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GIS Modeling of the Andean Coastline through the Holocene

Preliminary Research for a Greater Project

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ABSTRACT

Using Geographic Information Systems (GIS) to model the Andean coastline and reviewing literature to compile Holocene epoch archaeological sites are vital, preliminary steps in beginning research on an overall, interdisciplinary project currently titled: “12,000 Years of Life by the Sea: Bringing Holocene Archaeological Data to Bear on Human-Coastal Interaction and Contemporary Coastal Ecology and Conservation.” The greater project aims to address broad questions regarding long-term climate change, the periodicity and intensity of El Niño events, and coastal ecology and conservation through the application of archaeological data from the coastline of Peru. By modeling bathymetry, classifying potential coastline levels throughout the Holocene, and beginning to identify archaeological sites that contain evidence of the use of marine resources, researchers can prioritize future surveys and excavations, and begin to establish prehistoric baselines for marine fisheries. The greater project seeks to make archaeological data and analysis more relevant to critical issues in contemporary society. Through the preliminary research of this project, we can identify differences in sea levels through time, where prehistoric settlements were situated in relation to the changing coastlines, and better understand the intensity of prehistoric fishing and marine resource procurement. With this information, we can begin to address both present and future problems regarding sustainability, climate change, El Niño events, and the ecology and conservation of modern, industrial-level fisheries along the Andean coast.
INTRODUCTION

Preliminary Research for a Greater Project

Preliminary research is a vital step in preparing for future studies or for developing larger projects. To assist with the development of a greater project, “GIS Modeling of the Andean Coastline through the Holocene Period” is the preliminary research, data acquisition, and construction of Geographic Information Systems (GIS) datasets that will be used to address over-encompassing research questions and contemporary problems through an archaeological lens. Using GIS, this project aims to begin to organize archaeological site data based on proximity to the Andean coastline and create bathymetric contour lines of the submerged shelves along the coast. By utilizing GIS software and by researching archaeological literature, the appropriate data can be amassed, analyzed, and applied to create the foundation of a greater, interdisciplinary project titled: “12,000 Years of Life by the Sea: Bringing Holocene Archaeological Data to Bear on Human-Coastal Interaction and Contemporary Coastal Ecology and Conservation.”

GIS: A Brief Overview

GIS is an acronym for Geographic Information Systems, which is an integral software that can be applied in various types of disciplines, such as civic or urban management, natural resource management, or academic research. Concisely, GIS enables users to amass, maintain, manipulate, and map data with real-world spatial context. Regardless of application, GIS software assists with data management and data visualization – a key component of the foundation of the greater project.

GIS elements include types of data layers or datasets. Data can be maintained within differing datasets and if visualization is necessary, maps can be created by layering the various
datasets into a map layout, often over top of background imagery, or a basemap. Basemaps can be imagery, raster data types, or Digital Elevation Models (DEM). (See Figure 1, below).

Figure 1: An example of different datasets, layered on top of each other to create a map document. The basemap is located on the bottom and helps orient the map user. If this were the GIS data layers from this project, the layers on top of the basemap would be archaeological site locations, and contour lines.

From https://www.geologyin.com/2014/05/a-geographic-information-system-gis.html

Raster data types are made up of pixels to create an image and can be displayed in many ways. DEMs are similar to raster imagery and are derived from remote sensors – such as LiDAR, which uses lasers to create accurate representations of changes in ground topography or ocean floor bathymetry. DEM data is a vital component of this project: it allowed the bathymetry of the submerged, Andean coastline to be identified, and using these elevation changes, arbitrary contour lines were built in GIS.

Vector data types represent real-world data in the form of points, lines, or polygon features and store location and attribute information. An example of a vector data type in this project would be a dataset of archaeological sites, which include attribute information for various sites, such as nomenclature, radiocarbon date ranges, and time-periods of occupation. To complete the preliminary research for the greater project, GIS software provided valuable tools
used to build the necessary datasets and visually display the topography and bathymetry acquired from the DEM imagery.

**12,000 Years of Life by the Sea: Archaeology & the Greater Project’s Background**

Archaeology draws its evidence and data from physical remains covering the deep past, dating back thousands of years longer than any historically kept records. The material nature of archaeological data lends itself to quantification and comparative analyses. These characteristics make archaeology uniquely suited to address the greater project’s questions regarding both climate change and coastal ecology over long periods of time.

“12,000 Years of Life by the Sea,” will eventually analyze marine and coastal species’ biomass and diversity along the Andean coast over the span of the entire Holocene epoch, and by utilizing fish, marine mammal, coastal bird, and shellfish remains from dated archaeological sites as a proxy for shifting sea levels, surface temperatures, and El Niño events, researchers from multiple scientific disciplines can begin to address contemporary issues (Butler and Delacorte 2004; Carre et al. 2005; Casteel 1976; Church et al. 2013; Dietl and Flessa 2009; Fagan 2008; Grayson 2001; Joslin 2012; Jackson et al. 2011; Joslin 2012; Keefer et al. 1998; Lambeck 1990; Negendank 2004; Reitz et al. 2008; Sandweiss 2003; Smith et al. 2011; Wake et al. 2013; Woodroffe and Murray-Wallace 2012). Historically, the Peruvian coastal fisheries have been some of the richest in the world and only since the 1980s have they declined. The richness of the Andean fisheries and the well-developed archaeological record along the coast of Peru, where humans have lived roughly for the past 12,000 years, make the Andean coastline a perfect location for the greater project.
Sea surface temperatures shift periodically over long periods of time or they can shift rapidly in the short-term, often associated with El Niño events, which occur roughly every three to five years today (Carre et al. 2005; Fagan 2008). These events can have devastating effects on coastal and marine resources, and can be a detriment to human populations that are dependent on these fisheries. *(See Figure 2, below).*

*Figure 2: Scanned from Fagan (2008: 162), an image depicting the effects of El Nino events globally. Off the Andean coast, El Niño has detrimental effects on fisheries. These disturbances could be problematic for human occupations.*

According to Brian Fagan (2008), historical records from 1690 to 1987 indicate eighty-seven El Niño events in Peru; however, within the prehistoric climate record, the frequency of these events is uncertain because “they leave inconspicuous traces in the geological record, usually flood deposits in archaeological sites” (Fagan 2008: 163). The researchers involved in the greater project are interested in better understanding the frequencies and relative intensities of El Niño
events looking back through the Holocene epoch to more appropriately address contemporary issues regarding the potentially damaging effects of El Niño events and a changing climate.

Additionally, coastal ecologists, conservationists, and policy makers must monitor animal biomass and diversity across the globe to ensure we use our resources sustainably, regardless of periodically shifting sea surface temperatures and damaging El Niño events. In many regions across the globe, there have been observed precipitous drops in biomass and diversity over the past fifty years. Species reduction is arguably thought to have been caused by over-predation and industrial-level fishing; however, this debate is based on fishing and catch records that have only been documented for around the past seventy years (Grayson 2001; Jackson et al. 2011). A lack of knowledge regarding biomass and species richness prior to this century is problematic. It is important to establish what the natural baseline levels for marine biomass would have been, prior to modern, industrial-level fishing, and identify what species were present over time and in what ratios for various regions across the globe. Understanding how these levels shifted in prehistory is important to assess how detrimental over-predation and industrial-level fishing has been on marine and coastal species in modern history (Artz 1980; Bjorkman and Vellend 2010; Butler and Delacorte 2004; Cannon 1987; Casteel 1976; Chauchat 1988; Grayson 2001; Jackson et al. 2011; Joslin 2012; Pinnegar and Engelhard 2008; Reitz 2001; Reitz et al. 2008; Rick and Erlandson 2008; Wake et al. 2013).

**GIS Modeling of the Andean Coastline: This Project’s Background**

To begin preliminary research on the greater project and address its goals, well-dated archaeological sites needed to be located along the Andean coast from which to excavate and sample marine and coastal faunal remains – either via on-the-ground surveys in the future or by
reviewing archaeological literature for previously recorded data. A wide range of archaeological site types ranging from simple shell middens to villages and adobe platform mounds needed to be reviewed. Shell middens are the discarded food and trash remains of coastal human occupations and the strata of a shell midden often represent the repeated use of the location through time. One of the most important aspects of an archaeological site, within the parameters of this project, is the presence of stratified deposits that include faunal materials, like those often recovered from shell middens in archaeological sites (See Figure 3a and 3b, below).

Figure 3a: A stratified and sampled shell midden, from the Ring Site in southern Peru. The Ring Site is located approximately 750 meters from the modern shoreline.

From https://ars.els-cdn.com/content/image/1-s2.0-S0277379111002204-gr1.jpg

Figure 3b: An example of a simple shell midden archaeological site somewhere along the coast of Peru. Some archaeological sites consist of nothing but midden material.

From www.Washington.edu/news/files201408FigS4.jpg

By reviewing archaeological literature, previously excavated and sampled sites could be identified and recorded. For periods of time earlier in the Holocene, the stratified and well-dated
or date-able shell midden sites would take precedence. The data from these sites and their locations are vital aspects to understanding prehistoric climate and marine resource use.

From the late Upper Pleistocene to the middle Holocene period, between approximately 18,000 and 7000 years before present time (BP), the Andean coast witnessed a sea level rise of approximately 300 meters, resulting in the inundation of areas along the coastal shelves and the archaeological sites located on them (Church et al. 2013; Lambeck 1990; Smith et al. 2011; Woodroffe and Murray-Wallace 2012). (See Figure 4, below).

![Quaternary Period with the Anthropocene Epoch](image)

**Figure 4**: The approximate date ranges of the Pleistocene and Holocene epochs. The Anthropocene epoch is argued to have begun around 1950, the date we use for BP (before present). Sea levels did not start rising until the late Upper Pleistocene, around 18,000 BP.

From [https://www.britannica.com/science/Holocene-Epoch](https://www.britannica.com/science/Holocene-Epoch)

The modern mean sea level on the Andean coast has remained relatively constant since approximately 7000 BP; therefore, sites and their samples of faunal remains dating to time-periods since then are relatively easy to identify on the modern coastline. Sites like Las Haldas in the Chicama Valley exemplify these easy-to-identify coastal sites – Las Haldas is currently
located around 200 meters from the modern coastline, making it an important proponent of human coastal occupations in the past. (See Figure 5a, 5b, and 5c, next page).

Figure 5a and 5c: Las Haldas, an archaeological site located on the desert coast of Peru. The site is located within 200 meters of the modern shoreline.

Photo 5a courtesy of Dr. Jason L. Toohey. 5c from https://www.anywhere.com/peru/attractions/las-haldas-archaeological-site

Figure 5b: Within the Las Haldas site, an example of a shell midden near the entrance of a structure. Located behind the sunken plaza in 5a and 5c.

Photo courtesy of Dr. Jason L. Toohey

For this project and the greater project, we predict that certain locations on the submerged shelves and along the modern coast may be more likely to exhibit shell midden sites that date prior to 7000 BP. Sea levels along the Andean coastline have remained unchanged for the last 7000 years, so we want to prioritize future survey and excavations at sites that date before sea levels stabilized. Sites with occupations that date prior to 7000 BP are target sites. Our priority survey areas should be nearby and along the narrower shelves – places where the mid-Holocene sea level rise would have had less effect on the location of the sea surface level. Previously, an
extensive search of the existing literature on the archaeology of the early coastal Andes indicated that a spatial data-driven estimation of the changing coastline had not been done, or at least had not been published. At the core of this aspect of the broader project is the estimation of the locations of the changing Holocene coastline and the locations of coastal sites. Areas near specific coastal shelves could be prioritized for future on-the-ground surveys, and with remote reconnaissance and the construction of the arbitrary contour lines using GIS, promising areas could be identified.

METHODS

_Literature Review and Constructing the Site Dataset_

A literary review of past archaeological investigations was necessary to identify coastal sites with dated or date-able organic material. Within archaeological literature, information could be mined and gathered to begin the construction of the ‘Site’ dataset. Using Microsoft Excel, attribute information from each site was organized (See Appendix: Site Dataset). Compiled from the literature, attributes recorded included: site names, the early and late radiocarbon date ranges, the generic time-period(s) of human occupation, the approximate kilometers from the modern coastline, the references the information was derived from, and an estimated UTM location – based off figures in the literature, Google Earth, and assistance from my mentor, Dr. Jason Toohey. Using this excel sheet as the raw dataset, the sheet could be imported into the ESRI ArcGIS software, ArcMap 10.5. When importing to ArcMap, the UTM locations are used as XY data, spatially linking the data to their real-world locations. Because this project is ongoing, the raw excel dataset will periodically be re-imported, as additional sites and their attribute information is compiled. References included in this project include only a small fraction of
literature available on Andean archaeological sites; therefore, the construction of a ‘Site’ dataset is a continuing and evolving process.

**Acquire DEM Data and Create Bathymetric Contour Lines**

With the ‘Site’ dataset built, a DEM basemap was necessary, not only for orientation when viewing the data, but more importantly, to access the elevation information of the submerged ocean floor – the bathymetry. In the world of remotely sensed imagery, there is a wealth of data that is available for free download. Research was necessary to find the types of free, remotely sensed data available for the length of the Andean coastline. Multiple private and government websites were visited to locate the appropriate dataset. A relatively high resolution was also important because it provides more detail; thus, more accurate contour lines of the bathymetry could be created. Due to the limited amount of data that has been remotely acquired along the coast of Peru, it took some time to locate raster data that could be manipulated for the goals of the project. The GEBCO gridded bathymetric dataset from 2014 proved useful and was derived “... by combining quality-controlled ship depth soundings with interpolation between sounding points guided by satellite-derived gravity data” (gebco.net). (See Figure 6, below).

**Figure 6:** The GEBCO gridded bathymetric dataset 2014. The top portion (northeast) of Peru is not included because only the coastline was necessary for the project.

Acquired from http://www.gebco.net/data_and_products/gridded_bathymetry_data/

Displayed in ArcMap 10.5.
One of the most important tasks involved research on the creation of custom iso or contour lines in ArcMap. The GIS software, ArcMap 10.5, is a valuable program with countless tool options to manipulate data, and multiple ways to create custom contours using DEM or raster data types were identified. With the GEBCO dataset – my raster basemap – and the ArcMap tool, Spatial Analyst > Contour List, I was able to enter arbitrarily chosen z values, or elevation levels. The tool uses the raster basemap as the input, and the chosen z values can be entered. After the tool has run, the resulting output is a data file consisting of the custom contour line or lines. These lines could then be further symbolized based on specifics set in the symbol properties window of the ArcMap program. Because sea levels rose roughly 300 meters over time, starting in the Upper Pleistocene epoch – 18,000 BP – and stabilizing by the mid-Holocene – 7000 BP – we felt our arbitrary contour lines could be representative of Holocene-specific coastline levels. The arbitrary elevation levels chosen as z values were: 0 meters (current sea level), -6.67 meters below today’s sea level, -13.34 meters, -20.01 meters, -26.68 meters, -33.35 meters, -40.02 meters, -46.69 meters, -53.36 meters, and -60.02 meters below sea level. If the sea level rise was constant throughout the Pleistocene-Holocene transition, it could be safe to assume that our chosen cap of 60 meters below the modern sea level would be representative of a Holocene epoch sea level.

RESULTS

The GIS datasets that make up the overall map document are important to beginning the greater project. With the GEBCO basemap, the possible Holocene contour lines, and the current ‘Site’ dataset, visual examination of the coastal shelves could be completed. The resulting map includes the datasets, four modern, Peruvian cities, the boundary of the country, and Lake Titicaca on the southern border of Peru. (See Figure 7, next page).
Figure 7: The overall map, complete with the GEBCO basemap, custom bathymetry, the current compiled site locations, and the modern cities of Trujillo, Lambayeque, Lima, and Nasca. Lake Titicaca is to the south.

Created in ArcMap 10.5.
The basemap can also be symbolized. The GEBCO gridded raster is depicted with a graduation of light purple to a bright green coloring. Purple indicates the highest elevations – the Andes Mountain Range, reaching 6543 meters above sea level at their highest. The light blue colors indicate lower elevations along the desert coast to the west and in the lusher forests to the east of the Andes. The brighter blue color is representative of the submerged marine shelves off the Peruvian coast, and the greens represent the deep-sea floor, far off the South American coast in Pacific Ocean, reaching depths of -7644 meters below sea level.

The data layered on top of the GEBCO basemap includes the ‘Site’ dataset and the custom contour lines of the immediate inundated coastline of Peru. Very brightly colored, thin lines represent the custom contours. The darker green lines located farther out to sea indicate 60 meters below modern sea level, and the bright, red line closest to the land is indicative of the modern sea level. *(See Figure 8, below).*

*Figure 8: Using the Spatial Analyst toolbar, the arbitrary custom contour lines, depicted in bright colors and thin lines (red to green), were created with the GEBCO gridded bathymetry dataset. Dark green represents 60 meters below modern sea level, while the red represents 0 meters or today’s sea level.*

*Created in ArcMap 10.5.*

The black triangles represent the sites that are currently compiled in the ‘Site’ dataset that currently have their relative locations recorded. There are additional sites that have been identified from the literature, but are not included in the map due to the uncertainty of their
locations. There are countless archaeological sites along the coast of Peru, but only a few have been finalized in the 2017 raw data; therefore, there are only a handful of archaeological sites currently included in the existing ‘Site’ dataset and overall map. Numerous sites are still under review and will likely be included in the updated dataset versions in the future.

DISCUSSION

In northern Peru, from the Ecuadorian border to just south of the modern city of Trujillo, many places along the coast exhibit a wide marine shelf. These wider shelves would not take precedence for future surveys because they would have been affected heavily by the sea level changes throughout the Holocene epoch; however, there is potential for future underwater reconnaissance, as older sites are likely to be located along these wide, submerged areas. (See Figure 9, below).

Figure 9: A close-up of a portion of the northern region of Peru, complete with wide submerged coastal shelves and potential prehistoric lagoons (See arrows).

Created in ArcMap 10.5.
Located throughout the besieged shelves, there are also numerous sunken areas that could be prioritized for future surveys (See Figure 9, previous page). These areas are currently underwater, but during the late Holocene, the sunken pools could have been resource-rich, inland lagoons. Some sites within proximity to these lagoons, like Huaca Prieta just north of Trujillo, have series of dated occupations spanning from 14,200 BP to 4200 BP (Dillehay et al. 2012). Temporally, multiple occupations can help us understand how people may have adapted to the changing climate and the rising sea levels, as well as aid in identifying what types of marine and coastal resources were staples throughout the differing occupations. (See Figure 10a and 10b, below).

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**Figure 10a:** In the distance, the archaeological site of Huaca Prieta, located within 150 meters of the modern coastline.

*From* https://www.upressonline.com/wp-content/uploads/2017/06/Archaeology.jpg

**Figure 10b:** The mound and nearby excavations at Huaca Prieta. The mound is also pictured in 10a.

Even if the coastlines were still 100 meters or 200 meters out by the beginning of the Holocene epoch around 12,000 years BP, the inland lagoons could have contained rich, food resources for nearby coastal occupations. On-the-ground surveys in the future can prioritize locations nearest to these submerged lagoons or return to known archaeological sites for new excavations.

South of the modern city of Trujillo and north of the modern, capital city of Lima, there are numerous archaeological sites currently identified within close proximity of the coast that date throughout the span of the early to mid-Holocene. Though the northern region exhibited extremely wide, submerged coastal shelves and many potential lagoons, the shelves begin to narrow throughout the central regions of Peru. Lagoon areas are also relatively abundant along the expanse of coast between Trujillo and Nasca. *(See Figure 11, below).*

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**Figure 11:** The central region of Peru, with the capital city of Lima in the center. Various inundated shelves exist, as well as possible prehistoric lagoons. Multiple sites are situated near these lagoons.  
*Created in ArcMap 10.5.*
Farther south, from the modern city of Nasca to the Chilean and Bolivian borders, the submerged coastal shelves become quite narrow and relatively steep. There are few to no potential lagoons south of Nasca, but the extremely narrow shelves could be likely survey areas in the future. The areas on and near these extremely steep and narrow shelves would take precedence over wider shelves. *(See Figure 12a and 12b, below).*

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**Figure 12a:** The southern region of Peru exhibits much steeper marine shelves than identified in the northern and central regions (See Figures 9 and 11).

**Figure 12b:** Continuing south of Nasca, Peru, near the borders of Chile and Bolivia. Many sites are located directly on the modern coastline, including the Ring Site.

*Created in ArcMap 10.5.*

Although there are only a handful of archaeological sites in the current ‘Site’ dataset, there are numerous sites located throughout the entirety of the Peruvian coastline. Any coastal archaeological sites previously identified that contain stratified deposits with dated or date-able
organic materials and faunal remains are vital towards building a prehistoric fishing baseline. For the greater project, target sites should have occupations dating prior to the stabilization of sea levels around 7000 BP. Sites like Huaca Prieta, Las Haldas, or the Ring Site, with their series of occupations or well-stratified shell midden deposits are important areas to continue research.

The expanse of the Peruvian coastline hides possible prehistoric lagoons, a wide range of inundated shelves, and numerous coastal archaeological sites that have previously been identified. Archaeological sites in proximity to narrow shelves and inland lagoons can contain valuable faunal data that can aid in better understanding Holocene climate and prehistoric fisheries. Prioritizing new surveys and excavations along these prime areas can also help in identifying new target age-range archaeological sites for future investigations within the parameters of the greater project.

**CONCLUSION**

The goals of the preliminary project, “GIS Modeling of the Andean Coastline through the Holocene,” involved an in-depth literary review of Peruvian archaeology to identify coastal sites with dated or date-able organic materials and faunal remains, required the creation of possible Holocene epoch sea level contour lines from acquired DEM or raster data, and involved the construction of a map relating these data to help identify potential future survey and excavation areas. Using all the acquired data and the created map, this project aimed to build a foundation for the greater project, “12,000 Years of Life by the Sea: Bringing Holocene Archaeological Data to Bear on Human-Coastal Interaction and Contemporary Coastal Ecology and Conservation.” The GIS modeling exhibited priority areas along narrow shelves and possible inland lagoons where new data could be collected in the future. The archaeological sites included
in the ‘Site’ dataset in relation to the modeled contours could also take precedent. These priority sites could be returned to for new excavations in the future or researched for previously recorded data that stems from pre-7000 BP occupations.

Additionally, other aspects regarding a changing climate, sea levels, and marine life should be considered. Although sea levels began to rise in the Upper Pleistocene, it should be noted that the tectonic activity along the South American coast simultaneously led to an uplift of the shore (Lambeck 1990). In the future of this project, continued research into the archaeological data is necessary, but new research into other aspects of how a landscape and climate may change through time will be just as vital.

Using the foundation data and map, the greater project seeks to make archaeological data and analysis more relevant to critical issues in contemporary society regarding climate change, ecology, conservation, as well as prioritize future on-the-ground expeditions. Additional literary research is necessary, not only to identify supplementary coastal archaeological sites and continue construction on the ‘Site’ dataset, but to delve deeper into the types of faunal remains previously recorded at these sites. Through the preliminary research of this project, we can identify differences in sea levels through time, where prehistoric settlements were situated in relation to the changing coastlines, and better understand the intensity of prehistoric fishing and marine resource procurement. With this information, we can begin to address both present and future problems regarding sustainability, climate change, El Niño events, and the ecology and conservation of modern, industrial-level fisheries along the Andean coast.
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## APPENDIX: Site Dataset 2017

### Sites 1 – 21

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### Notes

- [Richards et al. 1996](#)
- [Richards et al. 2003](#)
- [Richards et al. 2003](#)
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