EXCAVATION SITE PREDICTION USING HIGH RESOLUTION SATELLITE IMAGERY AND GIS DATA DEVELOPMENT OF ARCHAEOLOGICAL DEPOSITS FOR EN BAS SALINE, HAITI

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

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This document is dedicated to my parents for supporting me through all my endeavors and teaching me to strive for the very best.
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Abstract of Thesis Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Master of Science

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Christopher Columbus wrecked the Santa Maria on a coral reef off northeastern Haiti on Christmas Eve, 1492, and was forced to leave thirty-nine men behind with orders to build a fort from the salvaged wood. Returning a year later, Columbus found the fort burned and his men murdered, and to this day the exact location of the first European settlement in the New World is unknown. Archaeological studies have long used aerial photography to identify potential sites for excavation. However, establishing whether the new technologies of high spatial resolution (0.61-cm to 2.4-m) satellite imagery are applicable for archaeological investigations is still a relatively untouched subject. This study examines whether the new technologies of high spatial resolution and multispectral satellite imagery are applicable for archaeological investigation of determining the site of La Navidad fort.
The first portion of this research describes how two DigitalGlobe™ Quickbird scenes of the general area were used to identify targets for archaeological excavation in En Bas Saline, Haiti. Standard panchromatic (61-cm spatial resolution) and multispectral (2.4-m) data bundles were acquired on January 17, 2003, and May 2003. Numerous derivative images were produced from the basic data and were visually scanned for characteristic shapes. Taino (indigenous people) construction was circular while European structures were generally rectangular. Objects that combine both shapes were probable targets or inexplicably disturbed areas. The most promising target was a circle 7 m in diameter and encompassed by a rectangle 15 m wide. Excavation disclosed a 13th century Taino structure, but not the La Navidad fort. Although the Spaniards’ first fort was not found this research expanded the known extent of the Taino village. Other targets revealed European artifacts dating to Columbus’ time. These artifacts and structures would not have been found without the analysis of the satellite imagery.

The second portion of this thesis describes the use of Geographic Information Systems (GIS) to build a personal geodatabase (geographic database) to store and analyze archaeological data. A geodatabase is an ArcGIS© data storage format that represents geographic features and their attributes as objects and is hosted inside a relational database management system. Archaeological studies have always generated large amounts of spatially referenced data, and spatial analysis has been a large part of the archaeological interpretation. The geodatabase provides more efficient data management and more flexible analysis than before. Locations of similar artifacts can be easily queried by their attributes. This will help the archaeologists map distributions of certain artifacts, error check the data collected, maintain data and produce reports.
CHAPTER 1
INTRODUCTION

Background

This research for this master’s thesis was conducted in En Bas Saline, Haiti (Figure 1). It was coordinated with an on-going archaeological project by the Florida Museum of Natural History, Gainesville, FL, searching for the remains of La Navidad, the name of the fort ostensibly built by Christopher Columbus’ men in 1492. The purpose of the research was to use new satellite remote sensing techniques and Geographic Information Systems (GIS) to identify excavation targets in En Bas Saline and to improve the spatial analysis of archaeological records.

This research was supported by a Discovery Quest grant (Contract #: FNH001/DEV/DSC/FG/CB/KW) to the Florida Museum of Natural History from Discovery Communications, Inc. The Government of Haiti and the Bureau National D’Ethnologie D’Haiti provided the project with permits, logistical assistance, and research collaboration.

This thesis consists of four chapters. Chapter 1 details background information and is an introduction to the research. The following two chapters serve as stand-alone publishable research papers. Chapter 2 discusses the techniques of using high spatial resolution satellite imagery to determine archaeological sites for excavation. Its target journal is the Journal of Field Archaeology. Chapter 3 is targeted for publication in ArcUser and covers building the personal geodatabase of all deposits recorded for En Bas
Saline from 1984 to 2003 and the analyses now possible for the archaeologists. The final chapter will summarize all research conducted for this project.

**Aerial Photography and Satellite Imagery**

Archaeological studies have long used aerial photography to aid in identifying potential sites for excavation. However, establishing whether the new technologies of high-resolution satellite imagery are applicable for archaeological investigations is still a relatively untouched subject.

The term “aerial archaeology” was coined for the technique of using distant views of the landscape for archaeological purposes. Archaeologists have used aerial photographs as a prospecting technique to find buried features from as early as the 1800’s. With the idea of using photographs for the production of maps, Gaspar Felix Tournachon took images from a balloon of the French village Petit-Bicetre (Estes et al. 1977). After images of Stonehenge were taken from a military aircraft in 1906 and published in the archaeological journal *Archeologia* in 1907, archaeologists started to realize the possibilities of aerial photography during the early days of aviation (Capper 1907).

With the advent of World War I came considerable advances in both aircraft and cameras fixed on aircrafts. The advancements in technologies exerted a significant effect on the way aerial photographs were used and interpreted (Reeves 1936). In the 1920’s O.G.S. Crawford, a pioneer in aerial archaeology, started recording archaeological sites from aircrafts and giving lectures on his findings. He was the first to show “soil marked” fields at Windmill Hill, England. Soil marks are variations in the color or texture of the soil, which can be caused by past human activity. If humans filled in an area of land the fill may hold more moisture and the darker organic soil will be visible within the aerial
photographs (Wilkinson 1993). After the war scientists in many disciplines were viewing aerial photographs as a tool to identify patterns and details of features not visible on the ground (Miller 1957).

By 1962 new sensor systems such as thermal infrared scanners and airborne radar were available and the term “remote sensing” was coined to encompass the extension of aerial photographs (Estes et al. 1977). Remote sensing is the science of collecting and interpreting information about the earth's surface through non-contact methods (Lillesand and Kiefer 1994).

With the launch of Landsat Multispectral Scanner in 1972 and the improvements to its spatial resolution ten years later with the launch of the Landsat 4 satellite carrying the Thematic Mapper, archaeologists had a new source of remotely sensed data available. In 1986 the French SPOT satellite showed even more improvement to the spatial resolution of satellite data when it produced scenes of 10-m (panchromatic) and 20-m (multispectral) spatial resolution (Fowler 1996). Although advancements were being made, the early relatively low spatial resolution satellite data were useful only in identifying large archaeological sites such as the Pyramids at Giza or linear features within the Roman Forum (Quann and Bevan 1977).

In the last few years new satellites (IKONOS: September 1999, Quickbird: October 2001 and OrbView: June 2003) have been launched, and they produce high spatial resolution satellite imagery. The spatial extents of these satellite data are comparable to aerial photographs but the satellite data are superior when it comes to the amount of spectral data available. Having multiple spectral bands (blue, green, red, near-infrared and panchromatic) allows for different site detection techniques to be employed
A band is a portion of the electromagnetic spectrum with a given spectral width. The boundaries of the visible bands (blue, green and red) are more precise without much overlap as there is with the infrared bands. Spectral resolution in imagery is vital for detecting fine features that can identify specific materials (Thenkabail et al. 2000). The colors within a satellite image are the result of the differential reflectance and absorbance, by different materials, as applied to different bands of wavelengths that make up white light (Avery and Berlin 1992).

**Relational Database Management Systems**

Computer applications in many fields of research require access to large quantities of data. Database software represents considerable infrastructure for these applications. In 1890, the U.S. Census Bureau asked a former employee, Herman Hollerith, to create a system that would automate the processing of information. Hollerith developed the first punched-card machines to process the censuses of 1890 and 1900. A decade later Hollerith’s company merged with another company that became known as International Business Machines (IBM) (Anderson 1988).

The government used new punched-card machines to classify draftees and collect income tax during World War I. In 1935, IBM developed new collection equipment after the passing of the Social Security Act to keep records of the employment in the United States. In the decades to follow the United States’ businesses and government dominated the punched-card processing industry (Committee on Innovations in Computing and Communications 1999).

In the 1960’s the term “database” was coined to encapsulate the idea that data stored within a computer could be structured and manipulated independently of the computer in which it resides. Early application of databases were in intelligence and
military operations, but then quickly became mainstream in educational research and commercial industries (System Development Corporation 1964 and Fry & Sibley 1974). These early database management systems required the user to program around a dataset.

In 1970, a landmark article written by Edgar F. (Ted) Codd was published on relational databases. This relational model proposed by Codd consisted of the data being independent from the hardware and storage of the computer. It also summarized how non-technical users could employ relational calculus and algebra to store and retrieve large amounts of data. His vision included a system that stored data in tables and where the user could access information with commands (Codd 1970).

Codd’s model inspired IBM to start a research group called System R. The System R prototype’s purpose was to provide high-level, non-navigational, data-independent interface to many users simultaneously, with a high robustness (Astrahan et al. 1976). The second phase of this system was a multi-user version that was evaluated between the years of 1978 to 1979. The most prominent advancement from this system was the development of the Structured Query Language (SQL), which is now an international standard for database access (Chamberlin et al. 1981 and McJones 1995). SQL is used for creating, updating and querying relational database management systems (Date 1986, Melton and Simon 1993, and McJones 1995).

Through the 1980’s updates and revisions were continually made on the relational database management system after receiving feedback from customers and advancement in computer technologies (Committee on Innovations in Computing and Communications 1999). It was in the mid to late 1980’s when disciplines, such as social science, began to store, analyze and manipulate their data in relational database management systems.
Archaeologists took advantage of database capabilities by creating inventories of artifacts from archaeological excavations (Deagan 2003).

With the advent of GIS and its mainstream distribution by the Environmental Systems Research Institute (ESRI®) in 1981, came many possibilities for research. GIS is a computer-based system used for capturing, storing, integrating, manipulating, analyzing and displaying data related to geographic location (Bolstad 2002). Over the past two decades archaeological studies have incorporated different GIS techniques, with the research (Gilman 1999, Capobianco 2005a).

In 2002, ESRI® introduced the geodatabase, a relational database that is used to store spatial and attribute data and the relationships that exist between them. Archaeologists have used this data format to map locations of sites and artifacts (Craig 2002, Prohaska 2002 and Erdi et al. 2003). The geodatabase allows the information to be more easily displayed and analyzed.

**Research Goals and Objectives**

There were two main goals of this research project; the first was to help the team of archaeologists locate potential targets for excavation in En Bas Saline by using remote sensing techniques. The second goal was to improve the ability to query and analyze the data records of past archaeological projects by transferring non-spatial but geographically referenced artifact records to a spatially referenced geodatabase.

In order to accomplish the two goals set forth four main objectives were established:

1. Investigate and analyze the two Quickbird satellite scenes acquired from DigitalGlobe™ by remote sensing techniques and procedures.

2. Determine potential excavation sites that meet criteria outlined by the archaeologists.
3. Gather all data from 1984 to 2003 and create a personal geodatabase.

4. Develop the geodatabase so that the archaeologists can perform queries to answer research questions in En Bas Saline.
CHAPTER 2
CHRISTOPHER COLUMBUS TO QUICKBIRD: UTILITY OF HIGH SPATIAL RESOLUTION SATELLITE IMAGERY IN THE FIRST NEW WORLD HISTORICAL ARCHAEOLOGY

Abstract

Christopher Columbus wrecked the Santa Maria on a coral reef off northern Haiti on Christmas Eve, 1492, and was forced to leave thirty-nine men behind with orders to build a fort from the salvaged wood. Returning a year later, Columbus found the fort burned and his men murdered, and to this day the exact location of the first European settlement in the New World is unknown. This study examines whether the new technology of high spatial resolution, multispectral satellite imagery is applicable for archaeological investigation of determining the site of La Navidad fort. Two DigitalGlobe™ Quickbird scenes of the general area were used to identify targets for archaeological excavation. Standard panchromatic (61-cm spatial resolution) and multispectral (2.4-m) data bundles were acquired on January 17, 2003 and May 03, 2003. Numerous derivative images were produced from the basic data, and were visually examined for characteristic shapes. Taino (indigenous people) construction was circular while European structures were generally rectangular. Objects that combine both shapes were likely targets or inexplicably disturbed areas. The most promising target was a circle 7 m in diameter and encompassed by a rectangle 15 m wide, located 75 m beyond the previously known extent of a large village. Excavation disclosed a Taino structure, but not the La Navidad fort. Although the Spaniards’ first fort was not found this research expanded the known extent of the Taino village. Other targets revealed European artifacts
in locations previously thought to be underwater in 1492. These artifacts and structures would not have been found without the analysis of the satellite imagery.

**Introduction**

Christopher Columbus was forced to leave thirty-nine of his men in En Bas Saline, Haiti after wrecking the Santa Maria on the coral reefs just off-shore on Christmas Eve, 1492 (Figure 1). At the time En Bas Saline was the site of a large Taino town. The Tainos were indigenous people of the Caribbean region during the time of Columbus (Deagan and Cruxent 2002b). A local chief, Guacanagari, helped Columbus’ men carry out their orders to build a fortress from the salvaged wood of the Santa Maria. When Columbus returned almost a year later he found the fort had been burned to the ground and his men were dead (Deagan 2004).

When Columbus found En Bas Saline burned he abandoned the area and established a new settlement eastward in an area called La Isabela (present day Puerto Plata) in the Dominican Republic (Deagan 2004). For an expanded discussion on the settlement at La Isabela, see Morison 1940; Wilson 1990; Deagan and Cruxent 2002a; and Deagan and Cruxent 2002b. The establishment at La Isabela ended the European presence in Guacangari’s town (Deagan 2004). In 1503 the Spaniards established a new town in Puerto Real, Haiti. This settlement was located about two kilometers from the site of En Bas Saline and is recorded as being close to the actual La Navidad fort (Deagan 2004) (Figure 1). For an expanded discussion on Puerto Real see Deagan 1995 and Hodges 1979.

Presently, there have been only four attempts to locate the remains of La Navidad. The first attempt by Moreau de Saint-Mery (eighteenth century); second attempt by Samuel E. Morison (twentieth century); third attempt by William Hodges (twentieth
century) and the fourth attempt by Kathleen Deagan (twentieth to twenty-first century) (Hodges 1983).

In 1780 an anchor was discovered in the area of Bellevue-Fournier and four kilometers southeast workers digging a canal came upon skeletal remains and coins. In 1892, Moreau de Saint-Mery, French historian and geographer believed the anchor to be from the Santa Maria and brought it to a museum in Port-au-Prince, Haiti. He believed the skeletal remains were of Columbus’ men from that first voyage (Hodges 1983). Subsequent discovery and excavation of Puerto Real, Haiti by Hodges have proven Moreau de Saint-Mery was actually looking at the cemetery and ruins of Puerto Real (Hodges 1983).

In 1940, the naval historian, Samuel Morison hypothesized the location of La Navidad to be in the area of Caracol Bay and in the vicinity of Guacanagari’s town using evidence from early maps, topography, accounts from Columbus’ journal, and letters written from Columbus’ crew (Morison 1940). Morison however did not take into account key evidence outlined in Columbus’ journal about distances from the wreck site to the Taino village (Ferdinand 1959 and Hodges 1983).

William Hodges, archaeologist and medical missionary, had many approaches to identify the site of La Navidad including: examining all references including maps to Columbus and Guacanagari; attempting to chronicle all Indian sites in the area; examine the geological changes within the area to reconstruct coastlines and rivers as they were in the fifteenth century; retrace previous work by Moreau de Saint-Mery and Morison; recruit local Haitian farmers to search for artifacts on their land and visit all areas that have yielded clues to this historical event (Hodges 1983).
In 1977 a Haitian farmer first led William Hodges to locate En Bas Saline as the tentative site of Columbus’ fort. Hodges immediately identified a large central mound that had abundant amount of pottery identified as “Carrier,” which is associated with Indians that lived at the same time as Columbus. Hodges investigated the area by carrying out limited excavations (Hodges 1983).

Hodges brought his finding to the attention of archaeologist and distinguished research curator Dr. Kathleen Deagan of the Florida Museum of Natural History at the University of Florida. Between 1983 and 1988 the archaeologists and researchers of Florida Museum of Natural History, the Bureau National d’Ethnologie d’Haiti and the Musee de Guahaba in Limbe, Haiti, collaborated in surveying, mapping and excavating En Bas Saline (Deagan 2004).

The strongest evidence found by the University of Florida, between the years of 1984 and 1985, that En Bas Saline is the site of La Navidad is the findings of a European rat jawbone and a pig’s tooth; both animals were unknown to Haiti before Columbus (Keen 1991). Testing conducted by Dr. Jonathan Erickson, from the University of California, Irvine on the pig’s tooth revealed that the artifact dates to Columbus’ time and that the pig had been raised in Spain, not Haiti (Erickson 1986 and Spears 1987). En Bas Saline is thought to be the site of Guacanagari’s village because of the large size of the Taino village and prominence within the region and because of the accounts recorded in Columbus’ journal (Hodges 1983 and Deagan 2004). Due to Haiti’s political unrest there was a gap between 1988 and 2003 before research in En Bas Saline was continued.

The research conducted for this project was part of the larger archaeological study that was conducted in the 1980’s in Northeastern Haiti in the area of En Bas Saline.
(Figure 1). Although in years past the archaeological team had aerial photographs and some satellite images, this was the first time high-resolution, multispectral satellite imagery was available. This study was conducted to establish whether the new technology of high spatial resolution multispectral satellite imagery is applicable for archaeological investigations. Two Quickbird satellite scenes were acquired from DigitalGlobe™. These scenes were from January and May 2003 and were chosen to capture seasonal variability. The scenes were analyzed using different remote sensing techniques (tasseled cap transformation, normalized difference vegetation index, principal components analysis and brightness inversion) and used to identify excavation sites for the archaeologists. The main purpose was to identify potential excavation targets in En Bas Saline that fit the criteria given by the archaeologists. In order for the fort to be identified the following evidence must be found when excavating (Deagan 2003):

- Identification of a burned Taino structure approximately 25-m to 50-m in diameter with a palisade wall and possibly an associated moat.
- European artifacts and faunal remains associated with the Taino structure that date to the fifteenth century.

The principle objectives of this project were to locate and identify features within the landscape that meet the specified size given by the archaeologists and were within or near the area of interest. It is possible that these features could be caused by early Spanish construction and excavation will refine the search for La Navidad.

**Background**

Aerial photography has been used for site detection and archaeological mapping for over a hundred years. Scientists in many disciplines view aerial photographs as a tool to identify patterns and details of features not readily visible by ground examination (Miller
Navigational tools such as aerial photographs have been used to help guide archaeologists on their excavations, which in turn saves time, money and energy. Archaeologists visually scan aerial photographs for variations within the natural color, texture or moisture of the soil. These variations can be a direct result of earth fills, canals, depressions or previous disturbances by human occupation (Avery and Berlin 1992).

The history of aerial photography dates back to the 1800’s when an image of the French village Petit-Bicetre was taken from a balloon at an altitude of 80 meters by Gaspar Felix Tournachon (Estes et al. 1977). The first aerial photographs taken of an archaeological site from fixed-wing aircraft occurred in 1903 by Wilbur Wright and then again in 1906 by Albert Maul from a rocket. From 1906 on there has been an expansion of the use of aerial photography in archaeological research (Estes et al. 1977). In 1907 aerial photographs of Stonehenge were published in an issue of *Archeologia*, a journal published by London’s Society of Antiquaries (Capper 1907). Army engineer Lt. W.F. Sharpe out on an exercise took the photographs of Stonehenge when the winds happened to blow his balloon over Salisbury Plain directly above Stonehenge. Although these photos were not taken with the intention of archaeological use they were published to reveal a site of archaeological interest from a perspective never before seen (Capper 1907). World War I broadened the use of aerial photographs even further for archaeological research since military operations accelerated the development of both aircraft and cameras specifically designed for aerial photography (Reeves 1936).

Satellite imagery has not been widely used by archaeologists for site detection due to the low spatial resolution (10-m to 1000-m pixel size) of the imagery compared to that
required by their research questions. Remotely sensed data were primarily used to provide researchers with a general sense of the regional landcover rather than specific details about an area (Read 2003). Landsat Multispectral Scanner (MSS; 80-m pixel), Landsat Thematic Mapper (TM) and Enhanced TM (ETM; 30-m pixel), SPOT (20-m pixel) and Advanced Very High Resolution Radiometer (AVHRR; 1-km pixel) are the satellites most widely used in the archaeological community (Lillesand and Kiefer 2000).

The relatively low spatial-resolution satellite data are an excellent source of information in the exploration of poorly mapped areas in the world. Shorelines, large water bodies, large structures and vegetation classes can all be differentiated within these images (Mott 1978). Landsat MSS has been widely used to monitor landcover and landuse in many regions of the world. Studies using Landsat and SPOT to monitor forests and clear cut areas have proven a valuable resource (Wastenson et al. 1981). Landsat TM imagery has been utilized to serve as a valuable addition to prehistoric canal identification and mapping in the Prehistoric Hohokam Canal System, Phoenix, Arizona (Showalter 1993). Extraction of linear archaeological features is one of the main advantages of Landsat (Wastenson et al. 1981).

With the advent and affordability of high spatial-resolution satellite imagery in the past few years archaeologists and anthropologists are able to do more with the imagery than landcover analysis or detection of large features. Since the satellite imagery records reflectances in many spectral bands, as compared to aerial photographs, analyses that were not possible before are now being performed to produce useful results (Gibbons 1991). For instance, using satellite imagery allows for analysis of different color composites, the creation of derivative images such as tasseled cap transformation,
principal components analysis and the normalized difference vegetation index and the infrared band reflectance, not normally visible, provides the imagery with new perspectives, colors and identifiable features. As shown in a recent study, high spatial-resolution imagery is capable of the evaluation and monitoring of logging impacts (Read 2003). Another successful study conducted by the Department of Medieval Archaeology at University of Siena used IKONOS satellite images to study archaeological landscapes and identify features. They combined the traditional methods of identification of crop and soil marks with remote sensing techniques and were able to identify targets on the satellite that when excavated unearthed the structures for which they were searching (Campana 2001).

Advances in image processing techniques are being paralleled by the development of high spatial resolution satellite imagery. The spatial extents of these satellite data are comparable to aerial photographs but more spectral data are available, which allows for different site detection techniques to be employed (Ricchetti 2004). This study examines whether the new technology of high-resolution satellite imagery is useful for determining archaeological excavation targets, especially for the search for La Navidad in En Bas Saline, Haiti.

**Methods**

**Description of Study Site**

The site location is in the area of En Bas Saline, which is located in Northeastern Haiti (Figure 2). The center point of the area of interest is 19.7° N and 72.1° W. The general area of interest for location of targets covers approximately 350 meters in the north-south direction and 270 meters in the east-west direction (Figure 2d). This area of interest is based on the 100% surface collection of the site that was conducted by the
archaeologists between the years of 1983 to 1985. The surface collection extended well beyond the 350-m by 270-m but was determined by surface distribution of remains, shovel transect tests and the earthen ring structure of the ridge. The northern portion of the study area has a raised ridge that has the shape of a “C” that opens to the south and southwestern direction (Figure 3a). This ridge is visually apparent within the Quickbird images and measures about twenty meters in width (Figure 3b). The ridge is about 0.5-m to 1.0-m higher than the rest of the very flat site (Deagan 2003).

The local people have divided the land into gardens where they farm different crops. These gardens are used as spatial units by the archaeologists and have been assigned (A through S) for reference (Figure 3a). Cactus fences separate each of these gardens and can grow to be two meters in height. To the north and northeast of the site is a saline flat that borders a mangrove swamp, which extends all the way to the coast. The western portion of the site is bordered by an oxbow lake known as Bassin Cayman. Fertile farmland continues past Bassin Cayman and to the south of the study site (Deagan 2003).

The study area has some distinguishable structures and features that were used as arbitrary spatial data. There has been little change since the 1980’s to the buildings and only one new hut has been constructed since the last excavation.

Description of Imagery

We used the Quickbird satellite (DigitalGlobe™ processing level one: standard geometrically projected) panchromatic (spatial resolution 61 cm) and multispectral data (spatial resolution 2.4 m) for this project (Figure 4). Two scenes were acquired: one from January 17, 2003 (Table 1) and the other May 03, 2003 (Table 1) both covered the 25-km² area of En Bas Saline. Both of the DigitalGlobe™ Quickbird satellite scenes were
ordered as standard bundles that come with a panchromatic band (spectral resolution 450 – 900-nm), along with four multispectral bands: blue (450 – 520-nm), green (520 – 600-nm), red (630 – 690-nm) and near infrared (760 – 900-nm). The images come preprocessed for radiometric, geometric and sensor corrections and were mapped to Universal Transverse Mercator (UTM), Zone 18N, WGS84.

**Image Georeferencing**

To georeference the images ground control points were selected based on known locations that were easily identifiable within the image. The few buildings within the area were used as tie points as were corners of the gardens and isolated trees. A visually apparent landmark on both the satellite scene and on the ground was a large mango tree located in Garden C. This tree was used to tie together all maps and images and pinpoint our location on the ground (Figure 5). These locations were directly recorded with the Garmin™ 12 XL and Magellan™ NAV 1000 Global Positioning System (GPS) receivers. Since there were no geodetically accurate benchmarks within the area, to acquire the most accurate reading from the handheld GPS unit I took multiple readings at each location and then calculated the mean and standard deviation for the northing and easting. This is a common practice called “averaged positions” that is described in many GPS user guides (Magellan 1990). The multiple readings over a long period of time (reading taken every hour) provided independent location measurement and gave base points with an accuracy of one to two meters in both the north and east direction. The root mean square error (RMSE) was then calculated for each point and total error for each point was between two to three meters (Table 2).
In 1983 the archaeologists created a grid based on Cartesian coordinates oriented to magnetic north on the landscape to serve as a guide while excavating, surveying and mapping. The grid point 1000N 1000E is the center of the area of interest and lies in Garden C. Three markers were constructed with PVC pipes and concrete (1000N 1000E, 1045N 1000E, 1080N 1000E) and remain intact. GPS data were collected at the three markers to create a conversion calculation to transform the archaeological Cartesian coordinate grid into UTM data (Table 2).
Remote Sensing Techniques

No automatic pattern-recognition methods have been developed specifically for these high spatial resolution data, so analysis relied on visual interpretation for target identification. Five main elements of visual image interpretation that were vital in identifying target were size, shape, tone, pattern and texture. Five processing steps (resolution merge, tasseled cap transformation, principal components analysis, brightness inversion and normalized difference vegetation index) were done for each satellite image.

A likely target was circular or rectangular in shape and approximately twenty-five to fifty meters in diameter or length. La Navidad fort was reported to have been constructed around an existing Taino structure that had been given to Columbus’ men from chief Gucanagari (Deagan 2003). Taino structures were typically circular in construction while European structures were generally rectangular (Figure 6) (Morison 1940). Features that combined both shapes within the satellite imagery were identified as targets. If these features within the imagery appeared on the landcover classified as barren or grassy land then the tone within that area needed to be a dark shade of gray or black. Slight variations in soil coloration can indicate buried features (Weber and Yool 1999). These variations on the natural color, texture, and moisture of the soil are called soil marks and may result from human intervention such as excavations, earth fills or structures (Jensen 2000).

Crop marks can also produce anomalies within the landscape of an image. Variations within the soil can also indicate differences in the crop-root penetration, which can be a direct result from remains of artifacts or buried features. Crop marks will appear even long after soil marks have disappeared (Hammond 1971). Buried features can affect the rate at which crops change color and also affect the speed and height to which they
grow (Avery and Berlin 1999). Crop marks can be either classified as positive or negative. A negative crop mark results when plant growth is inhibited because their roots cannot penetrate buried material such as the remains of buildings or palisade walls. A positive mark results when a ditch has been covered and plant growth is stimulated (Figure 7). Positive marks are more noticeable when the ditch was large and deep (Fowler 1996).

The area being studied is mostly farmland so regular crop patterns were easily recognized and disregarded when distinguishing potential target sites. Anomalies in the height, color and density of crops within a garden might indicate that they are planted above a buried feature. Even though some features in the image had similar spectral characteristics they still exhibited different texture characteristics. Differences in texture on the landcover may suggest there has been a prior disturbance and that a feature may be buried (Jensen 2000 and Weber and Yool 1999).

The January 17, 2003 image was acquired and analyzed prior to the reconnaissance trip to Haiti in May in order to identify potential targets. I first defined the main area of interest (AOI), which included the central mound and the gardens (Figure 2d).

In order to improve the interpretability of the multispectral data a resolution merge was performed to enhance the visual appearance of the imagery (Figure 8). A resolution merge lets you merge a red, green, blue (RGB) image with a higher resolution panchromatic image to create a new image with the RGB color and panchromatic spatial resolution. (Garzelli et al. 2004). The panchromatic (61-cm) and multispectral (2.4-m) bands were merged to create 61-cm pan-sharpened images that were used along with the panchromatic bands for the rest of the analyses (Read 2003). After analyzing several
resolution merge algorithms (Brovey Transform, RGB to IHS, Multiplicative) the Brovey Transform was used because it introduced the least amount of error and has been used in previous studies with high spatial-resolution multispectral satellite imagery (Jensen 2000). The Brovey transform with the resolution merge visually increased contrast in the low and high ends of the image’s histogram (Chavez et al. 1991).

The two spectral enhancements that provided beneficial information for identifying targets were principal components analysis (PCA) and the tasseled cap transformation. When PCA was performed on the image it reduced the data to fewer bands and made the image interpretation for some targets more easily identifiable (ERDAS 1999). PCA is a multivariate statistical method that is useful for reducing the number of variables in a dataset and produces new sets of images, known as components, which are uncorrelated with one another and are ordered in terms of the amount of variance they explain in the original dataset. Data with normal distributions form a cluster of points (typically oval in nature). PCA of the data will calculate the perpendicular axes (eigenvectors) through the cluster of points. The First Principle Component (PC1) is always the longest axis with the Second Principle Component (PC2) and Third Principle Component (PC3) being the next two major axes (Klawiter 2000). PC1 explains the maximum amount of variation in the 4-dimensional space defined by the four Quickbird multispectral bands. The images produced from the PC1 data resemble aerial photographs.

The major advantage to using PCA is that the PC1 and PC2 axes intersect the center of the cluster of points and the datasets become decorrelated while still maintaining the variation within the imagery (Klawiter 2000). This technique works well with all multispectral data but was originally applied to the four band Landsat MSS and
seven-band Landsat TM in order to maximize the amount of information that can be contained within a single color composite, which can display data from three bands simultaneously (Chavez et al. 1982; 1984).

When PCA was performed on the satellite images the soil marks that had deep tones stood out immediately within the image but those that were faint disappeared entirely. By comparing PC2 to the resolution merge image the gardens within the main area of interest display a greater number of smaller tonal patterns that vary in gray scale than is evident in the Quickbird image. These patterns stood out after the highly correlated data of the resolution merge were minimized by the aggregation of the spectral data in the PC2 technique (Avery and Berlin 1992).

Tasseled cap transformation originally developed by Kauth and Thomas in 1976 is a widely used vegetation index. This is a linear transformation that rotates the data onto a new axis that is associated with the physical characteristics of the vegetation. The tasseled cap transformation is another technique used to aggregate spectral data into fewer bands. This transformation is associated with physical scene characteristics and converts readings in a set of channels into weighted sum values. Each weighted value measures something different: brightness of each pixel, greenness of the pixels, wetness of the soil and degree of yellowness of vegetation (Kauth and Thomas 1976).

Originally this technique was applied to the Landsat MSS satellite data to monitor agricultural crop development (Crist and Cicone 1984, Yuen 2002 and Jensen 1996). However in recent years it has been modified for use with Landsat Thematic Mapper (TM), Landsat Enhanced TM (ETM+), IKONOS and Quickbird data (Yuen 2002). The tasseled cap transformation was used to create four vegetation indices: soil brightness,
greenness, wetness and yellowness. In 2003, James Horne from Space Imaging created
tasseled cap weighted coefficients based on over two hundred IKONOS images. The
weightings are as follows: soil brightness index (SBI) = 0.326_{blue} + 0.509_{green} + 0.560_{red} +
0.567_{nir}. SBI is roughly a sum of the original bands and accounts for 73% of the variance
within the image. SBI is very similar to the Quickbird panchromatic band. This
transformation made those crop and soil marks that had a faint tone and slight difference
in texture stand out more readily. The greenness vegetation index (GVI) = -0.311_{blue} –
0.356_{green} – 0.325_{red} + 0.819_{nir}. The GVI accounts for 25.3% of the variance within the
image and distinguishes well between different surface types. Vegetation tends to be
very bright, plowed fields and sandy areas tend to have average brightness, roads and
man-made structures tend to be dark while water is the darkest in the image. This band is
a general approximation of the NIR minus the visible bands. The wetness index (WI) = -
0.612_{blue} – 0.312_{green} + 0.722_{red} –0.081_{nir}. WI accounts for 1.5% of the image’s variance.
The equation for the yellowness index (YI) is as follows YI = -0.650_{blue} + 0.719_{green} –
0.243_{red} –0.031_{nir}. This index accounts for only 0.2% of the image’s variance. Since this
band has such low variance the resulting image tends to be very noisy. These coefficients
have proven useful across a variety of conditions and study areas (Gibson 2003,

The normalized difference vegetation index (NDVI) is a linear transformation of
the visible (red) and near-infrared bands of satellite information. NDVI is the difference
between the visible (red) and near-infrared (NIR) bands, divided by their sum and is
calculated by the following equation: \text{NDVI} = (\text{NIR} – \text{RED})/(\text{NIR} + \text{RED}).
NDVI is correlated with green leaf biomass and its values range from –1 to 1 with the greater values representing healthier vegetation. Chlorophyll is the primary photosynthetic pigment in green plants and absorbs light from the red portion of the spectrum while reflecting light from the infrared band. The red band indicates amount of photosynthesis taking place in a plant and the NIR band specifies the reflectance of healthy vegetation. Pixels will be brightest when there are large amounts of photosynthesizing vegetation present (Jensen 1996). Water and clouds in an image have higher reflectances in the red band and will return negative NDVI values, while bare soil and rocks will have similar reflectances in both the red and NIR bands and will yield values close to zero (Avery and Berlin 1992).

This index proved useful when comparing the two image dates of winter and summer by clearly showing that some targets that were incorrectly marked. When compared to the January image, some of the targets identified in the May image were actually regular crop patterns and old garden boundaries. This distinction could be made since the January image had bare soil in some places where the May image had healthy vegetation.

Brightness inversion was the radiometric enhancement that provided valuable information for interpretation. This procedure produced images that had the opposite contrast of the original image so all of the dark details became light and the light details became dark. Previous studies proved this technique useful in detection of features in highly vegetated areas (Gipprich 2003). This inversion is useful to identify features that would normally be lost in the darkness of the digital number (DN) pixels (Booth-Lamirand 2003). The main reason this analysis was useful was that it eliminated the
shadows within the imagery and made some features stand out more readily within vegetation.

All analyses that were performed on the January 17, 2003 image were also performed on the May 03, 2003. Since these images were taken during different seasons there were different crops planted in the gardens and some gardens had crops in one scene and not the other. The differences between the images proved useful for deciding whether a target should remain a target or if it was identified improperly.

Before excavation began in En Bas Saline the archaeologists chose targets and performed shovel tests. They chose their excavation sites based on the following criteria (Deagan 2003):

- The ranking each target had been given (one being highly probably to twelve being less probable) and their location within the area of interest.
- Their reevaluation of an electromagnetic electrical conductivity survey that was acquired in 1984-1985.
- The locations of areas thought to be chiefly structures in En Bas Saline. This criterion was based on the accounts from Columbus’ journal that his men were given one to two of Guacanagari’s best houses (Deagan 2003).

Once the archaeological team navigated to the center point of the target a test pit was dug every five meters in the north-south direction and then a transect from the center point in the east-west direction was also dug. Each test pit was about thirty to thirty-five cm deep and if pottery or artifacts were discovered then excavation would begin. The excavation at this site in En Bas Saline was then broken up into test trenches that are one-meter wide by three-meters long. These trenches are then divided into individual sections. If enough archaeological data were collected within the test trenches, excavation units were dug and were 2 meters wide by 2 meters long.
Results

The analysis and interpretation of the satellite-derived images identified twelve potential targets (Figure 9). Center points for each target were located and transformed into the archaeological grid. Both sets of coordinates were supplied to the archaeologists along with a reference map of targets (Table 3).

Although the initial area of interest identified by archaeologists was an area 350-m by 270-m, some targets were located outside of this area. The initial area established was the main region where excavations had previously taken place and believed to be the “most likely” site of Columbus’ fort. While this area was useful as a guide, the analysis of potential targets was not restricted to it. Eight targets were located within the pre-established grid. The remaining targets were within three hundred and fifty meters of the grid.

Most targets were visually apparent using all four techniques and therefore could have been identified using only one transformation. However, targets 1,3,4, 7 and 9 were only visible using one or two of the techniques. Targets 1, 3 and 4 were all soil marks on the landscape and were identified by visually interpreting the panchromatic band. These targets were barely visible using PC1 and disappeared with the other techniques. Target 7 was identified by brightness inversion and tasseled cap transformation, while target 9 was identified by PC1 and PC3.
Table 3. The twelve targets with their UTM coordinates, archaeological north (EBS-N) and east (EBS-E) grid coordinates with a brief description of the results of ground surveying.

<table>
<thead>
<tr>
<th>Target</th>
<th>UTM (X center)</th>
<th>UTM (Y center)</th>
<th>EBS-E</th>
<th>EBS-N</th>
<th>Perimeter (m)</th>
<th>Area (m²)</th>
<th>Brief Description</th>
<th>Ground Truth Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>802794</td>
<td>2183068</td>
<td>954</td>
<td>1068</td>
<td>64.42</td>
<td>258.87</td>
<td>garden B</td>
<td>1300 AD Taino structure excavated</td>
</tr>
<tr>
<td>2</td>
<td>802968</td>
<td>2182871</td>
<td>1128</td>
<td>871</td>
<td>54.79</td>
<td>183.74</td>
<td>east of Garden I</td>
<td>Shovel test</td>
</tr>
<tr>
<td>3</td>
<td>802806</td>
<td>2183140</td>
<td>966</td>
<td>1140</td>
<td>77.58</td>
<td>371.52</td>
<td>north of Garden B</td>
<td>Modern charcoal burning area.</td>
</tr>
<tr>
<td>4</td>
<td>802804</td>
<td>2183171</td>
<td>964</td>
<td>1171</td>
<td>57.47</td>
<td>201.76</td>
<td>north of Garden B</td>
<td>Modern charcoal burning area.</td>
</tr>
<tr>
<td>5</td>
<td>803044</td>
<td>2182938</td>
<td>1204</td>
<td>938</td>
<td>175.79</td>
<td>1838.56</td>
<td>east of garden H</td>
<td>Outside of site boundary, in the Saline. Heavily vegetated, no action taken.</td>
</tr>
<tr>
<td>6</td>
<td>803014</td>
<td>2182960</td>
<td>1174</td>
<td>960</td>
<td>122.5</td>
<td>937.72</td>
<td>east of garden H</td>
<td>Outside of site boundary, in the Saline. Heavily vegetated, no action taken.</td>
</tr>
<tr>
<td>7</td>
<td>803043</td>
<td>2183125</td>
<td>1203</td>
<td>1125</td>
<td>55.65</td>
<td>186.68</td>
<td>east of Garden B</td>
<td>Modern charcoal burning area.</td>
</tr>
<tr>
<td>8</td>
<td>802528</td>
<td>2183356</td>
<td>688</td>
<td>1356</td>
<td>93.87</td>
<td>538.78</td>
<td>NW of main AOI</td>
<td>Modern charcoal burning area.</td>
</tr>
<tr>
<td>9</td>
<td>802814</td>
<td>2182995</td>
<td>974</td>
<td>995</td>
<td>42.58</td>
<td>83.65</td>
<td>Garden E</td>
<td>15th century European artifacts excavated</td>
</tr>
<tr>
<td>10</td>
<td>803154</td>
<td>2182964</td>
<td>1314</td>
<td>964</td>
<td>84.76</td>
<td>431.26</td>
<td>east of Garden G</td>
<td>Outside of site boundary, in the Saline. Surface analysis.</td>
</tr>
<tr>
<td>11</td>
<td>803194</td>
<td>2182971</td>
<td>1354</td>
<td>971</td>
<td>98.55</td>
<td>642.01</td>
<td>east of Garden G</td>
<td>Outside of site boundary, in the Saline. Surface analysis.</td>
</tr>
<tr>
<td>12</td>
<td>803321</td>
<td>2183399</td>
<td>1481</td>
<td>1399</td>
<td>422.74</td>
<td>2790.22</td>
<td>NE corner of image</td>
<td>Outside of site boundary, in the Saline. Surface analysis.</td>
</tr>
</tbody>
</table>
Three targets identified by visual analysis of the imagery provided vital information and artifacts to this project. These were targets 1, 9 and 12.

The most prominent and important target was Quickbird Target 1. This target was identified very simply as a pattern expressed on the panchromatic image of the January 17, 2003, and had the appearance of a circle seven meters in diameter and encompassed by a rectangle fifteen meters wide (Figure 10). This target was visible only with the analysis of the panchromatic band, as were targets 3 and 4. The other analyses did not disclose these targets because they used the resolution merge image as the input layer, which has a coarser spatial resolution. This slight difference in the spatial resolution made the soil marks unidentifiable.

Target 1 was located in Garden B where there was very sparse vegetation. It contained mostly grasses and some small shrubs and was enclosed by cactus fences with trees in the distance. Garden B test trench 2 (GardenB-TT2) was excavated at the coordinates provided for Quickbird Target 1 and ran in the east-west direction with an excavation unit to the north of section three (Figure 11). In section two of GardenB-TT2 a circular Taíno structure was found measuring about eight meters in diameter (Figure 11b). This structure contained a shallow wall trench, two large posts that contained charcoal and six smaller posts along the structure’s wall (Deagan 2003). This structure was tested in the lab and dates to 1300 AD.

The next target that proved to be valuable was Quickbird Target 9, which the archaeologists named Garden E test trench 8 (GardenE-TT8). This target was located in an area that had been extensively excavated in 1984, 1985 and 1988. This target was
located using PC1 and PC3 on the January 17, 2003 image and then relocated using the May 03, 2002 image. This target was not visibly apparent using the other techniques. I believe the reason for this was the target bordered a highly vegetated area and was in a location that had considerable shadows. Using PC1 and PC3 decorrelated the data to allow for the target to be identified. While zoomed to a large extent, a rectangular shape around ten meters in length was apparent within the image (Figure 12). This anomaly bordered a highly vegetated area and once at the study site it was obvious the vegetation was very dense. Before excavation could begin some trees and cacti had to be removed. GardenE-TT8 was broken up into ten sections, eight of which were dug until sandy soil was reached. At this site European pottery from the twentieth century were found along with a fifteenth century musket ball and artifacts of Taino origin (Figure 13).

Quickbird Target 12 was located using the tasseled cap transformation (Figure 14) and brightness inversion (Figure 15) imagery analysis. This site was believed to be underwater at the time of Columbus after researchers reconstructed the fifteenth century shoreline (Hodges 1983). Due to the location of the target and time constraints of the project, there was not enough time to excavate this site. However, the site surface analysis found numerous pieces of European pottery distributed around the site. The abundance of European pottery suggests that this target may be a useful location for further investigation by archaeologists.

With the assistance of Clark Moore, an archaeologist with the Bureau National D’Ethnologie, Haiti, we navigated to and investigated every target that I located by analysis of the Quickbird imagery. Making charcoal is a common practice in Haiti, and through our field reconnaissance, we discovered that three modern charcoal burning areas
had been true anomalies within the satellite image and on the landscape that did not turn out to be a Columbus-era site or Taino feature (Figure 16). Satellite images cannot be used as substitutes for fieldwork or other source material; they should be used as tools and in conjunction with other data to produce the best interpretation of the land surface (Stone 1964).

Discussion

My findings show that it is possible to use Quickbird satellite data for determining potential excavation sites in archaeological studies. The advancements in the spatial resolution of this imagery make it possible for future studies of this nature to occur. I found that identifying precise locations of emergent trees were possible and aided in the georectification process. Visual analysis on this imagery provided many features that were not recognized on the landscape or even aerial photographs. Out of the twelve features identified by remote sensing techniques the archaeologists examined seven. One of those seven targets unearthed artifacts dating to the time of Columbus while another target revealed a structure from 1300 AD.

Since there had not been many studies that used high spatial resolution multispectral satellite data in archaeological research, I had to create methods for analysis. Many of the techniques employed produced no results and consumed great amounts of time. My overall analysis of the imagery shows that the most useful spectral bands in identifying archaeological features were the panchromatic (450 – 900-nm), red (630 -690-nm) and near infrared (760 – 900-nm). The red and near infrared bands provide good definition in crop and soil marks and are the least affected by atmospheric haze. The infrared band is particularly sensitive to healthy vegetation and distinguished areas of stress.
The four remote sensing techniques that were derived from the pan-sharpened satellite data are NDVI, tasseled cap transformation, PCA and brightness inversion. These four techniques continually produced useful results by making anomalies stand out within the landscape. Although not all of the excavations unearthed artifacts the imagery showed there was a disturbance in that area.

The spectral bands used in each technique play an integral role when identifying targets and it is possible that the bands used in some techniques make the targets less visible. For instance, NDVI only uses the red and near-infrared bands and the panchromatic band was needed in identifying targets 1, 3 and 4. Using multiple techniques insures that all anomalies within the landscape will be visible and human interpretation will be needed to identify them.

These analyses are able to expand upon the previous method of using aerial photography for site detection. The main weakness is that no true automated pattern recognition method can be created for these studies. Analysis will strictly rely on visual interpretation and errors can be made in interpretation. Any feature identified within an image should always be coupled with field reconnaissance. After many archaeological studies have documented using high-resolution satellite imagery similar features identified on the satellite scene and on the ground can and should be compared for their similarities in color, texture and shape.

Although Columbus’ fort was not discovered the results of the excavations at the targets provided artifacts that expanded the archaeologist’s knowledge and organization of En Bas Saline. The techniques employed in this research may be useful for future studies of this nature. The techniques are simple to employ in any remote sensing
software and a trained remote sensing specialist with archaeological background will be able to identify patterns or features within the imagery. Another method that may be suitable in future studies is to acquire high-spatial multispectral satellite scenes from different companies such as DigitalGlobe™ and Space Imaging™ and perform the same techniques on the two images and compare the number of targets and how they appear on the landscape. Although these satellites have similar spatial resolution, studies have shown that there are differences when comparing the images (Jacobsen and Passini 2003 and Iscan et al. 2004).

**Conclusions**

Remote sensing tools such as the use of high-resolution multispectral satellite imagery have proven useful for archaeological prospecting, by assisting in the identification of potential excavation sites. The results of this study show that it is possible to use remote sensing to locate sites that contain artifacts. Remote sensing guided excavation at the En Bas Saline site disclosed a Taino structure along with many European artifacts, but not the actual La Navidad fort. The combined evidence of a burned Taino structure and fifteenth century European artifacts were not discovered, a requirement established by archaeologists and historians. Although the Spaniards’ first fort was not found, this research expanded the known extent of the Taino village by discovering a substantial Taino structure seventy-five meters beyond the presupposed limit of its extent. These artifacts and structures would not have been found without the analysis of the satellite imagery.
Figure 1. Location of En Bas Saline, Haiti. Cartographer: Kristy M. Capobianco. Data source: ESRI® Digital Chart of the World.
Figure 2. Study area map. (A): Map of Haiti broken down by administration units; (B): Landsat image of En Bas Saline area; (C): aerial photograph of En Bas Saline (photo credit Florida Museum of Natural History; Gainesville, FL); and (D): Quickbird panchromatic (61-cm) image (01-17-03) of En Bas Saline area of interest.
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CHAPTER 3
GIS DATA DEVELOPMENT OF ARCHAEOLOGICAL DEPOSITS FOR EN BAS SALINE, HAITI

Abstract

Archaeological studies have always generated large amounts of spatially referenced data and spatial analysis has been a large part of the archaeological interpretation. This paper demonstrates the use of Geographic Information Systems (GIS) to build a geodatabase to store and analyze archaeological data. The geodatabase provides more efficient data management and more flexible analysis than the pre-existing non-spatially referenced data storage system. Locations of similar artifacts across different excavation years or within the same year are easily queried by their attributes. This helps the archaeologists map distributions of certain artifacts, check for errors in the data collected, maintain data and produce reports.

Artifacts and deposits of European and Taino (indigenous people) descent from En Bas Saline, Haiti have been collected and documented through the years of 1984 to 2003. En Bas Saline is thought to be the site of Christopher Columbus’ La Navidad fort, Spain’s first settlement in the New World. In 2003 new methods for identifying excavation targets were implemented by using DigitalGlobe’s™ Quickbird satellite imagery, and Global Positioning Systems (GPS) were used to document each excavation unit (Capobianco 2005a). ArcGIS® 8.3 coupled with Microsoft Access® provided the tools necessary to build the geodatabase and spatially reference all excavation units with locational information.
I designed a geodatabase for easy querying and mapping by the archaeologists. Using the geodatabase, the archaeologists were able to recognize spatial patterns of artifacts and determine which classes of people lived in certain parts of the study area and what activities were conducted.

**Introduction**

On Christmas Eve of 1492 Christopher Columbus wrecked the Santa Maria off the northeastern coast of Haiti. Forced to leave thirty-nine of his men behind, he established the first European settlement in the area of En Bas Saline, Haiti, which is approximately 12-km east of present-day Cap Haitian (Figure 17a). When Columbus returned almost a year later to gather his men, he found that his men had been killed and the town of En Bas Saline had been burned to the ground (Deagan 2003).

En Bas Saline was one of the largest Taino (indigenous people) villages in all of Haiti and has been intensely surveyed and mapped (Moore 1997, 1998). Under the direction of archaeologist and distinguished research curator Kathleen Deagan, PhD., of the Florida Museum of Natural History (FMNH), researchers from the FMNH, the Bureau National d’Ethnologie d’Haiti and the Musee de Guahaba in Limbe, Haiti, collaborated in surveying, mapping and excavating En Bas Saline between 1983 and 2003 (Deagan 1986, 1987, 1988, 1989, 2004).

During this time, a total of 17,144 artifacts of both European and Taino descent were recorded and documented. While these records provided valuable information to guide investigations, it wasn’t until recently that fine-resolution satellite imagery became available for their use. In 2003, Geographic Information Systems (GIS), high-resolution multispectral satellite remote sensing and Global Positioning Systems (GPS) were used for inquiries and analysis in the area (Capobianco 2005a). Two Quickbird satellite scenes
were acquired from DigitalGlobe™, one from January 17, 2003 and the other May 3, 2003 to help determine potential targets of excavation. With these new data, a spatially referenced component was incorporated, along with the ability to easily query, manage and analyze the data in a geodatabase.

GIS were first invented to work with and map spatial data. The field of archaeology has always produced large amounts of spatially referenced data and many techniques have been employed throughout the years to analyze these data. Archaeological surveying includes the collection of archaeological material over a region and properly documenting the location of each artifact is extremely important. These attributes and their associated geographic locations have traditionally been stored in databases or spreadsheets on computers and then mapped by hand. Using GIS enhances the capabilities of the traditional storage methods.

Over the past two decades archaeological studies have incorporated different GIS techniques, with the research. Kohler and Parker (1986), Kvanme (1986(a)(b), 1989) and Brandt et al. (1992) first used raster data coupled with statistical analyses to produce sensitivity maps that possessed a predictive capacity for archaeological studies. Further studies by Kvanme documented the power of vector GIS data for archaeological research by using map algebra for locational analysis (Kvanme 1992(a)(b)). These vector GIS data are stored as coverages and shapefiles, two commonly used geographic vector data storage structures developed by Environmental Systems Research Institute, Inc. (ESRI®).

Increasingly, geodatabases are being used to store spatial and non-spatial data together in a relational database structure. A geodatabase, first introduced by ESRI® in 2002, is a relational database that is used to store spatial and attribute data and the
relationships that exist between them. ESRI geodatabases store spatial data as feature datasets, feature classes, non-spatial tables, and relationship classes (ESRI 2002). A feature dataset is a collection of feature classes stored together in order for them to participate in topological relationships with one another. Feature classes contained within a feature dataset must share the same coordinate system and spatial extent (ESRI 2003).

There are two types of geodatabases: personal and multi-user. A personal geodatabase works directly with Microsoft Access® and can be read by multiple people at the same time, but edited by only one person at a time. A personal geodatabase stores vector data and can handle moderately sized projects (maximum size two gigabytes) that have 250,000 objects or less. The multi-user geodatabase is intended for large enterprise GIS implementations and are comprised of ArcSDE© (advanced spatial data server) software and a database management system such as Oracle or standard computer language (SQL) servers (MacDonald 2001).

Although traditional GIS vector data formats (shapefiles and coverages) have spatial components in conjunction with attribute data the geodatabase provides a more robust format. With the advent of ArcGIS© 8.3 the user was no longer able to edit coverages. Using a geodatabase solves this problem. The geodatabase provides one central storage component for all vector data in an associated area (En Bas Saline) and topological relationships can be created, a function not available with the use of shapefiles. Topology is the spatial relationships between connecting or adjacent features in a dataset. It is a mathematical procedure used to determine the spatial relationships (connectivity, direction, length, adjacency) and the properties of feature data. Topology makes most types of geographic analysis possible because it allows us to query and
answer questions that deal with spatial relationships between features (ESRI 2002, Reed 1999 and Theobald 2001).

Some aspects of attribute accuracy are much greater for geodatabases than for coverages or shapefiles. Adding or changing attributes and inserting new records are seamless operations in the relational geodatabase (Childs 2001). The changes can be made in either ArcGIS© or Microsoft Access® and are immediately recognized by the other program. This editing feature eliminates the problem that attribute errors will occur within the same record within a table, since both programs simultaneously recognize any changes that were made. User errors such as misspelling or mistyping attributes can still occur but can be minimized within the geodatabase by creating a maximum output length for the attributes or by setting up pick-lists for the attribute information.

The United States government has mandated many of their GIS contracts to be delivered in geodatabase format instead of the traditional coverages and shapefiles. For example, a project monitoring the health of coral reefs conducted by the U.S. Fish and Wildlife Service (USFWS) created a geodatabase of all existing vector data, attribute information, and bibliographies. Creating the geodatabase allowed for both graphic selection and query methods of all data, whether tabular or spatial (Coleman et al. 2002). The United States Geological Survey (USGS) built a geodatabase of a digital archive of historic aerial photography in the greater Everglades Ecosystem, for the intended use of answering scientific questions in this study region (Coffin et al. 2003). Another USGS project includes mapping all fires that occurred between 1948 and the present in the Everglades National Park and Big Cypress National Preserve. Researchers are building a
geodatabase to centralize all information and data created, so that they can then be queried to answer questions about fire behavior (Capobianco et al. 2004).

No technique used to delineate distribution patterns of artifacts or error check is comprehensive. Many times archaeologists use a combination of techniques employing aerial photographs or satellite imagery. Landsat images have even been used in conjunction with modeling spatial distribution of artifacts to delineate likely environmental settings for archaeological sites (Custer et al. 1986). Recently, high-resolution multispectral satellite imagery has been used for fine spatial-scale studies (Read 2003, Capobianco 2005b).

This study used high-resolution multispectral satellite images and ArcGIS© 8.3 to build a GIS geodatabase, the En Bas Saline Geodatabase (EBS GDB), for analysis of archaeological sites previously excavated in En Bas Saline, Haiti. The EBS GDB contributes to spatial analyses conducted by the archaeologists by allowing them to more efficiently determine spatial patterns of artifacts. Distribution mapping in En Bas Saline has been difficult in the past since all mapping was done by hand. Records of artifacts were stored in a Paradox® spreadsheet. The archaeologists were able to query the original database producing output tables, not map referenced data. The EBS GDB is designed to be easily queried to produce reports as well as maps; it centralizes the data in one storage structure, and allows the archaeologists to easily pinpoint data entry errors.

The utility of this project is to have spatial and attribute data directly linked with every deposit that was recorded. All of the original data along with the newly collected data were exported into Microsoft Access®, and converted to a geodatabase using ArcGIS© 8.3 personal geodatabase creation.
The EBS GDB manages datasets from archaeological finds recorded by FMNH researchers in En Bas Saline, Haiti. The EBS GDB allows for easy querying of data and making comparisons across different years and areas within En Bas Saline. The archaeologists are able to see where large groups of European artifacts are located compared to the artifacts of the Taino people and postulate about human settlement patterns within the area. For example, after querying the EBS GDB, we noticed that elite items were found in the locations of the chief’s dwellings. European artifacts dating to the time of Columbus were also found in these areas, supporting the hypothesis that this is where Columbus built his fort.

**The En Bas Saline Archaeological Site**

The site is located about 12-km east of the city of Cap Haitian (Figure 17a). The main archaeological area of interest is rectangular in orientation and covers approximately 270 meters in the east-west direction and 350 meters in the north-south direction (Figure 17). A raised ridge in the shape of a “C” faces a south to southwesterly direction and bounds the northern portion of the study area. The ridge is approximately 0.5 to 1.0 meters higher in elevation than the rest of the site (Deagan 2003). To the west of the site is an oxbow lake named Bassin Cayman and fertile farmland extends past the lake to the west and the south. Bordering the site to the north and northeast is a saline flat that is adjacent to a mangrove swamp, which extends to the coast (Deagan 2003).

In En Bas Saline the local residents have divided the land where they farm crops into gardens using cactus fences. In 1983 each of these “gardens” was assigned an associated letter (A through S) to provide spatial reference units to the archaeological team (Figure 18). This facilitated on-the-ground orientation for fieldwork and this letter is included within the attribute tables of data recorded in the field (Deagan 2003).
Garden C contains a mango tree that is used as an easily identifiable reference point on
the ground, from the oblique photograph and from the Quickbird satellite image (Figure
17(c)(d)).

In 1983 the archaeologists created a grid based on Cartesian coordinates on the
landscape to serve as a guide while excavating, surveying and mapping. The grid point
1000N 1000E is the center of the area of interest and also lies in Garden C of the area of
interest. Three markers were constructed with PVC pipes and concrete (1000N 1000E,
1045N 1000E, 1080N 1000E) and still remain intact. GPS data were collected using a
Garmin™ 12 XL and Magellan™ NAV 1000 at the three markers to create a conversion
calculation to transform the archaeological Cartesian coordinate grid into UTM data.

The spreadsheet of archaeological data from En Bas Saline included twenty-three
attributes that were generated, collected, and recorded for each of the 17,000 plus
deposits found there. The data collected by the archaeologists is organized based on the
study-wide Cartesian coordinate grid of north and east, which was converted to a
Universal Transverse Mercator (UTM) grid. Within the grid are excavation units that
have square (2-m by 2-m) or rectangular (1-m by 3-m) sections, which are recorded when
artifacts are unearthed. When an artifact or deposit such as lead or copper was
discovered within a unit, it was assigned a “provenience location,” a general term given
for the place in a site from where something came. An artifact is one single item whereas
a deposit is a group of similar artifacts found in the same provenience. Field Specimen
(FS) numbers are the numerical identifying labels assigned to a provenience. All objects
in a provenience are assumed to be associated or part of the same event or process
represented by the deposit so they all share the same FS number. Following discovery,
artifacts were then labeled with a provenience, FS number and the layer of soil from which it was removed. Finally, the item or the type of vessel was recorded for each individual deposit. Once this information was assigned and documented then the attributes of the artifacts were recorded.

**Structure and Design of the En Bas Saline Geodatabase (EBS GDB)**

There are two ways to create a personal geodatabase: to build one in ArcCatalog©, or to import existing spatial data into the geodatabase in ArcCatalog©. Combinations of these two methods are often employed when building a geodatabase (MacDonald 2001). The EBS GDB was built ad hoc using Microsoft Access® and ArcCatalog©. The preexisting data were only in a tabular format, not shapefiles or coverages. These attribute data were imported into the geodatabase after its structure was created in ArcCatalog©. The EBS GDB was structured into feature datasets corresponding to each year the archaeologists were in the field, containing feature classes by year of the deposits found and recorded, and topological groupings on the feature classes within the feature datasets (Figure 19). This geodatabase structure followed the design standards and recommendation of ESRI® and other similar applications (ESRI 2002, 2003, Coleman et al. 2002, Coffin et al. 2003 and Capobianco et al. 2004).

ESRI geodatabases are comprised of structural elements that are developed during the creation of the geographic data model. The elements used for the EBS GDB are as follows (ESRI, 2003):

- **Feature datasets:** feature datasets contain both spatially related feature classes along with the topology that binds them. Any feature class that is contained within a feature dataset must have spatial reference.

- **Feature classes:** these are spatial tables that contain a shape field that specifies whether it is point, line or polygon geometry for one specific geographic feature.
- Topology: predefined rules that define the behavior of geographically integrated features.
- Tables: these are non-spatial tables that only contain attribute data and not feature geometry. The EBS GDB tables exist as stand-alone tables in the geodatabase, but they can be related to other tables or feature classes.

Creating the EBS GDB

The creation of the EBS GDB followed the protocol diagrammed in Flowchart A (Figure 20a) of reformatting the Paradox® spreadsheet data to an Access© table, while creating the geodatabase in ArcCatalog© and establishing feature datasets with projection parameters. Following the creation of feature classes of point-referenced data, the feature class attribute tables were populated with data imported from the Paradox® spreadsheet and topologies were created (Figure 20c, steps 1-5).

The geodatabase was created using the structure described previously. The UTM coordinate system for Zone 18 north was selected as the spatial reference system for all the feature datasets. These projection parameters were imported into the feature datasets from the georectified satellite imagery used in the remote sensing analysis.

The Paradox® spreadsheet was converted into an ASCII text file and then imported into Access© (Figure 20b, steps 1-5). Table 4 gives the name of the attributes as they appear in the Access© table along with the type of data the attributes are and a short description of the data. All of the attributes recorded within the geodatabase were coded to the standards found in the Historical Archaeology (HA) Codebook (HA 1992).

After importing Paradox® EBS into Access©, the three attributes of ObjectID, Northing and Easting were extracted and imported into their own tables within Access© (EBS) (Figure 20b, steps 6-10). These tables were always labeled EBSXX_ID, with the XX standing for the two-digit year of excavation. In the design view of Access© the
Northing and Easting fields always were changed to the Double Number data type. Once this step was completed the tables were added to an ArcMap© view, and point records were displayed using the Northing and Easting coordinates. The resulting layouts were then exported as shapefiles called EBSXX_ID.

Table 4: Design view of the description and data types of all attributes in the Access©
table.

<table>
<thead>
<tr>
<th>FIELD NAME</th>
<th>DATA TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJECTID</td>
<td>AutoNumber</td>
<td>Automatically generated number by ArcGIS©</td>
</tr>
<tr>
<td>SHAPE</td>
<td>OLE Object</td>
<td>Point Database</td>
</tr>
<tr>
<td>UTM-X</td>
<td>Number</td>
<td>UTM Zone 18 Easting</td>
</tr>
<tr>
<td>UTM-Y</td>
<td>Number</td>
<td>UTM Zone 18 Northing</td>
</tr>
<tr>
<td>EAST</td>
<td>Number</td>
<td>Archeological east unit coordinate</td>
</tr>
<tr>
<td>NORTH</td>
<td>Number</td>
<td>Archeological north unit coordinate</td>
</tr>
<tr>
<td>SITE</td>
<td>Text</td>
<td>Three letter site abbreviation (EBS: En Bas Saline) and two digit year of study</td>
</tr>
<tr>
<td>FS</td>
<td>Number</td>
<td>Unique field specimen context identifier</td>
</tr>
<tr>
<td>UNIT</td>
<td>Number</td>
<td>Excavation unit</td>
</tr>
<tr>
<td>PROV</td>
<td>Text</td>
<td>Provenience</td>
</tr>
<tr>
<td>ITEM</td>
<td>Text</td>
<td>Type of artifact (shell, bone, charcoal, etc.)</td>
</tr>
<tr>
<td>FREQ</td>
<td>Number</td>
<td>Frequency or count of artifact type</td>
</tr>
<tr>
<td>WEIGHT</td>
<td>Number</td>
<td>Weight of item</td>
</tr>
<tr>
<td>GROUP</td>
<td>Number</td>
<td>Functional category of objects</td>
</tr>
<tr>
<td>COMP</td>
<td>Text</td>
<td>Composition (shell, pottery, iron, glass, etc.)</td>
</tr>
<tr>
<td>COLOR</td>
<td>Text</td>
<td>Color of item</td>
</tr>
<tr>
<td>FRGFRM</td>
<td>Text</td>
<td>The part of the vessel (rim, base, etc.)</td>
</tr>
<tr>
<td>OBJFRM</td>
<td>Text</td>
<td>Object form, vessel type</td>
</tr>
<tr>
<td>DÉCOR</td>
<td>Text</td>
<td>Decorations on the vessel or object</td>
</tr>
<tr>
<td>MODIFICATIONS</td>
<td>Text</td>
<td>Modifications to the object</td>
</tr>
<tr>
<td>GARDEN</td>
<td>Text</td>
<td>The garden in which the item was located</td>
</tr>
<tr>
<td>HORIZON</td>
<td>Text</td>
<td>Horizon time period (A: most recent to C: oldest)</td>
</tr>
<tr>
<td>GARDEN/HORIZ</td>
<td>Text</td>
<td>Combination of both the garden and horizon</td>
</tr>
</tbody>
</table>

After the shapefiles were created the rest of the attributes were added in a three-step process. First, in ArcCatalog© the shapefiles were exported into point-feature classes associated with a specific feature dataset and named EBSXX_Coordinates, with the XX standing for the last two digits of the excavation year (Figure 20b, step 12 and Figure
20c, step 6). Following this, the attribute fields were added in ArcCatalog© based on the fields in the Access© table EBS. Finally, the original attribute data was copied into the spatial feature class EBSXX_Coordinates, populating those fields (Figure 20B, steps 13-16). Once this final step was completed and topologies were created and verified for all feature datasets (Figure 20c, steps 7-10) the new spatial feature class could be opened and viewed in ArcMap©.

**Error in the EBS GDB**

There are two main sources of location error inherent within the EBS GDB that must be noted. First, all of the archaeological site data were based on their Cartesian coordinate grid, which were measured imprecisely from the three PVC stakes. Inaccuacries in recording the exact North and East location were inevitable, as measuring tape and compasses were used over long distances at En Bas Saline. GPS error is the second source of error. Even though two to three GPS receivers were used and multiple points were taken and averaged for each location, the GPS receivers have inherent error (Spennemann 1992). The GPS points were highly accurate with their readings but according to the Magellan user guide, the receiver obtains spatial accuracy of 5-m to 20-m (Magellan 1990). This means that no matter how carefully the technique is performed, the accuracy can never be better than the inherent error in the receiver.

There are many sources of inherent error within a GPS receiver that will degrade the accuracy of positions computed. When a GPS signal passes through the ionosphere and troposphere it is refracted, causing the speed of the signal to be different from the speed of a GPS signal in space. Minor variations in the atomic clock on the satellites can account for large positional errors. For example, a clock error of 3 nanoseconds translates to 1-m user error on the ground. Errors in the information about satellite orbits
will also cause errors in computed positions, due to the satellites’ position not actually being where the GPS receiver calculated their positions.

These two sources of error coupled together makes it unlikely that an automated shift can be added to the data to correct for the inaccuracies because each archaeological site has a different amount of error.

**Application of the Geodatabase**

With 17,144 records there are many potential applications of the EBS GDB. Archaeologists Kathleen Deagan and Alfred Woods tested the utility of the geodatabase by examining patterns and frequencies of distributions of artifacts in the study site. In their first query, Deagan and Woods were searching the excavation sites for carrier-decorated ceramics (CARDEC), a typical type of pottery used by the Tainos. The simple query 
\[ \text{ITEM} = '\text{CARDEC}' \] was performed in ArcGIS©. Out of the 17,144 records, 450 were selected (Figure 21). To narrow the search further, we created a nested equation, 
\[ \text{ITEM} = '\text{CARDEC}' \text{ AND } \text{FREQ} \geq 10 \] that located the sites where at least ten carrier-decorated ceramics were found. This query only returned seven records in two distinct locations (Figure 22). Changing this nested query once again to 
\[ \text{ITEM} = '\text{CARDEC}' \text{ AND } \text{FREQ} \geq 20 \] returned only one record and one location (Figure 23). In this example Deagan and Wood quickly determined where large quantities of this item were found. Patterns such as this may be found for quantity or frequency of items in the geodatabase.

The next query by Deagan and Woods was to identify parts of the study area that contained ornamental Taino artifacts. These items were considered to be elite and were typically only owned by the chief and other prominent people within the town (Deagan 2003). There are many types of artifacts (beads, decorated shells, bowls) that are
considered ornamental so the attribute “Group” was created to combine features that are from similar time periods or are descriptively similar. The query [GROUP] = '9' (ornaments) returned only twenty-one records. The result was a distribution map of these types of artifacts across the study area.

Finally, Deagan and Woods queried the location of European artifacts. Items classified within Group 1 are European artifacts that date to Columbus’ time. The query [GROUP] = '1' returned twenty-eight records of European artifacts during the time of Columbus. These artifacts include a fifteenth century musketball, glass and brass.

By identifying these patterns of similar artifacts contained within one area of the study region, characteristics based on patterns of human behavior can be identified by the archaeologists.

**Discussion and Conclusions**

The application of GIS in archaeological research has been increasing over the last few years with the advent of desktop GIS software packages such as ArcView that primarily used the shapefile vector data format. The geodatabase provides a way for archaeologists to store, manage and analyze all of their data in one central location using the data structure of a relational database. In archaeology, if geodatabases are created at the beginning of archaeological projects, attribute information can be more streamlined. For instance, if the archaeologist knows that the field named “Horizon” can only contain the letters A, B or C, a pick-list can be created that contains only these values. Although this may take some time in the initial stages of building the geodatabase it will help eliminate user errors such as misspelling or typographical errors.

The layout and design of the geodatabase makes it easy for the user to work with more intuitive datasets while in ArcMap©. Since Access© and ArcGIS© are directly
linked, the tables can be simultaneously viewed and mapped in a GIS. Instead of just viewing a large database table one could overlay any year’s deposits with aerial or satellite imagery while viewing the table at the same time to see the exact spatial location of each deposit (Figure 24).

Another benefit resulting from the creation of this geodatabase is the ability to create substantially more accurate attribute maps of the area of interest. The geodatabase allows querying of all artifacts whether there is spatial information associated with the attributes or not, a function not available with shapefiles or coverages.

Having the power to overlay the deposit data onto the satellite imagery or aerial photographs with exact UTM coordinates attached to them allows the archaeologist to determine future target locations and to query existing excavations. Certain types of deposits such as ceramic, bone or charcoal can easily be extracted out of the main dataset and made into its own feature class within the geodatabase.

Building the EBS GDB enhanced the archaeology of this site by providing a central storage location for all data collected in the study area with its spatial reference. At a minimum it provides a more attribute-accurate historical record of all excavation work conducted in En Bas Saline from 1984 to 2003. This geodatabase was designed to replace the existing system (Paradox, ASCII, Excel) and to facilitate new research questions and excavation site planning.

By building these GIS data layers, the spatial relationships between mapped features were analyzed for patterns that were not readily apparent if the data were viewed in tabular format. After working with the geodatabase, archaeologists Deagan and Woods, found the design easy to understand. They found that querying the geodatabase and then
being able to visually see the results enabled them to draw many conclusions about the
distribution of the artifacts. For instance, by querying Group 9 (ornaments) artifacts, four
distinct clustered areas were highlighted (Figure 25). Decorated items such as ornaments
are typically associated with elite people and clusters 2, 3 and 4 support is known about
the organization of the study area. Clusters 2 and 4 were identified on the ground as
areas of higher elevation (mounds). The chief of the town would have had his dwellings
in these locations and so it makes sense that ornamental items were found in these two
areas. Deagan and Woods identified cluster 3 as the feast area of the Tainos and finding
ornamental artifacts in this location means that the elite also frequented this area. The
results of this query also indicated a confounding result in cluster 1, as archaeologists did
not believe that this spot would have contained ornamental artifacts. After further
investigation, it was realized that a data entry mistake had taken place back in 1988. Had
the geodatabase not been created mistakes like these are not easily recognizable.

Group 1 was the category given to all European artifacts that date back to
Columbus’ era. When this group was queried it showed that the western part of the study
area had no artifacts of this nature. These European artifacts were located in the area of
one of the mounds, the feast area and the northern portion of the study area (Figure 26).
After producing a frequency map of these artifacts, the two areas with the greatest
number of artifacts are the northern portion and the mound (Figure 27). While
excavating in the summer of 2003 the archaeologists discovered a Taino structure in the
northern portion of the study area that could be ascribed to Columbus’ men. The artifacts
found in the northern portion or the mound area support the historical accounts that
Columbus’ men were given “the best” houses in En Bas Saline by the chief, or that the men shared their property with the chief (Deagan 2004).

Although error checking is not the main purpose of the geodatabase, it is nevertheless a benefit of the geodatabase. Many errors in the attributes were found and fixed throughout the process of creating the geodatabase and working with it. Typographical errors were the main source of error, however other errors such as attributes being input into the incorrect column were also found and corrected.

This technique of storing, managing and creating data in a geodatabase is useful for any archaeological project. A spatially referenced database can contribute to identifying spatial patterns of artifacts and creating distribution maps with far greater ease and attribute accuracy than a non-spatial database. Other data layers such as soil type or topography may also be added as feature classes in the geodatabase and used in conjunction with existing feature classes for more robust queries.

Archaeologists have always collected large amounts of spatially referenced data and employed many techniques to analyze these data. The newer geodatabase advancements of GIS have opened up possibilities to new ways of viewing and analyzing data. The ability to query feature datasets is expedited with far greater powers than with a non-spatial database. Spatial references for each deposit are included within the attribute information and the process of extracting vital information is greatly simplified. In the EBS GDB each excavation year can be layered with the satellite imagery (Figure 28). Patterns of similar artifacts were recognized by the use of simple data queries.
Figure 17. Study area map. (A): Map of Haiti divided by administrative units; (B): Landsat image of En Bas Saline area; (C): aerial photograph of En Bas Saline (photo credit Florida Museum of Natural History; Gainesville, FL); and (D): panchromatic Quickbird image (61-cm spatial resolution) of En Bas Saline area of interest.
Figure 18. Diagram of main study area broken down into local owner’s gardens. (A): Gardens digitized from satellite image and (B): actual satellite image with labeled gardens (panchromatic band 61-cm resolution).
Figure 19. Design and structural elements of the En Bas Saline personal geodatabase viewed in ArcCatalog©.
Figure 20. Data workflow of creating En Bas Saline Geodatabase (EBS GDB).
Flowchart B: reformatting, editing and populating the Access© tables.
Flowchart C: creating and editing the EBS GDB in ArcCatalog.
Figure 21. Map depicting locations of all excavation sites, those highlighted contained item named carrier-decorated ceramics (cardec). Quickbird panchromatic image (January 17, 2003) (61-cm spatial resolution) used as background image.
Figure 22. Map depicting locations of all excavation sites, those highlighted contained item named carrier-decorated ceramics (cardec) with a frequency of at least ten. Quickbird panchromatic image (January 17, 2003) (61-cm spatial resolution) used as background image.
Figure 23. Map depicting locations of all excavation sites, those highlighted contained item named carrier-decorated ceramics (cardec) with a frequency of at least twenty. Quickbird panchromatic image (January 17, 2003) (61-cm spatial resolution) used as background image.
Figure 25. Map depicting locations of all excavation sites and shovel tests, those highlighted are excavations that contain “Group 9” ornamental artifacts. Quickbird panchromatic image (January 17, 2003) (61-cm spatial resolution) used as background image.
Figure 26. Map depicting locations of all excavation sites and shovel tests, those in blue depict European artifacts dating to Christopher Columbus’ era. Quickbird panchromatic image (January 17, 2003) (61-cm spatial resolution) used as background image.
Figure 27. Map depicting locations of all excavation sites, shovel tests, and frequency of European artifacts dating to Christopher Columbus’ era. Quickbird panchromatic image (January 17, 2003) (61-cm spatial resolution) used as background image.
Figure 28. Excavation sites broken down by year overlaid on (61-cm spatial resolution) panchromatic Quickbird satellite scene taken January 17, 2003.
CHAPTER 4
SYNTHESIS, SUMMARY AND CONCLUSIONS

This study shows the application of new technologies to archaeological research. The first technique used high-spatial resolution, multispectral satellite imagery to identify potential excavation sites. The second technique created a geodatabase in GIS to manage archaeological data for an area allowing for easy querying and mapping the distributions of artifacts.

Christopher Columbus’ men used the salvaged wood from the Santa Maria to build a fort in the area of En Bas Saline, Haiti. Archaeologists have been searching for over a century for the remains of the La Navidad fort.

When this project began, high-resolution satellite imagery had not been explored for determining archaeological targets. Aerial photographs had been a proven asset to scientists and this study took that tool a step further. Since the imagery acquired had five bands (green, blue, red, near-infrared, and panchromatic), different analyses were preformed with varying results. Those that had the most successful results in identification of targets were the tasseled cap transformation, brightness inversion and principle component analysis (PCA). The excavated targets unearthed artifacts of both European and Taino descent.

The target identification procedure was created based on strict search criteria outlined by the archaeologists. Every transformation and analysis performed on the imagery was then visually scanned to find anomalies. Taino construction was circular while European structures were generally rectangular. Objects that combine both shapes
were likely targets traces of a moat that may have been associated with La Navidad fort were also scanned for within the images.

Excavation disclosed a Taino structure, but not the fort-like structure. Although the Spaniards’ first fort was not found, this research expanded the known extent of the Taino village. Other targets revealed European artifacts that would not have been found without the analysis of the satellite imagery. Using satellite imagery for analysis expanded previous techniques. These images provided views of the topography and differences in ground cover across the study site.

For many decades previous archaeological studies used aerial photography to identify crop and soil marks not visible from ground level (Capper 1907, Reeves 1936, Miller 1957, Hammond 1971, Jones and Evans 1975, Estes et al. 1977, Spennemann 1987, Durham County Council 2005). Using high-resolution multispectral satellite imagery is still in the very early stages for archaeological application. Only a few studies have been documented using this imagery for archaeological research (Fowler 1996, Campana 2001, Read 2003 and Ricchetti 2004). However, the techniques employed in this research can be used to find archaeological targets in other study areas. The spatial resolution of Quickbird permits the identification of many types of archaeological features (linear, circular) and also allows for spatially accurate surveying of a study site. If this technology is used in conjunction with other methods for determining sites, such as aerial photographs, time and money will be saved in the identification and excavation of archaeological sites.

The impact of human existence on the environment in history can be traced through archaeology. The tools of today’s technology can be used to realize greater benefits in
archaeological research. Our knowledge about human interaction with the earth can be traced through archaeological research and enhanced through the application of remote sensing techniques. This study shows the potential of implementing remote sensing and its use in detecting and inventorying archaeological data. The use of remote sensing technology offers the archaeologist the opportunity to detect these impacts, which are often invisible to the naked eye when investigating on the ground. These applications, which will evolve into greater utility, benefit the study of human settlement as it affects environment.

All the artifacts and deposits of European and Taino Indian descent from En Bas Saline, Haiti, were collected and documented through the years of 1984 to 2003. To provide efficient data management of this spatial data with the other attribute data collected the En Bas Saline Geodatabase (EBS GDB) was created. ArcGIS© 8.3 coupled with Microsoft Access® provided the tools necessary to build the geodatabase and give spatial reference to previous years.

The EBS GDB allows the archaeologist to view and analyze the data more efficiently. Locations of similar artifacts across different excavation years or within the same year are easily queried based upon their attributes. After querying the geodatabase archaeologists were able to see the results of the queries and draw conclusions about the distribution of the artifacts. Clusters of artifacts such as Taino ornamental items and European artifacts that date to Columbus’ time were identified in key locations of the village. Distribution mapping of the artifacts allowed the archaeologists to draw conclusions about the organization of the village along with the location of different classes of people within the village.
The geodatabase is a container for all GIS data and represents all geographic features and their attributes. Conceptually, the geodatabase is similar to the coverage and shapefile, except that it expands on the capabilities in many important ways. Geodatabase feature datasets can store multiple feature classes that all share the same spatial reference and extent. Building topology is more streamlined, while editing features becomes more efficient when working with feature classes. Building a GIS geodatabase does many things: integrates a variety of data sources and types, maintains and manages inventories, visualizes data and related information using maps, and allows for decisions about management, modeling and analysis to be performed.

Only a small percentage of social science research takes the spatial perspective into account. Location can be an integrating theme across social science and should be incorporated in more than just the attribute table. GIS and remote sensing provide integration of disparate layers of information, making demographic, economic and social patterns more readily identifiable (Goodchild 2004).

The technologies of high-resolution multispectral remote sensing and GIS will never take the place of traditional archaeological excavation but instead be integrated as tools to aid the archaeologists. When properly incorporated these new techniques can help archaeologists better understand historical human interaction on the landscape. The integration of satellite imagery, GIS, and fieldwork enhance social science research possibilities and analyses by permitting the synthesis of environmental and ecological data with ethnographic, historic and archaeological research.

There is great potential for the future of remote sensing techniques in the field of archaeology. Continued progress of the development of sensor capabilities in terms of
resolution and sensor features will enhance the research methods and capabilities for research. Factors that will contribute to future implementation of remote sensing technology in archaeological research includes the improvement of satellite sensor resolution, building image archives, accessibility to data, and the acquisition of the technological skills in processing and applying the data.
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BIOGRAPHICAL SKETCH

Kristy M. Capobianco was born April 13, 1979, in Brooklyn, NY, where she lived until 1989 before relocating to Naples, FL. From 1997 to 2001 she attended the University of Florida, where she earned her Bachelor of Arts degree in environmental science from the College of Natural Resources and Environment. The following year she began her master’s work at the University of Florida in the Department of Geography to specialize in Geographic Information Systems (GIS) and remote sensing. While completing her master’s work she was employed by both the University of Florida, where she taught Foundations of GIS, and the United States Geological Survey (USGS) as a GIS Analyst. She graduated with her Master of Science degree in August of 2005. She plans to relocate to Jacksonville, FL, to work in her field.