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Diálogo Andino

SPATIAL MODELING OF EARLY HOLOCENE MANGROVE FORMATION IN THE SANTA ELENA PENINSULA, SOUTH WESTERN ECUADOR

MODELADO ESPACIAL DE UNA FORMACIÓN DE MANGLAR DURANTE EL HOLOCENO TEMPRANO EN LA PENÍNSULA DE SANTA ELENA, ECUADOR

*Miriam E. Domínguez**

Human occupations in South America during the late Pleistocene and early Holocene need to be considered from a hemispheric perspective. It is also important to recognize the uniqueness and variety of environmental ecotones found in Northwestern South America. Within the context of the Santa Elena Peninsula in Ecuador, the most complete and earliest record of human occupation comes from the Las Vegas' sites dated between 10,800 and 6,600 BP. The marine faunal record from Early and Late Las Vegas phases reflects a change in the configuration of the littoral caused by tectonic uplift and eustasy, along with other ecological changes. The use of Geographic Information Systems can be effectively implemented in the modeling of ancient coastal configurations.
Key words: Ecuador, Holocene, geomorphology.

Los asentamientos humanos en América del Sur durante el Pleistoceno tardío y el Holoceno temprano deben ser considerados desde una perspectiva hemisférica. Es también importante recalcar la singularidad y variedad de ecotonos ambientales que se encuentran en el noroeste de América del Sur. En el contexto de la península de Santa Elena, en Ecuador, el registro más completo y más temprano de ocupación humana proviene de los sitios de Las Vegas, fechados entre 10.800 y 6.600 años antes del presente. El registro de la fauna marina de las fases Temprana y Tardía en Las Vegas refleja un cambio en la configuración del litoral causado por el levantamiento tectónico y eustasia, junto con otros cambios ecológicos. El uso de sistemas de información geográfica puede ser efectivamente implementado en el modelado de estas antiguas configuraciones costeras.
***Palabras claves:** Ecuador, Holoceno, geomorfología.*

Introduction

Unwinding the interplay between environmental changes and societal shifts that are found in the archaeological record is complicated at best and yet, in the process of analyzing human settlement patterns and resource exploitation, we are called upon to do just that. The Santa Elena Peninsula of Ecuador (Figure 1) presents us with such a situation but, by employing a historical ecological approach and considering the "life history" (*sensu* Crumley 2003) of the region from the terminal Pleistocene through the Early and Late Las Vegas occupations, we can better understand the bi-or multi-directional relationships that existed between tectonic movement, coastal uplift, mangrove ecosystems, and human settlement patterns. Data driven models constructed using Geographic information systems, while having their limitations, can prove to be useful tools for modeling, visualizing and analyzing such relationships.

Within the wide array of climatic zones of Northwestern South America, the Las Vegas sites located on the Santa Elena peninsula present a unique adaptation of generalized hunters and gatherers (Stothert et. al 2003). The pre-ceramic Vegas type site, OGSE-80, located on the Santa Elena Peninsula was first identified during a survey undertaken in 1964 by Edward Lanning. In 1970 Karen Stothert began extensive excavations at OGSE- 80, originally identified by Lanning as the largest and deepest Vegas type site on the peninsula (Stothert 1983; 1985; 1988). Evidence from Site 80 occupations, which lasted approximately 4,000 years from 10,800 to 6,600 BP, suggests an early exploitation of areas ranging from formerly rich maritime-riparian ecotones to the alluvial plains. In addition, the assumption that there was an absence of sites during dry periods is not supported by paleoenvironmental data. Thus we may infer that climate change was not the principal cause of settlement abandonment, mobility or cultural

* University of Florida, Department of Anthropology, Estados Unidos. Correo electrónico: mdoming1@ufl.edu

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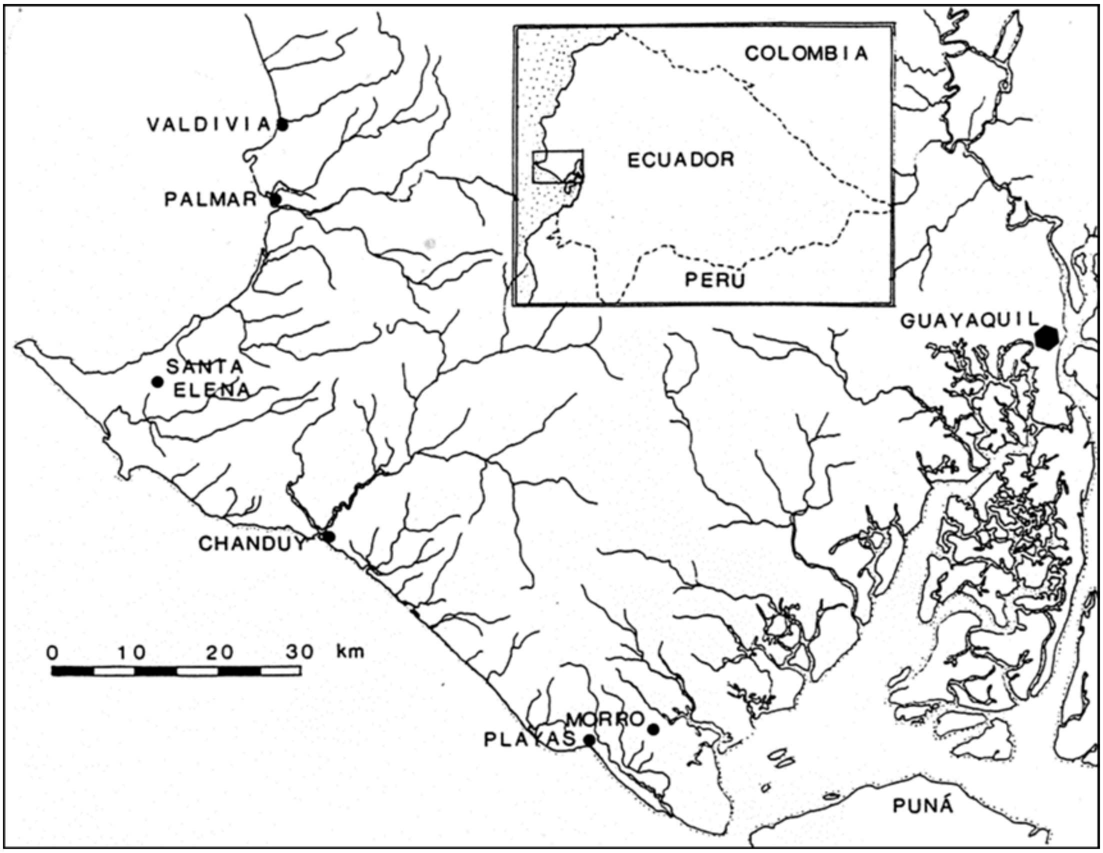

Figure 1. The Santa Elena Peninsula and Southern Guayas Province, Ecuador (Stothert et. al 2003).

change. While climatic changes may have occurred during the Late Pleistocene-Early Holocene, they mostly affected the composition of ecosystems but did not have the same consequences for human adaptations throughout the continent. This project will attempt to model the geological history of the Santa Elena Peninsula and its mangrove formation processes using Geographic Information Systems. This research is based upon the model proposed by Stothert and colleagues in 2003 and will examine mangrove origins in the peninsula and their relationship to early human occupations.

The Sites

The Early Holocene Las Vegas occupations are recorded from 32 archaeological sites in the western portion of the Santa Elena peninsula (Figures 3, 4, 5, 6). Most of the archaeological material was recovered from the Las Vegas type-site (Site 80), which includes a deep midden that accumulated over the course of 4,000 years. Approximately 300 m^2 of the deepest deposits were excavated as a series of trenches to depths from 150 to 450 cm below datum (50 to 320 cm below ground surface;). Regardless of the absence of discernible stratigraphy, a shell layer marker in the midden is used to divide the occupation into early (10,000-8,000 BP) and late phases (8,000-6,600 BP). Site 80 appears to have been either continuously occupied or intermittently re-occupied from the terminal Pleistocene until 6,600 BP (Piperno and Stothert 2003; Stothert 1983; 1985; 1988; Stothert, Andres and Piperno 2003).

The recovery of the partial skeletons of at least a hundred and ninety two individuals from Site 80, suggests that during the late Las Vegas phase its inhabitants were engaged in elaborate funerary activities. The burial patterns identified in this assemblage, consisting of primary, secondary, and ossuary interments, support Stothert (1988: 133-169) and Ubelaker's (1988) suggestions that these practices were based on ancestors' worship.

By 6600 BP there is no archaeological evidence of preceramic occupations, followed by a thousand year hiatus of human occupation in the peninsula, which we will discuss further on (Stothert 1985: 620).

The Mangrove in the Dynamic Santa Elena Littoral

Archaeological evidence suggests the existence, in Las Vegas context, of prehistoric mangrove formation, from the genus *Rhizophora,* which may have provided the major subsistence base for the early populations of the peninsula. The disappearance of mangrove may have been caused by tectonic uplift at a swifter rate than the rise of sea level, which would have also caused the disappearance of other areas rich in marine resources; however, the generalized economy developed by the late Las Vegas showed a decrease in dependency on mangrove resources during the late period (Stohert *et al.* 2003; Raymond 2008: 82).

Mangroves often occur within the 20 °C isotherm, although mangroves on the Pacific Coast of South American are geographically restricted by the cold Humboldt current to north of 3°40' S (Hogarth 2007: 4), approximately 140 km south of the Santa Elena peninsula. Physiographic constraints are perhaps the most compelling explanation for barriers that limit mangrove dispersal. Mangrove zonation is altered by topography, which determines tidal and freshwater runoff, and by soil composition and stability (Tomlinson 1986: 16). Research in Mexican and Australian coasts has established a correlation between mangrove dispersal and coastal geomorphology, showing that mangroves do not supersede the dynamics of topography but are affected by them (Tomlinson 20: 1986).

The dynamic and resilient mangrove forests are naturally stressed ecosystems that are affected by soil salinity, and tidal and wind action, which act as selective forces that determine species distributions. Under Lugo and Snedaker (1974) classification, the mangrove ecosystem in the Santa Elena Peninsula falls under fringe mangrove wetlands. Fringe mangrove wetlands are dominated by red mangrove located in line waterways with a high rate of organic exports, and are susceptible to ocean pollution. Mangrove ecosystems that transform themselves to the point of being replaced by other non-mangrove species are successional systems; the steady state of the ecosystem not only maintains a single species but also may be cyclically replaced by other mangrove species. Periodicities in mangrove cycles, caused by hurricanes, tidal flushing, or eustatic or tectonic sea-level change, make it difficult to determine the successional or steady state of a mangrove ecosystem. Various physical and biological processes operate in mangrove ecosystems on a time Scale. Mangroves create sediment that retards the erosion of shorelines, which may either create a successional state by permitting other plant species to occupy the forest or to maintain mangrove species. Lugo (1980) suggests coastal systems, like the Santa Elena Peninsula have characteristics between steady and successional states due to acute environmental stressors (Domínguez 2010).

Mangrove formation in the Santa Elena Peninsula and the Las Vegas occupation

George Sheppard (1937) described the Santa Elena Peninsula's topography as defined by eroded chert outcrops, which are the remnants of a peneplane that was covered by salt marshes. The lowlands between La Puntilla and Punta Carnero are part of an ancient estuary of the Rio Grande delta, which transforms into a lagoon during years of torrential rainfall. This saline plain is separated from the ocean by a sand bar (Sheppard 1937: 31-32). During the 1920's before Sheppard published his volume, the Rio Grande, which enters the sea at Punta Carnero, a headland that consists of chert marks in the low southeastern salt plain of the peninsula, was landlocked by the barrier beach and formed a large estuary (Sheppard 1937: 32). This estuary drained underground as suggested by the wells of Muey and Salinas, which are surrounded by rock outcrops that help to lock the water (Sheppard 1937: 33). The barrier beach, which extends from La Puntilla to Punta Ancon, not only helped the formation of the Rio Grande estuary but also protected it from wave action.

The formation processes of the sandbar and the deltaic coast began during the worldwide Late Quaternary marine transgression, and for the ensuing 6,000 years, coasts and river mouths have been affected by sedimentation produced by marine tidal incursion as well as fresh water from rivers. In the case of Santa Elena we see this process represented by a sand bar built up across the embayment of the peninsula (Sheppard 1937; Ferdon 1981; Bird 1993: 60). Patterns of erosion and accretion of deltaic coastlines and estuaries are also affected by rainfall and river inflow, where fluvial sediment yields increase in river draining catchment (Bird 1993: 66). As sea level rises coastal lagoons are deepened and enlarged; also erosion and submergence affects the enclosing barriers and reopens the embayments (Bird 1993: 61). The ecological condition of a salinity gradient in the estuary increases from the river mouths to the tidal entrance; this is crucial for how it affects the extent to which vegetation such as *Rhizophora* can disseminate (Bird 1993: 60).

Mangroves spread seaward in front of salt marshes or other vegetation formed by sediment accretion in tidal shores of bays, estuaries, and lagoons. Sea level will affect sediment accretion on the tidal shores and will result in different scenarios. If there is enough sediment accretion, the mangle spreads inland while maintaining the seaward edge. When there is not enough sediment accretion the seaward margin becomes cliffed and the mangroves spread landward. Sediment depletion will cause nearshore deepening and stronger tidal action that causes a rapid retreat of mangroves inland (Bird 1993: 80,81). In this last scenario the mangrove fringe will displace fresh water swamps and vegetation in low lying estuarine areas, become narrower, and eventually disappear. In Southern Australia, where tide gauge levels indicate an increase in sea level, mangrove has gradually spread into salt marshes. Before the Late quaternary transgression, mangroves were relegated to inlets where they could migrate inwards and settle on vertical accreting muddy substrates as submergence continued (Bird 1993: 83). From stratigraphic studies in Australia and South East Asia, mangroves appear to have been growing in estuaries where sediment accretion kept pace with sea level rise, and between

7000 and 5500 years ago they spread to the outer coast where more sediment accumulation had taken place (Bird 1993: 85). In the Santa Elena Peninsula, isostatic land uplift kept pace with sea level, which has important implications for mangrove communities, which may have existed before the Late Quaternary marine transgression (Domínguez 2010).

Geomorphology and Geology of the Santa Elena Peninsula

During the transition from the late Pleistocene to the early Holocene, Ecuador experienced a mosaic of shifting temperatures, rates of precipitation, and geophysical changes. Faunal evidence from Las Vegas and the Talara Tar-seep sites in Peru suggest that the late Pleistocene and early Holocene environments were characterized by seasonal precipitation, which maintained the river courses and open savanna grassland (Lemon and Churcher 1961; Richardson 1978; Stothert 1988). Nevertheless, precipitation is not the only factor that affected the environment in the peninsula. The Ecuadorian littoral experienced tectonic uplift and rise in levels, which resulted in a dynamic configuration of the littoral through the mid-Holocene (Stothert 1998; Stothert *et al.* 2003; Ferdon 1981; Domínguez 2010).

The topology of the Santa Elena Peninsula coast includes outcrops of igneous rocks in proximity to the wells of Salinas and Muey, which delimit the shape of the peninsula in the areas of La Puntilla, Ballenita, Lomas del Engorroy, Punta Carnero and Punta Ancón (Sheppard 1937). These coastal formations are the aftermath of major tectonic movements associated with the Andean uplift. Most of these rocks are post-Eocene and pre-Oligocene in age. Their orientation suggests that the most recent tectonic movements originated in the northeast (Sheppard 1937).

The lithological nature and geological structure of the Ecuadorian coast is reflected in coastal platforms or *tablazos* that can be as high as 300 masl (Clapperton 1993: 603). Along the Pacific coastline of South America these tablazos are Pleistocene marine terraces stranded above modern sea levels (Cantamalessa and Di Selma 2004: 633). These geomorphological features are crucial markers of recent geological uplift. In northern Peru, tablazo formations between Rio Chira and Rio Mancora are underlain by a thin layer of inclined Quaternary fossils (coquina shell beds) situated within Tertiary marine littoral shale beds (Clapperton 1993: 602; Sheppard 1937: 9). The erosion patterns and directionality of the riverbeds formed meanders; studying the formation processes of the resultant ox bow lakes is highly informative of the isostatic activity in the region. Calcareous rock formed during the Quaternary was eroded down to Tertiary tablazos that formed small drainage channels and v-shaped gorges, present today in the Chanduy hills. The denudation of the landscape caused by the El Niño precipitations has revealed downward gravitational migration of Quaternary blocks in the clay slopes of Tertiary formations near the hills of Colonche

(Sheppard 1937: 12). In La Puntilla, brecciated cherts are found in association with local crush zones where intense tectonic movement has modified the Tertiary beds by infilling with crush- breccias (Sheppard 1937: 210).

The Santa Elena terraces have three seemingly smooth surfaces of tablazos with subtle undulations from the movement of the plates (Cantamalessa and Di Selma 2004: 633); uplifted marine terraces are split into steep scarps that correspond to sea-cliffs. The first terraces reported in the Ecuadorian coast are located at approximately 30, 150, and 225 masl at Isla de la Plata, 100km north of the Santa Elena Peninsula (01°16'S, 81°04') (Sheppard 1937; Cantalamessa and DiCelma 2004: 635). In recent studies Cantalamessa and DiCelma (2004) identified a fourth offshore terrace opposite the southern side of Cabo San Lorenzo, 20 km east of the Ecuadorian trench and 25 km west of the mainland. Due to the limited publications on the formation processes of the Santa Elena marine terraces, studies of Isla de la Plata are both relevant and useful when considering the Santa Elena Peninsula as Sheppard (1937) has correlated them with both the Santa Elena marine terraces and the Cabo San Lorenzo landforms.

The Northwestern South America Plate tectonic presents a well-documented record of smaller morphological features that are a product of crustal uplift and help to elucidate the formation processes of Southwestern Ecuador (Domínguez 2010). The North Andean Convergent Margin (NAB) is an area of intense crustal deformation in which tectonic plates move toward one another and collide. The structure of the continental margin reflects intense tectonic activity from the Cretaceous. The Ecuadorian coastal block of oceanic substratum is the southernmost portion of the NAB. The NAB is separated from the Nazca Plate by the Dolores-Guayaquil megashear (DGM) (Cantamalessa and DiCelma 2004: 634; Gutscher et. al 1999; Bourdon et. al 2003).

For the purposes of analyzing Ecuadorian coastal uplift it is informative to examine marine terraces and their tectonic formation along the Talara Arc. The Talara Arc is a regionally uplifted structure extending from 6,5° S to 1,5° N and corresponding to the westernmost part of South America (Pedoja *et al.* 2006). In Ecuador, the subducting oceanic plate also carries the aseismic Carnegie Ridge, which is caused by the passage of the Nazca Plate over the Galapagos hotspot (Bourdon *et al.* 2003: 124). The shape of the Talara Arc and the erosion of the coastal margin affected quaternary coastal uplift in Ecuador. Uplift rates in the range of 0.10 mm/yr up to a maximun of 0.42 mm/yr were maintained in the Manta Peninsula (Pedoja *et al.* 2006: 17). This contributed also to the rapid eastward subduction of the Carnegie Ridge (Gutscher *et al.* 1999). The marine terraces of Cabo de San Lorenzo and Isla de la Plata are uplifted high depositional sequences of Late Pliocene and Pleistocene age that show the region to have experienced vertical movement (Cantamalessa and DiCelma 2004: 634; Gutscher *et al.* 1999). Along the Talara arc the highest terraces are observed on the Manta Peninsula and Isla de la Plata. The lowest uplift is in the Santa Elena Peninsula to the south, and the Esmeraldas area to the north.

While Gustcher and coworkers (1999) have previously suggested that the Carnegie Ridge is responsible for the uplift of the Ecuadorian coast, recent studies by Pedoja and coworkers (2006) show that coastal uplift in the Santa Elena Peninsula along the northern margin of the Gulf of Guayaquil is located out of the effect zone of the Carnegie Ridge. The southern border of the ridge is affected by the NE-SW trending structures parallel to the Grijalva fracture zone (Pedoja *et al.* 2006: 19), which extends underneath the uplifted part of the peninsula and gives it its homogeneous appearance (Pedoja *et al.* 2006: 16).

Sea Level Changes

The ENSO (El Niño Southern Oscillation) also plays an important role in the uplifting process. The ENSO events in the Pacific Basin cause interannual climatic variability and elevated sea surface temperatures in the eastern Pacific, near western South America (Sandweiss *et al.* 1996: 1531). The southern coast of Ecuador and the northern coast of Peru lack the coral reefs and coastal pollen catchments that could serve as paleoclimatic indicators, thus archaeological remains, including fauna, pollen, and charcoal, are the proxy records for ENSO periods before ~ 1500 yr B.P. Analysis of mollusks from sites located along the north and central coasts of Peru, which date between ca. 5800 and 3200-2800 cal yr B.P., indicate that the modern ENSO activity was less frequent (Sandweiss *et al.* 2001: 603). These sites, located north of latitude 10° S, contain specimens that are members of taxa presently found only north of 4° S, which indicates a warmer front in the southern latitudes (Sandweiss *et al.* 2001: 604). Considering the absence of the molluscan species *C. chorus* and *M. donacium* north of 10° S prior to 5,800 yr. B.P., and their reappearance from 3.2-2.8 k ya at 7° S southward, and finally their disappearance from Peruvian sites between 7° S and 9° S by 2.8 k ya, this would indicate that the zone experienced intervals of high ENSO SSTs (Sea Surface Temperature) (Sandweiss *et al.* 2001: 604).

Because of the effects of sea level rise, archaeological sites dating from 11,000 yr B.P. to 5,000 yr B.P. are now submerged. However, on one narrow strip of northern Peru, near Talara, the Amotope campsites, which yielded dates between 11,000 to 8000 yr B.P, have been important in providing data on early maritime occupations. In the Amotope sites the presence of the mangrove mollusk *Anadara tuberculosa* indicates a warmer and wetter climate than at present (Sandweiss *et al.* 1996: 1531). Also, avifauna and insect fauna recovered in sites located close to the Talara Tar Seeps (dated approximately 14,000 yr B.P.) and in other early Peruvian sites such as Quebrada Jaguay (~11,000 to 7500 yr B.P.) and the Ring Site (~10,500 to 5000 yr B.P.) coincide with the molluscan data, suggesting changes in paleocirculation in the Pacific (Sandweiss *et al.* 2001: 1533). Nonetheless, a more southern position of the ENSO did not appear to have affected the species distribution in the Santa Elena peninsula as much as it had in Peru, as the same species that were exploited at the Las Vegas occupation are still available close to the Santa Elena peninsula (Stothert *et al.* 2003: 27).

Working from intra-shell oxygen and carbon isotope profiles ($d^{18}O$, $d^{13}C$) of *Mesodesma donacium* sea shells from the site of Quebrada de los Burros (ca. 13,000-11,000 B.P.) on the coast of Peru at 18° S., Carré and coworkers (2005) reconstructed the SST variation to estimate the changes of ENSO interannual events during the early Holocene. This analysis suggests that ENSO variability, between 7.9 and 9 k ya., was characterized by high interannual variability and frequent, short, and strong warming events (Carré *et al.* 2005: 46). The low $d^{13}C$ values from *M. donacium* during the early Holocene, which correlate with the fact that deep waters are devoid of $d^{13}C$, suggest a larger influence of upwelled water. Upwelling is associated with a shallower thermocline and stronger trade winds, thus the mollusks also show stable isotopes that show an SST gradient increase during the early to middle Holocene (Carré *et al.* 2005: 45).

Moy and coworkers (2002) analyzed core sections from Lake Pallcacocha in the southern Ecuadorian Andes. Based on the observation of light colored laminae deposited in the past 200 years that have been positively correlated to ENSO events, they found evidence of continuous ENSO oscillation activities for the last 12,000 years. Pallcacocha exhibits a trend of low concentration of events in the early Holocene and an increasing occurrence after 7,000 cal yr B.P., with the highest frequency at ~ 1,200 cal yr B.P. The absence of laminae in some sections of the cores suggests that the ENSO was weak or absent during the early Holocene, therefore it did not leave enough alluvial deposition in the alluvial drainage of the lake. Also, pollen records from the lake indicate no significant changes in regional vegetation during the early Holocene (Moy *et al.* 2002: 164). This lack of variance in the ENSO sections from ~15,000 to 7000 cal yr B.P. indicates that the zonal SSTs (Sea surface temperature) were subdued because the tropical Pacific is a coupled ocean-atmosphere system. The destabilized zonal SST gradient was caused by either a less intense western Pacific warm pool or by warmer SSTs in the equatorial and coastal upwelling zones of the eastern Pacific (Rodbell *et al.* 1999). An alternative explanation for the presence of Holocene molluscan assemblages ^{14}C dated at > 5000 years B.P. along the Peruvian coast north of 10° S and in southern Ecuador suggests that these thermally anomalous molluscan assemblages (TAMAs) are present because the zonal Walker circulation, which characterizes normal or La Niña years, decreased during the early Holocene and thus the oscillation between El Niño and La Niña states was muted (Rodbell *et al.* 1999).

Sea levels partially depend upon the volume of oceans, which is determined by the hydrological cycle and by the size and shape of crustal depressions in the ocean floor. Changes of sea level are caused by the uplift or lowering of coasts (tectonic movements), by eustatic movements, or both (Bird 1993: 9). Sea level also changes in relation to weather conditions, such as wind action and atmospheric pressure cycles such as ENSO, which causes and reverses high pressure and low sea levels over the southeast Pacific and low pressure and high sea levels in the Indian Ocean (Fairbridge and Krebs 1962).

The Quaternary oscillations were characterized by advancement and retreat of glaciers and, after 18,000 years, when the climate became warmer and water from the ice sheets melted into the oceanic basins, the sea level started to rise. These events are known as the Late Quaternary Marine transgression. When the radiocarbon assays of materials associated with shore deposits are plotted they produce curves that show the sea level was averaging a swift rate of change of 1m per century between 18,000 and about 6000 years ago (Bird 1993: 14).

The Holocene epoch, before the past 10,000 years, has been characterized by a more stable sea level after the end of the Last Glacial Maximum, with the exception of the coasts that have experienced minor oscillations; the last 6000 year are considered the Holocene standstill period (Bird 1993: 14-15).

In addition to postglacial deglaciation, another cause of sea level change is the sedimento-eustatic process that consists of the accumulation of sediment carried by the sea, which occurs in areas of high tectonic activity or where sediment boundaries change abruptly (Bird 1993: 16; Robertson *et al.* 1991: 359). Also, sedimentation along the coasts and deltaic areas caused by tectonic movements and the ensuing isostatic response of loading and unloading results in downwarping; this can be seen in some areas of the Mississippi where sedimentation has not been maintained and sea level rises as a consequence (Bird 1993: 17). Tectonic movement upward and downward, especially with tectonically active coasts around the Pacific, causes intermittent rising of the coasts. This can be observed in the north coast of New Guinea, which has been rising intermittently and has experienced oscillations of sea level; this is also the case on the island of Atauro in Indonesia and Timor (Chappell 1974; Chappell and Veeh 1978). Another cause of sea level change may be the influence of changes in the ocean surface topography that result from geoid changes. This topography is caused by geophysical phenomena such as tides, Earth rotation, and climatic patterns (Mörner 1976; 1983).

Stothert and coworkers (2003), based on readings using bathymetric soundings of the sea floor off the coast of the Santa Elena peninsula and the Fairbridge (1962) sea level curve, showed that sea level fluctuated rapidly between 10,000 and 9000 years B.P. and fell 20 m below its present level by 8000 B.P. so site OGSE 80 would have been located around 12 km further from the north shore. By 7000 B.P. the sea level would have been 10 m below its present level (Stothert *et al.* 2003: 27-28).

Methods

Two approaches were applied to model sea level and land uplift in the Santa Elena Peninsula. The first approach consists of modeling the coast based on the bathymetric readings from the Instituto Oceanográfico de la Armada (INOCAR 1980). The second approach consists of modeling the coast based on the modern sea level isolines created from bathymetric readings from the Instituto Geográfico Militar Ecuatoriano (Dominguez 2010; ESRI 2007; IGM 1981; 1998; Mitchell 1999). Stothert and colleagues indicate in this table that in the case that tectonic uplift in the Ecuadorian littoral occurred at a steady rate of 0.5 vertical meters per 1000 years, as suggested by Richardson (1998) and Sandweiss and colleagues (1989), the distance between the modern coastline and paleocoastline would appear as indicated (Table 1).

Based on the INOCAR (1980) isobaths and the Fairbridge sea-level curve presented by Bird in 1993, I have reproduced the model by Stothert

Table 1. Extent of additional terrestrial zone exposed along the coast of the Santa Elena Peninsula when the world sea level was depressed, after Stothert and colleagues (2003: 29).

Years before present (uncal. 14C years)	Sea level in meters below present level	Amount of additional land exposed compared to today (in km^2)	Level of land (in meters) with respect to modern level	Difference (in meters) between modern shore line and sea level	Amount of land exposed given steady tectonic uplift of the land (in km^2)
10,000 BP	–30	600	–5	25	498
8000 BP	–20	450	–4	16	360
7000 BP	–10	97	–3.5	6.5	63
5000 BP	–5 to 0	20 to 0	–2.5	2.5 to 0	10
Present	0		0	0	–

and colleagues for the Santa Elena Peninsula coast using Geographic Information Systems which provides us with the opportunity to better visualize the coastal geomorphology and the situation of the identified Las Vegas sites at different moments in time. While there are several studies that have suggested different rates of oscillation, discrepancies have been found in the configuration of coastlines around the world during the Holocene. The complicating effects of land uplift and depression, shifts in ocean surface topography that result from geoidal changes, and climatic fluctuations are local regional phenomena.

Most of the features found in present coastlines were formed during the Holocene still-stand, a period characterized by relatively stable sea level for at least the last 6000 years, which came after the Late Quaternary marine transgression.

During the worldwide Late Quaternary marine transgression, characterized by a surge of sea level, coastal lowlands and valleys were inundated and formed estuaries and broad embayments. The Santa Elena littoral experienced these episodes combined with coastal uplift and changing climatic conditions and consequently the Las Vegas people lived through the creation and destruction of lagoons, estuaries and marshland (Stothert *et al.* 2003: 27-28).

Changes in the type and density of marine fauna that can be distinguished between the late and early Las Vegas indicates that mangrove clams (*Anadara tuberculosa)* and other estuarine and mangrove species including *Certhidea pulchra*, *Tagelus rufus*, and *Thais kiosquiformes* dominated the early Las Vegas assemblages Stothert et. al 2003: 30-32). Heusser and Shackleton (1994) recovered deep-sea cores that suggest that the presence of mangrove was at its highest level between 12,000 and 7000 years B.P., which coincides with the distribution of mangrove clams in the early and late Vegas assemblages (Stothert et. al 2003: 28).

Terrestrial animal and plant communities were also affected by fluctuations in sea level and tectonic uplift. In spite of the supposition of climate change, which would have been indicated by the presence of tropical forest fauna, the Las Vegas assemblages of terrestrial animals are characterized by species that are presently found in sub-humid and arid environments, which is the present day environment (Tellkamp 2005). The avian assemblage from Site 80, analyzed by Tellkamp (2005) comprises species that are still common locally (within a radius of 20 km), but also species that occur outside a radius of 100 km. The overall composition indicates that Vegas people hunted birds in mangroves as well as freshwater marshes, ponds, lakes and terrestrial habitats, as oppose to other Early Holocene sites from the more arid Peruvian coast, marine birds are absent (Tellkamp 2005).

Aside from mangroves, other freshwater wetlands may have been present during the Early Holocene. These wetlands would have required either a higher amount of rainfall or a higher water table. Ferdon (1981) suggested that a shallow water table could have formed near mangroves as a freshwater lens sitting on saltwater that percolates inland at sea level, which would have provided a freshwater environment at least for several months after the rainy season (Tellkamp 2005: 221).

According to Stahl (2012) the hunting efficiency of the Las Vegas people, may have been increased by the close association to the canid, *Lycalopex sechurea*. In Stothert's 1988 report, nearly 3000 fox bones and teeth are identified at OGSE-80 alone.

The prevalence of grass and shrub phytoliths in the floristic assemblages recovered from Las Vegas sites by Piperno and Stothert (2003), suggest that plant use was part of these wide-ranging foraging economies *Cucurbita sp*. (squash and gourd) phytoliths recovered from site 80 date as early as 10,100 years B.P. It is important to note that phytoliths from palm and other tropical plant species have not been identified in the Las Vegas assemblages, which suggests that the western part of the peninsula was dry and supported primarily savanna and thorn scrub vegetation (Piperno and Pearsal 1998; Stothert *et al.* 2003: 30).

The distribution of mangrove and estuarine species in the early Las Vegas assemblages, in conjunction with the decline of mangrove exploitation, agrees with the evidence for intensification of terrestrial resources and plant domestication during the Late Las Vegas occupation. Sea level changes and tectonic uplift during the Las Vegas occupation resulted in a dramatic change in the Santa Elena littoral.

It is probable that early Las Vegas sites are located as far as 5-10 km west of the modern mainland of the peninsula. The cultural dynamics of shifting coastlines cannot be predicted without fine-grained paleoenvironmental research (Figures 2, 3, 4). Figure 2. 30 Meter Coastal Uplift at 10,000 B.P. (Domínguez 2010).

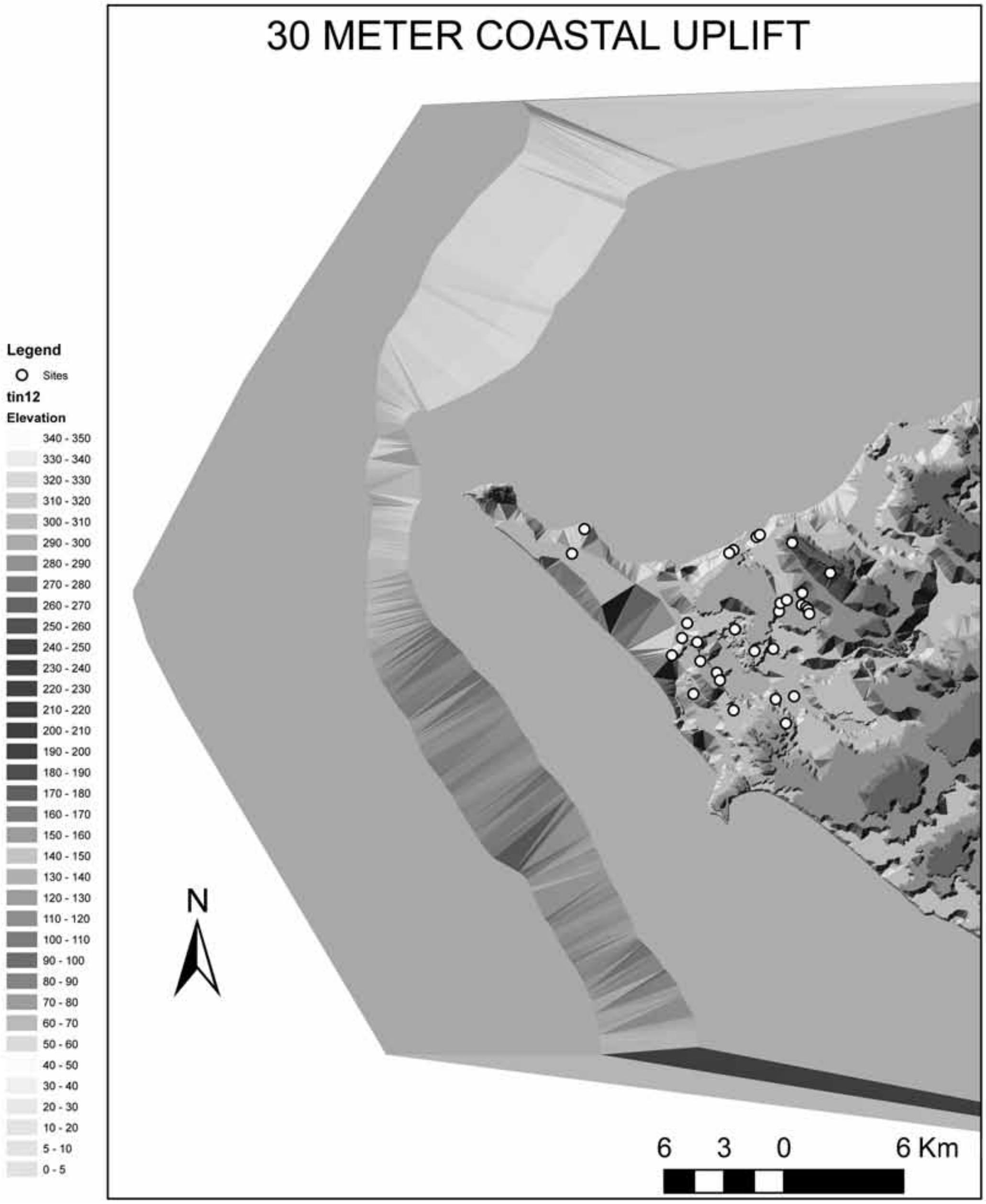

Figure 2. 30 Meter Coastal Uplift at 10,000 B.P. (Domínguez 2010).

For the viewshed analysis (Dominguez 2010; ESRI 2007; Mitchell 1999`) of the area I have used the TIN model of the isobaths produced by the Instituto Geográfico Militar (IGM 1981; 1998). This model is beneficial in that it demonstrates which land and water features are visible from the Las Vegas sites. Cells in light gray are visible from the sites, while the cells in dark gray are not. Visibility is an important spatial analytical unit since it allows us to understand how the landscape was perceived from the known archaeological sites (Figure 5).

Discussion

The faunal and floral remains suggest that, during the early Las Vegas phase, people must have traveled around the peninsula for long distances and that this territory included, based on the GIS

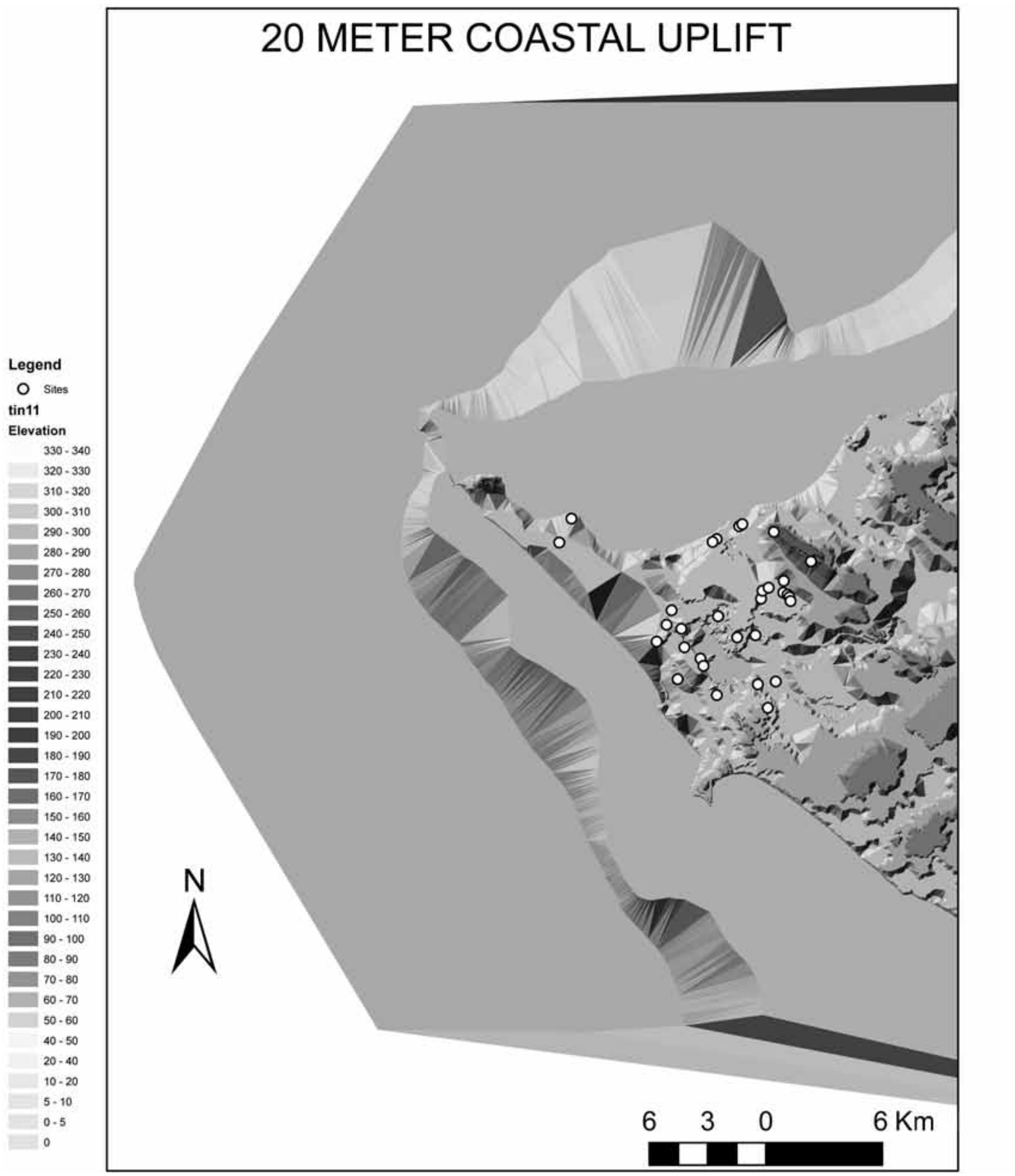

Figure 3. 20 Meter Coastal Uplift at 8,000 B.P. (Domínguez 2010).

models, between five and ten kilometers of land that is now below the modern sea level. Social dynamics and environmental oscillations in these early communities may have also contributed to subsistence innovations such as early plant cultivation. In the Late Vegas period, the historical association of the people with the landscape becomes manifest in mortuary rituals.

Perhaps specialized camps of itinerant fisherman and collectors were located close to the ancient mangrove embayments and lagoons. The thousand year hiatus of human occupation that appears in the record around 6600 BP is puzzling. The disappearance of mangrove may have been caused by tectonic uplift at a swifter rate than the rise of sea level, which would have also caused

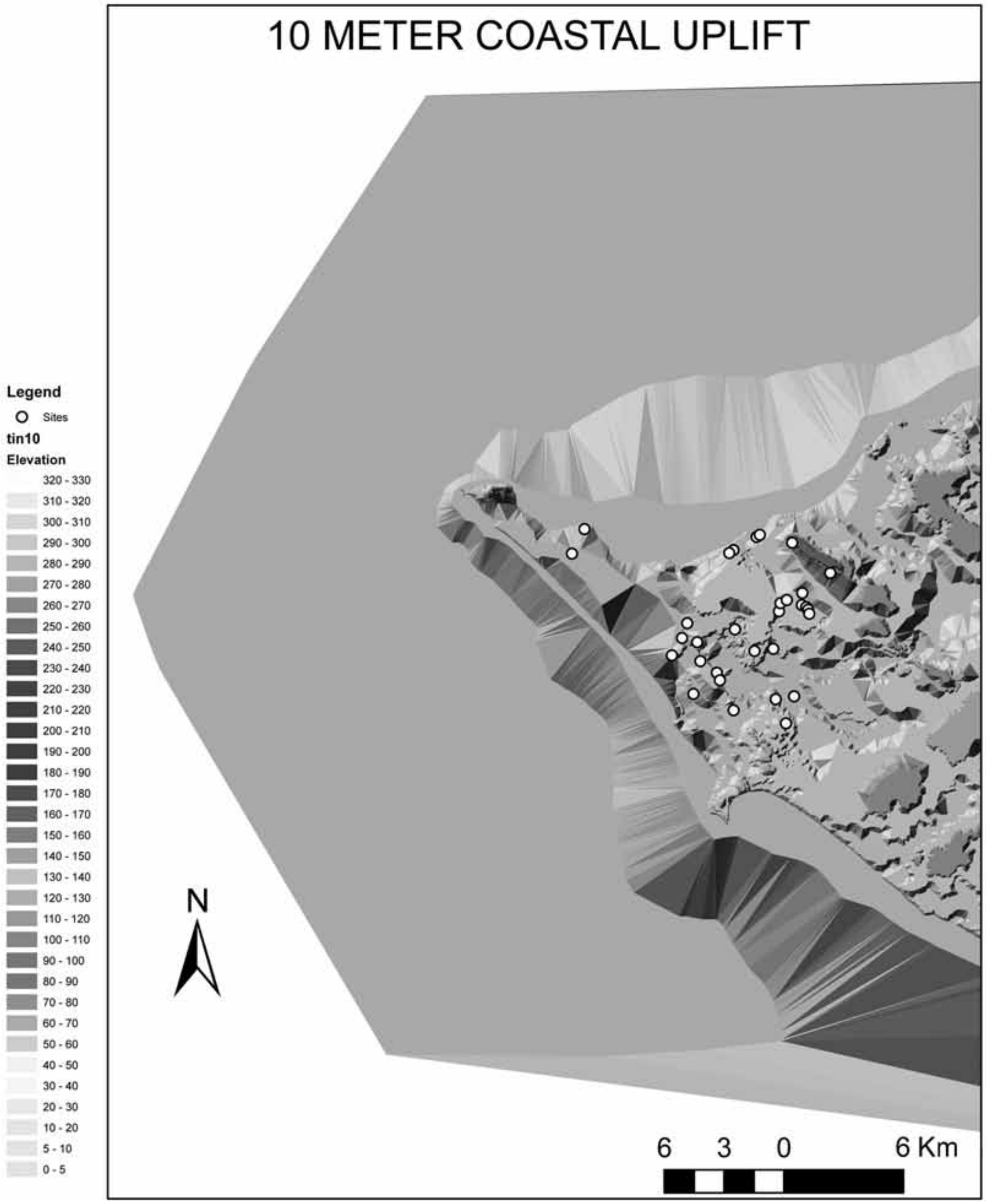

Figure 4. 10 Meter Coastal Uplift at 7,000 B.P. (Domínguez 2010).

the disappearance of other areas rich in marine resources; however, the generalized economy developed by the Las Vegans showed a decrease in dependency on mangrove resources during the late period. It seems unlikely that the abandonment of the peninsula was caused by geomorphological changes more than by the choices of a society that had a clear understanding of resource management and was involved in social practices that were more than subsistence oriented– or perhaps there was never even such a hiatus.

It is useful, when investigating whether or not there was a pause in the human occupation of the peninsula, to consider archaeological approaches to agency, as proposed by Joyce and Lopiparo in 2005. By incorporating the archaeologically

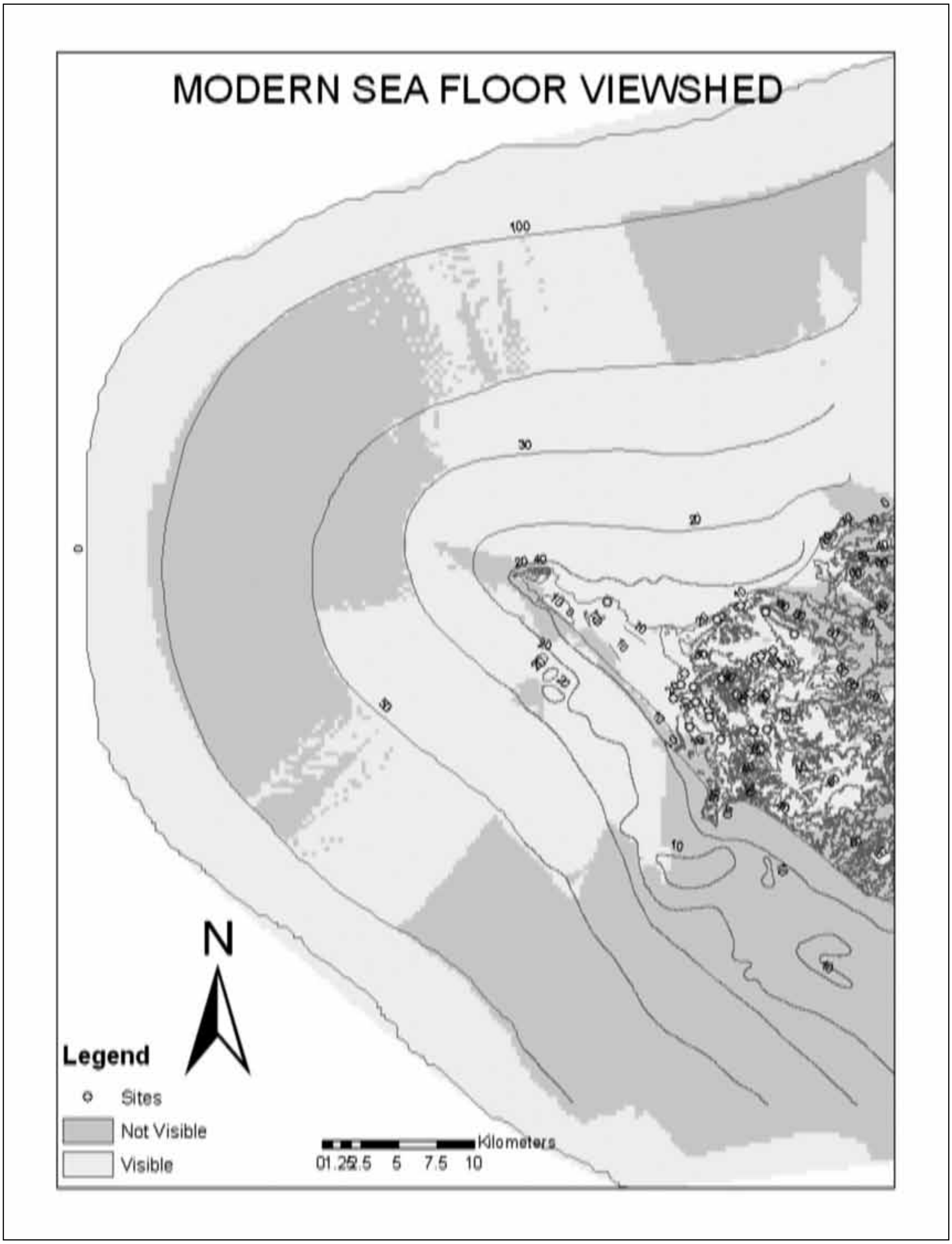

Figure 5. Viewshed model (Domínguez 2010).

discernable landscape we can endeavor to address the coordination of experiences among peoples that can discursively reproduce histories and mythologies but also demand innovation at scales from the individual to the regional and extra-regional, from the event to the *longue durée* (Balée 2006). As our understanding of the history of the peninsula develops as paleoeoenvironmental and zooarchaeological findings come to light our approach of those findings may be informed by the recent history of occupations, development and ecological change.

During the last century, it has been observed that environmental conditions in the peninsula have fluctuated significantly. As recently as 70 to 90 years ago riverine gallery forests and heavily vegetated grasslands characterized the area. These have since disappeared along with fauna such as deer (*Odocoileus virginianus*) and other small mammals. Also, small patches of mangrove by the embayments of Chanduy, Punta Carnero, Salinas and Pacoa have disappeared mainly because of deforestation and development (Stothert 1985). Of a total of one thousand nine hundred and seventy eight kilometers of open banks in Ecuador, five hundred and thirty three kilometers were originally lined with mangroves, which have historically been central to the livelihood of littoral human populations (Veuthey and Gerber 2011).

Local communities of the Ecuadorian coast have historically been interrelated with the mangrove ecosystem. Approximately one and a half million people are engaged in artisanal fishing, collecting shellfish, wood for charcoal and medicinal plants from mangrove ecosystems (Veuthey and Gerber 2011).

Since, in our brief window of observation in recent times, we have seen significant environmental changes, it would be folly to discount the possibility of centennial or decadal oscillations having taken place throughout the history of human occupation in the peninsula.

Our geomorphological models, which have given us a closer look at how coastal changes, mangrove habitat and human communities interacted in a dynamic manner, are inherently limited in resolution and will not evidence how nuanced oscillation have influenced the discursive production of identity and place on the Santa Elena Peninsula throughout the millennia.

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