From a Bird's Eye View: Using Satellite Imagery to Map and Analyze the Forest Islands of the Llanos De Mojos, Bolivia

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FROM A BIRD’S EYE VIEW: USING SATELLITE IMAGERY TO MAP AND ANALYZE THE FOREST ISLANDS OF THE LLANOS DE MOJOS, BOLIVIA

by

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ABSTRACT

Recent discoveries about pre-Columbian societies in the Amazon have revolutionized the way researchers think about the environment, and the degree of interaction that humans have with their surroundings. New evidence indicates that ancient Amazonian populations were not only much larger and more complex than previously thought, but they were also modifying their environment and creating artificial landscapes. Although information about pre-Columbian cultures can be gained from archaeological excavations and historical accounts, the advent of new technology allows archaeologists to conduct research remotely.

Earthworks were constructed by pre-Hispanic peoples to create higher ground for occupation and agriculture, as an adaptation to the annual flooding of the Llanos de Mojos in the Bolivian Amazon. Over the centuries, patches of forest have grown on these earthworks due to their higher elevation and drier soils. By mapping these ‘forest islands’ using the satellite imagery from Google Earth and transferring the data into Quantum GIS, spatial patterns between the geographical features have been analyzed to reveal relationships between pre-Columbian earthworks, natural and artificial landscape features, and settlement patterns.

This research supports theories of large and complex pre-Columbian populations in the Bolivian Amazon. Patterns between the different size, shape, and location of forest islands show a correlation between specific types of forest islands and water sources, which indicates that pre-Columbian societies were constructing earthworks based on function and distance to water.
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CHAPTER ONE: INTRODUCTION

Recent discoveries about Pre-Columbian societies in the Amazon have revolutionized the way modern people think about the environment and the degree of interaction that humans have with their surroundings. Within the Department of Beni in the Bolivian Amazon is a region called the Llanos de Mojos, a savanna known for its annual cycle of flooding and drought. Today, the region is sparsely populated with cattle ranches, but recent archaeological research has shown that large pre-Columbian populations once inhabited the savanna. One of the debates initiated by this discovery is the extent that these people were affecting their surroundings: were they simply surviving, modifying the environment, or creating artificial landscapes? Some crucial evidence for pre-Columbian activities comes from looking at the landscape itself. These ancient peoples constructed various types of earthworks, leaving imprints on the landscape that are still visible to this day. Remnants of these earthworks are detectable on satellite imagery, upon which this thesis is based. The purpose of this project is to further the research of the physical evidence of pre-Columbian occupation in the Llanos de Mojos, utilizing modern technology to answer archaeological questions.

Several researchers have conducted archaeological excavations on mounds present in the Llanos de Mojos, demonstrating that the frequent presence of ceramics and altered soils indicates human presence, habitation, and modification. The majority of the mounds also have vegetation growing on them, as higher elevations provide dry soils and protection from the annual floods. These forested mounds are called forest islands, since they appear as patches of forest dotting the landscape. A debated issue is whether forest
islands should be considered natural features, man-made constructions, or a combination of both. Determining exactly how these forest islands formed would shed some light on the issue of whether pre-Columbian people were simply adapting to their environment, or creating their own landscape. Among the earthworks constructed by pre-Columbian societies were house mounds, built to provide dry ground for villages among other purposes. This thesis investigates what the consequences would be if the forest islands are indeed wholly of human origin, rather than shaped by natural forces. If forest islands were being purposely located, altered, and cultivated by the native population that lived on the savanna before Spanish Contact, then it is possible that by analyzing their spatial patterns, some information can be inferred about how these people arranged themselves physically and socially. It is possible that these forest islands may be located in relation to resources such as water, to agricultural fields, to accessible areas for transportation, or to other social groups (for purposes such as trade or political/social organization). To test this idea, original data have been gathered about the geographic locations of forest islands and other features by mapping them and comparing them to natural and man-made features.

For this research project, the spatial patterns of the forest islands have been compared to other features within a specific study area in the Llanos de Mojos in the Department of Beni, Bolivia. The contrast between the savanna and the forest islands renders them clearly distinguishable, making it possible to map them on satellite imagery using the program Google Earth, a program that is open to the public and free to download from their website. Using the tools in this computer program, the location of rivers, lakes, ranches and forest islands could be traced. After saving these mapped
features as files, they were transferred to Quantum GIS ‘Mimas,’ a Geographic Information System program, free for the public to download, which helped to analyze the geographic information of the features. In addition, research on ethnographic and historical data has been conducted to compare with the findings, in an effort to construct potential relationships between the analyses of satellite images and associated cultural activities.

The next chapter includes a brief discussion on the geography, geology, biology, climate, history, and people of the Llanos de Mojos. This background information is paramount for understanding the changes that took place in the Llanos de Mojos over time, and how those changes affect what is still visible today. In order to understand why the landscape looks like it does today, one must look at the events and changes that have occurred during its past. Chapter 2 also covers the development of research conducted in the region, highlighting important discoveries, concepts, and theories by leading Amazonian archaeologists. Chapter 3 discusses the computer program Google Earth, the methods used for obtaining the data, the definitions set for mapping each feature, and the problems encountered in the process. Chapter 4 introduces the Quantum GIS program and includes the results of the data with analyses of the findings. Chapter 5 is the conclusion and suggestions for future research.

This research was conducted as part of a larger project, the Archaeological GIS Project of the Beni, directed by Dr. John Walker. While the larger Project of the Beni aims to map all significant natural, artificial, ancient and modern geographical and structural features in this region using Google Earth, this thesis only focuses on the forest islands, rivers, lakes, and ranches of the chosen study area.
It is important to note that the author has not yet physically been to Bolivia, and that the work in this thesis is a personal interpretation of the satellite imagery, data and graphs. Although the goal to be as objective as possible to avoid imposing personal biases, there is the unavoidable link between who a person is and how they view and interpret information, which may be in a different manner than other researchers who have had different experiences and training. In order to connect satellite imagery with archaeological research, some inferences must be made about the data. The author is by no means an expert in either computers or archaeology, but it is the author’s hope that this research will be beneficial and accepted by the academic community as an attempt to investigate the relationships between humans and their environment, culture and nature, and to apply modern technology to achieve a fresh perspective on archaeological research questions.
CHAPTER TWO: LLANOS DE MOJOS

Overview of the Environment

The Llanos de Mojos (or Mojos, for short) is located in the Department of Beni, in northeastern Bolivia in South America. As part of the Amazon watershed, it occupies over 90,000 square miles in the middle of the Beni Basin, between the foothills of the Andes and the Brazilian highlands (Denevan 1966; Walker 2004). It is characterized by several geographic and geological features, which create a unique environment seen only a few times throughout South America (Cleary 2001; Hamilton 2002).

Figure 1: Study Area. This is a map showing the study area within the Llanos de Mojos, in northeastern Bolivia. The outline of the Llanos de Mojos is an approximation. Bolivia, Mojos, and the Study Area are to scale.
savannas where they grazed them are still used for that same purpose today in many areas of Mojos. All modern agriculture is now practiced on forested high ground, and very rarely on the savannas (Block 1994).

Other documents that are highly useful for studying the Llanos de Mojos became available with the use of airplane surveys by the Standard Oil Company. Aerial photographs, while intended for surveying purposes, also provide a unique look at the landscape. Archaeologists have found them particularly informative in providing an aerial view of the savannas, revealing wide expanses of pre-Columbian earthworks (Denevan 1966; Lathrap 1968; Plafker 1963).

**Archaeology of Pre-Columbian Cultures**

Although archaeological studies in the Llanos de Mojos only began a few decades ago, it has become the focus of several scholars (Block 1994; Calandra 2004; Denevan 1966; Dougherty 1981, 1984; Erickson 1995, 2000; Hanagarth 1993; Walker 2004, 2008a). Particular places of archaeological interest on the landscape include mounds, forest islands, and agricultural fields (which were not the focus of this project but which were included to present the potential for future research to include them in the mapping). During excavations at these three types of features, several scholars have discovered the presence of *terra preta*, an anthropogenic soil that indicates human habitation and modification of the soils (Walker 2004). The study of settlement patterns in the Llanos de Mojos takes into account all of the archaeological evidence discovered, and various theories have been reviewed as a comparison to the findings of this project.
Archaeological excavations are essential background information for this project, as this project is based off of archaeological interpretations from the excavation of natural and artificial landscape features.

Although the ethnic groups that inhabited the savanna at the time of Spanish Contact and the Jesuit period may not represent the tribes that have always occupied Mojos (Plafker 1963; Walker 2008a), these tribes may have some relationship to the ancient pre-Columbian tribes who constructed the earthworks found in the Llanos de Mojos. The Summer Institute of Linguistics has mapped 28 different tribes, noting six of the more distinct ones: the Arawak-speaking Mojo, the Arawak-speaking Baure, the Cayuyava, the Itonama, the Movima, and the Canichana (Denevan 1966). These groups, though they had many differences in their subsistence, technological sophistication, and social structure, were noted for several similar features that they shared. They all had surplus agriculture, trade, warfare, political and religious specialists, and a belief system with a hierarchy of deities (Block 1994). By looking at the cultural characteristics of these tribes, scholars may be able to infer that their pre-Columbian predecessors might have had similar characteristics. However, despite the information about native Mojos peoples at the time of Spanish contact, there is no direct relationship between the pre-Columbian earthworks and the Arawak-speaking tribes at the time of contact (Walker 2008a). Although native people may have been using some of the earthworks at the time of Contact, there is no evidence they were actively building them. Other pre-Columbian constructions, that are not the focus of this paper, include causeways, canals, ditches, and other types of drained fields (Denevan 1963; Walker 2008b).
Mounds

One of the most common adaptations to the annual flooding was the construction of mounds (Denevan 1966; Erickson 2000; Erickson 2006; Erickson and Bale 2006; Langstroth 1996). By piling earth into a platform, pre-Columbian people were able to build houses and live on the mounds above the floodwaters. Among Amazonian archaeologists, however, there are still debates about the origin, purpose, construction and artificiality of the mounds (Erickson 2000).

Mounds can be the results of years of accumulation of debris and piled earth (Erickson 2006). Houses were constructed atop these platforms, lasting anywhere from five to ten years, after which they were abandoned. After leveling the abandoned houses, new ones were constructed on top. The gradual accumulation eventually forms a mound. As fill was removed for initially building up the mound, oftentimes it resulted in the creation of deep depressions around the mound, filling with water. According to Erickson (2006), mounds have two ‘structural principles’: that there are two distinct structures (a large flattened platform with a smaller cone structure on top), and that the concept of duality can be seen in the pairing of mounds.

While people are occupying the mound, there is very little vegetation present on it due to the density of the housing and the amount of activity (Erickson 2000). However, when pre-Columbian people began moving from the savannas to the mission sites after the arrival of the Jesuits, the houses and mounds were abandoned. This absence had a large effect on the vegetation, which quickly colonized the abandoned mounds. These areas were ideal, as the plants were supported by the anthropogenic and artificially enriched soils, and protected from fires by the water-filled pits surrounding the mounds.
Balleé and Erickson (2006) believe that much of the presently forested areas in the Llanos were once open savanna grassland, and that vegetation has been increasingly advancing across the savanna after the dispersal and absence of pre-Columbian people.

According to Denevan (1966), there are three types of man-made mounds found in northeastern Bolivia. Artificial mounds are 3 to 16 meters high and up to 300 meters long. Artificial islas are made by refuse accumulation or intentional piling of earth, 1 to 2 meters high and 10 to 15 meters long. House mounds are small, circular, less than 1 meter high, and 3 to 7 meters in diameter. Denevan also describes the characteristics of a mound that is artificial: 1) there is the presence of urns and potsherds, 2) there is a sudden rise in elevation from the surrounding ground level, 3) it has an unusual height compared to natural islas (which are normally less than 2 meters high), 4) it is located on a deep alluvial plain away from rock outcrops, 5) the soil composition of the mound is unpacked and unconsolidated material, 6) it has an oval shape (rather than an irregular shape), and 7) there are borrow pits at the base of the mound (Denevan 1966). This information is critical to archaeologists who, during excavations, should be able to identify and locate artificial mounds when studying settlement patterns.

Erickson and Balée (2006) have shown through archaeological interpretations that mounds were originally used as settlements, burials, and important ritual functions. Some are used currently for a variety of functions: as swidden fields, gardens, temporary hunting camps, or farmsteads. Some of the earthworks they are associated with are barrow puts, causeways, and canals. According to the excavations conducted by Erickson (2000), nearly all of the smaller isla mound sites contained pottery, clear indicators of human habitation.
An important aspect of mounds in relation to this thesis is their location. Erickson (2000) notes that most mounds are rarely isolated and that they occur in clusters or groups. He notes that the mounds along rivers (both active and old) appear to be regularly spaced from one another. Small mounds “...cover less than 1 hectare and...are often located in the open savannas or on old abandoned river channel levees as “forest islands” (islas) and are often associated with raised field agriculture” (Erickson 2000:5-6). In addition to small mounds, Erickson describes large mounds to “…[cover] at least several hectares...[and] tend to be located on the forested high ground either along the edges of floodplains or on levees of...the Rio Mamoré, or important tributaries” (Erickson 2000:5). The mounds’ location next to areas rich in natural resources, fishing, hunting, gathering, and farming makes them ideal perfect for settlement. Continued occupation would have added accumulation soil, and these areas would continue to be reused over the years due to the benefits of their artificial elevation (Erickson 2000). The results from this project may support Erickson’s conclusions (see Chapter 5). The forest islands observed in the Study Area have similar sizes and locations that fit Erickson’s descriptions, including both the large and small forest islands. These forest islands may represent similar types of mounds as analyzed by Erickson, and therefore the mapping of the forest islands in this study has allowed an analysis of potential settlement patterns.

Forest Islands

A forest island can be most basically described as an isolated unit of forest. A forest island, or isla, in Mojos is characterized by Langstroth as “a patch of trees or shrubs in an otherwise open landscape, often upon a slightly elevated surface.”
The origins and modification of forest islands is a debated subject, as many scholars have differing opinions as to whether forest islands should be considered wholly natural, wholly artificial, or somewhere in between. This debate is essential to this project because the analysis of these forest islands is based on archaeological evidence that they are artificially created as settlement mounds.

With the establishment of missions in Mojos, the majority of the population left their villages to live with the Jesuits (Block 1994). Once their house mounds were abandoned, vegetation was able to take root and thrive due to the higher elevation, free from the flood waters. In addition, the pits around the mounds tended to protect the vegetation from the savanna fires. In this way, where there were once cleared house mounds and raised fields scattering Mojos, there are now forest-covered mounds. Once natives stopped setting savanna fires, the forest began to creep back onto the savanna. It’s possible that much of the forest surrounding Mojos today was once a cleared savanna (Walker 2008). However, abandoned mounds and fields are just one explanation for the presence of forest islands.

Researchers in the Bolivian Amazon have proposed a number of ideas on the origins and formation of forest islands, including insect mound building or eroded levees.
Dougherty believes that forest islands "are the relics of very old river activity, sometimes modified by human action" (Dougherty 1984:166). These particular views don’t credit pre-Columbian populations with the entire creation of the mound; rather, they believe that ancient societies simply utilized an already-formed and conveniently elevated area.

Due to their enhanced drainage and anthropogenic soils (see Terra Preta, page 18), forest islands are sought out as settlements, gardens, orchards, corrals, and as sites for slash-and-burn agriculture (Erickson 2006b:257). Many forest islands are cultivated today due to their beneficial characteristics. These farmed forest islands (see Appendix B, Figure 14) have also been mapped in this project.

Raised Fields

Raised fields are a distinctive type of agriculture that is specifically adapted to the annual flooding of the savannas. While similar fields have been studied in central Mexico and by Lake Titicaca in the Andes, the fields found in Mojos are some of the most extensive ever recorded (Denevan 1966). It was not until within the last few decades that researchers became aware of the vast quantity of raised fields in the Llanos de Mojos (Denevan 1966; Erickson 1995). Since their low relief makes them hard to see at ground level, aerial and satellite photos have been the primary way of cataloguing them. Raised fields are "large earthen planting surfaces elevated above the seasonally flooded savannas and wetland" (Erickson 2006b: 251). Several different types of raised fields have been recorded, based on shape, length, width, and depth (Denevan 1966).
Raised fields have not been included in the actual mapping of this project, due to the low visibility of raised fields on the LANDSAT imagery in the Google Earth program; however, they have a potential association with irregular shaped forest islands. According to Walker, "[r]aised field islands retain their shape from their construction as raised fields. The dimensions of raised field islands are consistent with the measured dimensions of raised fields" (Walker 2004:105). If the raised fields appear irregular on the landscape (see Figure 5), then the forests that grow atop them will be irregular-shaped as well (see page 29 for Forest Island Shapes).

**Terra Preta**

A recent discovery in the Amazon is the presence of anthropogenic soils, known as *terra preta* (literally, ‘dark earth’). They have been found in several locations throughout the Amazon region (Heckenberger 2005), and in particular, have been discovered in excavations of mounds and forest islands (Walker 2004). These soils reveal
human modifications and occupation and are associated with ancient settlements (Heckenberger 2003). It is now thought that pre-Columbian people had “…discovered the importance of soil carbon and used low-temperature incomplete burning to produce charcoal that they incorporated into soils, thus creating black earths” (Erickson 2006b:263). Terra preta is characterized by three main components: charcoal/burned clay, human artifacts, and having a dark color (Graham 2006; Heckenberger 2005; Walker 2004).

Terra preta is most often associated with the archaeological remains of refuse disposal and cultivation. It is rich in phosphorous, calcium, with an abundance of artifacts. Terra preta can contain up to 70 times more carbon than the surrounding soils, and that carbon retains nutrients, stabilizes the soil’s organic matter, raises the pH levels, maintains the soil’s moisture, helps repel insects, reduces nutrient leaching, and improves the soil fertility (Graham 2006).

There may be a link between the ancient behaviors of pre-Columbian cultures and the chemical composition of the soils they lived on (Graham 2006). When looking at how people have modified their environment, it is clear that terra preta can be considered an example of the intentional domestication of soils, where “the creation of ideal conditions or habitat for certain microorganisms that improve and sustain fertility through the incorporation of organic matter and of carbon produced under low temperatures into the soil” (Erickson 2006b:245). The discovery of terra preta on earthworks, then, may prove a degree of intentional modification of nature, and the creation of an artificial environment.
Settlement Patterns

It is thought that humans settled in the area of Mojos by 500 B.C. This temporary settlement is marked by waves of migrations, with the most recent one being of Arawak origin (Block 1994). There are several theories about the settlement patterns of the native people living in Mojos. One theory, according to Block (1994), is that tribes fought to live on the riverfront land, as it was the most valuable for agriculture and settlement. The weaker tribes, unable to gain any riverfront land as it became more populated with stronger tribes, were forced to live on the open savanna. However, even though the savanna was not originally as fertile as the riverfront, pre-Columbian tribes developed a sophisticated culture based on manioc cultivation, constructing earthworks and raised fields to adapt to the seasonal flooding that would otherwise ruin their crops (Block 1994).

Denevan (1994) notes that village sites were not permanent; rather, they shifted frequently because of the hazards of the annual flooding and the changing river courses. Villages located on riverbanks, in the reeds, in the forest, or near lagoons have access to better soils, avenues of communication, better fishing, and the availability of water.

Excavations

The methods and analysis of this project are based on the archaeological work conducted by scholars in the Amazonian region. By looking at the evidence and interpretations of Amazonian archaeologists, it is possible to connect their archaeological data with the landscape features on the satellite imagery in Google Earth. If there has been previous evidence found of human habitation on certain types of earthworks, such
as mounds or forest islands, then looking at all of the forest islands within a Study Area may reveal information about the how people lived on, used, and modified those earthworks. It should be noted that although archaeological evidence may be found in certain forest islands, that does not necessarily mean that all forest islands were occupied (or if they were, perhaps not all at once). However, because these scholars argue that humans were present at these sites, then it is important to look at all features in Google Earth that are similar to the excavated features. By looking at all forest islands within a specified study area, the independent excavations can be connected to the larger picture of complex societies thriving in the Amazon.

Erland Nordenskiöld (1802-1857) is considered the pioneer of archaeology in the Llanos de Mojos. He was a Swedish ethnologist, archaeologist, and anthropologist, and he was the first to conduct archaeological excavations in Mojos. Between 1908 and 1909 AD he excavated three mounds south of the city of Trinidad, discovering evidence of human occupation in the form of ceramics and cultural debris (Calandra 2004; Denevan 1966).

Walker (2004) has conducted several excavations in the Llanos de Mojos (see Appendix B, Figure 16). He has conducted tests on raised fields, levees, and forest islands. Walker categorized the forest islands he excavated into three categories: Large, Small, and Raised Field Islands. One of the main goals of Walker’s excavations (2004) was to record the locations of terra preta. He excavated at three different types of locations: levees, raised fields, and forest islands. The results of the tests showed that terra preta was present in large/small forest islands and at the levee site of Cerro, but not on raised field islands. The presence of terra preta at these sites indicates that they can be
classified as occupation sites. Therefore, this project will aim to map all forest islands along with other features, because this archaeological evidence provides the support that these forest islands do represent areas of pre-Columbian habitation.

Summary

Historical documents, when analyzed in conjunction with archaeological research, can provide the crucial background information and informative basis required for the formation of a hypothesis. Historical documents claim that large populations inhabited the Amazon at the time of the arrival of the Spanish. Jesuit documents detail the lives, cultures, agricultural methods, and numbers of the pre-Columbian people living in the Llanos de Mojos. Archaeological evidence supports the claims of large, complex societies living in the Amazon at the time of and before Spanish Contact, by revealing evidence such as terra preta, man-made earthworks, and raised agricultural fields. Archaeological excavations have also shown that certain types of forest islands and mounds were probably sites of pre-Columbian habitation. This evidence has led scholars to propose a number of theories about settlement patterns.

This project utilizes the evidence from historical and archaeological sources to conduct a new type of experiment. By using computer programs such as Google Earth (which provides satellite imagery and tools to map it) and Quantum GIS (which uploads Google Earth files for analysis), the natural and man-made features within a study area have been mapped and analyzed. The locations of these features have been compared to one another, to determine if this spatial analysis can support or refute the proposed patterns of scholars. It is believed that indeed, the patterns that have emerged from the
program do indicate that there is a pattern to how and why mounds and forest islands are located in Mojos. But first, the computer programs shall be introduced and discussed, along with the methods used to map and classify the landscape features.
CHAPTER THREE: METHODOLOGY

An Introduction to Google Earth

Google Earth became available to the public in June 2005. Since then, the diversity of its users along with its practical applications has increased dramatically. Google Earth is a program that uses satellite imagery to create a detailed projection of the Earth. This research project used the free version of Google Earth, which is available to the public to download at their website.¹ Google Earth has two different types of satellite imagery provided in the region of this project’s Study Area. Images with a higher resolution (Quickbird) have more visible detail, which may increase the accuracy of mapping features. Lower resolution imagery (LANDSAT) results in an image with less detail, appearing much more blurry at any elevation when compared to the Quickbird. The majority of the Study Area consists of the LANDSAT imagery, with a very small portion of Quickbird in the upper right corner. Several of the features available on Google Earth were employed to map the features analyzed, including the Polygon, Path, and Placemark tools.

¹ http://earth.google.com/
Figure 6: Screenshot of the Google Earth program with Study Area and Features. The Folders with the mapped data are on the left hand side of the image. The toolbar along the top includes the tools I used the most for this project: Placemark, Polygon, and Path.
Methods

The Study Area is approximately at 13°39'13"S and 65°47'40" W. The Study Area is approximately 105 km wide at its longest point, and about 50 km tall at its tallest point. The total area of the Study Area is approximately 4,950 km². The Study Area for this project is bounded by three rivers: the Iruyañez River to the north and west, the Mamoré River to the east, and the Yacuma River to the south. The Iruyañez and the Yacuma are both tributaries of the Mamoré. Not every type of vegetation and feature were mapped on the Google Earth satellite imagery. The features that were focused on while mapping the Study Area in Google Earth were: Forest Islands (see the categories in Table 1), Ranches, Oxbow lakes, Lakes, and Rivers.

The Google Earth program includes several tools that facilitate the mapping of features on the satellite imagery: the Polygon tool, the Path tool, and the Placemark tool. The Polygon tool is used to trace objects, by either clicking to create points or dragging the cursor for a continuous line. The Path tool traces a line, in customizable width and length. The Placemark tool marks a point of interest on the imagery, with a variety of symbols available.

Mapping a landscape in Google Earth required the creation of categories in order to organize the different types of landscape features. Rivers were traced in a yellow color, using the Path tool. All forest islands were outlined in a green color using the Polygon tool. Ranches were marked using the Placemark tool, using a thumbtack symbol. Lakes, including oxbow lakes, were outlined using the Polygon tool in a blue color.
Forest Island Classifications

Similar to the classification methods employed by other scholars (Walker 2008a, Erickson 2000), the classifications chosen for categorizing forest islands were based on size, shape, and location. These categories were defined after a preliminary review of the forest islands in the area, to better suit the types that were found. Initial categories quickly became irrelevant, so this was a learning process in determining the attributes of a forest island that may make it classifiable.

The three sizes are: Small, Medium, and Large. These size categories were determined after a preliminary observation of the forest islands within the Study Area. During the mapping process, not every forest island was measured, but compared to the forest islands set as a type for each size category. It would have been very inefficient, time-wise, to specifically measure each of the 893 forest islands in the Study Area. There is a major distinction between the scattered, small forest islands mainly found on open savanna, and the large patches of forest island that dwarf them in comparison. The forest islands that were between those two distinctive sizes were categorized as medium. The average size of the Small forest islands (see Figure 8) ranges from 5,000 m$^2$ to 3 hectares (with 10,000 m$^2$ per hectare). The average size of Medium forest islands ranges from 4 to 30 hectares. The average size of Large forest islands ranges from 31 ha to 2 km$^2$. Forest islands smaller than 5,000 m$^2$ were too small to clearly see in the LANDSAT imagery, so they were not included.
Figure 7: Small Forest Islands.

Figure 8: Varying Mapped Forest Island Sizes and Shape. Shown with outlines and traced river.
The four classifications for shape are: Circular, Oval, Irregular, and Farmed. While mapping forest islands, several were noticed as being peculiarly and perfectly circular in their shape, and so Circular became a category to distinguish it from the shape of Oval. Many forest islands were oval in shape, being neither perfectly circular nor distinctly irregular (see Figure 10). Irregular forest islands were inconsistent in their specific shapes, either sprouting long strips of forest from its sides or appearing unique in its form (see Figure 10). These irregular-shaped forest islands may be associated with raised fields, as will be discussed further on. There are several documented examples of forest islands being farmed in Mojos, and since farming a forest island may erase part of its initial shape, it may be more accurate to label farmed forest islands in a separate category rather than guessing at their original shape. They appear to have geometric chunks missing from the interior of the forest, usually in a different color than the surrounding forest or savanna.
Figure 10: Forest Island Examples. Irregular shaped forest islands bordering gallery forest and small round forest islands dotted along a stream across the top part of the image.

Figure 11: Additional Forest Island Examples. Mostly irregular forest islands, a Ranch located in the middle/bottom part of the image, and some small forest islands on the savanna.
The three location classifications are: Bordering Water, Bordering Gallery Forest (see Chapter 1, Overview of the Environment, Terrain; also see Figure 14), and On the Savanna (see Figure 13 for examples). Forest Islands defined as bordering water appear, on the satellite imagery, to directly touch the edges of water sources. Forest islands defined as bordering gallery forest appear to directly touch the edges of gallery forest, which occur on the banks of rivers. Gallery forest is different than forest islands in that it only occurs along rivers, at lower elevations and is often flooded. Forest Islands defined as being on the savanna do not directly border water sources or gallery forest. These forest islands may be in close proximity to water, or be isolated in the middle of the savanna. These categories were chosen as the main ones, although there are several problems with them. Classifying by location makes it easier to identify forest islands on satellite imagery; however, none of the satellite imagery available on Google Earth will represent what the savanna looks like throughout the entire year (with the changing seasons). Seasonal inundations will raise the water levels considerably, and forest islands that previously mapped as being on the savanna may border water directly. Also, the mobility of the rivers to change their course rather rapidly could mean that forest islands that were interpreted as bordering water may not have been a handful of years ago. However, this classification was chosen because it has been greatly helpful in generally sorting the forest islands, and the analysis did uncover some correlations between Location and Size. Although the actual landscape may be dynamic, the satellite imagery is static. Keeping this in mind, the analysis of the data does not exclude any potential correlations that may occur when focusing on other feature characteristics besides location.
Figure 12: Image Showing Forest Islands in Various Locations: 1) Bordering Water, 2) Bordering Gallery Forest, and 3) On the Savanna.

Figure 13: A Forest Island bordering Gallery Forest. A closer image which shows how the side of the forest island is bordering the gallery forest.
White Features

Another feature that was discovered during the mapping process was dubbed 'White Features.' Throughout the Study Area, there were splotches of white that could not be identified as something natural or artificial. Although they are not the focus of this research project and are not included with most of the data analysis, they were mapped and noted in the event that there is some correlation between them and other landscape features. Figure 15 shows two images that are close ups of white features next to forest islands. These images are meant to compare and contrast the two features, to show why they were mapped as separate and distinct features, and to show that they appear consistent throughout the region, with some shape variation. One possibility includes a modern ditch for cattle. It should be noted that no white features were noticed in the Quickbird images.

Table 1 sorts out the 893 forest islands into specific categories, based on the previously mentioned classifications: Location (Borders Water, Borders Gallery Forest, On the Savanna), Shape (Circular, Oval, Irregular, Farmed), and Size (Small, Medium, Large). The totals for each category are included beneath the title of the categories, from the broader to the more specific. On the right side of the table, the white features previously described have also been classified, and are included for comparison.
<table>
<thead>
<tr>
<th>Location</th>
<th>Shape</th>
<th>Size</th>
<th># of Forest Islands</th>
<th>(White)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borders Water</td>
<td>Circular (Total=23)</td>
<td>Small</td>
<td>22</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Oval (Total=29)</td>
<td>Small</td>
<td>22</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Irregular (Total=47)</td>
<td>Small</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Farmed (Total=12)</td>
<td>Small</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Borders Gallery Forest</td>
<td>Circular (Total=6)</td>
<td>Small</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Oval (Total=29)</td>
<td>Small</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Irregular (Total=52)</td>
<td>Small</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Farmed (Total=11)</td>
<td>Small</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>On the Savanna</td>
<td>Circular (Total=131)</td>
<td>Small</td>
<td>127</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Oval (Total=250)</td>
<td>Small</td>
<td>219</td>
<td>137</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Irregular (Total=273)</td>
<td>Small</td>
<td>156</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>85</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Farmed (Total=30)</td>
<td>Small</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1: Forest Island Categories. This chart shows how each forest island was categorized by location, shape, and size. The white features are included on the right side for comparison.
<table>
<thead>
<tr>
<th>Borders Water</th>
<th>Borders Gallery Forest</th>
<th>On the Savanna</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>65</td>
<td>44</td>
<td>509</td>
</tr>
<tr>
<td>Medium</td>
<td>40</td>
<td>47</td>
<td>137</td>
</tr>
<tr>
<td>Large</td>
<td>6</td>
<td>7</td>
<td>38</td>
</tr>
<tr>
<td>Totals</td>
<td>111</td>
<td>98</td>
<td>684</td>
</tr>
</tbody>
</table>

Table 2: Comparing forest island size to location. The numbers for the white features are included for comparison.

<table>
<thead>
<tr>
<th>Circular</th>
<th>Oval</th>
<th>Irregular</th>
<th>Farmed</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>155</td>
<td>257</td>
<td>197</td>
<td>618</td>
</tr>
<tr>
<td>Medium</td>
<td>5</td>
<td>50</td>
<td>131</td>
<td>224</td>
</tr>
<tr>
<td>Large</td>
<td>0</td>
<td>1</td>
<td>44</td>
<td>51</td>
</tr>
<tr>
<td>Totals</td>
<td>160</td>
<td>308</td>
<td>372</td>
<td>893</td>
</tr>
</tbody>
</table>

Table 3: Comparing forest island shape and size. The numbers for the white features are included for comparison.

<table>
<thead>
<tr>
<th>Borders Water</th>
<th>Borders Gallery Forest</th>
<th>On the Savanna</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular</td>
<td>23</td>
<td>6</td>
<td>131</td>
</tr>
<tr>
<td>Oval</td>
<td>29</td>
<td>29</td>
<td>250</td>
</tr>
<tr>
<td>Irregular</td>
<td>47</td>
<td>52</td>
<td>273</td>
</tr>
<tr>
<td>Farmed</td>
<td>12</td>
<td>11</td>
<td>30</td>
</tr>
<tr>
<td>Totals</td>
<td>111</td>
<td>98</td>
<td>684</td>
</tr>
</tbody>
</table>

Table 4: Comparing forest island shape to location. The numbers for the white features are included for comparison.
Problems

There are a few problems with mapping an area like the Llanos de Mojos. The fact that it is a seasonally flooded savanna means that the landscape changes dramatically throughout the course of a year. Due to this variability, the appearance of the landscape will depend on what specific date that a satellite image was taken. An image taken during the wet season may be a misrepresentation of what the landscape looks like during the dry season, thus adding to a margin of error in mapping landscape features.

This type of problem is important to keep in mind when looking at the data from Google Earth. However, since the satellite imagery for the region has only been recently updated with better quality images, this was the only source of data available for the project. If Google Earth updates their program with images taken during a different time of the year, it might be helpful for future research in comparing the way the Llanos appears in different seasons. It should also be noted that if Google Earth updates their satellite imagery, this research pertains only to the images from the 2009 archives. Updated files may reveal clearer imagery in which more vegetation, pre-Columbian earthworks, and landscape features are more visible and distinguishable.

Summary

The totals for each of those features are: 50 ranches, 254 oxbow lakes, 7 lakes, 99 rivers, and 893 forest islands. The 893 forest islands include all categories, as shown in Table 1. Besides looking at the numbers in the tables when comparing the size, shape, and location of the forest islands, the bar graphs also help to illustrate their distribution.
Table 2, which compares forest island location and size, shows that a considerably large portion of the small forest islands are located on the savanna. It also shows that the majority of the forest islands, of all sizes, are considered as being on the savanna (rather than directly bordering water, or bordering gallery forest). However, it is important to keep in mind that even if a forest island is not directly bordering water, it still may be associated with a stream or tributary (see Figure 16), within a few kilometers of the water source.

![Figure 15: Forest Islands on the Savanna. These forest islands are not directly bordering the tributary, but they do seem to be associated to it by their proximity.](image)

Table 3 compares forest island shape and size. It shows that the majority of circular forest islands were either small, or consisted of the white features (which were included in this table for comparison). It is interesting to note that there are almost an equal number of circular forest islands and white features in the Small category. There
are very few medium forest islands that are circular, and there were no circular large forest islands in the study area. The oval column includes the most small forest islands, probably due to the fact that the oval classification included all forest islands that weren’t perfectly circular, but not considered irregular. There are an increased number of medium forest islands of this shape, and only one large oval one. This category contains the most amount of white features, suggesting that these features do not occur in a large size very often. Surprisingly, there are a large number of small forest islands that were irregular. While the author initially considered small forest islands to be the ones that were circular and scattered across the savanna, a good deal of small ones had an unusual irregular shape. The majority of medium forest islands were irregular. The irregular category is the only one with a significant amount of large forest islands.

Table 4 compares forest island location and shape. The two types of forest island shapes that occur most on the savanna are oval and irregular, along with the white features. Farmed forest islands occur much less often than oval or irregular, but occur more often on the savanna than bordering gallery forest or bordering water. The shape that occurred most as bordering water or bordering gallery forest was irregular (even though most irregular shaped forest islands occurred on the savanna). White features either bordered water or were on the savanna, and never occurred as bordering gallery forest. Most circular forest islands were on the savanna, and some bordering water, but very few bordered gallery forest. Circular forest islands and white features are the most associated with on the savanna, and the oval and irregular shaped islands are more associated with bordering gallery forest or bordering water.
Chapter Four: Analyses and Findings

An Introduction to Quantum GIS

Quantum GIS 1.3.0 Mimas is an Open Source Geographic Information System (GIS) licensed under the GNU General Public License. QGIS is an official project of the Open Source Geospatial Foundation (OSGeo). The program runs on Linux, Unix, Mac OSX, and Windows and supports numerous vector, raster, and database formats and functionalities. Since it is volunteer-driven, this program is free for the public to download at their website. The website offers user manuals in English, Spanish, German, French, and Italian.

Methods

This program is user friendly, and the website offers a free manual for learning the basic tools. It was easy to upload the KML files from Google Earth using the Add Vector Layer tool. Once all of the KML files were all uploaded, each file was shown as a layer in a panel on the left hand side of the screen, and the name of each file is next to a sample of the color that represents that layer on the map. The map automatically includes a North Arrow, and a Scale Bar. Three rows of toolbars (which are optional to view) are displayed along the top of the panel and map (see Figure 20).

---

2 http://www.qgis.org/
Two measurement tools were useful for this project: the Measure Line and Measure Area tools. The Measure Area tool allowed for an approximation of the total area of the Study Area (4,950 km²) and of the areas of the different size forest islands. However, these tools were slightly difficult to use because of their potential inaccuracy, since they have to be measured manually. There is no tool that automatically measures the interior space of a polygon, or that can calculate the average size of a particular feature.

After all the KML files were uploaded, each file had to be converted to the correct CRS position. The CRS of a file is its Coordinate Reference System, and for this project, UTM was used. The UTM (Universal Transverse Mercator) for where the Study Area is...
geographically located is WGS84 - UTM zone 20S. This CRS was also specified under the Project Properties. The scale bar is measured in kilometers.

Since each file is now a layer in the program, it is possible to pick and choose which layers to view. Appendix A: Figures 1—16 are maps generated in QGIS, with each image showing the Study Area outline, rivers, lakes, and a particular feature (For example, there is an image for each type of forest island, an image for all small forest islands, an image for all forest island bordering water, etc). These images are included in Appendix A for the reader to and view compare.
Summary

Unfortunately, due to time constraints only the basic features of QGIS were utilized for this project (although what could be done with those basic features was enough to achieve a preliminary analysis). QGIS includes a variety of data analysis tools that may be helpful in further interpreting the files imported from Google Earth, with more time and experience with the program. Based on a visual interpretation (rather than looking at statistics, averages, or computer simulated buffers, none of which are yet completed through QGIS program), some inferences can be proposed about the data.

Appendix A: Figure 14 is a map of the Ranches and Farmed forest islands in the Study Area. Previous to using the QGIS program, it was believed that there may have been a strong correlation between farmed forest islands and ranches, since the ranchers were supposedly the people farming the fertile soils of the forest islands. However, this image shows that in very few cases are there ranches directly next to the farmed forest islands. This could be for a number of reasons: A) the people who are farming the forest islands in the Llanos de Mojos are not the same people who are living on the ranches, B) the author misinterpreted the satellite imagery and mislabeled certain islands as farmed, C) the author did not recognize certain farmed islands, perhaps due to the quality of the satellite imagery, and labeled farmed forest islands as a different category, D) the author did not recognize a certain number of ranches or communities that may indeed be closely located next to the farmed forest islands, or E) perhaps the ranchers travel farther from their ranch to farm the forest islands. These are only a few suggestions; and the possibility of an oversight by the author is always entirely possible, which is why further mapping, testing, and analyses are always necessary before stating a solid conclusion.
When comparing Figures 2, 3, and 4 in Appendix A, some patterns start to emerge. It appears that in Figure 2, which maps only small forest islands (including all shapes), that the majority of small forest islands are dispersed across the savanna. Sometimes, as can be seen in the top left corner of the close-up image of Figure 2, the small forest islands cluster along small rivers at consistent intervals. Figure 3 shows the locations of Medium forest islands, and Figure 4 shows the location of Large forest islands. Both of these seem to have a similar pattern, occurring along the larger parts of the Omi river (which runs down the middle of the Study Area), and just north of the swamp on the right side.

Images in Appendix A showing the Circular (Figure 8), Small (Figure 2), and On the Savanna (Figure 7) categories show similar patterns. Figures showing the Medium (Figure 3), Large (Figure 4), Bordering Gallery Forest (Figure 6), Bordering Water (Figure 5), and Irregular (Figure 10) categories show similar patterns. These similarities implicate that there is a correlation between these two contrasting groups of characteristics. The analysis of these patterns takes place in Chapter 5.
CHAPTER FIVE: CONCLUSIONS AND FUTURE RESEARCH

Conclusions: The Larger Picture

Archaeological discoveries within the past few decades now support a theory counter to the one that has been widespread for decades- that indigenous societies of the Amazon are, and always have been, primitive hunting and gathering tribes whose size and complexity are restrained by the environmental obstacles (Meggers 1971). Rapid depopulation and abandonment of the pre-Columbian constructed earthworks have led to this misleading belief (Denevan 1992). However, the earliest historical documents describe large amounts of people occupying the Amazonian basin before and at the point of Spanish Contact (Block 1994; Denevan 1970), and archaeological excavations since the 1970’s have revealed evidence of extensive human habitation with a sophisticated culture (Arnold, et al 1988; Calandra 2004; Denevan 1970; Dougherty 1981, 1984; Erickson 2000, 2006b; Heckenberger, et al 1999; Heckenberger 2008; Langstroth 1996; Mann 2008; Neves 2006; Plafker 1963; Walker 2000, 2004, 2008a, 2008b).

This thesis has explored the uses of computer programs and satellite imagery, which when in conjunction with historical research, leads to exciting new ways of interpreting this archaeological evidence. The computer programs featured in this thesis are a prime example of how the progression of technology allows researchers to analyze information in different ways, allowing them to revise old theories, compare modern satellite imagery with previously drawn maps or aerial photos, and to view a landscape and environment from a fresh perspective (Erickson 1995). The use of satellite imagery
and a geographical information system (GIS) computer program in this project have revealed several interesting settlement patterns which support the theory of large, complex societies living in the Amazon prior to European contact.

Although the specific statistics and extended analysis of the features have not yet been completed, there are several correlations that can be noted when comparing the QGIS images with historical data and archaeological interpretations. Preliminary results show that there is a strong correlation between forest island size and proximity to water. Larger forest islands tend to follow along the banks of the larger tributaries, while the small rounder forest islands are scattered in the areas between the tributaries, and follow along the smaller streams that branch off from the tributaries. Archaeology has shown that small, round mounds were once occupied as settlements. The forest islands classified as Small and Circular or Oval in Google Earth appear to match the type of mounds described by Erickson (2000). It is possible that these types of forest islands represent the settlement mounds that Erickson describes. Erickson’s observations of the mounds reveal that “Thousands of smaller mounds or islas are found in the vast savannas of the central and northern Moxos regions. Many of these mounds are in clusters or are found within one km of another. The mounds found along active and abandoned rivers appear to be regularly spaced” (Erickson 2000:13). These types of small forest islands, as mapped in Google Earth, occur dotted along small streams at regular intervals or in clusters on the savanna, as can be seen in the GIS images (see Appendix A: Figures 2, 8, 9) and in the Google Earth image below.
Figure 19: Small forest Islands along Water. The river running down the middle of the image has forest islands along both sides, at regular intervals. The rivers that have gallery forest in the corners of the image have irregular-shaped and farmed forest islands bordering them.

The presence of raised agricultural fields has been established by Denevan (1966), revealing that pre-Columbian societies in the Llanos de Mojos were practicing large-scale, intensive agriculture. These raised fields, as argued in Chapter 2, may be represented by irregular shaped forest islands on the satellite imagery. Even though this project did not map raised fields themselves in Google Earth, their most probable locations are where the irregular fields are located. These larger, irregular forest islands mainly occur along the major rivers and water sources, such as the Omi River, which runs through the Study Area (see Figure 2 in Chapter 2, and Appendix A: Figure 10).
Figure 20: Forest Islands along Rivers. The upper, smaller stream has small forest islands along its banks, while larger, more irregular forest islands flank the gallery forest along the bottom of the image.

The Google Earth and Quantum GIS images, along with the tables (Chapter 3), indicate that there is a correlation between forest island size, shape, and distance from water sources. If small round mounds represent house mounds, and irregular forest islands represent raised fields, then it can be determined where pre-Columbian people were living and farming. If large irregular forest islands occur mostly along the major rivers, then pre-Columbian people may have practiced their intensive agriculture there, while constructing their small house mounds dispersed along the savanna and flanking smaller streams. The small round forest islands which occur at consistent intervals along the smaller rivers (see Figure 19 and 20), as observed by Erickson, seem too conveniently and purposefully placed to be just naturally elevated areas. Instead, it appears that these mounds were planned and constructed, in relation to the rivers. A planned settlement
pattern reinforces the idea that these indigenous tribes were organized, and that there was a standard for house mound size and shape. Being located along a river would have provided access to marine resources, transportation, and communication and trade with other groups of people (Denevan 1966). These observations correlate with Erickson’s conclusions, that “in general, the data indicates that the general settlement pattern was dense and populations were high throughout Moxos prehistory, but individual settlements were dispersed over the landscape,” and that “despite the dispersed nature of the populations in Moxos, mechanisms such as the vast intra- and inter- regional networks of causeways, canals, and natural waterways would have organized local and regional interaction” (Erickson 2000:13-14).

When looking at Figure 20, it becomes clear that there is a significant difference between the forest islands along the smaller river (top of image), and the larger, more irregular forest islands along the larger river with gallery forest (bottom of image). Although it has been argued in this thesis that irregular fields represent raised fields, this may not be case for every irregular forest island. It can be argued that some raised fields occur along the major rivers, due to the high quantities of irregular forest islands (372 in totally), but the amount of raised fields cannot be accurately measured. Raised fields have been documented on the dry savanna on river levees, so the argument that they may be present in these areas is well founded (Walker 2004). It is also possible that these larger forest islands represent more settlement areas, since levees (which occur naturally along river banks) have been found to be settlement sites as well, with discoveries of terra preta and artifacts (Walker 2004). For the larger, irregular forest islands along the main rivers, the question of their formation is still debatable. Levees occur naturally along these
rivers, so it is possible that pre-Columbian people were taking advantage of these sites to produce agriculture or locate large settlements. If that is the case, then these elevated areas would be considered part of a modified landscape, but not a wholly created one.

These patterns of settlement and agricultural earthworks, when compared to archaeological and historical evidence, supports the recent theories of large, complex societies who were capable of creating anthropogenic landscapes in the Llanos de Mojos before the arrival of Europeans. The evidence for this conclusion comes from observations of the vast quantity of the forest islands, the documented presence of mounds and an intensive form of agriculture. The analysis of those forest islands revealed a standardized pattern of settlement mounds and areas of potential raised fields, which supports the idea that pre-Columbian people living on the Llanos de Mojos were highly organized and complex.

Problems

This project encountered a variety of problems and obstacles. The free version of Google Earth that this project used comes with a limited set of tools. While the tools that were available worked well for the most part, the upgraded version would have offered more variety. For example, the free version of Google Earth includes a tool that measures distance, but not a tool that measures area (although Quantum GIS had a tool to measure area). Also, choosing to use the Quantum GIS program was taking a risk. It is a relatively new program, and without any prior experience with it the process of learning how to manipulate the images and analysis tools took a bit longer than expected. The result was that although not all the analysis tools were mastered, the basic tools were understood
enough to create maps that reflected certain aspects of the data. Each feature from Google
Earth was uploaded into QGIS, and on the map of the study area it was possible to pick
and choose specific layers to view. It is likely that with more time (and with more
experience with the program), new results could be discovered with some of the more
advanced QGIS tools.

**Future Research**

This project has great potential for future research, analysis and investigation. The
Google Earth and Quantum GIS programs are both free for the public to download, so
this type of research can be undertaken by anybody. This is very convenient, as it allows
for research to be conducted remotely and at no direct cost for travel, excavations,
accommodations, or analysis programs. This thesis may serve as an example for how to
identify, map, and analyze features on satellite imagery and in a GIS program.

The next immediate step for this thesis would be to employ all of the analysis
tools available in Quantum GIS. The Quantum GIS program has several tools for analysis
which were not employed for this project due to time constraints and limited experience.
These tools can create spatial statistics would be very useful as factual support for the
hypothesis that there is a correlation between forest island type and the forest island
distance from water. This can be tested during a project that has sufficient time.

Conducting archaeological excavations at key points within the Study Area would
be very informative in testing some of the ideas and conclusions stated in this chapter.
Places to excavate would include small, round forest islands and large, irregular forest
islands. Since the conclusions stated that these two classifications of forest islands represented different functions, it would be interesting to see what the archaeology reveals. Future data may support or refute the conclusions of this thesis.

Records of both modern indigenous Amazonian villages (Meggers 1971) and ancient (Heckenberger 1999, 2003, 2008) contain information on the sizes of the houses, villages, and population. If forest islands are indeed indicators of habitation, then by comparing the size of a typical village with the measurement of the overall area of the forest islands, it may be possible to achieve a rough estimation of potential population. Even though it is likely that not all islands were occupied at the same time, and that many mounds may have been destroyed by erosion or river movement, comparing the village sizes with the overall forest island area will give a good approximation of how much total land is habitable.

Google Earth advertises special satellite imagery taken by several companies that are available for purchase for commercial use. These images are highly detailed, and may prove more revealing than the free imagery that Google Earth provides. Although the entire region of the Llanos de Mojos does not seem to be covered by these special satellite images, there are several areas are covered by a company called Spot Image.\(^3\) Future research may include purchasing some of these images for analysis and comparison.

\(^3\) http://www.spot.com
APPENDIX A: QUANTUM GIS IMAGES
Appendix A: Quantum GIS Images

Figure 1. All features mapped on the Study Area (Forest islands, rivers, lakes, ranches, and white features).
Figure 2. Small Forest Islands (including Circular, Oval, Irregular and Farmed), Rivers, and Lakes.
Figure 3. Medium Forest Islands (including Circular, Oval, Irregular and Farmed), Rivers, and Lakes.
Figure 4. Large Forest Islands (including Circular, Oval, Irregular, and Farmed), Rivers, and Lakes.
Figure 5. Forest Islands Bordering Water (including all shapes and sizes), Rivers, and Lakes.
Figure 6. Forest Islands Bordering Gallery Forest (including all shapes and sizes), Rivers, and Lakes.
Figure 7. Forest Islands on the Savanna (including all shapes and sizes), Rivers, and Lakes.
Figure 8. Circular Forest Islands (including all sizes and locations), Rivers, and Lakes.
Figure 10. Irregular Forest Islands (including all sizes and locations), Rivers, and Lakes.
Figure 11. Farmed Forest Islands (including all sizes and locations), Rivers, and Lakes.
Figure 12: White features, Rivers, and Lakes.
Figure 13: Ranches, Rivers, and Lakes. Ranches shown as green dots.
Figure 14: Farmed Forest Islands (of all sizes and in all locations) Ranches, Rivers and Lakes. Ranches shown as green dots.
Figure 15: Irregular Forest Islands and Ranches. Ranches shown as green dots.
Figure 16: Archaeological Excavations.
Figure 17: Legend for QGIS features. Ranches are the only Points, Rivers are the only Paths, and the rest of the features are Polygons represented by different colors. White features are included.
REFERENCES

Arnold, Dean and Steven Pendery, Kenneth Prettol, Gary Webster, and Haskel Greenfield


Balée, William and Clark L. Erickson, eds.


Block, David


Burgess, Robert L. and David M. Sharpe, ed.


New York: Springer-Verlag.

Bustos Santelices, Victor

1976 Investigaciones arqueológicas en Trinidad, Departamento del Beni. Instituto Nacional de Arqueología, Publicación No. 22. La Paz, Bolivia.

Calandra, Horacio Adolfo and Susana Alicia Salceda


Cleary, David

Denevan, William M.


Dougherty, Bernardo and Horacio Calandra


Erickson, Clark L.


Graham, Elizabeth


Haase, Rainer and Stephan G. Beck


Hamilton, Stephen K, Suzanne J. Sippel and John M. Melack
2004  Seasonal inundation patterns in two large savanna floodplains of South America: the Llanos de Moxos (Bolivia) and the Llanos del Orinoco (Venezuela and Colombia). Hydrological Processes 18:2103-2116.

Hanagarth, Werner

1993  Acerca de la Geoecololía de las sabanas del Beni en el Noreste de Bolivia. Instituto de Ecología, La Paz, Bolivia.


Heckenberger, Michael J, James B. Peterson, and Eduardo Goes Neves.


Heckenberger, Michael


Höfer, Hubert, with Werner Hanagarth, Marcos Garcia, Christopher Martius, Elizabeth Franklin, Jörg Römbke, and Ludwig Beck


Langstroth, R.


Lathrap, Donald W.


Mann, C. C.


Mayle, Francis E, Robert P. Langstroth, Rosie A. Fisher and Patrick Meir


Meggers, Betty J.


Neves, Eduardo G., and James B. Peterson


Nordenskiöld, Erland


O’Broen, Michael J.


Plafker, George


Ranzi, Alceu, Roberto Feres and Foster Brown.


Walker, John H.


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