Modeling and monitoring submerged prehistoric sites during offshore sand dredging and implications for the study of Early Holocene Coastal Occupation of Southern California

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Abstract
Beach sand dredging projects off the coast of Southern California provide data for improved understanding of the stratigraphic setting for early Holocene sediments and the potential for offshore buried archaeological materials. Geophysical data, core sediments, and invertebrate fossils allow models to be developed for six borrow sites within drowned river valleys off San Diego County. These site-specific models were tested during dredging operations, and the dredge spoil was monitored for archaeological materials. Two of the borrow sites yielded stone bowls consistent with those found in previous offshore archaeological investigations in this region. These artifacts, however, were determined to come from nearshore and lagoonal sediments, not appropriate for direct occupation, raising questions about both the function of stone bowls and the process that resulted in their deposition. The competing hypotheses presented are that these bowls originated in settlements located adjacent to the lagoons, but were eroded and redeposited into the lagoon during transgression, or that they were part of a fishing toolkit used from boats or in shallow waters within the lagoon. This project illustrates the potential for commercial development projects to yield information on submerged archaeological resources, as well as the challenges.

KEYWORDS
coastal California, early Holocene, sand dredging, stone bowls, submerged archaeology

1 | INTRODUCTION

The potential for archaeological materials to be present on continental shelves exposed during the last glacial–interglacial cycle has long been known (Bickel, 1978; Fladmark, 1979; Shepard, 1964). During the last glacial maximum (LGM) at ~20,000 cal BP, eustatic sea levels were lower by as much as 125 m below the present sea level (mbsl), exposing continental shelves to human settlement and suggesting that components of the late Pleistocene and early Holocene archaeological record may be located within the now-submerged landscape. At ~15,000 cal BP, sea levels rose rapidly (Figure 1), beginning with the Meltwater Pulse 1A (Peltier, 2005), except for periods of pause during the cold periods of the Younger Dryas at 12,800 cal BP (Alley, 2000), and the 8.2 kyr event...
The challenge is often in associating these finds with a chronological and paleoenvironmental context based on details for their provenance and its geological setting. With directed research, the context for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizzard et al., 2014), for accidentally recovered offshore archaeological material can be provided, such as for Area 240 in the North Sea (Tizard et al., 2014), where geophysical survey, vibracoring, and bottom sampling were conducted following accidental artifact discovery.

1.1 Southern California–Early evidence

The nearshore environment off La Jolla, California, was one of the first locations where it became clear that prehistoric archaeological materials were present in a submerged context (Carter, 1955; Tuthill & Allanson, 1954). With the advent of scuba diving, and the presence of the adjacent Scripps Institution of Oceanography, these underwater prehistoric sites were further explored (Marshall & Moriarty, 1964; Moriarty, 1969) and their geological context was described (Moriarty et al., 1975) along with an emerging understanding of sea-level rise and the implications for their considerable antiquity. Understanding of coastal sediment transport and geomorphology were added in the 1970s and the 1980s (Inman, 1983; Masters, 1983, 1985) to provide a detailed model for these submerged landscapes and a context for the site localities.

From the earliest studies, it was found that a ubiquitous component of the Southern California submerged archaeological assemblages were stone bowls, an item of human manufacture, but uncommon in subaerial archaeological sites (Gallegos, 1987; Masters, 1983). These stone bowls were found offshore as far north as the Santa Barbara Channel Islands region, and there, Hudson and Howorth (1985) considered whether they may have been redeposited from a subaerial context, ceremonially deposited in the sea, or a byproduct of fishing activity. To be clear, smaller artifacts such as beads, lithic tools, and projectile points have also been discovered offshore (Hudson, 1979), but the stone bowls have become the iconic submerged artifact recognizable both by recreational divers (Fuson, 1958) and during systematic surveys (Muche, 1978).

1.2 Models for submerged landscapes

A key question is how archaeological materials and their associated paleolandscapes may have been preserved or altered during inundation. Modeling of submerged landscapes has been proven to be an effective means for understanding the presence of prehistoric sites (Faught, 2004; Flemming, 1985; Josenhans et al., 1997; Mombè, 2000). The key elements of these models include an estimate for local sea-level rise, an understanding of ancient settlement patterns, and an assessment of the impact of transgression on coastal sites. Data on marine bathymetry, stratigraphy, and sediment type can then be compared with the model to predict site location.

The sedimentary signature of marine transgression on the Southern California continental shelf has been studied using subbottom sonar surveys (Klotsko et al., 2015). This study documented an abrasion platform at ~72–53 mbsl associated with the Younger Dryas. Three sedimentary units were then identified, the deepest interpreted as infilling of the Younger Dryas abrasion platform, a middle unit infilling that may be interpreted as the 8.2 kyr event, and the upper unit modern sedimentary deposition associated with the current period of sea-level stability. Although the sedimentary sequence at the headlands between river valleys is presented, Klotsko et al. (2015) do not provide insight into the expected sequence within the drowned river valley, a zone where it may be possible to preserve late Pleistocene and early Holocene sedimentary sequences and potentially early archaeological materials.

Inman (1983) provided a geological model for the nearshore landscape, including river valleys, during the last glacial cycle. At the LGM, lowered sea level resulted in streams and rivers carving deep valleys into the continental shelf. During this time period, steepened stream valley gradients allowed transport of coarse sediments and cobbles to the shoreline, resulting in rocky and cobble beaches. After sea levels began to rise, these river valleys were flooded to form lagoons. River sediment was then deposited at the heads of the bays, but did not reach the shorelines, maintaining only rocky and cobble beaches. During periods where the rise of sea level paused, or slowed significantly, marine wave-cut platforms were developed on the coastal profile, with a nearly flat profile just offshore from a sea cliff.

FIGURE 1 Sea-level curve for the Southern California coast. Model (red line) for the Channel Island area (Reeder-Myers et al., 2015); boxes show dated Santa Monica Bay mollusks (Nardin et al., 1981), and dots show dated materials from this study. Gray bars show the period of Younger Dryas (YD) and the 8.2 kyr cold event. [Color figure can be viewed at wileyonlinelibrary.com]
at the shoreline, and these periods of stability provided the opportunity to develop sandy beaches. As sea level rose further, the now-offshore portions of the lagoons became drowned and filled with sediment eroded from the new shoreline. During the most recent time of sea-level stability, the remaining portions of the lagoons became filled with sediment, eventually resulting in a salt marsh or mudflat. As these lagoons were filled with sediments from inland rivers, the beach was transformed from one consisting of rocks and cobbles to one dominated by sand.

A model for drowned river valley sediments, based on Inman (1983), is presented in Figure 2. In the basal portion of the river valley are fluvial deposits that represent the pretransgressive fill of the valley. For the San Diego region, these deposits are poorly sorted sands and gravel, deposited during irregular periods of flooding. Freshwater marsh or mudflat sediments may be present in the pretransgressive sequence, located within or above the fluvial sediments. Overlying the marsh and fluvial sediments within the submerged valleys are sediments deposited following the marine transgression, consisting of intertidal, estuary, lagoon, and nearshore marine deposits. Typically, the marine sediments overlie fluvial/marsh sediments where they exist, or they alternatively may overlie basement (rocks of Miocene, Eocene, or Cretaceous age for the selected dredge sites, potentially capped by paleosols or Pleistocene sediments). The model may have limitations in its application to a specific field location, for instance, in variations of the impact of transgression on locations that might have been areas of settlement.

Despite the early discovery of archaeological materials and improved understanding of submerged paleolandscapes (Braje et al., 2019; Laws et al., 2020), there has been relatively little progress in underwater prehistoric site documentation off Southern California in the past few decades. At the same time, the existing coastline is increasingly threatened by reinvigorated sea-level rise related to climate change (Reeder et al., 2012) as well as a scarcity of terrestrial sand input due to damming of local rivers (Brownlie & Taylor, 1981).

### Offshore investigations

The paleolandscape modeling and dredge monitoring presented here was one component of a Regional Beach Sand Project (RBSP) to mitigate coastal flooding and erosion (Griggs & Kinsman, 2016). About 1.5 million m$^3$ of sand were mined in 2001 ($17.5$ million cost) and 1.3 million m$^3$ were mined in 2012 ($28.5$ million cost). As part of this effort, a model was created to predict the probability of encountering archaeological materials within a borrow site, and the sand deposited on nourished beaches was monitored for evidence of archaeological materials (York & Hildebrand, 2010). Stone bowls were detected in the monitored dredge spoils, and here, we consider their context and implications for site preservation.

## 2 | BACKGROUND

### 2.1 Early Holocene cultural context of Southern California

The earliest archaeological record for coastal Southern California comes from the Northern Channel Islands, where human occupation began by at least 12,000 cal BP (Erlandson et al., 2020; Johnson et al., 2002). Mainland Southern California sites have not been found with dates exceeding ~11,000 cal BP (Lebow et al., 2015). Early coastal sites, those dating more than 9000 cal BP, have been characterized as the Paleo-Coastal Tradition (Moratto, 1984). Early subsistence is primarily from fishing and shellfish collection, with milling not extensively practiced at these early times. These coastal populations are thought to have been at low density, and sites from this period are expected to be small, with minimal archaeological deposits. After 9000 cal BP, coastal cultures are better documented, with a population expansion at 9000–8500 cal BP, a period called the Millingstone Horizon (Fitzgerald & Jones, 1999; Wallace, 1955), reflecting the abundant use of metates and manos. Most sites of this period are at or near the coast, and environmental data suggest cooler seawater temperatures and marine productivity higher than at present (Kennett et al., 2007), so that the coastal zone supported higher populations than the interior during this time. In addition, rising sea levels would have produced widespread lagoons, estuaries, and tidal wetlands. Coastal sites of this time frequently contain high densities of marine resources. At around 6000 cal BP, there was an ocean warming trend (Kennett et al., 2007; Scott et al., 2011), and mortars and pestles were used for the first time, suggesting that diets may have included a greater variety of plant foods, such as acorns.

### 2.2 Data collection

The focus of our study was the submerged extensions of river valleys along the San Diego County coast (Figure 3) in the depth range 10–30 mbsl, which corresponds to the shoreline during the period 9000–6000 cal BP (Figure 1). Subbottom profiler data were used to delineate stratigraphy, along with sediment cores that were obtained from 111 locations distributed across six borrow sites. Analyses were conducted to determine the grain-size distribution, examine the range of invertebrate species, and collect organic samples for dating.
Geophysical data, vibracore logs, and core photographs, as well as sediment grain-size analyses produced by our study are available in the Dryad Digital Repository (Hildebrand & York, 2021). The invertebrate fossils found in the vibracores helped determine the sediment depositional context by comparison to known habitat by species (MacGinitie & MacGinitie, 1968; McLean, 1978; Oldroyd, 1924; Palmer, 1958). Table 1 lists invertebrate fossils found in the cores and their habitats. These species are divided between those that require sedimented and those that require rock or cobble substrates. Their habitats are further divided between those that inhabit the shallow back lagoon and the deeper fore lagoon versus those that are found in the intertidal outer coast, shallow (<100 m) offshore, and deep (>100 m) offshore. Both shell and charcoal were collected from the cores for radiocarbon dating, selected to be at or near the beginning of marine transgression. Marine shells were selected for species representing intertidal habitats, while charcoal samples were selected based on their position in the sedimentary sequence.

The RBSP conducted two sand dredging campaigns separated by 10 years (RBSP1 in 2001 and RBSP2 in 2012). The project mined sand from six submerged borrow sites and the sand was deposited on 12 receiver beaches (Table 2). Both campaigns used trailing suction hopper dredges with dual dredge heads. Ship position was monitored using GPS, and the two hopper dredge head positions and depths were estimated relative to the ship and corrected for the tides. The dredge vessels loaded sediment from the borrow sites into an onboard hopper and then transited to the receiver site, where discharge lines were positioned to receive a slurry of sediment and water. Earthmoving equipment repositioned the sand between periods of active discharge.

Monitoring for archaeological materials was conducted during daylight hours over the duration of the projects. The use of heavy equipment and the high rate of discharge of the sand slurry made the process of monitoring the discharge intermittent, during the time period after the completion of offloading the vessel and spreading of the newly discharged material using the heavy equipment.

3 | RESULTS

3.1 | Radiocarbon dates

Samples obtained from the sediment cores were submitted for radiocarbon dating, selected to be at or near the period of marine transgression (Table 3). With one exception, all the calibrated dates fall within 500 years of the 8.2 kya event, consistent with the idea that this period resulted in an erosional platform and development of an intertidal deposit. The implication of these dates will be further discussed in the context of each borrow site.

3.2 | Borrow Site Models

For each borrow site, a model for the submerged extent of the river valley and the sedimentary structure within the river valley was created using the geophysical and sediment core data.

3.2.1 | SO9 Santa Margarita River

Borrow site SO9 (Figure 4) is located along the southern margin of the Santa Margarita River Valley (SMRV) Valley in northern San Diego County (City of Oceanside). Here, the seafloor is covered by Holocene nearshore sediments, and evidence of the river valley margins of the SMRV extension is limited to only a small area of rock outcrops along the southern margin of the valley, and along the north, only small patches of kelp are present (requiring a rocky sea bottom to anchor). The SMRV is shown by previous seismic data (Darigo & Osborne, 1986) to converge with the next drainage system to the south (San Luis Rey River) and the SRBP subbottom profiling and core data suggest a southward turn to the SMRV southern margin (Figure 4). Cores collected at water depths of 15–18 m reveal an intertidal sediment layer at ~3 m depth. The paleochannel apparent in the geophysical data appears to extend deeper than the vibracore depths. Cores collected along the 10 m contour...
contain only nearshore and lagoonal sediments with ill-defined or non-existent intertidal sediments at this depth. Dredging at SO9 (shaded area Figure 4) removed 28,000 m$^3$ of material, with a maximum dredge bottom penetration of ~1 m, and yielded only fine sediment. No archaeological materials were detected during beach monitoring.

### 3.2.2 SO7 Batiquitos Lagoon

Borrow site SO7 (Figure 5) is located offshore from Batiquitos Lagoon, within the paleochannel of San Marcos Creek. The margins of the river valley are well defined by areas of rocky sea bottom and kelp as well as being encountered at shallow depths in cores. At sea bottom depths of 18–25 m, sediment cores within the river valley reveal a thin layer (<1 m) of nearshore sediment above 4 m or more of intertidal and fluvial sediments. The thick intertidal deposit and its ~20 mbsl depth suggest that it is on the erosional platform of the 8.2 kyr event. Although this transgressive surface is expected to date from ~8000 cal BP, a donax (bean clam) shell collected from just above the transgressive interface yielded a date of 1150 cal BP (Table 2), suggesting that the intertidal deposit may have been reworked over an extended period, perhaps as a tidal bar at the entrance to the lagoon. Owing to the desirable sand present at this borrow site, 729,000 m$^3$ of material was removed, with an average depth of removal of 2 m and a penetration of <5 m beneath the seafloor. Ample shell was present in the monitored deposit, including within the final dredge loads, suggesting that the dredge may not have extensively sampled beneath the intertidal/fluvial boundary, although the dredge ship reported that "hard bottom" conditions were encountered in

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<th>Outer coast intertidal</th>
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Note: All are mollusks except for Dendraster, the sand dollar.
some areas of the dredge pit during the latter phases of dredging. No archaeological materials were recovered during monitoring.

### 3.2.3 | SO6 San Elijo Lagoon

Site SO6 is offshore from San Elijo Lagoon and Escondido Creek (Figure 6). Two borrow sites were used here: one on the northern margin and one within the paleochannel. In this area, bedrock shelves border the paleochannel to the north and south, with extensive areas of bare rock and kelp cover. Geophysical data suggest that the deepest portion of the paleochannel is along the southern margin of the river valley, the location of the 2012 borrow. Sediment cores reveal a ∼1 m layer of nearshore sediment, above 2–5 m of lagoonal deposit. The transgressive interface has a well-defined intertidal sand. A *Mytilus* shell within the deepest portion of the paleochannel provided a date of 7940 ± 40 cal BP above the transgressive interface and an *Olivella* shell a shallower depth within the intertidal sand provided a date of 7520 ± 0 cal BP (Figure 6); both occur during the time period following the 8.2 kyr event. In the northern (2001) borrow site, 91,000 m³ of material was removed, primarily in the southern 1/3 of the borrow area, with penetration of no more than ∼3 m; little shell was encountered in the dredged material. In the southern (2012) borrow site, 227,000 m³ of material was removed, with penetration of no more than ∼3 m.

A stone bowl mortar or basin metate (Figure 7) was recovered during the third day (October 7, 2012) of dredging operations at SO6 in the southern borrow, collected from the Oceanside receiver site (load 108, 109, or 110). Although the exact depth is uncertain, it was buried no deeper than ∼1 m within the deposit, within the nearshore sediment, or at the nearshore/lagoonal sediment interface. The bowl was fashioned from a roughly rectangular cobble of fossiliferous sandstone derived from the Delmar Formation. The artifact was broken in the dredge pipe and only ∼50% of it was recovered (weight 7.7 kg). The exterior is unshaped and, it appears that the interior grinding surface was created by rough pecking. The interior surface is heavily ground, and the bottom of the grinding surface has been resharpended by additional pecking. The surface concavity is ∼7 cm deep and ∼60 cm wide, with unknown length.

### 3.2.4 | SO5 San Dieguito River

The SO5 borrow site (Figure 8) is located within the submerged paleochannel of the San Dieguito River. The geophysical data suggest a set of relic channels within the river valley, with the deepest in the northern portion of the river valley. Bedrock shelves border the river valley to the north and south, with extensive areas of bare rock and kelp cover. Sediment cores reveal a ∼1 m layer of nearshore sediment above 2–5 m of lagoonal deposit. A *Donax* shell within the deepest portion of the paleochannel provided a date of 7940 ± 40 cal BP above the transgressive interface and an *Olivella* shell a shallower depth within the intertidal sand provided a date of 7520 ± 0 cal BP (Figure 6); both occur during the time period following the 8.2 kyr event. In the northern (2001) borrow site, 91,000 m³ of material was removed, primarily in the southern 1/3 of the borrow area, with penetration of no more than ∼3 m; little shell was encountered in the dredged material. In the southern (2012) borrow site, 227,000 m³ of material was removed, with penetration of no more than ∼3 m.

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## Table 2

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<td>6</td>
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<tr>
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<td>2766</td>
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</table>

Note: All values in 10³ × m³. Figure 4 shows the borrow site locations.

## Table 3

<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth (mbsl)</th>
<th>Age (cal yr BP)</th>
<th>Core</th>
<th>Depth in core (m)</th>
<th>Material</th>
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<td>7770 ± 50</td>
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Note: Depth in meters below the present sea level. Age in calibrated years BP. Borrow site and core number. Depth from the top of the core. Material used for dating, either species of mollusk or charcoal. Abbreviation: mbsl, meters below present sea level.
sediment, above 2–4 m of lagoonal deposit. The transgressive interface has a 1–2 m thick layer of intertidal sand. An *olivella* shell within the southern portion of the paleochannel provided a date of 7960 ± 40 cal BP within the intertidal sand (Figure 8). In the western (2001) borrow site, 543,000 m$^3$ of material was removed, with penetration of no more than ∼2 m; ample shell was encountered in the dredged material. In the eastern (2012) borrow site, 598,000 m$^3$ of material was removed, with penetration of no more than ∼4 m.

A sandstone bowl mortar (Figure 9) was recovered at the Solana Beach receiving site from dredging operations at SO5 on November 6, 2012. This specimen is a fragment of ∼25% of the original artifact, including portions of the rim and wall. Although its original dimensions cannot be determined, the bowl was approximately 3.4-cm thick. It appears to have been well shaped, with evidence of pecking visible on the exterior surface, and evidence of use can be seen on the mortar’s interior surface. Dredge records indicate that on the day this artifact was removed, the dredge was operating entirely in the west half of the borrow area in water depths between about 13.5 and 16.5 m. The great majority of the dredging was done between 13.5 and 14.5 m, along a relatively narrow strip near the center of the borrow. The recorded depths of the draghead range from about 14–18 m below the surface, indicating that the dredge was working between 0.3 and 3 m of sediment depth, with the majority of the work (>80%) between 1 and 2.4 m. The upper 1 m of sediment at SO5 consists of nearshore deposits, while between 1 and 3 m is lagoonal sand (Figure 8), making it likely that the artifact was recovered from the lagoonal deposits.

A nearly complete sandstone mortar (Figure 9) was found at the North Carlsbad receiver site in spoil that was removed from SO5 on November 26, 2012. It is roughly circular, shaped by percussion-removal of large pieces around the exterior. One piece was recently removed from the rim, probably during the
dredging process. The concavity measures 14 cm in diameter and 3.9 cm in depth and was created by pecking to form a working surface. Although this bowl’s rough exterior shaping presents an unfinished appearance, there is substantial wear on the surface of the concavity that indicates use. This specimen was fashioned from a distinctive marine sandstone material containing fossil oyster shells, likely from the Delmar Formation that is exposed along sea cliffs between La Jolla and Encinitas (Bergen et al., 1997). On the day the artifact was removed from SO5, approximately 90% of the dredging operations were conducted in the west half of the borrow area, in water depths between ~14 and 16.5 m. Recorded dredge head depths range from 14 to 19 m, indicating that the dredge was operating at 0.4–4 m of sediment depth. However, where the dredge activity was concentrated in the western portion of SO5, it appears that the majority of the dredging was conducted in sediment depths between 1 and 3 m, suggesting that the dredging took place within lagoonal deposits.

3.2.5 | MB1 Mission Bay

The Mission Bay borrow site, MB1, is located offshore from the San Diego River (Figure 10). The paleochannel appears as a broad feature that extends to the northwest; the geophysical data suggest that the Holocene deposits with this paleochannel may be deeper (~20 m) than those of other river valleys in this study. West of the 20 m contour interval, a shelf is present on the northern portion of the river valley that is separate from the deeper channel to the south. Cores from the shelf (e.g., 203 in Figure 10) reveal a complex sequence of sediments: offshore, lagoon, intertidal, mash, and fluvial in the upper 4 m of deposit. In the deeper channel to the south, below the upper layer of ~1 m of nearshore sediment is a thick layer (~5 m) of intertidal sand whose lower extent was not revealed by the deepest (~6 m) core. In the western (2001) borrow site, 185,000 m^3 of material was removed, with penetration of no more than ~3 m; ubiquitous shell was encountered in the dredged material. The high quality of the beach sand recovered suggests
that this portion of the borrow site was primarily within the thick intertidal sand deposit within the deep channel. In the eastern (2012) borrow site, 348,000 m³ of material was removed, with penetration of no more than ∼4 m. Hard bottom conditions were not encountered by the dredging at either site. No archaeological materials were detected during monitoring.

The MB1 area includes several historic cultural features. Three intentionally sunken vessels are located in this area including the Yukon, Ruby E, and El Rey. Artificial reef materials from the Mission Bay Bridge are found in several locations south of the borrow sites. The NOSC tower, a navy research platform, collapsed in 1986, and lies on the seafloor at the eastern edge of the borrow area (Figure 10).

**FIGURE 6** San Elijo Lagoon.
(a) Extension of the river valley margin (dashed lines), sediment core locations (circles, red if used in cross-section), subbottom profiling lines (dotted lines), and borrow site SO6 (shaded polygon). The stippled area has sea bottom with a hard substrate and kelp in the water column. Cross-section location is in red. The bold line indicates the shoreline, bathymetric contours in 10 m interval. (b) Cross-section of stratigraphy. The sequence of sediments includes nearshore, lagoon, intertidal, and fluvial. [Color figure can be viewed at wileyonlinelibrary.com]

**FIGURE 7** Stone bowl recovered from dredging at SO6, shown with ground surface facing (left) and in profile (right). Scale with 2 cm increments. [Color figure can be viewed at wileyonlinelibrary.com]
3.2.6 | SS1 Tijuana River

The borrow area SS1 is offshore from Imperial Beach along the extension of the Tijuana River Valley (Figure 11). Cores with penetration >4 m reveal underlying fluvial deposits; none of the cores reached basement rocks. In 2001, dredging within the southern portion of the river valley removed 17,000 m$^3$ of material, with a penetration depth <1 m. A mix of cobbles and fine sediment was encountered. Shell was consistently present in the dredge spoil, but no archaeological materials were encountered during monitoring.

Extremely high levels of charcoal were encountered in some of the cores, and a charcoal sample at 20 mbsl depth yielded a date of 8360 cal BP (Core 122 in Figure 11). Analyses of pollen collected just above and below the depth of the dated sample suggest that the sedimentary environment was tidally influenced mudflats (Davis, 2002). The pollen was dominated by the sunflower family (60%), with low-moderate percentages of Chenopodiaceae-Amaranthus pollen (10%–17%), and with the pollen of trees not abundant (2%–10%). The weak influence of marine waters is shown by the low percentages of Foraminifera tests (1%), and the low percentages of pollen of aquatic plants preclude the presence of extensive

**FIGURE 8** SOS San Dieguito River.
(a) Extension of the river valley margin (dashed lines), sediment core locations (circles, red if used in cross-section), subbottom profiling lines (dotted lines), and borrow site SOS (shaded polygon). The stippled area has sea bottom with hard substrate and kelp in the water column. Cross-section location is in red. The bold line indicates the shoreline, bathymetric contours in 10 m interval. (b) Cross-section of stratigraphy. The sequence of sediments includes nearshore, lagoon, intertidal, and fluvial. [Color figure can be viewed at wileyonlinelibrary.com]
freshwater marsh ecosystems. Likewise, the relatively low values of Chenopodiaceae-Amaranthus pollen suggest that a halophytic salt-marsh was not present.

4 | DISCUSSION

The drowned river valleys considered by this project are both subject to commercial exploitation for sand and have the potential for preservation of archaeological materials. The model for expected sedimentary sequences within these river valleys was found to apply, but with a unique geological history for each of the six sites. The encouraging result is that at all six sites, pretransgression sediments of more than ~8000 BP age were identified in cores, both fluvial sediments from river valley bottoms, and marsh/mudflat sediments. The significance of the former for preservation of archaeological materials can be understood in the context of the C W Harris Site (SDI-149 and SDI-316) in the inland portion of the San Dieguito River Valley (Rogers, 1966; Warren, 1967). The C W Harris Site is used to define the San Dieguito Complex of lithic tools dating from the pre-9000 cal BP period in San Diego County, and is located in a fluvial sedimentary context. The primarily lithic materials that comprise the Harris site were found in situ in fluvial sediments in the basal portion of the San Dieguito River Valley, and it provides an analog for archaeological materials that may be preserved in fluvial sediments of similar age. The presence of freshwater marsh and mudflat sediments capping the fluvial deposits provides additional potential that low energy depositional processes might have protected these pretransgression sediments from coastal erosion.

The model that certain geologic settings are conducive to burial of cultural deposits, placing them beneath the impact of shoreline erosion during marine transgression, may apply to these river valley deposits. River valley settings are conducive to site preservation, since fluvial and marsh sediments may provide protection from erosion during transgression. River valley floors tend to accumulate sediment during transgression and benefit from the erosion of adjacent uplands. When sea-level rise creates landward erosion, the amount of sediment deposited offshore is roughly equal to the amount removed by shore face erosion. The preservation of prehistoric sites in river valley settings, therefore, may be aided by erosion of adjacent regions. In locations that have been inundated by marsh or lagoonal mud, stratigraphic facies may be preserved as the shoreline passes above them. Conversely, sites along the river and lagoonal margins may be subject to erosion and the cobble fields lining the nearshore extension of river valley today may attest to their previous erosion. It is noteworthy that the sites where stone bowls were discovered (SO5 and SO6) did not have marsh sediments in their river valleys, at least suggesting that the presence of a marsh environment is not necessary for artifact discovery.

The preponderance of dates obtained from the 20–30 m depth interval by this project falls within the 8000 ± 300 cal BP time interval (Figure 1 and Table 2), the period of the 8.2 kyr event when a stable sea level is expected. The preceding time of rapid sea-level rise would have drowned the river valleys to create lagoons, and the subsequent period of stable sea level would then allow a marine ecosystem to mature, potentially providing ample resources for population growth in the early Holocene. The area along the margins of these lagoons may have been particularly desirable for occupation, as documented for their remaining on-shore components (Warren & Pavesic, 1963). It has been suggested that during the earliest occupation of the California coast, shellfish may have provided >90% of consumed dietary meat (Porcasi, 2011). Since the near-coastal archaeological record from the 8000 cal BP and older period was produced at elevations that are now submerged, it is reasonable to assume that we still may be underestimating the dependence on marine resources since much of the early Holocene record is missing. It is further understood that the siting of coastal estuaries (Gallegos, 1987; Masters, 1998) in San Diego County may have resulted in what was a dense early Holocene population becoming diminished over time, with a corresponding decreased reliance on shellfish (Warren & Pavesic, 1963) and an increased reliance on vertebrates (fish and mammals) for food during the remainder of the Holocene (Porcasi, 2011).
sea-cliff-exposed sandstone or Santiago Peak metavolcanic rock transported by local rivers), and from this perspective, they were not moved far from their site of manufacture. Therefore, being a local, ubiquitous, and labor-intensive item, they can be assumed to be an important component of prehistoric culture, and yet, their actual function is uncertain.

The stone bowl mortars found during sand dredging are the first such items to be collected from a buried context. Previous discoveries have all resulted from divers finding them on the seafloor in fields of cobble and kelp or near submarine canyons (Masters, 1983). The context of the stone bowls reported here, however, were from nearshore or lagoonal sediments, not an appropriate setting for occupation. Two alternative explanations are considered: (1) the stone bowls were lost or deposited in the sea during fishing or other marine activities, or (2) they have been eroded and transported from their original depositional context.

The provenience of previous stone bowl discoveries, in shallow rocky reefs, kelp beds, and along the rims of submarine canyons, together with their almost complete absence from early-middle Holocene terrestrial components, is an argument for their use in fishing (Masters & Schneider, 2000). Rocky nearshore areas where kelp can attach to the sea bottom are precisely the locations where fishing might take place, and stone bowls are proposed to have played a role in chumming and/or fish trapping from watercraft. Their presence at nearshore locations would imply loss during their use for fishing. The recovery of stone bowls in the sedimented interior of the drowned river valleys, reported here, does not preclude their use in fishing, but it is a new location for their discovery.

The conventional interpretation for stone bowl mortar function is in grinding or pulverizing of food stuffs, and in a coastal context, their usage may have been to process roots from coastal marshes (Glassow, 1996). If they were originally a tool for subsistence along

**FIGURE 10** MB1 Mission Bay. (a) Extension of the San Diego River valley (dashed line), sediment core locations (circles, red if used in cross-section), subbottom profiling lines (dotted lines), and borrow site MB1 (shaded polygon). The stippled area has sea bottom with hard substrate and kelp in the water column. Cross-section location is in red. The bold line indicates the shoreline, bathymetric contours in 10 m interval. (b) Cross-section of stratigraphy. The sequence of sediments includes nearshore, lagoon, marsh, intertidal, and fluvial. Three shipwrecks and artificial reef materials are also present in this area. [Color figure can be viewed at wileyonlinelibrary.com]
the margins of coastal lagoons, then they would have been present within occupation sites along the lagoon margins. During the time of marine transgression, the headlands and margins of the river valley would have been subject to erosion. This is the pattern observed on the near-shore margins of the river valleys examined here; the eroded margins of the river valley are characterized by the presence of bedrock and cobble sea bottoms, and at appropriate water depths, a zone of kelp is attached to this substrate. If there had been occupation sites lining the margins of the river valley, only the heaviest site materials—such as the stone bowls—would be left at the original site location. Likewise, erosion of the river margin sites and their redeposition into the river valley, particularly following complete submergence of the lagoon, would result in stone bowls being deposited in the lagoonal and nearshore sediments, as reported here.

5 | CONCLUSIONS

The results from two regional beach sand dredging projects are presented to help refine understanding of the stratigraphic setting for early Holocene sediments within drowned river valleys along the coast of San Diego County in Southern California.

Geophysical data, core sediments, and analysis of recovered fossils allowed the creation of models for six borrow sites. These models were tested during dredging operations, and the dredge spoil was monitored for archaeological materials. Two of the borrow sites yielded stone bowls consistent with previous offshore archaeological investigations in this region. These artifacts, however, were determined to come from nearshore and lagoonal sediments, not appropriate for occupation, raising the question of both the function of stone bowls and the process that resulted in their deposition. Use of stone bowls in fishing operations is one potential explanation, as previously suggested (Masters & Schneider, 2000). An alternative explanation involves site erosion along the margins of drowned river valleys. This project illustrates the potential for commercial development projects to yield information on submerged archaeological resources, as well as the challenges.

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![Image](wileyonlinelibrary.com)
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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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