RESEARCH PAPER

Working from the Known to the Unknown: Linking the Subaerial Archaeology and the Submerged Landscapes of Santarosae Island, Alta California, USA

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Since the collapse of the Clovis-first model of the peopling of the Americas some 30 years ago, there has been growing interest in the Pacific Coast as a potential early human dispersal corridor. With postglacial eustatic sea level rise inundating most New World paleoshorelines older than ~7000 years, however, locating terminal Pleistocene sites along modern coastlines is challenging. Using the distribution and archaeology of subaerial Paleocoastal archaeological sites on California's Northern Channel Islands as a guide, we developed a Geographic Information Systems (GIS) predictive model to locate and map submerged high probability landforms, which might contain Paleocoastal sites. Our results illustrate how archaeologists can narrow targets in their search for evidence of the first Americans along submerged Pacific Coast paleoshorelines.

1. Introduction

Less than three decades ago, most archaeologists believed the first peoples to enter the Americas were Ice Age hunters who walked across the Bering Land Bridge, passed through an Ice-Free Corridor (IFC), and spread rapidly across the New World beginning ~13,500 years ago, hunting mammoths, mastodons, and other Pleistocene megafauna with fluted and fishtail points (e.g., Holliday, 2000; Meltzer, 1995, 2009; Waters and Stafford, 2007). This Clovis-first model of New World colonization became dogma and, despite some opposition (e.g., Fladmark, 1979; Erlandson, 1994, 2002; Gruhn, 1988), was supported by most of the available archaeological, genetic, and paleoecological data. Under the Clovis-first model, coastlines were an afterthought and most archaeologists believed people did not turn their attention to aquatic and maritime resources until after the Pleistocene megafauna went extinct, a decision thrust upon New World hunter-gatherers as their highest-ranked food resources disappeared.

By the late 1990s, the discovery and widespread acceptance of the ~14,500 to 14,000-year-old occupation of the Monte Verde site in southern Chile (Dillehay, 1997, 2000; Dillehay et al., 2008) caused archaeologists to reconsider long-held paradigms about when and how the first Americans arrived. Some turned their attention to long marginalized Pleistocene coastlines as a potential dispersal corridor into the Americas (e.g., Dixon, 2001; Erlandson, 2002), open and viable millennia prior to the IFC (Darvill et al., 2018; Lesnek et al., 2018). In recent decades, evidence for the deep antiquity of coastal adaptations, seafaring, and island colonization has been discovered and maritime resources are no longer considered marginal or less productive than their terrestrial counterparts (e.g., Cortés-Sánchez et al., 2011; Erlandson, 2001, 2010; Marean et al., 2007; Steele and Álvarez-Fernández, 2011). The antiquity of seafaring stretches back at least to 800,000 to 1,000,000 years ago, with short marine crossings by archaic members of our genus, including the colonization of Flores and other Southeast Asian islands (Brown et al., 2004; Ingicco et al., 2018; Morwood et al., 2004) and the discovery of greater Australia (Sahul) by Anatomically Modern Humans as much as 55,000 to 60,000 years ago (Clarkson et al., 2017). After

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50,000 years ago, there is evidence for a dramatic increase in seafaring, island colonization, and the exploitation of maritime resources in Island Southeast Asia, Australia, and New Guinea (O'Connell and Allen, 2012; O'Connor et al., 2011), New Ireland and the Solomon Islands (Allen et al., 1989; Wickler and Spriggs, 1988), Okinawa (Fujita et al., 2016) and the other Ryukyu Islands (Matsu'ura, 1996), and Honshu in Japan (Ikeya, 2015).

The Pleistocene archaeological record along Pacific New World coastlines remains exceptionally thin, which is, perhaps, the primary reason that debates continue about the relative likelihood of the IFC versus the Pacific Coast Route (PCR) as the earliest dispersal corridor for the first Americans (see Braje et al., 2017, 2018; Potter et al., 2018a, b). Currently, the earliest evidence of Pleistocene-aged archaeological sites along the New World Pacific Coast comes from the Monte Verde II (~14,600–14,000 cal BP) and Huaca Prieta (~15,000–13,500 cal BP) sites in Chile and Peru, respectively (Dillehay et al., 2008, 2012). In North America, the earliest evidence of coastal occupations comes from British Columbia, where deeply buried chipped stone artifacts and a hearth feature date to ~13,800 cal BP on Triquet Island and stone tools and human footprints in Pruth Bay on Calvert Island date to ~13,000 cal BP (McLaren et al., 2018). Human remains discovered on Santa Rosa Island in southern California also date to around 13,000 cal BP (Johnson et al., 2002).

The foremost obstacle in finding earlier archaeological sites along the modern Pacific Coast shoreline is confronting the preservation and discovery challenges that have almost certainly impacted the record of early human settlement. This includes the destructive effects of taphonomic processes such as earthquakes, tsunamis, marine erosion, coastal development, and a variety of others that have impacted or destroyed coastal archaeological records (e.g., Erlandson, 2012; O'Rourke, 2017). The greatest challenge, however, has been created by the rise of post-glacial seas since the end of the Last Glacial Maximum (LGM, ~20,000 cal BP), which submerged nearly all the shorelines early coastal peoples would have relied upon and followed into the Americas if they dispersed along a PCR. Certainly not all Late Pleistocene shorelines are underwater today, as isostatic rebound has resulted in some shorelines at or above modern sea level in parts of Southeast Alaska and British Columbia. Detailed paleogeographic reconstructions and systematic archaeological surveys in these highly dynamic areas, however, are hindered by thick forest cover and remote, difficult-to-access landforms (Dixon 2013; Dixon and Monteleone 2014; Fedje et al., 2018; Josenhans et al., 1997; McLaren et al., 2018; Shugar et al., 2014).

The systematic search for submerged Late Pleistocene archaeological sites along the Pacific Coast of North America has just begun and scientists are grappling with how to effectively and efficiently search the ocean floor for archaeological resources (Gusick and Faught, 2011). The scale of this challenge is immense. If we assume, for example, that the PCR opened ~17,000 years ago (see Darvill et al., 2018; Lesnek et al., 2018) and modern sea levels stabilized around 7000 years ago, the intervening 10,000 years of eustatic sea level rise resulted in the inundation of ~10 million km² New World Pacific coastal plains, with as little as 5–10 km of shoreline transgression in areas with steep offshore bathymetry and up to ~500 km in areas, such as Beringia, with shallow offshore bathymetry. The Pacific Coast is also characterized by relatively high wave energy, with relatively few protected shorelines south of the convoluted coastlines of Alaska and British Columbia. Identifying the best places among the vast submerged landscapes off the Pacific Coast to look for archaeological sites remains a formidable challenge.

In terrestrial archaeological contexts, every student on their first field excavation is likely told by the project director to move from the known to the unknown. That is, when excavating an archaeological site, it is best practice to broaden excavations out from an existing exposure. This might be, for example, from the eroding exposure of a sea cliff, the face of an arroyo wall, or the sidewall of a previously excavated unit. By doing so, archaeologists can carefully follow features and soil stratigraphy in a systematic and controlled fashion, maximizing the contextual information that can be gleaned from the recovery of artifacts and ecofacts. Here, we describe our ongoing research to apply the same concept in the search for archaeological sites on the extensive submerged landscapes that surround Alta California's Northern Channel Islands.

2. Geologic Settings and Environmental Setting
The Northern Channel Islands (NCI) are located offshore southern California and consist of San Miguel, Santa Rosa, Santa Cruz, and Anacapa islands (**Figure 1**). The islands have not been connected to the mainland during Quaternary times, so watercraft of some kind would have been required for human settlement. During the LGM, with relative sea level ~100–110 m lower than present (Clark et al., 2014; Reeder-Myers et al., 2015), the NCI were connected by a series of land bridges into a single ~125 km long island known as *Santarosae*, exposing wide tracts of the now-submerged shelf (Erlandson, 2016; Orr, 1968; Reeder-Myers et al., 2015). Shoreline reconstructions using modern seafloor bathymetry indicate that *Santarosae* reached its greatest extent at ~20 ka, then rapidly shrank until the islands separated beginning about 11 ka (Reeder-Myers et al., 2015). *Santarosae* is estimated to have lost roughly 75 percent of its land area during this process (Reeder-Myers et al., 2015). Rising sea levels during the terminal Pleistocene and Early Holocene would have inundated any archaeological sites left behind by coastal hunter-gatherers who occupied the now submerged portion of the once exposed continental shelf. Many of the geologic features observed onshore the modern NCI likely would have also characterized the exposed shelf during lower sea level and some features may still be preserved.

Due to their active tectonic setting, the NCI are uplifting at rates of 0.12–0.20 m/ka (Pinter et al., 2003; Laws et al., 2019). As such, the geomorphology near the coast of much of the NCI is characterized by step-like marine terrace features formed during sea level highstands (Muhs et al., 2014; Sorlien, 1994; Pinter et al., 2003). Each terrace was formed by wave erosion and consists of a gently seaward dipping abrasion platform that terminates landward
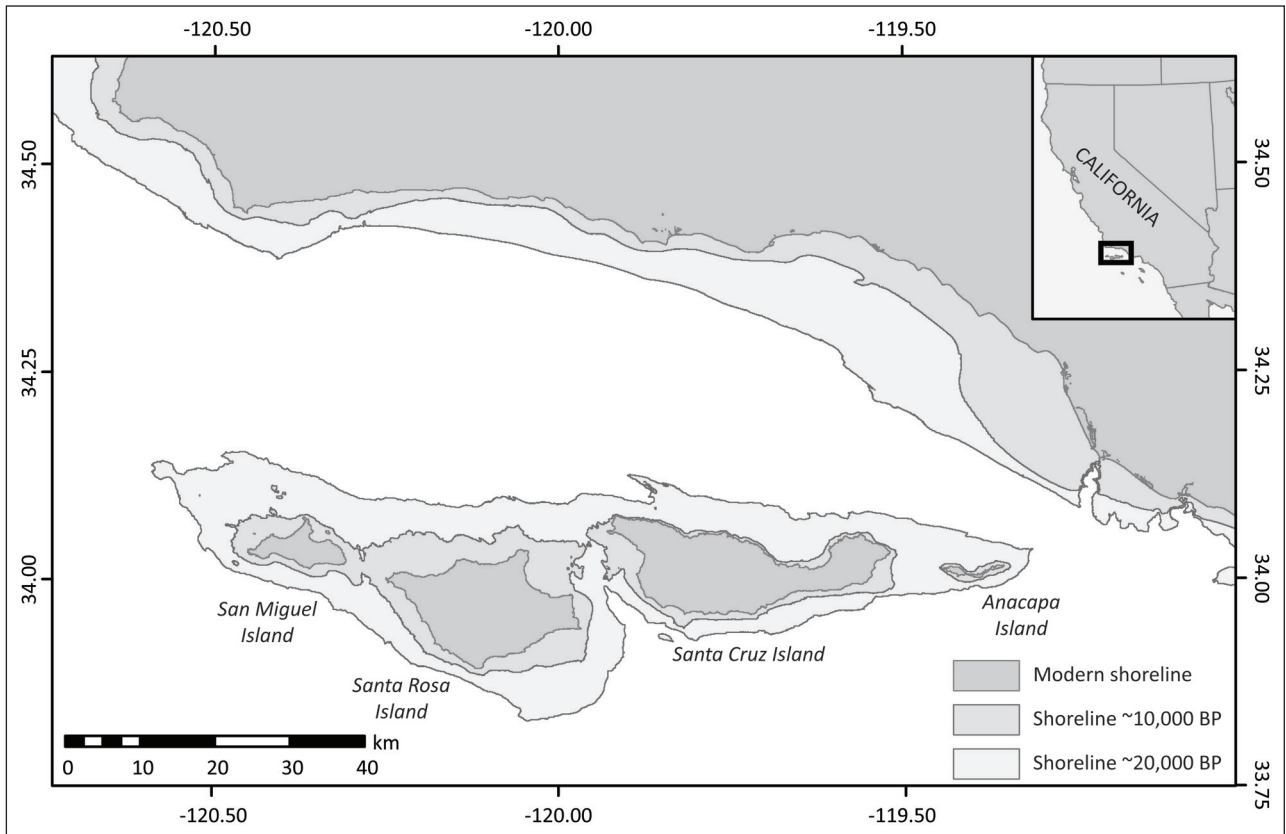
Figure 1: Physiographic map of southern California showing the location of the Northern Channel Islands and the reconstructed shorelines of *Santarosae* at 20,000 and 10,000 cal BP.

at a steeper paleo-seacliff (a.k.a. a terrace riser). The intersection of the abrasion platform and paleo-seacliff represents the paleoshoreline that formed near the end of the corresponding sea level highstand (e.g., Anderson et al., 1999; Chaytor et al., 2008; Grant Ludwig et al., 1999; Kern and Rockwell, 1992; Lajoie, 1986; Haaker et al., 2016; Muhs et al., 2012; Muhs et al., 2014; Reeder-Myers et al., 2015). Some Last Interglacial highstand paleoshorelines associated with Marine Isostope stages 5a and 5e are preserved onshore the NCI (e.g., Dickinson, 2001; Muhs et al., 2014; Pinter et al., 2003; Sorlien, 1994). On the now submerged NCI shelf, several paleoshorelines have been mapped using the same morphological identification of abrasion platform and paleoseacliff as the highstand sub-aerial terraces (Chaytor et al., 2008; Emery, 1958). These submerged terraces represent times of lower sea level and could have been active coastlines during early habitation of *Santarosae*. Chaytor et al. (2008) interpreted an LGM shoreline at ~90 m below modern sea level located near the edge of the platform on the southern side of Santa Cruz Island.

Santa Rosa and Santa Cruz islands are both bisected by left-lateral strike slip faults that generate lineaments through the center of each island (E-W striking Santa Rosa Island fault and NW-SE striking Santa Cruz Island fault). The faults influence drainage patterns by generating topography and deflecting channels. On Santa Rosa Island, streams flowing south of the fault drain steep topography and are v-shaped, while streams flowing north incise wider, trough shaped channels into a flatter marine terrace topography

(Dibblee and Ehrenspeck, 1998; Schumann et al., 2016). During periods of lower sea level, streams would have extended across the NCI shelf. The shelf varies in width and slope, with the narrowest and steepest shelf areas on the northwest and southern sides of Santa Cruz Island, and flatter, wider shelves off northwest San Miguel and Santa Rosa islands, as well as under the 10–16 km wide Santa Cruz Channel that now separates Santa Cruz and Santa Rosa islands. This last area is relatively flat, except where it is dissected by the south-flowing Santa Cruz submarine canyon. The features of the modern islands and characteristics of the shelf are important considerations for documenting submerged landscapes and potentially associated archaeological resources.

3. The Terminal Pleistocene Archaeological Record
The inundation and erosion of former shorelines and coastal lowlands has likely destroyed or obscured landforms and severely impacted our understanding of early human occupations on *Santarosae*. Despite the fact that ~70–75% of Late Pleistocene *Santarosae* is now underwater, archaeologists have identified nearly 100 subaerial Paleocoastal (~13,000–8,000 cal BP) sites on the NCI, including several radiocarbon dated between ~13,000 and 11,700 cal BP (Gusick and Erlandson, 2019). The oldest documented archaeological site (Arlington Springs, a.k.a. CA-SRI-173) on the NCI contained deeply buried human bones dated to ~13,000 cal BP on northwestern Santa Rosa Island (Johnson et al., 2002; Orr 1968). Other Late Pleistocene sites include two buried middens eroding from coastal

terraces near the mouth of Arlington Canyon (CA-SRI-26 and −512; Erlandson et al., 2011b), two low density middens located on bluffs overlooking the southwest coast of Santa Rosa Island (CA-SRI-723 and −706; Rick et al., 2013), several small shell middens and a massive lithic scatter (CA-SMI-678, −679, −680, −701) located near Cardwell Point on eastern San Miguel (Erlandson et al., 2011a), and a low density shell midden stratum in Daisy Cave (CA-SMI-261) on San Miguel (Erlandson et al., 1996).

Until about a decade ago, little was known about the technologies (chipped stone tools, etc.) used by these early Paleocoastal peoples. A growing number of early sites have produced distinctive and sophisticated chipped stone technologies in dateable contexts, however, including crescents and Channel Island Barbed (CIB) and Channel Island Amol (CIA) points that appear to be reliable terminal Pleistocene and Early Holocene time markers on the NCI (Braje et al., 2013; Erlandson, 2013; Erlandson et al., 2011a; Glassow et al., 2008; Rick et al., 2013; see **Figure 2**).

There is little doubt that most CIB and CIA points were used as projectile tips in hunting. Together they come in a variety of shapes and sizes, persist for ~4000 years, and are found in sites containing a variety of faunal assemblages (Braje et al., 2013; Erlandson et al., 2011a; Gusick and Erlandson, 2019). It seems most likely that these ultra-thin bifaces with delicate barbs, serrations, and needle-like tips, were used primarily in marine hunting where they would have been less likely to fracture. Glassow et al. (2008) suggested that CIB points may have been used in fishing, but some larger specimens seem more likely to have been used in marine mammal hunting, and numerous very small specimens have been found at CA-SRI-512, where they may have been used to hunt birds. Crescents are strongly associated with lake, marsh, and coastal habitats in the American Far West (Moss and Erlandson, 2013; Sanchez et al., 2016) and the bilaterally-symmetrical lunate technologies likely were used as transverse points for hunting

waterfowl and/or seabirds, although they may also have been used for other purposes by early or later peoples. On the NCI, where land animals are relatively limited, an association with bird hunting seems most likely—especially given their association with thousands of waterfowl and seabird bones at CA-SRI-512 (Erlandson et al., 2011a).

4. Modeling and Methods

To identify potential high probability areas for submerged Paleocoastal sites around the NCI, we designed a geographic information systems (GIS) predictive model using, as the critical guiding component, what we know about the distribution, geographic setting, and archaeology of the nearly 100 documented subaerial Paleocoastal sites. We know that terminal Pleistocene and Early Holocene sites on the NCI occur near freshwater and toolstone sources, caves and rockshelters, productive kelp forest, estuarine, and wetland habitats, and on elevated landforms with strategic viewsheds. We believe early coastal mariners along the Pacific Coast occupied similar areas of the then-subaerially exposed continental shelf. Detailed mapping of offshore landforms can provide high-resolution reconstructions of landforms, rock outcrops, and other features to help identify areas of high archaeological potential. As described in a 2013 Pacific Outer Continental Shelf (POCS) submerged site predictive model report (ICF International et al., 2013), the potential for site preservation on the submerged continental shelf is based on several factors: rate of sea level rise, tectonics, sedimentation rate and patterns, wave energy, seafloor geology, and the distribution of natural resources targeted by foragers. Prehistoric sites may be found offshore only when mechanisms are in place to preserve a locale from the taphonomic effects of transgressive shorelines.

Our method of relying on the archaeological record to guide where to focus our efforts was based on regionally specific data that could be applied on a project basis. The
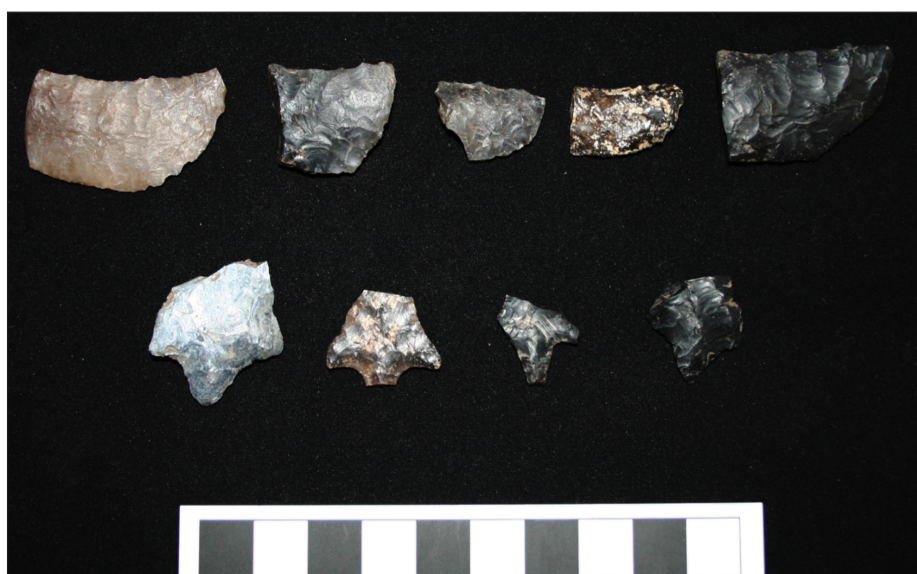

Figure 2: Photograph of distinctive Paleocoastal technologies from eastern Santa Rosa Island, NCI. Top Row: Broken chipped stone crescents from CA-SRI-997/H, a massive archaeological site along the western margins of Crescent Bay. Bottom Row: Broken Channel Island Barbed points from CA-SRI-997/H.

use of terrestrial analogs to guide underwater research is one that should always be explored, but not without applicability considerations. Currently subaerial sites may lie in different landscape and environmental contexts than during the time period of habitation. This may be particularly true for deeply submerged landscapes (Ford and Halligan, 2010: 278). Sites near modern shorelines may have been far removed from the coast during time of habitation and characterized as inland sites prior to marine transgression, which can present different patterns of settlement and resource use. Also, as sea levels rose, massive changes in landscapes and habitats occurred and may have influenced behavioral patterns that differ from those recognized during times of more stable sea level changes. These factors were considered for our research, but based on our current knowledge of the Pleistocene archaeological record as well as knowledge of the continental shelf from previous studies, we were confident that using land-based analogs as one of numerous guiding factors for developing a model was appropriate.

For that reason, we also used existing knowledge of the terminal Pleistocene paleogeography of the NCI to identify potential locations where preservation of submerged sites was most likely to occur. The strong and predominantly northwesterly wind and wave patterns today and in the late Pleistocene, for instance, suggest that marine erosion along *Santarosae*'s unprotected northern shore would have hindered site preservation. The relatively protected southern shore of *Santarosae*, in contrast, would have seen less erosion and potentially higher rates of site survival. Particularly intriguing was a large south-facing embayment dubbed Crescent Bay that existed in the current vicinity of the Santa Cruz Channel from ~17,000 to 10,000 years ago (Erlandson, 2016).

Post-glacial marine transgression forced coastal foragers to relocate their nearshore settlements across the POCS through time. To account for this, research emphasis was placed on ground-truthing high probability areas that coincide with slower periods of sea level rise, which are expected to have enabled longer periods of repeated occupation at coastal sites, potentially leading to the formation of larger and more discoverable archaeological targets on the POCS. However, periods of slowly rising sea levels might offer poor preservation contexts as they are exposed to wave action for longer periods, encouraging the formation of sea cliffs and destructive sea cliff retreat. Targeting areas near paleocoastlines with substantial archaeological deposits inundated quickly could mitigate this challenge. Periods of slower eustatic sea level rise occurred during the Younger Dryas (ca. 12,900–11,700 cal BP) and after the 8200 cal BP meltwater pulse. By conducting a series of high-resolution remote sensing surveys at different depths that correspond to these particular shoreline positions, within well-developed ancient drainage networks or on other key landform features, we increase the chance of locating submerged sites of different ages that reflect inland displacement of coastal foragers during post-glacial marine transgression.

Building an effective GIS model for predicting the locations of preserved archaeological sites offshore involved

several critical steps. Our approach to modeling potential precontact period site locations on the Pacific outer continental shelf (POCS) is based on methods reported by ICF international et al. (2013) and is a two-part process wherein coastal paleolandscape reconstructions are first created and associated precontact period site location predictions are then made. We began by creating a GIS-based paleolandscape model that showed the extent of emergent lands on the POCS at 19,000 cal BP. We then projected the positions of relative shorelines at each millennium since the 19,000 cal BP onto this maximum paleolandscape extent model using glacioisostatic adjustment calculations provided by Clark et al. (2014). To generate the potential site preservation models, we assigned heuristic numerical values to 10-meter digital elevation model (DEM) grid squares imposed on the POCS, which allowed us to establish a semi-quantitative basis for making predictions about where past coastal sites were probably distributed on now-submerged coastal landscapes. These numerical values are arbitrary but relate to different environmental aspects of the paleolandscape that Snethkamp et al. (1990: Table III-1) correlate with different frequencies of precontact period coastal settlement patterns along the Washington, Oregon, and California coastlines. In their study, the greatest number of precontact period terrestrial coastal sites were found along the outer coast, followed by aquatic environments (bays, estuaries, rivers, lakes), and finally by sites located on islands and on coastal bluffs.

Ethnographically and historically, the largest archaeological sites are known to occur adjacent to estuaries and within bays. For ease of modeling potential site locations in GIS, we collapsed these sub-environmental types into four categories: outer coast, estuary (which includes embayments), streams (fluvial reaches of all sizes), and interfluve areas (i.e., in the areas between all other environmental categories). We modeled potential site locations across the POCS through a process by which numerical values associated with grid squares are summed; higher values are interpreted to reflect more favorable locations for precontact period site placement than grid squares with lower numerical values. Coastline rasters were buffered to 200 meters, extending landward, and were assigned a value of 75. Stream rasters were buffered to 100 meters (50 meters to each side of stream) and given a value of 75. A background value of 25 was given to the entire POCS to assign a fundamental numerical value to areas away from coastlines and streams. In this way, we were able to model the locations of estuaries in places where stream rasters overlapped with coastline rasters, resulting in a base value of 150.

To further simulate the environmental variance of the POCS paleolandscape in greater detail, we applied slope and aspect/insolation raster modifiers following Jenevein's (2010: 56–57) method:

A slope raster in degrees was created from the DEM using the slope function of the Spatial Analyst extension in ArcGIS. The slope raster was reclassified to reflect desired slope values to equal 0–2° = 50, 2°–5° = 30, and >5° = 5. The solar radiation analysis tool within the Spatial Analyst extension of ArcGIS

was then used to determine the amount of radiant energy that was received from the sun for each grid square included within the DEM. This function was used in place of the "aspect" function that calculates the downslope direction of grid squares where a value is assigned by the operator, which corresponds to the expected amount of radiant energy that particular aspect would receive. Before running the solar radiation analysis tool, the integrated DEM was resampled to a grid cell size of 100 m to reduce the file size and processing time. Solar insolation was calculated for the winter solstice and classified into seven standard deviation (STD) levels to include: STD 1 = 408–476, STD 2 = 476–481, STD 3 = 481–487, STD 4 = 487–492, STD 5 = 492–497, STD 6 = 497–503, STD 7 = 503–568 (values rounded to the nearest whole number). Winter solstice was used to represent the low end of values expected within an annual insolation pattern of each cell being sampled. The seven classes were then reclassified into grid values equaling STD 1 = 0, STD 2 = 5, STD 3 = 25, STD 4 = 40, STD 5 = 65, STD 6 = 80, STD 7 = 100. The 100 m grid was then resampled back to a 10 m cell size for analysis.

We purposely removed the categories of bay/estuary, river/stream mouth, and coastal bluff from our calculation matrix because these areas would receive numerical modifiers simply on the account that they represented zones of overlap between buffered coastline and stream rasters. We envisioned difficulty in correctly identifying headlands within modeled paleolandscapes on the POCS and simply increased the coastline buffer inland by 200 meters to capture its heightened site location potential value. The summed values of POCS rasters produced quantitative variance across space that symbolize hypothetical patterns of coastal site location.

The POCS became inundated as sea level rose after 19,000 cal BP, steadily moving the coastline and its buffered raster values farther eastward through time, ultimately resulting in a distribution of coastline raster values across the entire POCS. This reflects an important postglacial pattern of marine inundation—the Pacific shoreline and its associated settlement potential stood at thousands of different positions during the past 19,000 years, moving the higher productivity shoreline and estuary zones inland through time. When viewed from a modern perspective, this complete distribution of raster values across the POCS provides a realistic model of potential site locations given that every grid square was either coastline or estuarine habitat at some point during the history of marine transgression. However, we expect that sites are most likely to be concentrated or will have the greatest area extents in those areas that experienced estuarine conditions at one point in time. Therefore, estuary locales consistently scored highest in our GIS model.

Our GIS model also aggregated geophysical data from all available datasets near the NCI (e.g., USGS, NOAA, BOEM, MBARI). A thorough literature review and search for available data was conducted, and results from previous geophysical surveys were collected and reviewed. A critical component of this was mapping all the recorded subaerial terminal Pleistocene and Early Holocene archaeological sites on the NCI older than ~8500 cal BP, which can provide a roadmap for narrowing targets in our offshore exploration. These data were synthesized into our GIS analysis and aggregated potential site distribution scores into one-hectare grid squares between and adjacent to the shorelines of interest (**Figure 3**).

We then consulted our GIS model to target high probability areas for geophysical surveys, first broad regional surveys and then more targeted surveys. In total, we collected ~190 km of high-resolution subbottom Chirp survey lines around the NCI from NOAA's R/V *Shearwater*, using Scripps Institution of Oceanography's Edgetech 512i X-star Chirp system. A Klein 455 sidescan sonar was towed simultaneously, and a total of 65 regional survey lines were run. These initial geophysical surveys were designed to capture images of large swaths of the seafloor and sub-seafloor for broad scale paleolandscape interpretations. Chirp data were processed using SIOSEIS and Seismic Unix software to remove heave artifacts and adjust gains. Sidescan sonar data were processed by the National Park Service and provided as mosaic seafloor images, and all data were imported into an IHS Kingdom Suite software package (www.kingdom.ihs.com) and ESRI ArcGIS v. 10.5 (www.esri.com) for interpretation. Kingdom Suite was used to calculate layer thicknesses and the depth to acoustic reflectors. A nominal sound velocity of 1500 m/s was used to convert time to depth.

Regional data were interpreted and four 1 km² areas were selected for targeted, high-grid spacing (25 m) geophysical surveys. This survey focused on small sections of the landscape deemed to have high potential to yield paleolandscape and paleoenvironmental data, and to potentially contain submerged prehistoric archaeological sites. The second geophysical cruise effort was completed aboard the R/V *Point Loma* using a Reson 7125 multibeam sonar operated at 400 kHZ and an Edgetech 512 profiler at 1–15 kHz. A total of 112 survey lines, covering ~112 km, were run during this effort. To fill gaps in this survey, a second set of high-grid spacing lines were collected aboard the R/V *Sally Ride*, using a Kongsberg EM712 multibeam and Knudsen 3.5 kHz subbottom profiler.

Erlandson (2016) had previously identified and our GIS predictive model confirmed one locality along the NCI with the highest research potential for identifying preserved prehistoric archaeological sites – the submerged paleolandscape between Santa Cruz and Santa Rosa islands (**Figure 4**). During the terminal Pleistocene, sea levels around the NCI were between about 65 and 55 meters below present. At the time, Santa Rosa and Santa Cruz islands were connected by a broad coastal lowland now submerged beneath the Santa Cruz Channel, through which five of the largest drainages on the islands flowed into a large submarine canyon that would have provided access to pelagic and deepwater fisheries. Reconstructions of the paleogeography of this area identified a large south-facing embayment (Crescent Bay) protected from the northwest wind and wave patterns that
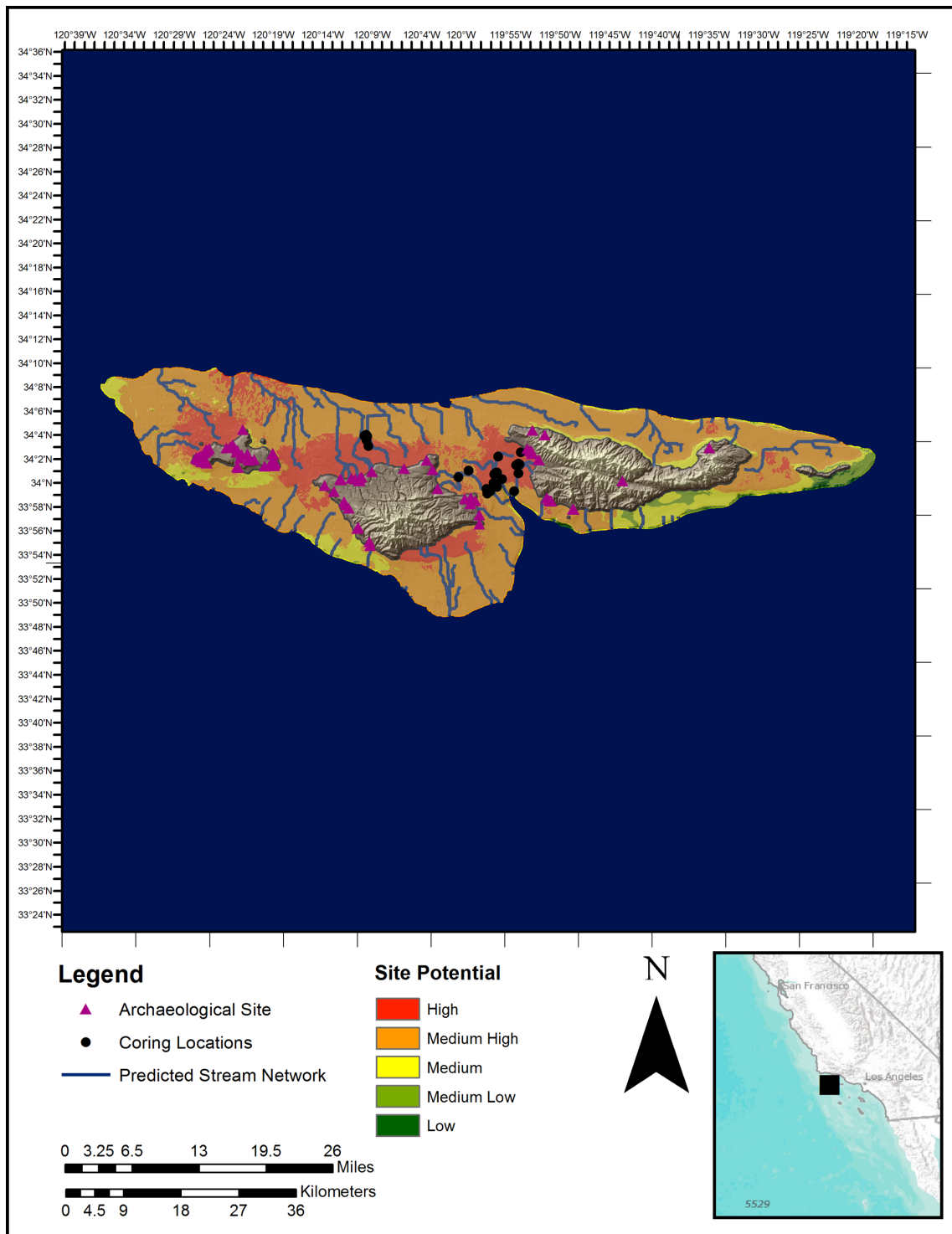
Figure 3: GIS predictive model results from the Northern Channel Islands showing a heat map of high probability areas (the warmer the color, the higher probability) for submerged prehistoric archaeological sites. The approximate locations of subaerial terminal Pleistocene and Early Holocene sites also are included. Shoreline contour at ~18kya derived from Clark et al. (2014), map by Nyers.

hammer the north coasts of the islands for much of the year (Erlandson, 2016). Only after about 9,000 years ago was the land bridge that connected northeastern Santa Rosa and northwestern Santa Cruz Island sundered, creating a Santa Cruz Channel that is now a minimum of 9 km wide. At least one estuary existed in the Crescent Bay area and probably extensive marshes and wetlands, as well, along with abundant freshwater and a variety of marine and terrestrial resources. Today, there are no estuaries on the NCI, but archaeological data show that an estuary existed near the mouth of Old Ranch Canyon on southeastern Santa Rosa between about 11,200 and 5,000 years ago (Erlandson et al., 2019; Rick, 2009); and pollen cores in the area document a transition from estuarine to freshwater marsh habitats over the past ~6,000–7,000 years (Anderson et al., 2010).
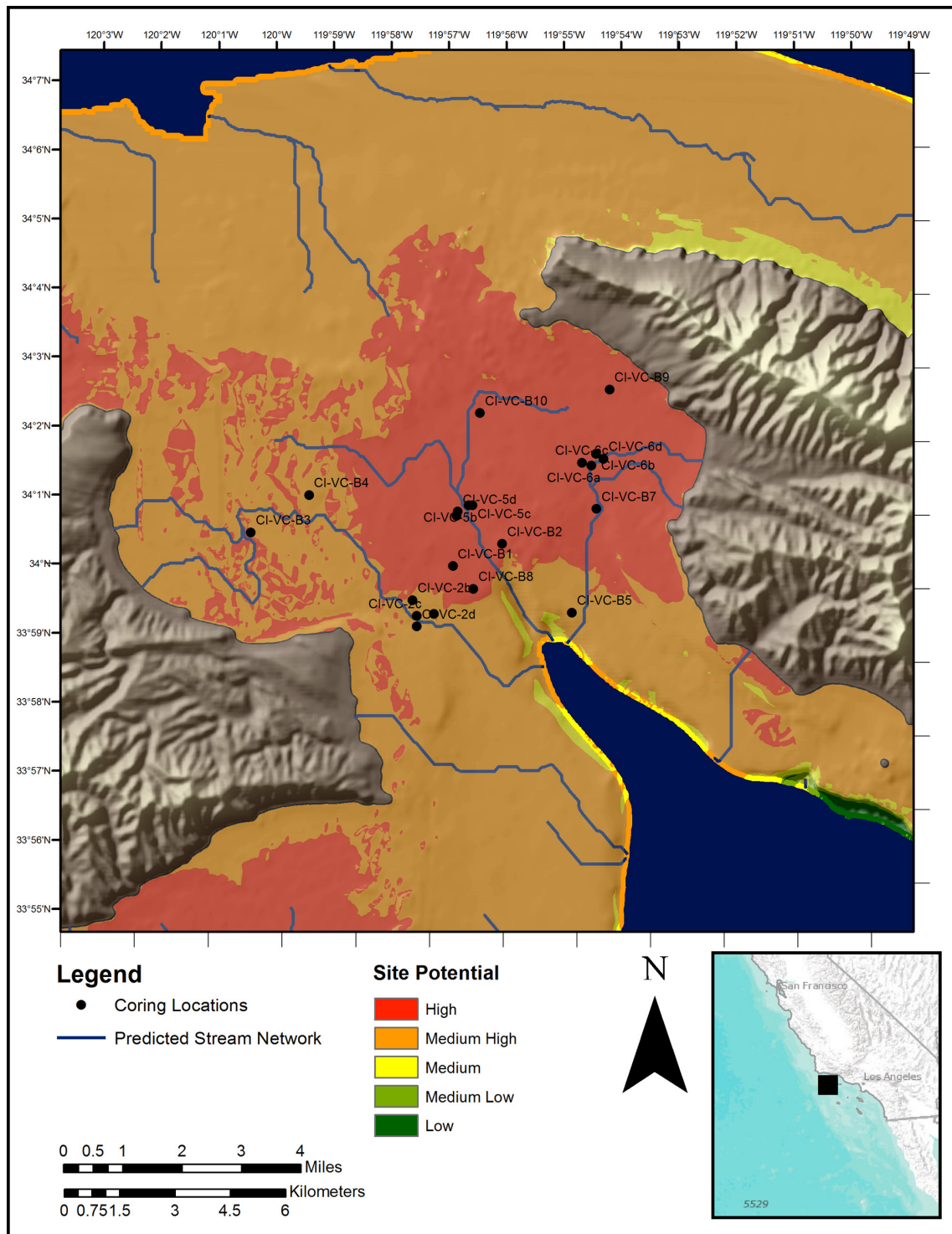
Figure 4: Map of the location and paleogeography of *Santarosae* at the Crescent Bay locality. Results of our GIS predictive model heat map are included, along with the locations of offshore coring locations, map by Nyers.

Subaerial archaeological reconnaissance on eastern Santa Rosa and western Santa Cruz islands demonstrate that the uplands surrounding the larger Crescent Bay area were a magnet for Paleocoastal peoples—with at least 26 sites that produced crescents and CIB points and/or radiocarbon (^{14}C) dates older than ~8500 cal BP have been identified (Erlandson et al., 2019; Gusick and Erlandson, 2019). Most of these sites appear to be short-term encampments overlooking the paleoestuary, where hunter-gatherers retooled their hunting technologies and scouted seabird prey at Crescent Bay. Two sites, however, demonstrate that Paleocoastal peoples also established longer-term occupations in the area. One of these is CA-SRI-708, a large and multicomponent shell midden located near the current mouth of the perennial Water Canyon, which produced a diverse array of rocky shore and estuarine shellfish remains, bird, fish, and marine mammal bones, and several crescents and CIB points from an indurated paleosol dated to ~11,100 cal BP (Erlandson et al., 2019).

To the north, a discrete paleosol in an even larger site known as CA-SRI-997/H, ^{14}C dated between ~11,700 and 10,500 cal BP, produced crescents and CIB points and thousands of pieces of chipped stone tool production debris. Paleogeographic reconstructions suggest that CA-SRI-997/H may have been situated as much as 5 to 8 km from shoreline and coastal habitats during its occupation and was probably positioned to take advantage of the freshwater along Cherry Canyon (Braje and Erlandson, 2019). Flotation samples from CA-SRI-997/H produced carbonized *Brodiaea*-type (c.f., *Dichelostemma capitatum*) corm and Mariposa lily (*Calochortus* spp.) bulb fragments – two geophytes that were harvested by the Island Chumash and their ancestors for millennia (Gill, 2015, 2016) – suggesting that plant foods also drew Paleocoastal peoples away from the coast beginning at least 11,600 years ago. CA-SRI-997/H is one of four Paleocoastal sites recorded recently along a 750 m stretch of the south bank of Cherry Canyon (Erlandson et al., 2019), suggesting that the offshore extension of Cherry Canyon should be considered an area of high archaeological potential.

5. Results and Interpretations

Guided by this impressive cluster of terminal Pleistocene and Early Holocene sites located around the upland margins of Crescent Bay, we concentrated much of our geophysical mapping efforts in the Santa Cruz Channel (**Figure 5**). Geophysical surveys resulted in the identification of interpreted dune environments, paleochannels where several large streams flowed into the Santa Cruz Canyon (**Figure 6A**), and buried paleoshorelines. Sonar surveys also identified what may be preserved estuarine deposits capped by Holocene marine sediments along the margins of the Santa Cruz Canyon (**Figure 6B**). Broadly, the subbottom data revealed variable acoustic units below a regional unconformity that is interpreted to represent the subaerial surface exposed during lower sea level and re-worked during sea level transgression (transgressive surface). In many areas, the transgressive surface is capped by what are interpreted as Holocene sediments deposited during sea level rise and subsequent highstand.

Several subbottom profiles revealed morphology associated with paleoshorelines. As in subaerial marine terraces, the transgressive surface was imaged and interpreted, identifying gently dipping abrasion platforms and more steeply dipping paleo-seacliffs. Intersections of these surfaces are believed to represent paleoshorelines, formed during times of lower sea level. In total, seven paleoshorelines were mapped around the NCI platform. Using a local sea level curve (Clark et al., 2014), three of these paleshorelines were attributed to the Younger-Dryas (~12.8–11.5 ka), a period of slowly rising sea level after the LGM (~18.5–13.0 ka), and the LGM (~20 ka). Many of the mapped paleoshorelines are buried beneath Holocene sediments and are not observed in modern seafloor bathymetry. Therefore, while useful over larger regions, models of paleoshorelines that use modern bathymetry may miss preserved paleoshoreline features and misinterpret the distance of modern shorelines and subaerial Paleocoastal sites from ancient shorelines (Laws et al., 2019). However, the burial of submerged paleoshoreline features by Holocene sediments may also mean that archaeological resources are preserved in these locations.

Several paleochannel features were also identified in subbottom profiling data within the Santa Cruz Channel. These paleochannels appear as irregular, chaotic, erosive surfaces below the transgressive surface that have a U- or V-shaped morphology (**Figure 6A**). The features are filled with sediments that have a different character than the surrounding geology. One such feature was observed in the center of the Santa Cruz Channel, immediately northwest of the head of the submarine canyon. The feature appears as a wide paleovalley with several smaller, V-shaped paleochannels within the valley (**Figure 6A**).
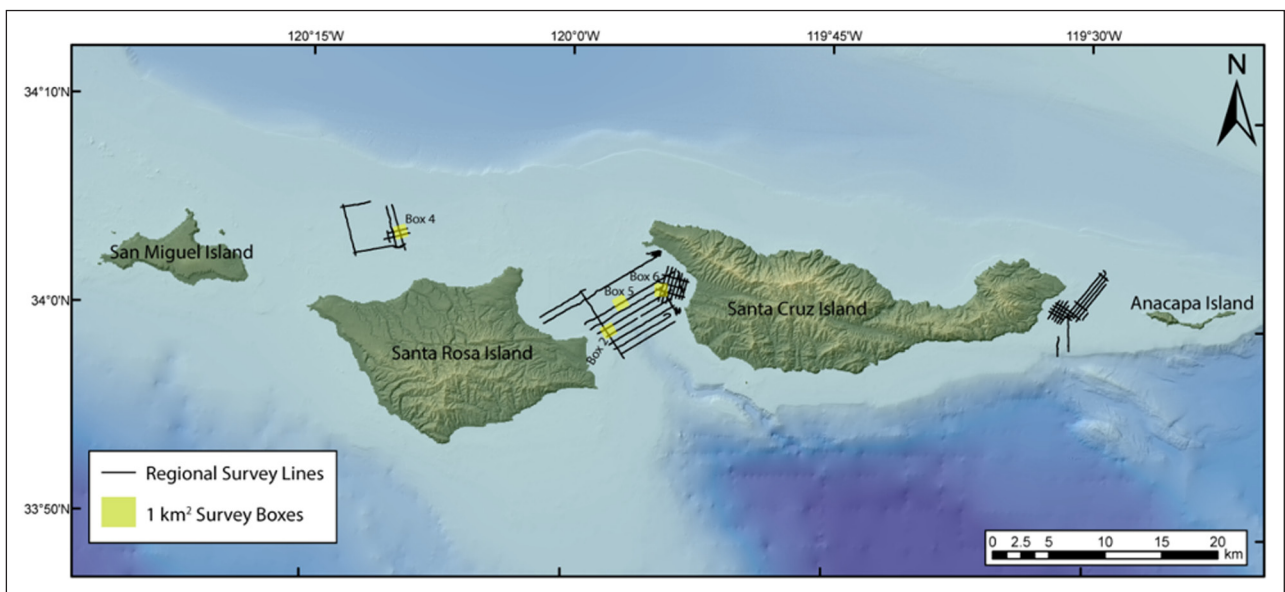

Figure 5: The Northern Channel Islands geophysical survey study area with the locations of our regional track lines and the four 1 km² detailed survey box locations.
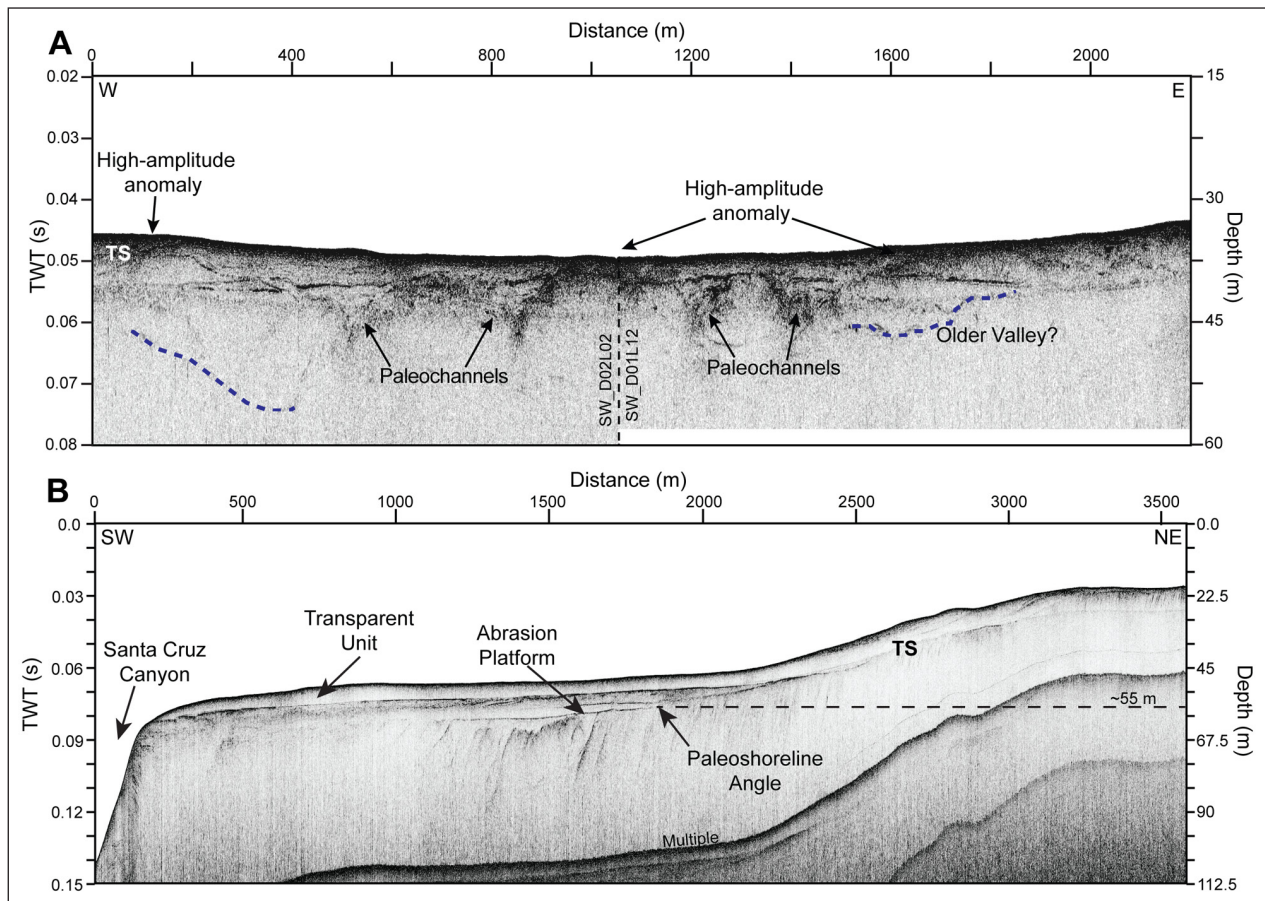
Figure 6: Two subbottom profiles within Santa Cruz Channel. **A.** Located just north of the head of Santa Cruz Canyon, a wide, deep valley is interpreted (dashed blue lines) with several smaller v-shaped channels at shallower depth. The paleochannels have a chaotic signature at the bottom with some lamination at the top, differing from the more homogeneous surrounding units. Several high amplitude anomalies are imaged along the banks of these channels. As sea level rose, the incised channels could include fluvial deposits, followed by estuarine and coastal deposits, and then finally marine sediments at the top. The dashed vertical line at center indicates where two adjacent profiles were stitched together; TS = transgressive surface. **B.** Profile extending east from Santa Cruz canyon showing characteristic paleoshoreline morphology with gently dipping abrasion platform that increases in slope moving landward. The location of change in slope is interpreted as the paleoshoreline. The upper transparent unit is interpreted as Holocene marine sediment. More chaotic sediment near the canyon edge could reflect a different depositional environment, such as an estuary.

The channels and valley are covered by Holocene sediment of variable thickness. At the banks of the V-shaped channels, several subbottom profiles imaged high-amplitude (dark) anomalies that represent material different from the surrounding sediments. The channel margin location and acoustic character of the anomalies are similar to subbottom profiles from other areas (e.g., the Gulf of Mexico) where archaeological ecofacts and artifacts have been discovered (e.g., Faught, 2014).

6. Conclusions and Future Directions

Around the world, submerged maritime landscapes represent one of the last frontiers for archaeologists working in island and coastal settings. In the search for submerged terrestrial sites on the continental shelves of the Americas and around the globe, archaeologists, marine geologists, and other scientists must develop methods for effectively and efficiently narrowing search targets. The distribution of terrestrial archaeological sites along adjacent shorelines and

other landforms, along with the careful mapping of paleoecological and paleoenvironmental resources that may have attracted human settlement, can be an effective first step (e.g., Dixon and Montelone, 2014; Mackie et al., 2017; Fedje and Josenhans, 2000). For late Pleistocene sites, the challenges grow with greater water depths and distances from shore. Offshore sonar mapping can target paleoshorelines and paleolandforms that may have been suitable for human habitation on the continental shelf that are within depths that can be sampled and ground-truthed. Sea floor coring can reach even relatively deep waters, although the sample size of such excavations is very limited.

Our predictive GIS model, informed by the subaerial Paleocoastal archaeological record and knowledge of *Santarosae*'s paleogeography and paleoecology, helped direct high-resolution offshore geophysical mapping and the identification of paleolandscapes and features that could contain submerged archaeological resources. The next step in our research is the analysis of numerous

sediment cores that targeted offshore paleochannels, high-amplitude reflectors, and possible paleosols identified in sonar imaging. The results will help refine GIS modeling efforts and build best-practices in the search for early maritime peoples along the New World Pacific Coast and in similar regions around the globe.

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Competing Interests

The authors have no competing interests to declare.

Author Contributions

TB conventionalized and drafted the manuscript. JM, JE, and LD helped write sections. All authors contributed data, helped edit and revise the manuscript.

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