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Research Article

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Geological and Archaeological Evidence of El Niño Events along the

Introduction

El Niño-Southern Oscillation is a band of anomalously warm ocean water related to changes in oceanic currents and trade winds. El Niño represents a general warming of surface sea temperatures along the Eastern Paci c, and a lessening or reversal of NE trade winds, creating warm humid air and reducing upwelling of cold waters resulting in dramatic perturbations to maritime and terrestrial ora and fauna [1,2]. El Niño events are di erentiated by intensity and duration, or a combination of both. Particularly extreme or intense events as in 1983/84, or 1997/98 are referred to as Mega El Niño that appear to have their origins 5800 years ago [3-5]. Such climatic and oceanographic perturbations have dramatic impacts upon human adaptation and sociocultural development. ese climatic and oceanographic alterations create a reduction of upwelling cold waters along the west coast of South America. ese climatic changes result in dramatic perturbations to maritime and terrestrial ora and fauna and, consequently, human adaptation. El Niño events are di erentiated by their intensity and duration, or a combination of both [6-8]. Particularly extreme or intense events as in 1983/84, or 1997/98 are referred to as Mega El Niño which appear to have their origins 5800 years ago [3]. ere is geological and archaeological evidence based upon the frequency of species of shell sh, to indicate they increased in frequency and duration between 5800 and 3200 BP and decreased in frequency between 3200-2800 BP [9].

Multidisciplinary evidence is presented including; regional survey, excavations, 14C and AMS dates, geomorphology and geology, statistical analysis of minimum number of individuals (MNI) of marine shell to determine the approximate antiquity and duration of El Niño events and their possible relationships to widespread changes in human adaptation and the natural landscape and geomorphology between c. 4200 and 3450 B.P. in southern coastal Ecuador. ese multiple lines of evidence are from archaeological research in southern El Oro Province, Ecuador (Figure 1). Excavation and regional survey uncovered indications of related to El Niño [10] Shell counts of minimum number of individuals (MNI) provide a basis for assessing the times of occurrence, intensity, and duration, as well as how such climatic events e ected human adaptation (see also Staller [11-15]. ere is evidence for a general trend of increased frequency of El Niño events that in some instances changed the climate and coastal habitats permanently. ese El Niño-induced alterations required major adaptive changes and short-term increased dependence upon certain seasonally speci c resources and suggest the long-term cultural response to such ecological and geomorphological transformations favored exibility or increased diet breadth rather than specialization and/or dependence upon particular resources such as maize [10,16,14,17].

Multidisciplinary evidence at the late Valdivia ceremonial center of La Emerenciana, documents repeated site abandonment related to El Niño events. Initial abandonment was in response to a Mega-El Niño radiocarbon dated to ca. 2150 B.C. associated with fossil beach ridge formation and reoccupation 2200 to 1450 B.C. Final abandonment was

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maintaining a constant supply of fresh water to the lowlands [31,33]. Average annual precipitation is insu cient to sustain a year-round agricultural economy [10,34]. Contemporary agriculture is generally by oodwater farming and small-scale pot irrigation. e coastal savanna is low relief topographically and does not lend itself to irrigation. Regional survey indicates that pre-Hispanic irrigation canals or raised elds are completely absent. e driest subregion is directly adjacent to the Peruvian frontier, the coastal savanna or *P* [illegible] *C* [illegible] (Figure 2a).

e coastal savanna is a dry tropical forest consisting of xerophytic thorn brush, dense clusters of [illegible] trees, and various species of columnar cactus (*C*[illegible] spp.). Ancient ceiba trees represent the last remnants of what was at one time a b T*v

Plate 2: A traditional house on stilts and made of cane on a knoll top along the Laguna Tembladera. Such habitations and locations are particularly common along or near rivers and lagoons in this region and such traditional architecture and site locations extend back to prehistoric times. (Photo by John E. Staller)

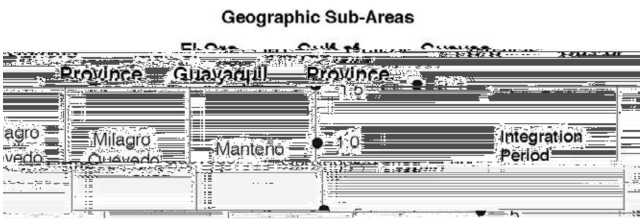

Figure 3: Cultural chronology of southern and southwestern coastal Ecuador based upon uncalibrated radiocarbon chronology.

reef may have been related to reoccurring El Niño related activity or to Mega events associated with site abandonments. e identi cation of tsunamis also provides a basis for understanding the extinction of oyster. Oysters reappear in El Oro during the Regional Developmental and Integration Period (Figure 3). A er c. 100 B.C., Jambelí Phase occupations with deep occupation horizons and large earthen mounds reappear in the foreshore. Shell middens throughout the *P* *C* near Huaquillas stand over 13 to 16 meters high and 150 to 200 meters at the base [10] (plate 1).

Archaeological and stratigraphic evidence indicates a mixed and diversi ed ancient economy, and included hunting, plant gathering, agriculture, and aquatic resource exploitation as primary components [10,13-16]. Stable carbon isotope signatures from the La Emerenciana skeletons indicate aquatic resources formed a major portion of the diet and, although maize was consumed, it played a minor role in the subsistence diet and appears to have been primarily consumed as beer or [34] (Tables 5 and 6). e climatic and environmental changes induced by El Niño, played a central role in fostering a greater dependence upon agriculture, although the overall response favored exibility or increased diet breadth over specialization [20].

Pre-Hispanic Occupations at La Emerenciana

La Emerenciana is 12.72-hectares in total size, one of the largest Valdivia sites in coastal Ecuador [50-52,16]. It is situated on a fossil beach ridge at 2.5 masl about 3 km from the present shoreline [14] (Figure 7). Primary occupation spanned between ca. 2200-1450 B.C or 650 to 700 years, (Figure 5a). e earliest pedestal bowls, stirrup-spouts and single spout bottles, as well as, the earliest red on white banded pottery in the Andes was identi ed with the Jelí Phase ceramic complex [10,14]. e red on white-banded ceramic tradition representative of the earliest pottery in southern highlands of Ecuador and northern highlands of Peru is believed to be associated with a cultural horizon called Chaullabamba [53-60]. ese regions of the Andean sierra relate to non-Quechua and Aymara speaking cultures involved in the early spread of ceramic technology, maize (L.), conch and spp. oyster shell to the adjacent highlands and south along the coast [56-58,61]. e earliest AMS and radiocarbon dated appearance of red on white-banded pottery occurs in coastal El Oro Province c. 2200 B.C. [16,56, 61,62,34]. Initial site abandonment and burial by a fossil beach ridge relates to a Mega-El Niño dated to 2150 B.C. consistent with other regions of the Andes [43,63] (Tables1). Reoccupation and fossil beach ridge formation occurred c. 2200-1450 cal B.C. Another abandonment followed by a brief nal reoccupation at around 1450 B.C. (Tables1).

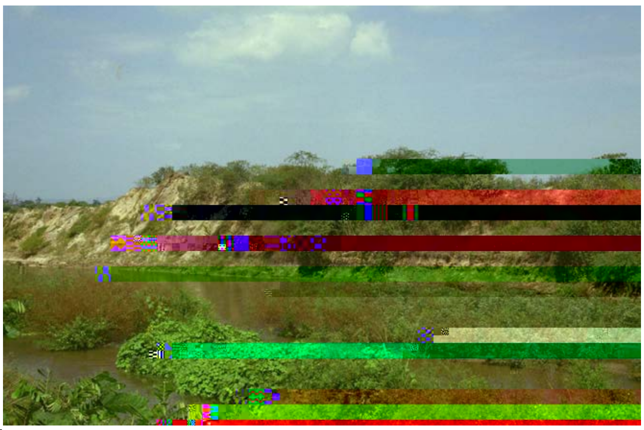

Figure 4: A vertical section of the fossil beach ridge associated with La Emerenciana as it appears along the modifed Arenillas River channel. The landscape feature was cut and exposed after modifcation of the river channel by the Ecuadorian military as part of the Tahuín Dam Project in the 1980s (SW). (Photo by John E. Staller).

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STRATUM	DEPTH	DESCRIPTION	HORIZON	COLOR
6	0-55 cm	A	10YR 5/3 -10YR 5/4	Brown fne silty loam, loosely consolidated in the upper levels, denser in lower levels, with evidence of bioturbation. (fuvial deposit)
5	15-93 cm	B	10YR 6/1 -10YR 5/1	Homogeneous grey ashy loam, loosely packed, very fne texture, fne quartz inclusions with the consistency of talc, and artifact and shell remains in the upper-most levels of the stratum. (Living Floor 2) (ethnostratigraphic)
4	36-92 cm	C	10YR 8/3	White dune sand, fnely textured very loosely consolidated, with calcium carbonate inclusions in the upper levels. (eolian deposit)
3	78-145 cm	Bwn	7.5YR 6/4 -7.5YR 7/4	Pink quartz sand fnely textured well consolidated, free of inclusions. (Living Floor 1) (ethnostratigraphic)
2	64-134 cm	Bwk	2.5Y 8/6 -2.5Y 8/8	Yellow sand fnely textured, loosely consolidated, with calcium carbonate small pebble inclusions (3 mm-1 cm) (eolian deposit)
1	97-cm	C	5Y 8/2 -5Y 8/4	Olive white sand, fnely textured, moderately packed, with small (3 mm-2 cm) beach pebbles and calcium carbonate inclusions (fuvial deposit)
6a	5-28 cm	Ap	10YR 8/2 -10YR 8/3	Fine white ash with carbon inclusions. A substratum is a result of recent agricultural activity (ethnostratigraphic)
5a	6-72 cm	Bwt	10YR 8/1 -10YR 8/4,	Densely packed pale white clay fne textured, free of inclusions, hard and densely packed. Represents a prepared clay surface. (ethnostratigraphic)

Excavations at La Emerenciana

La Emerenciana had direct access to maritime and estuarine resources. Excavations were restricted to the summit of the northwest earthen mound. e earthen mound had an oval shape, 2.5 meters high, and was 200 meters (N-S) by 150 meters (E-W) with two oval clay platforms on the summit [10]. Four trenches (A-D) were dug to sterile levels, and 332 m^2 of a buried prehistoric occupation surface (oor 2) exposed. Five-meter square units (Cuts 1 to 4, 6), and a 1 by 2 meter pit (Cut 5) were excavated to sterile to record more speci c data on stratigraphic variation (Figure 5b). A twenty-nine meter long vertical section (Pro le A) was cleared in order to provide continuous stratigraphic information on this portion of the mound [14] (Figure 13). Pro le A and the Trench D excavations uncovered three descending retaining walls or stepped terraces in the west and northern parts of the earthen mound, and these modi cations were veri ed in the Trench B excavation (Figures 6 and 7).

Excavations were primarily by natural stratigraphic layers and exposed 139 archaeological features, primarily architectural modi cations associated with mound construction, various ritual o erings and four fully articulated burials [14,49,62] (Figure 7). Initial occupation associated with stratum 3 was brief and dated to ca. 2400 B.C., followed by beach ridge formation (stratum 4). Later occupations associated with stratum 5 date to between 2000-1450 B.C. with a brief reoccupation associated in stratum 6 (Figure 8, Table 5). ere was no evidence of domestic activity. Artifacts primarily consisted of sherds. ere was evidence of a subterranean kiln [10]. Lithic debris was limited to 20 artifacts, but included two obsidian akes from two di erent outcrops in the Valley of Quito and represents the earliest dated obsidian in coastal Ecuador [10,64]. O erings include ocher covered pebbles, a [illegible] necklace, chipped quartz akes and some polishing stones [10].

Di erences in color, texture and composition were classi ed and grain size analysis of the various strata allowed for more detailed identi cation of stratigraphic layers (Tables 6a and 6b). Layers were divided according to artifact content and excavated following the conformities and contours of the natural stratigraphy and physical properties of the strata. Artifacts established the stratigraphic sequence and permitted the recognition of reversed stratigraphy, as well as primary and secondary deposits [65,66].

5b	65-80 cm	Bw	10YR 3/6 -10YR 4/2	Dark brown ashy loam fnely textured, the result of post- depositional weathering and decomposition of Stratum 5. (ethnostratigraphic)
5c	57-74 cm		various	Animal burrow
4a	37-45 cm	Bk1	10YR 7/4	Very pale brown, extremely hard calcrete conglomerate, calcrete sand with no sublayers identifed in profle, some inclusions. (post-depositional weathering)
3a	57-145 cm	Bk2	10YR 6/4	Light yellowish brown, extremely hard calcrete nodules high clay fraction. (post-depositional weathering)
1a	57-68 cm	Bt	5Y 6/4	Shell lag deposit, hard yellow olive clay fnely textured with shells inclusions throughout. (eroded deposit)
1b	65-82 cm	Bg	2.5Y 6/8	Light olive yellow clay fnely textured with organic nodules, high clay fraction, and shell inclusions on the bedding plane. (eroded deposit)
1c	45-150 cm	Bt	10YR 8/3	Fine fraction white clay with extensive small to medium sized beach pebble inclusions. (eroded deposit)
1d	57-145 cm	Bk3	10YR 6/4	Light yellowish brown, extremely hard calcrete conglomerate made up of calcifed sand, no inclusions, but nodules and internodular fllings. (post-depositional weathering)
1e	57-145 cm	Bk4	2.5YR 5/4	Reddish brown, extremely hard calcrete internodular, flling has a relatively high clay fraction. (post-depositional weathering)

Note: All soil colors are classifed using the Munsell Soil Color Chart 1975 Edition. Differences in color were sometimes noted within a particular stratum, and these designations were the most characteristic for the stratum as a whole. Depths are given as below datum, and indicated as minimum and maximum levels which of course varied in different areas of the excavations period.

Table 5: Stratigraphic Layers at La Emerenciana.

A concentration of marine shell extending over 40 cm in cross section was identi ed on the northern portion or seaward portion of the site in Trenches A, B, and northern portion of Pro le A. Arbitrary 20 cm increments were used, since the smallest natural unit of analysis (i.e., shell layer) was too large to detect subtle changes in the vertical distribution. On the summit of the mound the shell layer has a maximum depth of only 5 to 10 cm over the surface of oor 2 (Figure 9 and Tables5). e homogeneous grey ashy loam (stratum 5, living floor 2) has been identified at Valdivia sites throughout coastal Ecuador and later Jambelí sites [50,52,67-69]. The surface of stratum 5 is cultural, designated as living floor 2. Highest concentrations of cultural remains, primarily sherds and ancient shells, were in the uppermost 10 cm [10].

Natural Stratigraphy at La Emerenciana

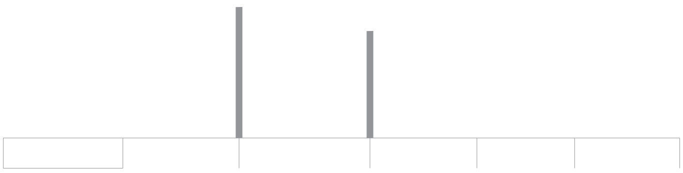
e A-Bw/Btn-Bk horizon sequence of soils characteristic of well-drained semi-arid conditions and ve lower strata were continuous across the site, and two stratigraphic layers (layer 3 and 5) contained prehistoric artifacts pertaining to Valdivia culture. Identi cation of the stratigraphic layers was documented through grain size analysis using both hydrometer and pipette (Tables 6a and 6b). ese data were critical to the interpretation of the various layers as documented in detail in the previous table. Stratum 6 was restricted to the NW sector and associated with the nal abandonment [16]. e geomorphological, archaeological and shellfish counts supports the hypothesis of repeated site abandonment and widespread geomorphological changes [10].

e lowest layer, stratum 1 identi ed at 97 cm below datum is olive beach sand with nodules of decomposing organic and gravel inclusions (Figures 8-10). A vertical section along the stream channel measuring 20 m long and 5 m deep suggests this layer is at least 3 m thick, with remnants of foreshore deposits of uvial origin, gravel lenses and shell lag deposits throughout. Cross-bedding at below 2.5 m is the result of uvial processes post-depositional weathering through the movement of groundwater, leaching and dissolution of carbonates altered the soil chemistry [70]. Various shell lag deposits and gravel lenses indicate of casitserv culture.faun20.1(i)-19Cof not preserved, however plant microfossils were recovered from carbon residues in pottery sherds [34,62,71].

Stratum 2 is yellow sand the result of post-depositional weathering associated with groundwater movement (Tables5). e deposition and decomposition of organic and inorganic compounds le concentrations of calcium compounds, carbon, phosphorous, and trace metals that apparently created chemical changes in the soil. Geological studies indicate this coloration may also be produced by the movement of iron oxides via water percolating through shell lag deposits [70].

Stratum 3, designated living oor 1, is a pink sand extending between 94 and 124 cm below datum, containing archaeological features; pits, post molds, portions of foundations of habitation structures, indicating this was a domestic occupation surface (Figures 8-9). Ceramic diagnostics correspond to middle Valdivia Phases 4-6, and there was a relative paucity of marine shells, and a total absence of organic and faunal remains perhaps related to leaching and post-depositional alterations in the lower layers. Leaching of phosphates and iron oxides from stratigraphic (layers 5 and 3) was evidenced in the underlying by calcrete deposits with a yellow to light brown coloration (Tables5). e abundant faunal remains found with various features in stratum 5 were not preserved in this layer.

Stratum 4 represents the fossil beach ridge, a sterile ne white quartzitic dune sand with calcium carbonate inclusions. Some blending was noted with the overlying grey ashy loam and part of



this beach ridge extends to the Peruvian border and beyond (Figure 4). Pallcacocha lake core deposits in the cordillera directly NE provide indirect evidence for the stratigraphic interpretation for repeated site abandonment. Beach ridge formation is a result of El Niño related phenomena and may correspond to a Mega-El Niño recorded in the Laguna Pallcacocha lake cores ^{14}C dated to 4040 B.P.[8,43] (Figure 3). e chronology coincides with a ca. 2150 B.C. El Niño recorded at various sites in the Río Jequetepeque valley [63]. Beach ridge formation is roughly contemporaneous with those from the Cuenca Valley lake cores and in northern coastal Peru suggesting they hypothesis are a result of El Niño.

Stratum 5 extends between 10 cm, to just under a 1m with an average thickness of 35 cm (Tables5). It constitutes the existing land surface over 75% of the site and represents the primary occupation oor. e earthen mound measures 75 m north-south by 47 m east-west and approximately 1.5 m high and few cultural remains were found in the lower and middle levels. It was kept meticulously clean, a pattern consistent with ceremonial centers throughout the Andes. [10,16]. However, the surface of stratum 5 was covered with oyster shell and sherds during the abandonment and the later reoccupation of stratum 6 to protect the mound from rising oodwater.

Evidence of disconformity in the lower interface of stratum 5 may be a result of depositional events (Figures 8-9). Most archaeological features were in the upper 10 cm. Architectural features include two complete oval or elliptically shaped daub platforms four retaining walls, and post impressions [10,14]. Ceramic diagnostics and ^{14}C dates ca., 2200-1450 B.C. suggest occupation corresponding to Late Valdivia ca. 1800-1450 B.C. (Tables1).

A carbonate duricrust formation under stratum 6 was identi ed on the SW side of the platform, and on living oor 2, stratum 5 (Figure 5b). It is 5 to 10 cm thick, it is a calci ed quartz sand crust made up of so and friable silici ed sands with no nodular development. is represents a silcrete, a result of super cial diagenesis that relate to seasonal uctuations in climate resulting in the chemical alteration of sediments through hydration [72]. ey form near stream channels in areas with a high water table. Silcrete crusts may be eolian, as the constant abrasion of ne-grained quartz sands lead to concentrations of ne siliceous dust, susceptible to solution and alteration by fog dew (·,,,) or changes in groundwater. is formation suggests the earthen mound and surrounding area underwent climatic uctuations including high wind velocities and increased ground water, consistent with the onset of El Niño. ese changes initially a ected the adjacent are re ected by gaps or separations of as much as 5 cm at the stratum 6-5 interface related to the buildup of rain water. e poorly drained lower (layers 4-1) are further evident by the presence of decomposed or hydrated organic matter throughout.

In summary, the stratigraphy is characterized by well-de ned interfaces with clear di erences in color, texture and composition. e brown silt and ashy loam, strata 6 and 5 respectively, essentially preserve the overall integrity and stability of the underlying strata. e moist and ne grain sands quickly lost their overall structure when exposed to the natural elements, making the delineation archaeological features extending into the lower sand layers (strata 4 to 1) di cult. Stratigraphic evidence and dates from the Pallcacocha lake cores support the interpretation of repeated site abandonment due to climatic upheaval and/or geomorphological changes consistent with El Niño. (Layers 4-1) represent seaward components of a barrier coastline, shoreface, foreshore, backshore, and dune facies respectively. With the exception of uppermost stratum 6, the stratigraphic sequence, is consistent with progradational coastal development. Stratum 6 represents transgression consistent with deposition due to ooding, tidal wave asymmetry, and/or a dramatic in ux of uvial sediments, an indicator of El Niño or tsunami if such climatic events may have been associated with seismic activity [19].

Species	Total No.	MNI.	Total (%)	MNI.(%)
Ostrea columbiensis				

Shell Frequencies: Analysis of Minimum Number of Individuals (%MNI)

In order to minimize sample bias shells were collected from randomly selected excavation units. Evidence of prehistoric El Niños was derived from variation in shell frequencies by raw counts according to species. When total counts were uneven, the extra bivalve was counted as a complete individual. Once categorized and quanti ed by species, totals were broken down to percentages of minimum numbers of individuals (%MNI) segregated on the basis of natural stratigraphic layers. However, frequencies were by arbitrary increments in Trench B (Tables 7a-d and 8a-d). Di erences in percentage MNI frequencies can re ect modi cations to aquatic habitats due to cultural preference and/or natural factors such as climate [66] Economic shi s and/or climatic change were inferred: A) A cultural bias for particular food species and, B) that various taxa inhabited the area during site occupation (Tables 7a-d). Potential factors complicating the statistical reliability, such as sea level changes, geomorphological, and environmental change (all side e ects of El Niño) were considered.

A random sample was selected from the surface, identi ed according to species and assessed by relative frequencies. e low frequencies of some specimens made them statistically insigni cant. Only ve species were used for comparison: e raw counts indicated nutritional bias for Oysters ([illegible] L.), Venus clams ([illegible]), and Protothaca clams ([illegible]) (Tables 7a-d). In more inland settlements, Simile Ark ([illegible]), constituted the predominant species during the Middle and Later Formative sites, but were rare in excavations. Fishermen related that when packed wet in salt water, [illegible] may be carried for several days without spoiling. eir abundance at formative sites indirectly re ects the importance of the mangrove forest and maritime resources and their absence at La Emerenciana was surprising because [illegible] impressed cambered jars are emblematic ceramic diagnostics (Figure 13)[1]

[1] The *Anadara* impressed diagnostics were also identifed at the Valdivia site of San Lorenzo del Mate in 2003 in the course of surface survey with my colleague and friend the late Lcdo. Felipe Cruz Mancilla, head of collections at the national museum.

Land snails called "[illegible]" and adapted to trees or the surfaces of mud ats beyond the limits of the high tide are a marginal food source and only exploited during periods of resource scarcity. Valide Horn Conch (*C*[illegible]) are buried in the brackish mud ats at high tide level or entirely out of water on reeds and twigs, and only consumed when more favorable species are unavailable. Both are indicators of environmental stress. However, they are sometimes ground into lime for chewing coca leaves. Specimens were restricted to the uppermost 10 cm of stratum 5, thus potential climatic and environmental indicators when the region was undergoing geo-climatic alteration during abandonment [10].

Minimum number of individual (MNI) shell sh counts from the northern portion of the mound provides additional lines of evidence

Species	Total No.	MNI.	Total (%)	MNI.(%)
Ostrea columbiensis	645	323	53.57	53.03
Chione subrugosa	57	29	4.73	4.76
Protothaca ecuadoriana	453	227		

related to an increase in white sandy dune sediments into the coastal bay due to the formation of dune ridges. Increase in sandy sediments in the intertidal zone could have buried the clams. Stability in Pointed Venus Clam frequencies suggest the lagoons scattered through both sides of the coastal streams, and particularly those behind the barrier reef and mangrove islands, continued to be exploited.

Relative changes in the percentage MNI frequencies and grain size analysis of stratum 6 support a hypothesis of rapid geomorphological change. Smaller oysters and constricted growth rings on most

prehistoric populations.

Recent El Niño Related E ects in Southern Coastal

and subsequent extinction of oysters, presumably an important source of protein for over a millennium.

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