposits in shallow underwater contexts in Apalachee Bay, Florida (Figure 1). We apply our approach to locate some of the most difficult to detect site types in the region—submerged Holocene and Pleistocene archaeological sites—including potential coastal occupations. In what follows, we begin by briefly describing the application of LiDAR in archaeology, including in underwater contexts and using semi-automated methods, before then providing a review of the archaeological context of the region, followed by a description of our methods, preliminary results and a discussion of the broader significance of this work for the region and remote sensing archaeology.

### 1.1 | LiDAR Methods: Onshore and Offshore

The challenges of submerged landscape research have some similarity to those encountered in detecting terrestrial archaeological sites that are similarly obscured, such as those buried beneath a sea of vegetation or vast forest canopies. Advancement in LiDAR technology has revolutionized the study of otherwise highly obscured contexts given its ability to penetrate through gaps in vegetation to record three-dimensional (3D) profiles of the landscape hidden below (e.g. Bewley, Crutchley, and Shell 2005; Chase et al. 2012). Most LiDAR for terrestrial purposes is recorded in wavelengths within the near-infrared spectrum (1064–1550 nm). These wavelengths are ideal for penetrating most types of canopy but not so for water columns, which scatter and attenuate visible light quite differently, and much more effectively, than air.

Thus, for bathymetric purposes, a different frequency range is necessary for successful LiDAR survey. Recent advancements have resulted in the creation of green or bathymetric LiDAR that can penetrate the water column by using smaller wavelengths. Originally, bathymetric LiDAR was hampered by its limited return point density and spatial resolution (Doneus et al. 2015), but over the past decade, the quality of these instruments has improved, allowing for a variety of archaeological applications (Character et al. 2021; Cook Hale, Davis, and Sanger 2023; Davis, Buffa, and Wrobleski 2020; Doneus et al. 2013, 2015; Lobb 2016; Tian-Yuan Shih, Chen, and Chen 2014). Bathymetric LiDAR data are increasingly used in tandem with other remote sensing methods, like sidescan sonar, to record archaeological information at submerged sites and have proven a useful survey tool (e.g. Guyot et al. 2019; Veth et al. 2020; Wiseman et al. 2021). Bathymetric LiDAR has also been used as a primary method of documenting submerged terrestrial human habitation sites (e.g. Benjamin et al. 2020; Cook Hale, Davis, and Sanger 2023; Doneus et al. 2013, 2020; Wiseman et al. 2021), although most applications have focused on shipwreck sites.

As bathymetric LiDAR is deployed more frequently and across greater areas, underwater archaeologists are increasingly faced with a similar challenge as their peers working in terrestrial environments—the resultant datasets are often massive, complex and diverse, making them difficult to analyse. Archaeologists working in terrestrial environments have addressed this challenge by utilizing computer learning and pattern recognition in order to create semi- and fully automated image analysis methods (e.g. Cerrillo-Cuenca and Bueno-Ramírez 2019; Davis et al. 2021; Freeland et al. 2016; Quintus et al. 2023; Rom et al. 2020; Trier, Reksten, and Løseth 2021; Verschoof-van der Vaart and Lambers 2019). Underwater archaeologists are only now beginning to develop similar tools, which have, again, largely been used to detect shipwrecks (e.g. Character et al. 2021; Davis, Buffa, and Wrobleski 2020).

### 1.2 | Geology, Geomorphology and Environmental Conditions in Apalachee Bay

Apalachee Bay is a low-gradient, low-to-no energy, sediment-starved marine basin. The low gradient (< 1 m in depth change

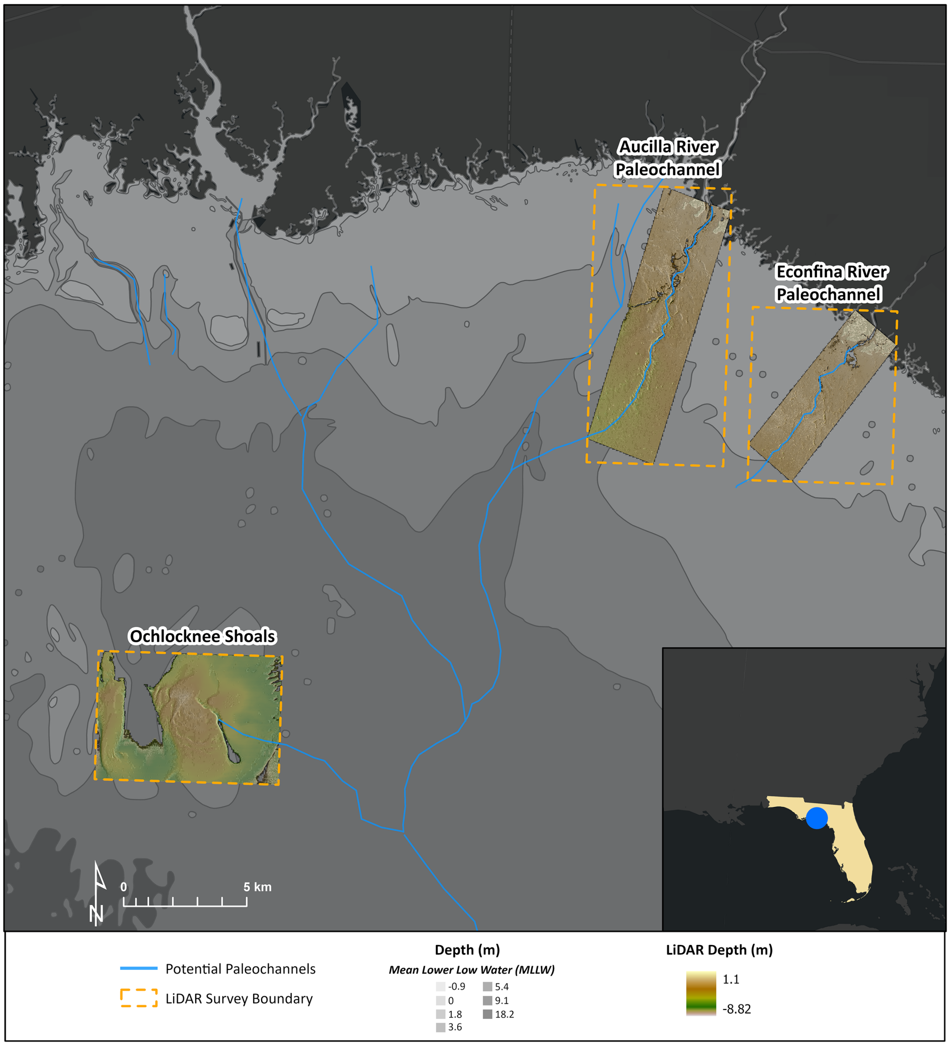


**FIGURE 1** | Map of the LiDAR survey boundaries and study areas. The Aucilla River palaeochannel is top-centre, the Econfina palaeochannel is top-right, and Ochlocknee Shoals is bottom left. *Source:* Cook Hale, Davis, and Sanger (2023).

over 1 km) inhibits wave action, and tidal range is less than 1 m as well. The sediment cover is often less than 1 m, with carbonate bedrock outcrops scattered across the seafloor, including along the edges of palaeochannels (Faught 1988). Sediment inputs into the bay are low to none from the St Marks/Wakulla, Aucilla and Econfina rivers because these rivers are sourced to the coastal plain region only; further, only the Aucilla River is sourced to the Cody Escarpment to the north, where there is a thicker cover of terrestrial sediments (primarily late Pleistocene clays, sands and gravels) (Upchurch 2007). The St Marks/Wakulla and Econfina rivers rise from the Woodville coastal karst plain, which has minimal relief and sediment cover of only a few metres. Sediments from the Appalachicola River to the west are currently infilling Appalachicola Bay instead of Apalachee Bay (Stone, Stone, and Stapor 1996). This leaves very little sediment available for transport (Hine et al. 1988).

Visibility in the Bay is thus variable. Major storms can reduce it to nearly 0 m due to turbidity effects on fine particulates in the water column. Reduced precipitation has the opposite effect, minimizing the already small fluvial sediment, and visibility can reach 5–6 m. This variation has implications for archaeological survey, including remote sensing. Diver survey obviously is more difficult in reduced visibility. Methods that rely on the visible and near-visible parts of the electromagnetic spectrum have reduced capacity in poor water visibility; this includes aerial and satellite-borne remote sensing systems, which operate most effectively during calm, clear conditions (see Guyot et al. 2019). Likewise, LiDAR also has reduced utility in water conditions with high turbidity but has been successfully deployed in a range of other oceanographic conditions. Acoustic marine geophysical methods have been and continue to be successfully deployed across the bay because they are not affected by water visibility, but they become difficult to carry out in depths of less than 2 m (e.g. Guyot et al. 2019). They are often time-intensive efforts, as well, and currently, marine geophysical datasets have primarily focused on the palaeochannel of the Aucilla River, with minimal data for other areas of the bay. Furthermore, these surveys have been restricted to sidescan sonar and marine seismic methods. Thus, they do not include multibeam echo sounder imagery, which offers much higher resolution of the seabed than side scan (Faught 1988, 2004a, 2004b; Faught and Donoghue 1997).

## 1.3 | Coastal and Underwater Archaeology of Apalachee Bay

Underwater archaeological investigations in Florida have documented evidence of submerged terminal Pleistocene and early Holocene sites since the 1950s (Royal and Clark 1960; Faught 2004a). Offshore investigations have centred on Apalachee Bay, where the peninsula meets the panhandle along the northeastern Gulf of Mexico. The majority of archaeological work in the bay during the 1990s focused on detecting evidence for the earliest known occupations in the region, during which time sea levels were lower than their present levels; subsequent sea level rise has left these sites drowned on the continental shelf (Blackwelder, Pilkey, and Howard 1979; DePratter and Howard 1981; Faught 2004b; Faught and Donoghue 1997). More recent work has highlighted studies of drowned, formerly coastal sites (Cook Hale et al. 2022; Cook Hale, Hale, and Garrison 2019).

The region appears to have been densely occupied compared to the rest of the lower southeastern United States, even during periods of much lower sea levels (Anderson et al. 2019; Anderson and Faught 1998), probably due to its favourable karstic carbonate geohydrology and comparatively warmer climate (Dunbar 2016; Russell et al. 2009; Watts, Hansen, and Grimm 1992). Two critical resources valued by early inhabitants commonly co-occur within the region: water and cryptocrystalline chert (termed flint in other regions). People appear to have settled in close proximity to freshwater sources, which during the terminal Pleistocene and early Holocene were restricted to karstic doline (sinkhole) features that dotted the landscape and attracted a variety of animal species (Duggins 2012; Faught and Donoghue 1997; Thulman 2009). The carbonate bedrock exposed in such karst landforms also contains abundant nodules of high-quality chert suitable for manufacturing sophisticated stone tools (Austin et al. 2014; Upchurch, Strom, and Nuckels 1982). These palaeochannels and karst features, such as dolines, are still visible in bathymetric datasets in Apalachee Bay today (Cook Hale, Davis, and Sanger 2023). Archaeologists observed the association between karst landscape features and early sites during the mid-20th century and successfully extended this correlation as a predictive model into Apalachee Bay.

These observations led to the documentation of multiple offshore terminal Pleistocene and early Holocene cultural deposits around such landscape features during the 1980s and the 1990s (Anuskiewicz and Dunbar 1993; Faught and Donoghue 1997). The typical site configuration for sites from these periods included the presence of a doline feature where stratified deposits could be found with abundant rocky outcrops visible above the seabed, usually in association with a detectable palaeochannel feature (Faught and Donoghue 1997). These sites usually yielded abundant lithic debitage associated with tool manufacture, faunal materials and floral remains such as wood. These sites were interpreted as representative of inland activities instead of coastal resource use due to both their assemblages and their depths, which were shallower than 12 m; the continental shelf at and above this depth did not undergo submergence until the end of the early Holocene (Joy 2019, 2020).

Younger sites from the middle Holocene do not fit this pattern, however. An excellent example that has been examined closely without an association with sinkhole features is the Econfina Channel site. This site instead consisted of large (> 10 m), anthropogenic shell midden deposits along the margins of the Econfina River palaeochannel in around 2–4 m of water (Cook Hale, Hale, and Garrison 2019; Faught 2004a, 2004b; Faught and Donoghue 1997). Minimal faunal remains beyond shell have been recovered from this location, and the site is interpreted to represent coastal resource use as this part of the continental shelf transitioned from inland to coastal towards the end of the middle Holocene (Cook Hale, Hale, and Garrison 2019; Faught 2004a, 2004b; Faught and Donoghue 1997). Thus, it appears that now-submerged early coastal occupations in the region may depart from the typical site configuration documented by Faught and colleagues. Detection of additional sites is clearly needed before any definitive interpretations can be offered.

## 1.4 | Automated Feature Extraction in Archaeology

Semi- and fully automated feature extraction has a growing history in archaeological research (Câmara et al. 2022; Davis 2019; Fiorucci et al. 2020; Lambers and Traviglia 2016). Researchers have successfully developed methods to identify a range of archaeological feature types, including mounds and earthworks (Berganzo-Besga et al. 2021; Caspari and Crespo 2019; Cerrillo-Cuenca 2017; Davis, Sanger, and Lipo 2019; Kokalj et al. 2023; Meyer-Heß, Pfeffer, and Juergens 2022; Orengo et al. 2020; Sărăşan et al. 2020), charcoal kilns and hearths (Bonhage et al. 2021; Davis and Lundin 2021; Trier, Reksten, and Løseth 2021), roadways (Verschoof-van der Vaart and Landauer 2020), agricultural and other subsistence features (Bickler and Jones 2021; Küçükdemirci et al. 2022; Trier and Pilø 2012) and craters from wartime artillery (Magnini, Bettineschi, and De Guio 2017), among others.

The most recent surge in automated feature extraction comes from the applications of deep learning algorithms—a specific form of machine learning that uses algorithms that mimic the human brain to make decisions—to archaeological prospection efforts (see Argyrou and Agapiou 2022; Câmara et al. 2022). Although such methods show increasing promise (e.g. Caspari and Crespo 2019), they require large volumes of training examples to work effectively. Though some studies have made strides in training effective models with limited training datasets (e.g. Davis et al. 2021), these methods also require high levels of computation resources that make them difficult to implement for all researchers.

Other semi-automated algorithms, in contrast, do not always require large training datasets and generally have lower computation requirements than more advanced machine learning and deep learning approaches. OBIA offers a variety of techniques that incorporate information about object morphology and texture to detect potential archaeological features from remotely sensed data (see Davis, Lipo, and Sanger 2019; Davis, Sanger, and Lipo 2019). Although OBIA methods vary widely, one particular form of object-based detection that relies on changes in elevation has shown to be particularly useful for archaeological purposes (e.g. Cody and Anderson 2021; Davis, Lipo, and Sanger 2019; Davis and Lundin 2021; Freeland et al. 2016; Rom et al. 2020). Hydrological algorithms are used in this process to identify changes in topographic concavity or convexity (i.e. rises and sinks). Then, using a series of thresholds (e.g. area, shape), these topographic anomalies can be assigned classes corresponding to archaeological or non-archaeological contexts. In the Pacific, Freeland et al. (2016) developed the *imound* algorithm, which co-opted pre-existing hydrological algorithms to identify mound architecture throughout the island of Tonga. In more recent follow-up research, Rom et al. (2020) use the *imound* method to develop a robust record of archaeological settlements in Lebanon. In North America, Davis (2019) developed a similar procedure using extant hydrological sinkhole algorithms to identify mound architecture and shell rings along coastal South Carolina.

All of the aforementioned studies are applied in solely terrestrial contexts. More recently, there have been some attempts to apply automated feature extraction to underwater archaeological environments. For example, Davis, Buffa, and Wrobleski (2020) use similar forms of hydrological depression algorithms to identify shipwreck sites in bathymetric datasets along the coastline of the United States. Their method resulted in a detection rate of over 70% and required no training datasets. Another example of automated feature extraction in underwater archaeology is a deep learning method developed by Character et al. (2021) to identify shipwreck sites in bathymetric LiDAR and sonar datasets. Their method required a training sample of over 400 shipwrecks, resulting in over 90% accuracy. Here, we follow a similar approach to Davis, Buffa, and Wrobleski (2020), as training data are more limited for our study region, making a deep learning model untenable for identifying underwater archaeological sites in this area. This is a common problem for underwater archaeological research as our knowledge of submerged sites is often confined to specific target areas, given the difficulty and expense of conducting underwater surveys and excavations.

This study examines a method by which semi-automated analysis of bathymetric LiDAR datasets can be used to study human occupations of prior shorelines and coastal regions. We posit that the identification and analysis of these submerged, formerly terrestrial sites has the potential to inform several critical questions, including those concerning human reactions to changing climates and coastline positions since the last glacial maximum (LGM) and into the middle Holocene. It will also further assist in the assessment of submerged site formation processes by offering offshore examples for additional analysis and comparison with onshore analogues. Depending on marine conditions (depths above or below wave base or storm wave base, sedimentation rates, tectonic effects, etc.), such sites may or may not be stable—a topic of current debate (Benjamin et al. 2022; Cook Hale et al. 2022; Ward et al. 2022).

Regardless of the outcome of the above debates, such efforts are essential for maximizing our ability to examine the entire cultural landscape, from earliest occupations to the final submergence of the middle Holocene coastal zone. This specific method will be evaluated for its efficacy in detecting archaeological deposits with a low degree of false negatives (Type II errors). It will also be compared against predictive models for the region that assume high archaeological potentials along the margins of palaeochannels. Finally, to mitigate against small sample sizes (a perennial problem in submerged landscape prospection), it will be tested against a random point distribution overlain across the study areas.

## 2 | Materials and Methods

### 2.1 | Bathymetric LiDAR Survey

Bathymetric LiDAR surveys of the Apalachee Bay were commissioned by the Aucilla Research Institute between 2016 and 2022. The areas included in these surveys consist of three zones of archaeological interest: the Aucilla River palaeochannel, the Econfina River palaeochannel (where prior archaeological sites have been documented) and Ochlocknee Shoals, which is poorly understood but is located near several palaeochannel systems with high probability of archaeological deposits (Figure 1). The specifications of these datasets are presented in Table 1.

To parse through the bathymetric LiDAR data systematically, a form of OBIA known as IDA was employed (Figure 2) (Davis, Buffa, and Wrobleski 2020; Davis, Lipo, and Sanger 2019). Depression algorithms, of which there are many, have been utilized for a wide range of purposes by hydrographers, geographers and archaeologists. This study specifically uses a hydrological depression algorithm originally designed for detecting sinkholes that operates using a contour-tree procedure (Wu et al. 2015; Wu and Lane 2016). The contour-tree procedure works by searching for low elevation values and then seeking out subsequently higher values surrounding that location to identify topographic depressions (Wu et al. 2015). This method has been adopted for archaeological research, including underwater archaeology (e.g. Davis, Buffa, and Wrobleski 2020). The Wu et al. (2015) algorithm is available as an ArcGIS toolbox

**TABLE 1** | Data specifications for bathymetric LiDAR used in this study.

| Study area | Area covered | Minimum point density | Root mean square error | Non-vegetated vertical accuracy | DEM resolution[a] |
|---|---|---|---|---|---|
| Aucilla River palaeochannel | 15.80 km$^2$ | 2 points/m$^2$ | 10 cm | 19.6 cm | 0.76 m (2.5 ft) |
| Econfina palaeochannel | 30.82 km$^2$ | 2 points/m$^2$ | 10 cm | 19.6 cm | 0.76 m (2.5 ft) |
| Ochlockonee Shoals | 38.66 km$^2$ | 6 points/m$^2$ | 10 cm | 19.6 | 0.91 m (3 ft) |

[a]All LiDAR data were collected using imperial measurements (ft), and all analyses thus were originally conducted using imperial units. As such, we report both the imperial and metric equivalents here.

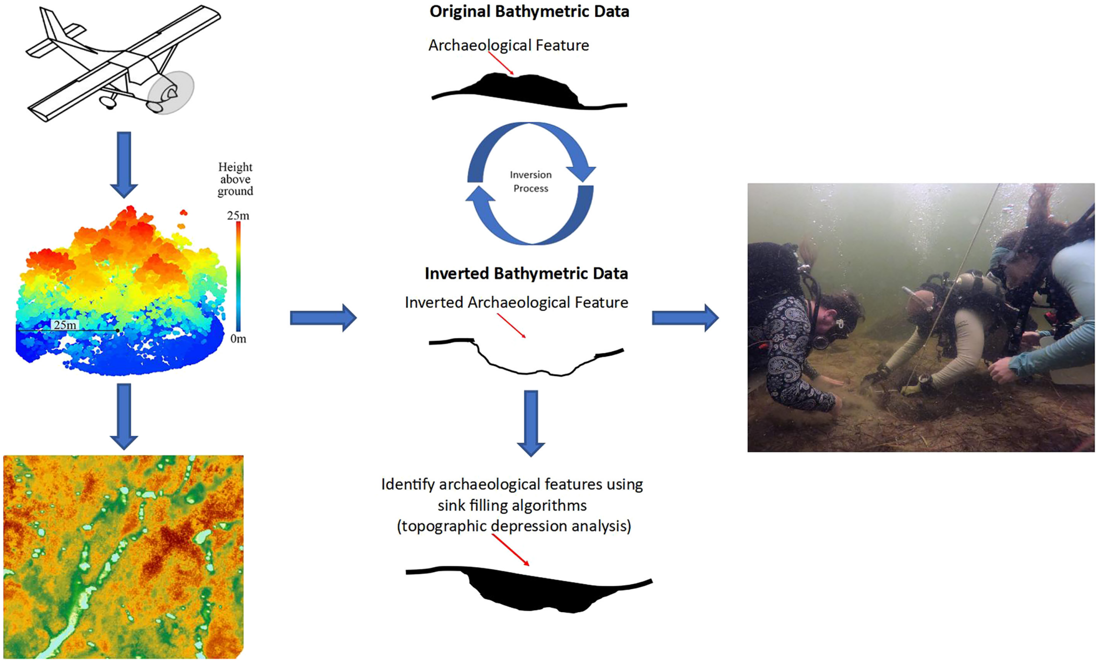


**FIGURE 2** | Illustration of methods workflow. Bathymetric LiDAR was collected from a Cessna aircraft. The point data were then interpolated into a digital surface model (DSM). Next, we inverted the derived DSM to allow established topographic depression (or sink filling) algorithms to identify anthropogenic mound/midden anomalies present in the data. These detections were manually evaluated, and select sites were chosen for ground verification via SCUBA survey. Photo credit: Trevor Johnson.

(Depression Analysis Toolbox), all analytical procedures were carried out in ArcGIS 10.8.1 (ESRI 2020). This same toolbox can also be run in ArcGIS Pro.

To identify elevated topographic anomalies that may be associated with anthropogenic activities (e.g. mounds and middens), this study modifies the Wu et al. (2015) method by creating an 'inverse DEM', wherein elevation values are inverted to allow for mounded features to be recognized by the depression detection algorithm. The formula to create an inverse DEM (or $\mathrm{DEM}^{-1}$) is as follows:

$$\mathrm{DEM}^{-1} = \left(\left(r - Z_{max}\right) \times (-1)\right) + Z_{min}$$

where $\mathrm{DEM}^{-1}$ = the inverse DEM, r = the original DEM, $Z_{max}$ = the maximum DEM value and $Z_{min}$ = the minimum DEM value.

Next, the Extract Sink tool was used next [parameters: depression minimum size (i.e. the minimum area for identified features) 300 ft$^2$; buffer distance (i.e. the minimum distance between identified features) = 5 ft] to isolate areas representing potential mound and midden features within the study region. The Identify Depression Hierarchy tool followed the Extract Sink tool [parameters: contour interval = 1 ft; base contour = 0 (default); minimum area = 100 ft$^2$; minimum depth = 1 ft] to map specific boundaries of suspected archaeological mound/midden deposits. These parameters were derived by examining the sizes of other known terrestrial archaeological mounds in the southeastern United States (Crusoe and DePratter 1976; Gibson 1994; Saunders 2017). We explicitly limited our parameters to target larger features that can be reliably identified within the available LiDAR data. With higher or lower quality LiDAR, the size of identifiable features changes, and so these parameters must be adopted to the specifics of the available data and environmental context of the study area. Finally, all results of the Identify Depression Hierarchy tool that were located above sea level in the original DEM (> 0 ft.) were removed, and the remaining results were evaluated manually on the basis of morphometry, environmental context, size and 3D profile to extract possible anthropogenic features. Specifically, circular and oblong features with 3D profiles showing elevations of at least 1.64 ft (0.5 m) tall and 100 ft (30 m) long were targeted because these are commonly characteristic of terrestrial mounds and midden sites in the southeastern United States. Finally, these features, which were originally delineated in polyline contours, were localized to their centroid locations for ease of assessment during targeted diver surveys.

## 2.2 | Model Testing

To assess the model's accuracy, results were assessed against known archaeological deposits in Apalachee Bay ($n$ = 17). Where available, high-resolution locational data on individual deposits, such as shell midden lithic quarry zones, were compared to results. In other cases, the only data from older site records were geospatial coordinates for the site centroid derived from Florida Master Site File records, and these were used when they were the only site data available. Site centroids do not represent specific deposits, only a datum point established during archaeological survey. Site centroids were compared against the contoured polylines of potential anthropogenic features identified during IDA. It is important to note that the centroids for the polyline contoured, potentially anthropogenic features identified during IDA were derived during out analysis, and site centroids from the Florida Master Site Files records were derived using the Florida Master Site File records themselves; thus these centroid locations were developed prior to, and very separately from, our analyses.

### 2.2.1 | Diver Survey

Diver survey using SCUBA was conducted at 16 locations. Eleven locations were centroids derived from polyline contours identified by IDA and were tested for false positives. Five locations that were consistent with previous predictive models (proximity to possible palaeochannels/possible spring locations) used in the region were tested at Ochlocknee Shoals to test for false negatives. Because of the challenges associated with underwater surveys, not all anomalies could be visited.

Diver surveys were carried out during three field campaigns during the summer of 2022 (see Cook Hale, Davis, and Sanger 2023) and one field campaign during the summer of 2023. At each survey site, divers conducted circular survey searches (Bowens and NAS 2009; Wilkes 1971) within 50 m of the identified centroid locations to search for artefacts that may be associated with the topographic anomaly. Water depth, sediment type, geologic conditions, the presence or absence of rock outcrops, vegetation (e.g. eelgrass), palaeochannels and archaeological materials were all recorded during surveys by dive computer, photography and field notes where possible. The discovery of cultural artefacts within this vicinity were marked as true positives, due to the potential for site disturbances. Sediment, archaeological material and geologic material were collected as samples during diving surveys. Photography and videography were carried out in the Econfina and Aucilla River palaeochannels, but reduced visibility at Ochlocknee Shoals did not permit for this kind of documentation in 2022; photography and videography were both successfully recorded during 2023 along the Aucilla palaeochannel.

### 2.2.2 | Correlation Analysis

Correlation analysis was carried out using ArcMap 10.8.1 (ESRI 2020). To augment diver survey results, 17 previously recorded archaeological sites were selected across the entire extent of the study areas and assessed for correlation to anomalies identified by IDA. IDA anomalies—in the form of the polyline contours identified in analysis—individual archaeological deposit locations, results from diver survey at IDA anomaly targets and site centroids were plotted and spatially assessed to see how well these features correlate to one another.

For correlation analysis, all locations were tabulated according to their proximity to IDA anomalies, previously recorded sites and previously recorded individual archaeological deposits. Locations that correlated to both IDA anomalies and archaeological deposits, whether previously documented or newly detected, were labelled true positives (TP). Where locations correlated to IDA anomalies but not archaeological materials, they were labelled false positives (FP) as a shorthand for Type I errors. IDA anomalies were labelled as true positives when the following conditions were met: Diver survey detected archaeological materials within 50 m of the anomaly centroid; when an individual archaeological deposit recorded in past surveys lay within 50 m of the anomaly polyline contours; or when a site centroid recorded in past surveys lay within 100 m of the anomaly polyline contours.

The wider search radius for site centroids and random points was used because site centroids do not represent specific deposits, only a datum point established during archaeological survey. Further, many of these earlier surveys were carried out during the late 1980s and the 1990s when LORAN-C coordinates were used because GPS technology was not yet available; this leads to potentially less accurate and precise locational data. Data for the individual archaeological deposits collected in previous surveys were acquired no earlier than 2014, however (Cook Hale, Hale, and Garrison 2019), and GPS coordinates are much better resolved. However, such deposits are potentially vulnerable to disturbance during marine transgression and may not lie exactly within an IDA anomaly boundary defined by polyline contours. Nevertheless, such materials are unlikely to be further than 50 m from their source, based on studies of archaeological site disturbances caused by marine forces in this region (Cook Hale et al. 2022; Marks 2006). Furthermore, an archaeological deposit must be further than 100 m away from another deposit to be classified as an individual archaeological site or find spot by the Florida State Master Site Files at the Florida Bureau of Archaeological Research.

To improve correlation analysis, it was also necessary to test for Type II errors, termed false negatives (FN), against true negatives (TN), where neither archaeological materials were detected or an IDA anomaly was present. Type II errors were identified where a documented site centroids or documented archaeological deposits did not correlate to an IDA anomaly using the same search radii (50 m for archaeological materials/deposits, 100 m for site centroids).

To improve the small sample size, a shapefile of randomly distributed points was generated in ArcMap within the boundaries of the bathymetric LiDAR footprints at a density of 0.24/km$^2$. This density was chosen by using the site density distribution within the bathymetric LiDAR footprint for the Aucilla. Site distribution varies within the LiDAR study areas; the Aucilla study area is the best surveyed of the three, the Econfina palaeochannel has only been intensively studied since 2014, and the 2022 field surveys at Ochlocknee Shoals were the first archaeological assessments for which records existed (though it may be the case that it was examined to some degree in during the 1980s and the 1990s by Faught, Dunbar and colleagues, no records could be found during this study demonstrating specific attention to the area). Therefore, the site density for the Aucilla palaeochannel may be more representative of archaeological distributions in Apalachee Bay. This resulted in the generation of 35 randomly distributed point locations within the boundaries of each of the LiDAR footprints for a total of 105 random points. These random points were then assessed for proximity to IDA anomalies and known sites within the bathymetric LiDAR footprints.

Although the nature of 'true' and 'false' positive and negative identifications is difficult to gauge with certainty given the limits of diving surveys, we adopt the following criteria for evaluating the results of our methods. We consider any locations that were both predicted to be archaeological by IDA and that yielded archaeological materials during diving surveys or previous investigations as a true positive. We consider any location predicted to be archaeological where archaeological materials were not recovered as a Type I error (false positive). A location predicted to be non-archaeological at which archaeological materials were recovered is labelled a Type II error (false negative). A location predicted to be non-archaeological at which archaeological materials were not recovered is labelled a true negative. In future investigations, 'true negatives' could yield archaeological data, but given our current understanding of these areas and capacity to investigate them, we have no current evidence to suggest anthropogenic origins.

Once the random point file was added to the database, we tested a total of 139 locations. This improved the sample size, but it is acknowledged that this is still small and represents a limitation in this study; it should be noted that the number of known submerged terminal Pleistocene to middle Holocene sites in the region and indeed, globally, is also small. The sample size problem cannot be addressed without detecting additional sites, which is one of the goals of this study.

## 3 | Results

### 3.1 | Diver Survey

IDA analysis revealed 30 centroids correlating to the contoured anomalies along the Econfina, 31 centroids along the Aucilla and 15 centroids in Ochlocknee suitable for diver surveys to ground test for archaeological materials (Figure 3). Due to limitations on time and weather conditions, not every target could be tested via diver survey. A total of 16 targets were tested. One target was visited along the Econfina palaeochannel (2022), five targets were visited along the Aucilla palaeochannel (2023), and 10 targets were visited at Ochlocknee Shoals (2022) (Table 2).

One target along the Econfina palaeochannel (Newton McGann, pending site number assignment) was positive for archaeological materials. Like the Econfina Channel site, this site consists of a shell midden situated along the margin of the Econfina palaeochannel (Cook Hale, Davis, and Sanger 2023). The deposits are approximately 1 km north of the Econfina Channel Site (site ID 8TA139). Midden materials were observed to be primarily interdigitated within rocky outcrops at the site as well as within the eelgrass beds. The Newton McGann site presented evidence of marine/estuarine subsistence and cooking activities in the form of burnt, disarticulated *Crassostrea virginica* (oyster) shells and one burned *Clypeaster rosaceus* (sea biscuit, likely representing by-catch).

Five additional targets along the Aucilla were tested in 2023, and three were positive for archaeological materials. The three locales all yielded lithic debitage; the first (Target 1; see Table S1) contained the remains of a small oyster shell midden below the sandsheet as well as a chopper tool and possibly a hammerstone; shell materials are consistent with coastal subsistence patterns, whereas the lithic items could have been used anywhere along

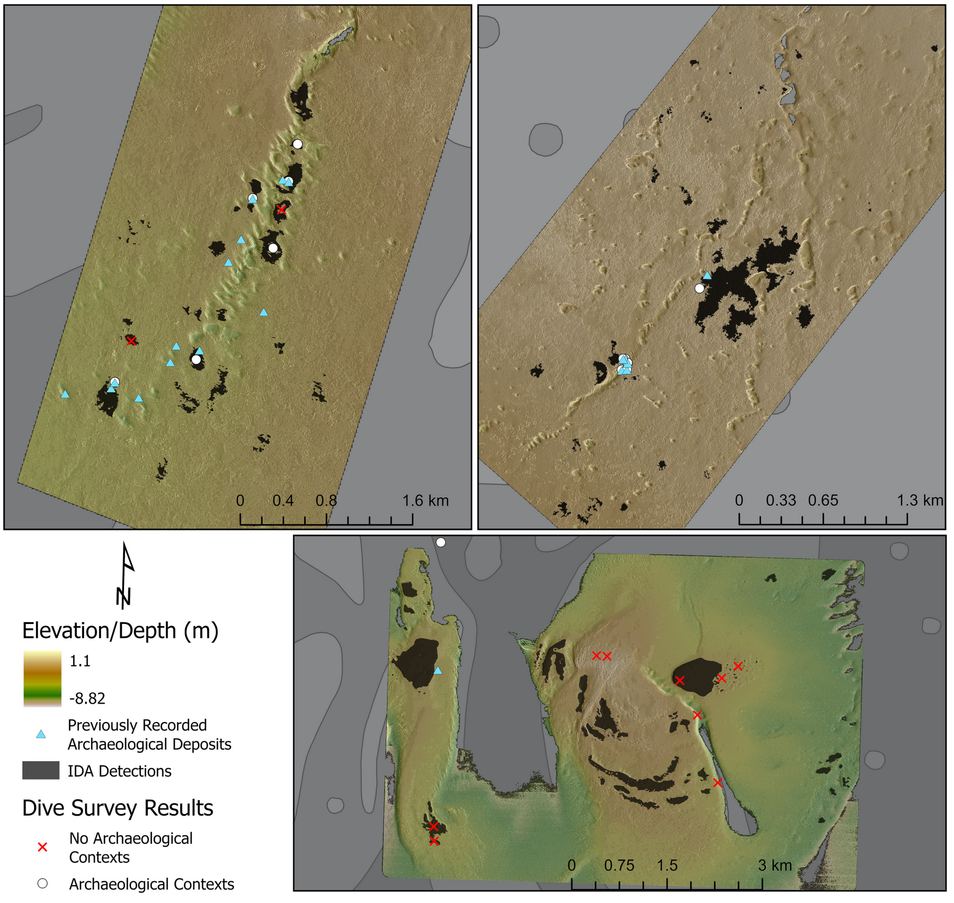


**FIGURE 3** | Results of IDA analysis and diving surveys.

**TABLE 2** | Summary of diver survey results.

| Study area | Total points tested | Predicted by IDA | Archaeological | Non-archaeological |
|---|---|---|---|---|
| Aucilla River palaeochannel | 53 | 16 | 17 | 36 |
| Econfina River palaeochannel | 41 | 12 | 6 | 35 |
| Ochlocknee Shoals | 45 | 10 | 1 | 43 |

*Note:* For additional information, see Table S1.


**FIGURE 4** | Items recovered from along the Aucilla palaeochannel during the 2023 field campaign. (A) Wood, likely bald cypress (*Taxodium distichum*) from Target 4; (B) fragmented secondary or tertiary lithic debitage from Target 4; (C) a potential chopper tool from Target 1; (D–F) primary lithic debitage with abundant cortex material recovered from Target 3. Photo credits: Jessica Cook Hale, Nathan Hale and Trevor Johnston.

the landscape (Figure 4). The second (Target 3) contained large debitage material consistent with primary reduction sequences such as those that might be carried out at a quarry site. The third (Target 4) contained smaller, secondary or tertiary reduction debitage consistent with tool finishing and/or resharpening, which may be carried out at multiple site types.

Ten locations were surveyed along Ochlocknee Shoals. Five corresponded with IDA identifications. No archaeological materials were recovered at any of these locations. We also tested five additional locations that IDA did not predict as archaeological. Archaeological materials were absent at four of these locations, but a single lithic item that is potentially an artefact was found at one of them. This target was located in the northwesternmost point in the Ochlocknee study area, at the location that was outside of full LiDAR coverage and within 100 m of a bathymetric low that may represent a palaeochannel feature (Figure 3; Cook Hale, Davis, and Sanger 2023).

### 3.2 | Correlation Analysis

Five discrete archaeological deposits in the region of the Econfina Channel site (8TA139) were correlated to within 100 m of anomalies identified by IDA. Three of these were composed of midden deposits, and two were composed of quarry zones where stone tool manufacturing was carried out next to rock outcroppings. Twelve previously recorded sites located inside of the LiDAR boundary along the Aucilla were also re-identified. Finally, the random point shapefile ($n = 105$) was tested for correlation to IDA anomalies and known archaeological site centroids across the study areas (Table S1 and Figure 5).

We calculated several different performance metrics to assess how well random distributions correlated to DA anomalies in comparison to study results (Table 3). Overall, accuracy was calculated at over 80% with low rates of false positives and negatives. However, precision, recall and F1 metrics indicate some issues with misclassification.

## 4 | Discussion

### 4.1 | Correlation Analysis

Results have several implications for detection and examination of archaeological deposits within submerged landscapes. The method was more effective in sediment starved locations like Econfina and Aucilla but has difficulties in isolating anthropogenic features in regions of high sedimentation like Ochlocknee (Table 2; also see Cook Hale, Davis, and Sanger 2023) where the only potential human-modified item was recovered in a context more consistent with older regional predictive models. In the sediment-starved eastern portion of the bay, however, IDA successfully re-identified all previously recorded archaeological sites and/or deposits in the Econfina palaeochannel and 11 out of the 16 previously recorded sites along the Aucilla. Additionally, IDA detected one new archaeological midden deposit along the Econfina and three new sites along the Aucilla.

Results indicate that the method does return false positives (Type I errors) but does not have the same potential for false negatives (Type II errors). This suggests that the method is less likely to identify a target as non-archaeological when it is, in fact, archaeological. This is critical because the geology of sea floors in this area could increase the prevalence of Type I errors, and yet IDA yields low Type I error rates. Geologic features (like rocky outcrops) are known to have trapped lag deposits within which archaeological

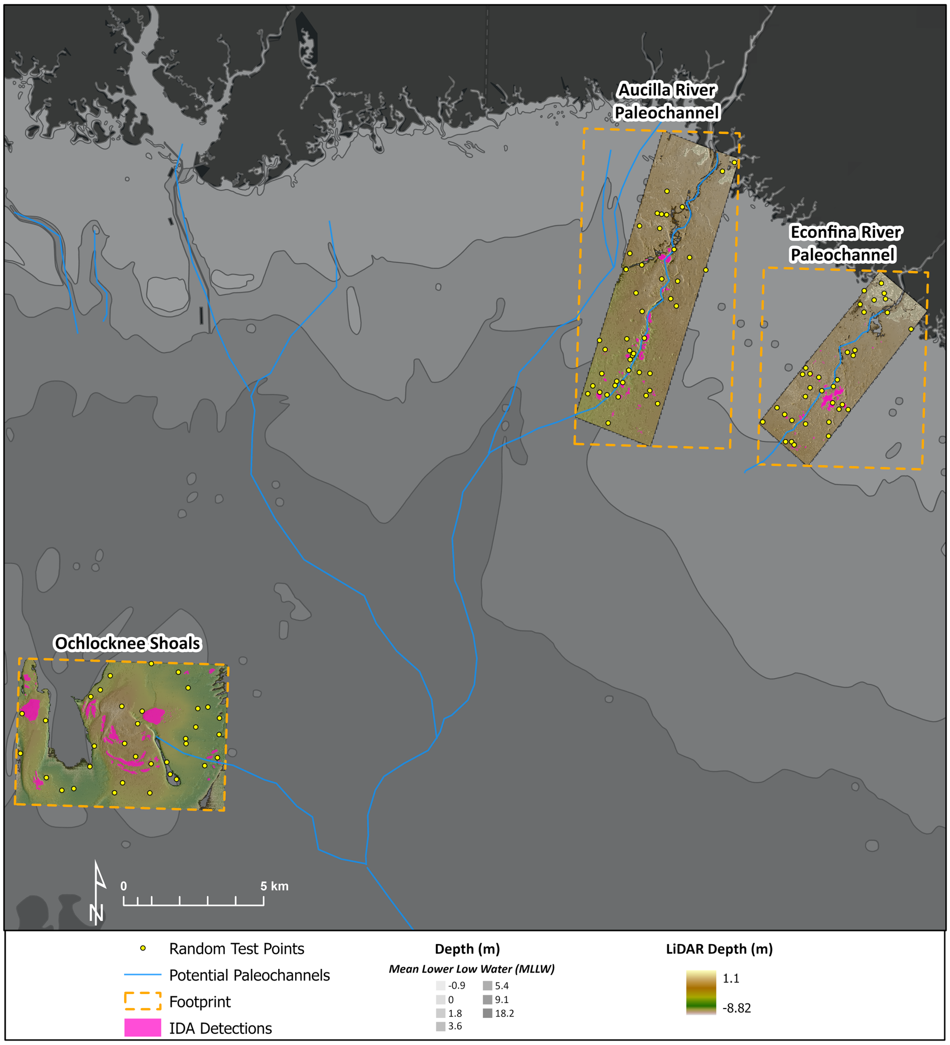


**FIGURE 5** | Locations of random test points used in correlation analysis.

**TABLE 3** | Confusion matrix and accuracy assessment of the IDA.

| | | Actual | |
|---|---|---|---|
| Predicted | | Archaeological | Not archaeological |
| | Archaeological | 16 | 24 |
| | Not archaeological | 8 | 91 |
| | | Accuracy | 0.77 |
| | | Misclassification | 0.23 |
| | | Precision | 0.40 |
| | | Recall | 0.67 |
| | | F1 | 0.50 |
| | | Type I error (false positives) | 0.12 |
| | | Type II error (false negatives) | 0.06 |

materials can be found and can act as barriers to erosion that preserved cultural deposits. Although such geologic features strongly correlate to documented archaeological features, the low prevalence of Type I errors suggest that IDA detections do not necessarily correlate with rocky outcrops. Additional study is warranted, however. Without a full diver survey across the entire study region, we cannot say with certainty that areas without detected archaeological materials are non-archaeological; this will require further model refinement and repeated follow-up surveys and excavations. Despite these statistical and logistical challenges, future applications of IDA to non-bedrock or hydrographic features will be useful for assessing the current conflation between archaeological deposits and seabed geomorphology.

### 4.2 | Significance for Studying Submerged Cultural Landscapes

The submerged continental shelf of the southeastern United States is important for exploring multiple critical archaeological questions with global implications. Key data associated with human adaptations to climate change, sea level rise and human use of coastline zones lie drowned on the continental shelves across the world (Bailey et al. 2007; Bailey and Flemming 2008; Benjamin and Bailey 2017; Fitch 2022; Walker et al. 2022). In the Americas, large portions of these shelves likely hold evidence concerning the evolution of human settlement patterns and articulation with changing ecologies in North America from the earliest occupations until the establishment of current climate and coastline conditions. The continental shelf of the southeastern United States represents a particularly significant proportion of land lost between the LGM and the late Holocene; Florida lost at least 40% of its total landmass (Joy 2019). However, there are relatively few demonstrated submerged sites to examine in comparison to this extent of lost coastal plain, making it difficult to assess human reactions to climate change and marine transgression; simply put, it is impossible to grasp the nature and degree of this data gap without detecting and examining more such submerged sites.

There are multiple hypotheses regarding the lives and cultures of the earliest inhabitants of North America. Some argue that these communities were highly mobile and focused on hunting activities as a primary mode of subsistence (Bense 2016; Haas et al. 2020; Moore et al. 2016). Other studies demonstrate that this was not ubiquitous (Anderson 1995; Jones 2018), including in the southeastern United States, where sites like Carson-Conn-Short (40BN190) in the Tennessee River Valley yielded evidence suggesting that sedentism and intensifying land use practices developed as early as the terminal Pleistocene (Anderson 1995; Jones 2018). However, most recorded terminal Pleistocene sites in the southeastern United States lie inland and above sea level. Coastal sites dating to this period that might offer insight into this question are rare in the southeastern United States (Anderson et al. 2019; Anderson and Faught 1998).

The contrast between inland and coastal sites is critical to evaluating variation in cultural adaptations before the late Holocene both in the Americas and across the globe because coastal zones are one ecological niche where early sedentism and intensified land use absent adoption of agriculture has been observed at a global scale (Boethius 2017; Erlandson et al. 2020; Thomas 2008, 2014). Coastal sites in the southeastern United States became increasingly archaeologically visible after the onset of the middle Holocene and experienced an impressive fluorescence by the onset of late Holocene conditions (Anderson et al. 2017). This trend may result from site preservation and survey bias (O'Donoughue 2007) but may also relate to warming climatic conditions, which improved the productivity of riverine and coastal fisheries (Cook Hale and Sanger 2020). These improved climatic conditions coincide with a cultural shift towards increased population sizes and sedentism, particularly in large complexes with mound architecture situated in river valleys (Anderson, Russo, and Sassaman 2007; Milner 2021). The exact nature of the cultural transition between highly mobile communities during the terminal Pleistocene and the shift towards sedentism in the early to middle Holocene in this region is not fully understood, partly due to this specific data gap. However, it is likely that key evidence for these cultural variations lies offshore (Cook Hale, Hale, and Garrison 2019; Stright 1986).

The analysis of bathymetric LiDAR and computer-assisted analytical methods therefore offer significant advances to southeastern archaeology of the United States. Dense coastal occupations with evidence for accelerating cultural developments such as sedentism, intensive use of estuarine and other coastal resources and incipient examples of monumental architectural and/or terraforming are widespread in this region after the onset of the middle Holocene (Anderson, Russo, and Sassaman 2007; Russo 1994, 1996; Saunders and Russo 2011; Thompson and Worth 2011). Some of the earliest coastal settlements in Florida appeared nearly 7000 years ago, though most post-date 5000 years ago (Russo 1994). However, regional sea level curves suggest that many now-submerged, formerly coastal sites exist (Anderson, Russo, and Sassaman 2007; Joy 2019; Jackson et al. 2023).

Apalachee Bay has already demonstrated significant cultural deposits from the terminal Pleistocene to the middle Holocene, and these submerged archaeological sites clearly show a shift from inland occupations around karst landscape features during the terminal Pleistocene to coastally adapted middle Holocene occupations characterized by shell midden deposits next to river channels in estuarine marsh settings (Cook Hale, Hale, and Garrison 2019; Cook Hale et al. 2021; Faught and Donoghue 1997; Faught 2004a, 2004b). Even more importantly, archaeological deposits can survive with reasonable horizontal integrity in at least some cases, including low-energy conditions such as those found in Apalachee Bay, making spatial interpretations within such deposits more sound (Benjamin et al. 2022; Cook Hale et al. 2022; cf. Ward et al. 2022).

As such, the presence of large (now submerged) sites including those with evidence for coastal resource use such as shell middens is needed to better grasp the deep history of coastal human presence and adaptation to fluctuations in climatic and environmental conditions, including sea level changes. Although much is known about human coastal occupation after the middle Holocene, inundated sites that date to earlier (> 7000 BP) (DePratter and Howard 1981) have the potential to shed badly needed light on the changes in subsistence, settlement and socio-political organizational patterns of communities living during and before the middle Holocene. This is especially important as these communities would have had to cope with notable changes to their environments along with rising sea levels and shifting climatic conditions (Anderson, Russo, and Sassaman 2007; Cook Hale and Garrison 2019; Cook Hale and Sanger 2020).

The use of methods like deep learning and machine learning has proven highly successful in many case studies (e.g. Berganzo-Besga et al. 2021; Caspari and Crespo 2019; Verschoof-van der Vaart and Lambers 2019), including underwater contexts (Character et al. 2021), but one major limitation of such approaches is the need for large training datasets to create reliable models. Submerged, formerly terrestrial sites are scant compared to their terrestrial analogues, making it more difficult to develop training datasets. The method we present here is particularly useful because it does not initially require training data, which expands its utility for investigating less documented and poorer known sites where such training data is not available (e.g. Davis and Lundin 2021). Although sample sizes are still small, the implementation of IDA aided in the direction of SCUBA surveys and led to new archaeological discoveries. However, it will be improved by continued applications.

Additional testing both in Apalachee Bay itself and in different regions will improve sampling size. It will also be helpful to explore whether results are dependent on regional archaeological trends and/or sampling methods used. Finally, additional testing can help assess the significance of potential correlations between submerged archaeological deposits and non-anthropogenic seabed features. This, in turn, can improve the performance of this method and inform the development of future methods.

Other 3D data types such as multibeam echosounder may also be suitable for the application of such automated feature extraction techniques, and this should also be explored. Bathymetric LiDAR can be hampered by sedimentation rates that bury archaeological deposits, water depth that attenuates the laser and overall water quality (e.g. turbidity). It would be useful to test IDA using high-resolution multibeam data (resolution $<= 0.25$ m, minimum) to explore the potential for applications to remote sensing data other than LiDAR.

Although these results are preliminary and require additional testing in larger and/or different areas, they are promising for expanding our knowledge of submerged archaeological site distributions. Future studies may provide important context to the nature of submerged human occupations. In light of the modern climate crisis, evidence of human adaptations to changing environmental conditions, particularly sea levels, can be invaluable for local and global responses to similar situations now and in the future (Douglass and Cooper 2020). There has been extensive research that documents evidence of early human occupations in now-submerged landscapes, including coastal human occupations around the world. New analytical approaches that help to automate some of our evaluations of these underwater landscapes have the potential to locate an abundance of submerged archaeological sites. These sites hold important information about how past people responded to climate change and long-term records of how human activities have impacted terrestrial (and now underwater) environments. Understanding the complex interrelationships between climate and society are vital for planning sustainability and resilience strategies in the present, and our approach offers one initial step that can expedite the rate of archaeological discovery needed to make these strides. The method presented here may allow for more efficient targeting of submerged cultural landscapes for archaeological assessment, which is highly useful for a sub-field that arguably involves more significant logistical challenges than terrestrial or shipwreck archaeology (Faught 2014; Faught and Flemming 2008).

## 5 | Conclusion

Our study demonstrates the potential for airborne bathymetric LiDAR datasets and computer-assisted image analysis to aid archaeological and cultural resource management projects in environments where conditions are conducive to its success, such as shallow, low-energy, low-sedimentation marine basins. Additionally, such shallow water environments can contain rich histories of human occupation. Likewise, advances in geophysical prospection techniques have greatly expanded our ability to study these hidden records of human history. Much like terrestrial archaeology, however, making effective use of massive datasets requires additional advancements in processing methods to ensure that we use these data to the fullest. As presented here, semi-automated processing of bathymetric LiDAR can successfully identify archaeological sites at a statistically significant level with an acceptable rate of error, both known and previously unrecorded, within locations where extant midden/mound-type deposits are exposed on the seabed surface. It is evident that such image analysis methods are important for the future of underwater archaeological investigations, particularly of widespread landscape-scale analyses of submerged settlements and palaeogeomorphology.

### Acknowledgements

DSD was supported by a National Science Foundation SBE Postdoctoral Fellowship (SMA-2203789). LiDAR collection and processing as well as diver survey at Ochlocknee Shoals was funded by Florida Department of Historic Resources grant 22.h.sm.200.012. LiDAR data collection and processing along the Aucilla and Econfina palaeochannels was supported by the Aucilla Research Institute (ARI); we are particularly grateful to Dr George Cole of ARI for his generosity in sharing these datasets. Diver surveys across Apalachee Bay were supported by ARI, Matthew Newton and Emilee McGann of the University of Florida, C. Andrew Hemmings of ARI and the Georgia-Florida Aerial Search Team (G-FAST). Map layouts are courtesy of Dr Katherine Graham Jones. JWCH is support by a postdoctoral fellowship funded by the Life On The Edge UKRI Future Fellow Leadership Project held by Dr Simon Fitch. We also want to extend our thanks to Dr Fitch and Professor Chris Gaffney, as well as the anonymous reviewers, for providing comments on earlier drafts of this manuscript. The work is much improved thanks to these generous inputs, and all errors are the authors' own.

### Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

## References


Anderson, D. G. 1995. "Recent Advances in Paleoindian and Archaic Period Research in the Southeastern United States." *Archaeology of Eastern North America* 23: 145–176.

Anderson, D. G., T. G. Bissett, S. J. Yerka, et al. 2017. "Sea-Level Rise and Archaeological Site Destruction: An Example From the Southeastern United States Using DINAA (Digital Index of North American Archaeology)." *PLoS ONE* 12, no. 11: e0188142. https://doi.org/10.1371/journal.pone.0188142.

Anderson, D. G., D. Echeverry, D. S. Miller, et al. 2019. "Paleoindian Settlement in the Southeastern United States: The Role of Large Databases." In *Early Floridians: New Directions in the Search for and Interpretation of Florida's Earliest Inhabitants*, edited by D. Thulman and I. Garrison, 241–275. Gainesville, Florida, U.S.A.: University Press of Florida.

Anderson, D. G., and M. K. Faught. 1998. "The Distribution of Fluted Paleoindian Projectile Points: Update 1998." *Archaeology of Eastern North America* 26: 163–187.

Anderson, D. G., M. Russo, and K. E. Sassaman. 2007. "Mid-Holocene Cultural Dynamics in Southeastern North America." In *Climate Change and Cultural Dynamics*, edited by D. G. Anderson, K. A. Maasch, and D. H. Sandweiss, 457–489. Amsterdam, The Netherlands: Academic Press.

Anuskiewicz, R. J., and J. S. Dunbar. 1993. "Of Prehistoric Man at Ray Hole Springs: A Drowned Sinkhole Located 32 km Offshore on the Continental Shelf in 12 m Seawater." In *Diving for Science 1993: Proceedings of the American Academy of Underwater Sciences Thirteenth Annual Scientific Diving Symposium*, 1–22. Pacific Grove, California.

Argyrou, A., and A. Agapiou. 2022. "A Review of Artificial Intelligence and Remote Sensing for Archaeological Research." *Remote Sensing* 14, no. 23: 23. https://doi.org/10.3390/rs14236000.

Austin, R. J., S. B. Upchurch, J. S. Dunbar, R. W. Estabrook, J. C. Endonino, and A. Burke. 2014. "The Quarry Cluster Approach to Chert Provenance Studies, With Examples From Florida." Southeastern Archaeological Conference. Greenville, SC.

Bailey, G. N. 2014. "New Developments in Submerged Prehistoric Archaeology: An Overview." In *Prehistoric Archaeology on the Continental Shelf*, edited by A. M. Evans, J. C. Flatman, and N. C. Flemming, 291–299. USA: Springer, New York, NY.

Bailey, G. N., and N. Flemming. 2008. "Archaeology of the Continental Shelf: Marine Resources, Submerged Landscapes and Underwater Archaeology." *Quaternary Science Reviews* 27, no. 23–24: 2153–2165. https://doi.org/10.1016/j.quascirev.2008.08.012.

Bailey, G. N., N. C. Flemming, G. C. King, et al. 2007. "Coastlines, Submerged Landscapes, and Human Evolution: The Red Sea Basin and the Farasan Islands." *The Journal of Island and Coastal Archaeology* 2, no. 2: 127–160.

Bailey, G. N., J. Harff, and D. Sakellariou, eds. 2017. *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*. Vol. 20. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-53160-1.

Bailey, G. N., and N. Milner. 2002. "Coastal Hunter-Gatherers and Social Evolution: Marginal or Central?" *Before Farming* 3–4, no. 1: 1–15. https://doi.org/10.3828/bfarm.2002.3-4.1.

Bailey, G. N., and J. Parkington. 1988. *The Archaeology of Prehistoric Coastlines*. Cambridge, UK: Cambridge University Press.

Benjamin, J. 2010. "Submerged Prehistoric Landscapes and Underwater Site Discovery: Reevaluating the 'Danish Model' for International Practice." *Journal of Island and Coastal Archaeology* 5: 253–270. https://doi.org/10.1080/15564894.2010.506623.

Benjamin, J., and G. N. Bailey. 2017. "Coastal Adaptations and Submerged Landscapes: Where World Prehistory Meets Underwater Archaeology." In *From Hunter-Gatherers to Farmers: Human Adaptations at the End of the Pleistocene and the First Part of the Holocene*, edited by M. Mărgărit and A. Boroneanţ, 171–183. Târgovişte: Editura Cetatea de Scaun.

Benjamin, J., M. O'Leary, J. McDonald, S. Ulm, P. Jeffries, and G. Bailey. 2022. "A Wet Strawman: A Response to Ward et al." *Geoarchaeology* 37: 813–818. https://doi.org/10.1002/gea.21936.

Benjamin, J., M. O'Leary, J. McDonald, et al. 2020. "Aboriginal Artefacts on the Continental Shelf Reveal Ancient Drowned Cultural Landscapes in Northwest Australia." *PLoS ONE* 15, no. 7: e0233912. https://doi.org/10.1371/journal.pone.0233912.

Bense, J. A. 2016. *Archaeology of the Southeastern United States: Paleoindian to World War I*. New York, New York, U.S.A.: Routledge. https://doi.org/10.4324/9781315433813.

Berganzo-Besga, I., H. A. Orengo, F. Lumbreras, M. Carrero-Pazos, J. Fonte, and B. Vilas-Estévez. 2021. "Hybrid MSRM-Based Deep Learning and Multitemporal Sentinel 2-Based Machine Learning Algorithm Detects near 10k Archaeological Tumuli in North-Western Iberia." *Remote Sensing* 13, no. 20: 20. https://doi.org/10.3390/rs13204181.

Bewley, R. H., S. P. Crutchley, and C. A. Shell. 2005. "New Light on an Ancient Landscape: LiDAR Survey in the Stonehenge World Heritage Site." *Antiquity* 79, no. 305: 636–647.

Bickler, S. H., and B. Jones. 2021. "Scaling up Deep Learning to Identify Earthwork Sites in Te Tai Tokerau, Northland, New Zealand." *Archaeology in New Zealand* 16–30.

Blackwelder, B. W., O. H. Pilkey, and J. D. Howard. 1979. "Late Wisconsinan Sea Levels on the Southeast US Atlantic Shelf Based on In-Place Shoreline Indicators." *Science* 204, no. 4393: 618–620.

Boethius, A. 2017. "Signals of Sedentism: Faunal Exploitation as Evidence of a Delayed-Return Economy at Norje Sunnansund, an Early Mesolithic Site in South-Eastern Sweden." *Quaternary Science Reviews* 162: 145–168.

Bonhage, A., M. Eltaher, T. Raab, M. Breuß, A. Raab, and A. Schneider. 2021. "A Modified Mask Region-Based Convolutional Neural Network Approach for the Automated Detection of Archaeological Sites on High-Resolution Light Detection and Ranging-Derived Digital Elevation Models in the North German Lowland." *Archaeological Prospection* 28: 177–186. https://doi.org/10.1002/arp.1806.

Bowens, A., and Nautical Archaeology Society, eds. 2009. *Underwater Archaeology: The NAS Guide to Principles and Practice*. 2nd ed. Oxford: Blackwell Pub.

Câmara, A., A. de Almeida, D. Caçador, and J. Oliveira. 2022. "Automated Methods for Image Detection of Cultural Heritage: Overviews and Perspectives." *Archaeological Prospection* 30: 153–169. https://doi.org/10.1002/arp.1883.

Caspari, G., and P. Crespo. 2019. "Convolutional Neural Networks for Archaeological Site Detection – Finding "Princely" Tombs." *Journal of Archaeological Science* 110: 104998. https://doi.org/10.1016/j.jas.2019.104998.

Cerrillo-Cuenca, E. 2017. "An Approach to the Automatic Surveying of Prehistoric Barrows Through LiDAR." *Quaternary International* 435: 135–145. https://doi.org/10.1016/j.quaint.2015.12.099.

Cerrillo-Cuenca, E., and P. Bueno-Ramírez. 2019. "Counting With the Invisible Record? The Role of LiDAR in the Interpretation of Megalithic Landscapes in South-Western Iberia (Extremadura, Alentejo and Beira Baixa)." *Archaeological Prospection* 26, no. 3: 251–264. https://doi.org/10.1002/arp.1738.

Character, L., A. Ortiz JR, T. Beach, and S. Luzzadder-Beach. 2021. "Archaeologic Machine Learning for Shipwreck Detection Using LiDAR and Sonar." *Remote Sensing* 13, no. 9: 9. https://doi.org/10.3390/rs13091759.

Chase, A. F., D. Z. Chase, C. T. Fisher, S. J. Leisz, and J. F. Weishampel. 2012. "Geospatial Revolution and Remote Sensing LiDAR in Mesoamerican Archaeology." *Proceedings of the National Academy of Sciences* 109, no. 32: 12916–12921. https://doi.org/10.1073/pnas.1205198109.

Cody, T. R., and S. L. Anderson. 2021. "LiDAR Predictive Modeling of Pacific Northwest Mound Sites: A Study of Willamette Valley Kalapuya Mounds, Oregon (USA)." *Journal of Archaeological Science: Reports* 38: 103008. https://doi.org/10.1016/j.jasrep.2021.103008.

Compton, J. S. 2011. "Pleistocene Sea-Level Fluctuations and Human Evolution on the Southern Coastal Plain of South Africa." *Quaternary Science Reviews* 30, no. 5: 506–527. https://doi.org/10.1016/j.quascirev.2010.12.012.

Cook Hale, J., J. Benjamin, K. Woo. 2021. "Submerged Landscapes, Marine Transgression and Underwater Shell Middens: Comparative Analysis of Site Formation and Taphonomy in Europe and North America." *Quaternary Science Reviews* 258: 106867. https://doi.org/10.1016/j.quascirev.2021.106867.

Cook Hale, J. W., D. S. Davis, and M. C. Sanger. 2023. "Evaluating the Archaeological Efficacy of Bathymetric LiDAR across Oceanographic Contexts: A Case Study From Apalachee Bay, Florida." *Heritage* 6, no. 2: 928–945. https://doi.org/10.3390/heritage6020051.

Cook Hale, J. W., and E. G. Garrison. 2019. "Climate Change, Cultural Adaptations, and Lower Coastal Plain Occupations of Georgia and Florida From the Early to Middle Holocene: Extrapolating Spatial Trends into the Offshore." *Journal of Anthropological Archaeology* 55: 101071. https://doi.org/10.1016/j.jaa.2019.101071.

Cook Hale, J. W., N. L. Hale, and E. G. Garrison. 2019. "What Is Past Is Prologue: Excavations at the Econfina Channel Site, Apalachee Bay, Florida, USA." *Southeastern Archaeology* 38, no. 1: 1–22. https://doi.org/10.1080/0734578X.2018.1428787.

Cook Hale, J. W., N. L. Hale, M. Newton, and E. G. Garrison. 2022. "The Tempest: Geoarchaeological Examinations of Tropical Cycle/Hurricane Signatures in a Submerged, Formerly Coastal Shell Midden Site, Econfina Channel, Florida, USA." *Journal of Archaeological Science* 144: 105636.

Cook Hale, J. W., and M. Sanger. 2020. "Cultural Spaces and Climate Change: Modeling Holocene Archaeological Settlement Patterns on the Coastal Plain of the Southeastern United States." *Journal of Anthropological Archaeology* 59: 101198. https://doi.org/10.1016/j.jaa.2020.101198.

Crusoe, D. L., and C. B. DePratter. 1976. "New Look at the Georgia Coastal Shell Mound Archaic." *Florida Anthropologist* 29, no. 1: 1–23.

Davis, D. S. 2019. "Object-Based Image Analysis: A Review of Developments and Future Directions of Automated Feature Detection in Landscape Archaeology." *Archaeological Prospection* 26, no. 2: 155–163. https://doi.org/10.1002/arp.1730.

Davis, D. S., D. C. Buffa, and A. C. Wrobleski. 2020. "Assessing the Utility of Open-Access Bathymetric Data for Shipwreck Detection in the United States." *Heritage* 3, no. 2: 364–383. https://doi.org/10.3390/heritage3020022.

Davis, D. S., G. Caspari, C. P. Lipo, and M. C. Sanger. 2021. "Deep Learning Reveals Extent of Archaic Native American Shell-Ring Building Practices." *Journal of Archaeological Science* 132: 105433. https://doi.org/10.1016/j.jas.2021.105433.

Davis, D. S., C. P. Lipo, and M. C. Sanger. 2019. "A Comparison of Automated Object Extraction Methods for Mound and Shell-Ring Identification in Coastal South Carolina." *Journal of Archaeological Science: Reports* 23: 166–177. https://doi.org/10.1016/j.jasrep.2018.10.035.

Davis, D. S., and J. Lundin. 2021. "Locating Charcoal Production Sites in Sweden Using Hydrological Algorithms and Deep Learning." *Remote Sensing* 13, no. 18: 3680. https://doi.org/10.3390/rs13183680.

Davis, D. S., M. C. Sanger, and C. P. Lipo. 2019. "Automated Mound Detection Using LiDAR and Object-Based Image Analysis in Beaufort County, South Carolina." *Southeastern Archaeology* 38, no. 1: 23–37. https://doi.org/10.1080/0734578X.2018.1482186.

DePratter, C. B., and J. D. Howard. 1981. "Evidence for a Sea Level Lowstand Between 4500 and 2400 Years B.P. on the Southeast Coast of the United States." *Journal of Sedimentary Research* 51, no. 4: 1287–1295. https://doi.org/10.1306/212F7E8C-2B24-11D7-8648000102C1865D.

Doneus, M., N. Doneus, C. Briese, M. Pregesbauer, G. Mandlburger, and G. Verhoeven. 2013. "Airborne Laser Bathymetry – Detecting and Recording Submerged Archaeological Sites From the Air." *Journal of Archaeological Science* 40, no. 4: 2136–2151. https://doi.org/10.1016/j.jas.2012.12.021.

Doneus, M., I. Miholjek, G. Mandlburger, et al. 2015. "Airborne Laser Bathymetry for Documentation of Submerged Archaeological Sites in Shallow Water." In *ISPRS—International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences XL-5/W5*, 99–107. https://doi.org/10.5194/isprsarchives-XL-5-W5-99-2015.

Doneus, N., I. Miholjek, K. Džin, M. Doneus, P. Dugonjić, and H. Schiel. 2020. "Archaeological Prospection of Coastal and Submerged Settlement Sites. Re-Evaluation of the Roman Site Complex of Vižula, Croatia." *Archaeologia Austriaca* 104: 253–281.

Douglass, K., and J. Cooper. 2020. "Archaeology, Environmental Justice, and Climate Change on Islands of the Caribbean and Southwestern Indian Ocean." *Proceedings of the National Academy of Sciences* 117, no. 5: 8254–8262. https://doi.org/10.1073/pnas.1914211117.

Duggins, R. M. 2012. "Florida's Paleoindian and Early Archaic: A GIS Approach to Modeling Submerged Landscapes and Site Distribution on the Continental Shelf." PhD thesis, The Florida State University.

Dunbar, J. S. 2016. *Paleoindian Societies of the Coastal Southeast (First Edition)*. Gainesville, Florida, U.S.A.: University Press of Florida.

Erlandson, J. M., and S. M. Fitzpatrick. 2006. "Oceans, Islands, and Coasts: Current Perspectives on the Role of the Sea in Human Prehistory." *Journal of Island & Coastal Archaeology* 1, no. 1: 5–32.

Erlandson, J. M., T. C. Rick, A. F. Ainis, K. M. Gill, N. P. Jew, and L. A. Reeder-Myers. 2020. "Shellfish, Geophytes, and Sedentism on Early Holocene Santa Rosa Island, Alta California, USA." *The Journal of Island and Coastal Archaeology* 15, no. 4: 504–524.

ESRI. 2020. "ArcGIS (10.8.1)." Environmental Systems Research Institute, Inc.

Farr, R. H., G. Momber, J. Satchell, and N. C. Flemming. 2017. "Paleolandscapes of the Celtic Sea and the Channel/La Manche." In *Submerged Landscapes of the European Continental Shelf: Quaternary Paleoenvironments*, edited by N. C. Flemming, J. Harff, M. Delminda, A. Burgess, and G. N. Bailey, 211–239. Wiley-Blackwell. https://doi.org/10.1002/9781118927823.ch9.

Faught, M. K. 1988. "Inundated Sites in the Apalachee Bay Area of the Eastern Gulf of Mexico." *Florida Anthropologist* 41: 185–190.

Faught, M. K. 2004a. "Submerged Paleoindian and Archaic Sites of the Big Bend, Florida." *Journal of Field Archaeology* 29, no. 3–4: 273–290.

Faught, M. K. 2004b. "The Underwater Archaeology of Paleolandscapes, Apalachee Bay, Florida." *American Antiquity* 69, no. 2: 275–289.

Faught, M. K. 2014. "Remote Sensing, Target Identification and Testing for Submerged Prehistoric Sites in Florida: Process and Protocol in Underwater CRM Projects." In *Prehistoric Archaeology on the Continental Shelf: A Global Review*, edited by A. Evans, J. Flatman, and N. Flemming, 37–52. New York, NY: Springer.

Faught, M. K., and J. F. Donoghue. 1997. "Marine Inundated Archaeological Sites and Paleofluvial Systems: Examples From a Karst-Controlled Continental Shelf Setting in Apalachee Bay, Northeastern Gulf of Mexico." *Geoarchaeology: An International Journal* 12, no. 5: 417–458.

Faught, M. K., and N. Flemming. 2008. “Submerged Prehistoric Sites: ‘Needles in Haystacks’ for CRMs and Industry.” *Sea Technology* 49, no. 10: 37–38.

Faulkner, P., J. M. Miller, E. M. Q. Morales, et al. 2021. “67,000 Years of Coastal Engagement at Panga ya Saidi, Eastern Africa.” *PLoS ONE* 16, no. 8: e0256761. https://doi.org/10.1371/journal.pone.0256761.

Fernández-Montblanc, T., A. Izquierdo, R. Quinn, and M. Bethencourt. 2018. “Waves and Wrecks: A Computational Fluid Dynamic Study in an Underwater Archaeological Site.” *Ocean Engineering* 163: 232–250. https://doi.org/10.1016/j.oceaneng.2018.05.062.

Fiorucci, M., M. Khoroshiltseva, M. Pontil, A. Traviglia, A. Del Bue, and S. James. 2020. “Machine Learning for Cultural Heritage: A Survey.” *Pattern Recognition Letters* 133: 102–108. https://doi.org/10.1016/j.patrec.2020.02.017.

Fitch, S. 2022. “From Extensive to Intensive: Moving into the Mesolithic Landscape of Doggerland.” In *Europe's Lost Frontier*, edited by S. Fitch and V. Gaffney, 55–62. Oxford, U.K.: Archaeopress.

Fitzpatrick, S. M., T. C. Rick, and J. M. Erlandson. 2015. “Recent Progress, Trends, and Developments in Island and Coastal Archaeology.” *The Journal of Island and Coastal Archaeology* 10, no. 1: 3–27. https://doi.org/10.1080/15564894.2015.1013647.

Flemming N.C., J. Harff, and D. Moura. 2017. “Non-Cultural Processes of Site Formation, Preservation and Destruction.”

Ford, B., and J. Halligan. 2010. “A North American Perspective: Comment on Jonathan Benjamin's ‘Submerged Prehistoric Landscapes and Underwater Site Discovery: Reevaluating the “Danish Mode” for International Practice’.” *Journal of Island and Coastal Archaeology* 5: 277–279. https://doi.org/10.1080/15564894.2010.506626.

Freeland, T., B. Heung, D. V. Burley, G. Clark, and A. Knudby. 2016. “Automated Feature Extraction for Prospection and Analysis of Monumental Earthworks from Aerial LiDAR in the Kingdom of Tonga.” *Journal of Archaeological Science* 69: 64–74. https://doi.org/10.1016/j.jas.2016.04.011.

Gaffney, V. L., K. Thomson, and S. Fitch. 2007. *Mapping Doggerland: The Mesolithic Landscapes of the Southern North Sea*. Oxford, U.K.: Archaeopress.

Gibson, J. L. 1994. “Before Their Time? Early Mounds in the Lower Mississippi Valley.” *Southeastern Archaeology* 13, no. 2: 162–186.

Guyot, A., M. Lennon, N. Thomas, et al. 2019. “Airborne Hyperspectral Imaging for Submerged Archaeological Mapping in Shallow Water Environments.” *Remote Sensing* 11, no. 19: 2237.

Haas, R., J. Watson, T. Buonasera, et al. 2020. “Female Hunters of the Early Americas.” *Science Advances* 6, no. 45: eabd0310. https://doi.org/10.1126/sciadv.abd0310.

Hine, A. C., D. F. Belknap, J. G. Hutton, E. B. Osking, and M. W. Evans. 1988. “Recent Geological History and Modern Sedimentary Processes Along an Incipient, Low-Energy, Epicontinental-Sea Coastline: Northwest Florida.” *Journal of Sedimentary Research* 58: 567–579. https://doi.org/10.1306/212F8DF5-2B24-11D7-8648000102C1865D.

Jackson, K., P. Wang, T. J. Pluckhahn, J. A. Rogers, and V. D. Thompson. 2023. “Stratigraphic Framework, Paleoenvironments, and Indigenous Terraforming of Inshore Estuarine Subbasins in Tampa Bay, Florida, U.S.A.” *Journal of Coastal Research* 39, no. 5: 779–815. https://doi.org/10.2112/JCOASTRES-D-22-00128.1.

Janowski, L., M. Kubacka, A. Pydyn, M. Popek, and L. Gajewski. 2021. “From Acoustics to Underwater Archaeology: Deep Investigation of a Shallow Lake Using High-Resolution Hydroacoustics—The Case of Lake Lednica, Poland.” *Archaeometry* 63: 1059–1080. https://doi.org/10.1111/arcm.12663.

Jones, J. S. 2018. “Late Pleistocene Adaptations in the Midsouth: The Paleoindian Occupation of the Carson-Conn-Short Site and the Lower Tennessee River Valley.”

Joy, S. 2019. “The Trouble With the Curve: Reevaluating the Gulf of Mexico Sea-Level Curve.” *Quaternary International* 525: 103–113. https://doi.org/10.1016/j.quaint.2019.07.023.

Joy, S. 2020. “Coastally-Adapted: A Developing Model for Coastal Paleoindian Sites on the North American Eastern Continental Shelf.” *The Journal of Island and Coastal Archaeology* 16: 150–169. https://doi.org/10.1080/15564894.2020.1803459.

Kirch, P. V., and T. L. Hunt, eds. 1997. *Historical Ecology in the Pacific Islands: Prehistoric Environmental and Landscape Change*. New Haven, Connecticutt, U.S.A.: Yale University Press.

Kokalj, Ž., S. Džeroski, I. Šprajc, J. Štajdohar, A. Draksler, and M. Somrak. 2023. “Machine Learning-Ready Remote Sensing Data for Maya Archaeology.” *Scientific Data* 10: 558. https://doi.org/10.1038/s41597-023-02455-x.

Küçükdemirci, M., G. Landeschi, M. Ohlsson, and N. Dell'Unto. 2022. “Investigating Ancient Agricultural Field Systems in Sweden From Airborne LIDAR Data by Using Convolutional Neural Network.” *Archaeological Prospection* 30: 209–219. https://doi.org/10.1002/arp.1886.

Lambers, K., and A. Traviglia. 2016. “Automated Detection in Remote Sensing Archaeology: A Reading List.” *AARGnews* 53: 25–29.

Lobb, M. A. 2016. “Developing Terrestrial Laser Scanning of Threatened Coastal Archaeology With Special Reference to Intertidal structures.” PhD dissertation, University of Southampton.

Magnini, L., C. Bettineschi, and A. De Guio. 2017. “Object-Based Shell Craters Classification From LiDAR-Derived Sky-View Factor.” *Archaeological Prospection* 24, no. 3: 211–223. https://doi.org/10.1002/arp.1565.

Marean, C. W. 2014. “The Origins and Significance of Coastal Resource Use in Africa and Western Eurasia.” *Journal of Human Evolution* 77: 17–40. https://doi.org/10.1016/j.jhevol.2014.02.025.

Marks, B. S. 2006. *Site Formation Processes and Activity Areas at Ontolo (8JE1577): A Submerged Prehistoric Human Occupation Site in Apalachee Bay*. Florida: The Florida State University.

Meyer-Heß, M. F., I. Pfeffer, and C. Juergens. 2022. “Application of Convolutional Neural Networks on Digital Terrain Models for Analyzing Spatial Relations in Archaeology.” *Remote Sensing* 14: 2535. https://doi.org/10.3390/rs14112535.

Milner, G. R. 2021. *The Moundbuilders: Ancient Societies of Eastern North America*. Second ed. London, U.K.: Thames & Hudson.

Moore, C. R., M. J. Brooks, L. R. Kimball, M. E. Newman, and B. P. Kooyman. 2016. “Early Hunter-Gatherer Tool Use and Animal Exploitation: Protein and Microwear Evidence From the Central Savannah River Valley.” *American Antiquity* 81, no. 1: 132–147.

O'Donoughue, J. 2007. “Paleoindian Settlement in the Southeastern United States: Insights From Examining Regional Databases.” *Current Research in the Pleistocene* 24: 126–129.

Orengo, H. A., F. C. Conesa, A. Garcia-Molsosa, et al. 2020. “Automated Detection of Archaeological Mounds Using Machine-Learning Classification of Multisensor and Multitemporal Satellite Data.” *Proceedings of the National Academy of Sciences* 117: 18240–18250. https://doi.org/10.1073/pnas.2005583117.

Plets, R., J. Dix, and R. Bates. 2013. *Marine Geophysics Data Acquisition, Processing and Interpretation*. London, U.K.: English Heritage.

Quinn, R., and D. Boland. 2010. “The Role of Time-Lapse Bathymetric Surveys in Assessing Morphological Change at Shipwreck Sites.” *Journal of Archaeological Science* 37, no. 11: 2938–2946.

Quintus, S., D. S. Davis, and Cochrane E.E. 2023. “Evaluating Mask R-CNN Models to Extract Terracing Across Oceanic High Islands: An Example From Sāmoa.” *Archaeological Prospection* 30, no. 4: 477–492.

Rom, J., F. Haas, M. Stark, et al. 2020. “Between Land and Sea: An Airborne LiDAR Field Survey to Detect Ancient Sites in the Chekka Region/Lebanon Using Spatial Analyses.” *Open Archaeology* 6, no. 1: 248–268. https://doi.org/10.1515/opar-2020-0113.

Royal, W., and E. Clark. 1960. “Natural Preservation of Human Brain, Warm Mineral Springs, Florida.” *American Antiquity* 26, no. 2: 285–287.

Russell, D. A., F. J. Rich, V. Schneider, and J. Lynch-Stieglitz. 2009. “A Warm Thermal Enclave in the Late Pleistocene of the South-Eastern United States.” *Biological Reviews* 84, no. 2: 173–202. https://doi.org/10.1111/j.1469-185X.2008.00069.x.

Russo, M. 1994. “Why We Don't Believe in Archaic Ceremonial Mounds and Why We Should: The Case From Florida.” *Southeastern Archaeology* 13, no. 2: 93–109.

Russo, M. 1996. “Southeastern Mid-Holocene Coastal Settlements.” In *Archaeology of the Mid-Holocene Southeast*, edited by K. E. Sassaman and D. G. Anderson, 177–199. Gainesville: University Press of Florida.

Sărășan, A., A.-C. Ardelean, A. Bălărie, R. Wehrheim, K. Tabaldiev, and K. Akmatov. 2020. “Mapping Burial Mounds Based on UAV-Derived Data in the Suusamyr Plateau, Kyrgyzstan.” *Journal of Archaeological Science* 123: 105251. https://doi.org/10.1016/j.jas.2020.105251.

Saunders, R. 2017. “Archaic Shell Mounds in the American Southeast.” In *Oxford Handbooks Online*, vol. 1. Oxford, U.K.: Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199935413.013.75.

Saunders, R., and M. Russo. 2011. “Coastal Shell Middens in Florida: A View From the Archaic Period.” *Quaternary International* 239, no. 1–2: 38–50. https://doi.org/10.1016/j.quaint.2010.08.008.

Somma, R., S. Iuliano, F. Matano, et al. 2016. “High-Resolution Morpho-Bathymetry of Pozzuoli Bay, Southern Italy.” *Journal of Maps* 12, no. 2: 222–230.

Stone, G. W., Jr., G. W. Stone, and F. W. Stapor. 1996. “A Nearshore Sediment Transport Model for the Northeast Gulf of Mexico Coast, U.S.A.” *Journal of Coastal Research* 12: 786–792.

Stright, M. J. 1986. “Human Occupation of the Continental Shelf During the Late Pleistocene/Early Holocene: Methods for Site Location.” *Geoarchaeology* 1, no. 4: 347–363.

Thomas, D. H. 2008. In *Native American Landscapes of St. Catherines Island, Georgia*, edited by D. H. Thomas, vol. 88. New York, NY: American Museum of Natural History.

Thomas, D. H. 2014. “The Shellfishers of St. Catherines Island: Hardscrabble Foragers or Farming Beachcombers?” *The Journal of Island and Coastal Archaeology* 9: 169–182. https://doi.org/10.1080/15564894.2013.840874.

Thompson, V. D., and J. E. Worth. 2011. “Dwellers by the Sea: Native American Adaptations Along the Southern Coasts of Eastern North America.” *Journal of Archaeological Research* 19, no. 1: 51–101. https://doi.org/10.1007/s10814-010-9043-9.

Thulman, D. K. 2009. “Freshwater Availability as the Constraining Factor in the Middle Paleoindian Occupation of North-Central Florida.” *Geoarchaeology* 24, no. 3: 243–276. https://doi.org/10.1002/gea.20268.

Tian-Yuan Shih, P., Y.-H. Chen, and J.-C. Chen. 2014. “Historic Shipwreck Study in Dongsha Atoll With Bathymetric LiDAR: Historic Shipwreck Study With Bathymetric LiDAR.” *Archaeological Prospection* 21, no. 2: 139–146. https://doi.org/10.1002/arp.1466.

Trier, Ø. D., and L. H. Pilø. 2012. “Automatic Detection of Pit Structures in Airborne Laser Scanning Data: Automatic Detection of Pits in ALS Data.” *Archaeological Prospection* 19, no. 2: 103–121. https://doi.org/10.1002/arp.1421.

Trier, Ø. D., J. H. Reksten, and K. Løseth. 2021. “Automated Mapping of Cultural Heritage in Norway From Airborne LiDAR Data Using Faster R-CNN.” *International Journal of Applied Earth Observation and Geoinformation* 95: 102241.

Turck, J. A., and V. D. Thompson. 2016. “Revisiting the Resilience of Late Archaic Hunter-Gatherers along the Georgia Coast.” *Journal of Anthropological Archaeology* 43: 39–55. https://doi.org/10.1016/j.jaa.2016.05.006.

Upchurch, S. B. 2007. “An Introduction to the Cody Escarpment, North-Central Florida.” Live Oak, Florida, USA.

Upchurch, S. B., R. N. Strom, and M. G. Nuckels. 1982. *Methods of Provenance Determination of Florida Cherts*. Florida: University of So.

Verschoof-van der Vaart, W. B., and K. Lambers. 2019. “Learning to Look at LiDAR: The Use of R-CNN in the Automated Detection of Archaeological Objects in LiDAR Data From the Netherlands.” *Journal of Computer Applications in Archaeology* 2, no. 1: 31–40. https://doi.org/10.5334/jcaa.32.

Verschoof-van der Vaart, W. B., and J. Landauer. 2020. “Using CarcassonNet to Automatically Detect and Trace Hollow Roads in LiDAR Data From the Netherlands.” *Journal of Cultural Heritage* 47: 143–154. https://doi.org/10.1016/j.culher.2020.10.009.

Veth, P., J. McDonald, I. Ward, et al. 2020. “A Strategy for Assessing Continuity in Terrestrial and Maritime Landscapes From Murujuga (Dampier Archipelago), North West Shelf, Australia.” *The Journal of Island and Coastal Archaeology* 15, no. 4: 477–503.

Walker, J., V. Gaffney, S. Fitch, et al. 2022. “The Archaeological Context of Doggerland During the Final Palaeolithic and Mesolithic.” In *Europe's Lost Frontier*, edited by V. Gaffney and S. Fitch, 63–88. Oxford, UK: Archaeopress.

Ward, I., P. Larcombe, P. J. Ross, and C. Fandry. 2022. “Applying Geoarchaeological Principles to Marine Archaeology: A Reappraisal of the “First Marine” and “In Situ” Lithic Scatters in the Dampier Archipelago, NW Australia.” *Geoarchaeology* 37, no. 5: 783–810. https://doi.org/10.1002/gea.21917.

Watts, W. A., B. C. Hansen, and E. C. Grimm. 1992. “Camel Lake: A 40 000-Yr Record of Vegetational and Forest History From Northwest Florida.” *Ecology* 73, no. 3: 1056–1066.

Wilkes, B. S. J. 1971. “Nautical Archaeology.” Newton Abbot.

Wiseman, C., M. O'Leary, J. Hacker, et al. 2021. “A Multi-Scalar Approach to Marine Survey and Underwater Archaeological Site Prospection in Murujuga, Western Australia.” *Quaternary International* 584: 152–170.

Wu, Q., and C. R. Lane. 2016. “Delineation and Quantification of Wetland Depressions in the Prairie Pothole Region of North Dakota.” *Wetlands* 36, no. 2: 215–227. https://doi.org/10.1007/s13157-015-0731-6.

Wu, Q., H. Liu, S. Wang, B. Yu, R. Beck, and K. Hinkel. 2015. “A Localized Contour Tree Method for Deriving Geometric and Topological Properties of Complex Surface Depressions Based on High-Resolution Topographical Data.” *International Journal of Geographical Information Science* 29, no. 12: 2041–2060. https://doi.org/10.1080/13658816.2015.1038719.

## Supporting Information

Additional supporting information can be found online in the Supporting Information section.