ARCHAEOLOGY, SATELLITE IMAGERY, AND GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN THE LLANOS DE MOJOS, BOLIVIA

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
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Popular portrayals of the Amazon traditionally depict Pre-Columbian people as small groups of hunter-gatherers; however, recent scientific research has proven that the Amazon basin was home to a myriad of agricultural and sedentary societies. The archaeological studies conducted within the past few decades have established the presence of large and socially complex Pre-Columbian populations living in the Amazon long before the arrival of Europeans. In particular, research in the region of the Llanos de Mojos in the Bolivian Amazon have revealed thousands of earthworks, including raised fields, mounds, ring ditches, causeways, canals, and fish weirs. These earthworks are visible on satellite imagery available through Google Earth™, which provides tools for digitally mapping them. Those digital files are then transferred to ArcGIS™, a Geographic Information System computer program which conducts spatial analyses. When combined with data from archaeological excavations, the digital map is infused with contextual data and reveals information about settlement patterns, spatial organization, agricultural production, transportation, and serves as a practical means of identifying and assessing archaeological sites. The final product is a digital map of a

select area of the Llanos de Mojos, an example of how researchers in multiple fields of study can utilize modern technology to further their understanding of the cultural activity taking place on the ground by analyzing the landscape from an aerial perspective. By combining the spatial information from satellite imagery and GIS with the cultural information from archaeological studies, Pre-Columbian earthworks can be further investigated for information on the cultural and political aspects of these Amazonian societies.

CHAPTER 1
INTRODUCTION

This thesis is meant to address several questions regarding Pre-Columbian settlements in the region of the Llanos de Mojos, in Bolivia. While the research conducted for this thesis provides some of the answers to those questions, many more questions were raised. It is hoped that this thesis will act as a precursor and a proposal to other scholars in both Bolivian archaeology and other fields to conduct future research utilizing the interdisciplinary methods as demonstrated here. While traditional archaeology has produced much information about Pre-Columbian lifeways, it is through the combination of archaeological fieldwork and remote sensing using tools such as Google Earth™ and Geographic Information Systems that even further data can be revealed. For this thesis, I will demonstrate how satellite imagery and GIS can reveal information regarding the pre-Columbian earthworks in Mojos, and in particular, the raised fields. While there is still controversy over the origins of forest islands, raised fields are clearly anthropogenic in origin and easy to identify on the satellite imagery. By using remote sensing, information about the raised fields can be obtained, such as their spatial patterns and associations with other earthworks. In order to understand the construction and location of these earthworks, however, a thorough background in the environment and history of the region is required.

The Llanos de Mojos is a seasonally flooded savanna, located in the department Beni in the Bolivian Amazon. It is a dynamic landscape shaped by the annual overflow of the rivers, shifting from a parched landscape to being nearly completely inundated within a matter of months. On average, seasonal floods cover up to a third of the landscape, forcing people and animals to high ground and restricting travel to the use of canoes (Denevan 1966). Today, the region is sparsely populated with cattle ranches, but recent archaeological research has revealed that large pre-Columbian populations once inhabited this savanna. As more information is revealed about these societies, the role of the landscape has come into question. While it is now clear that ancient peoples certainly had an effect on the formation of landscape features, the idea of a ‘pristine’ environment has been replaced with an anthropogenic landscape with earthworks whose current morphology is due to the constructive efforts of a variety of Pre-Columbian groups through time. But how can these landscape formations reveal information about the people who helped shaped them? To what degree are they anthropogenic or natural? Do the distribution of landscape features and constructed earthworks reflect sociopolitical variability, regional boundaries or regional networks? These are all questions which are approached in this thesis, through the use of both archaeological data and remote sensing.

Archaeologists have only recently within the past few decades turned their attention to these questions in the Llanos de Mojos. A review of the chronology and distribution of artificial earthworks and features, along with evidence of variation in earthworks’ form and function, could reveal information about the social and political structures throughout Mojos. Evidence of stylistic variation, increased defensive structures, and length of settlement occupation could relate to cultural aspects such as population movement, mobility, size, and expansion, along with increased warfare, local identities, or political organizations. These research questions and the methodologies of this project, while pertaining to the region of the Llanos de Mojos, could be applied to a variety of sites across the world. The debate about how much of ‘nature’ is pristine or affected by mankind could be answered by looking at how people have interacted with the landscape through time.

This proposed study has significant intellectual merit because the project integrates two different academic approaches to the study of past lifeways using two vastly different types of data, archaeological and digital. While informative on their own, when combined, scholars are given the opportunity to view a landscape and archaeological site not only from the dirt, but from the air as well. This type of approach, of combining archaeology with remote sensing, has had success in other projects in the Amazon (Heckenberger 2006). This project will reveal how archaeological data and spatial patterns can be juxtaposed to shed light on Pre-Columbian sociopolitical structures, regional networks, the relationship between organized settlements, and the degree of mobility across the landscape.

This research presents an approach to answering archaeological questions, which could be applied to many archaeological areas of interest across the world. The project will result in a database of digitized features in the form of shapefiles and vector data that could be used for answering any number of scholarly questions that are related to spatial analysis for this region. Learning more about the role and use of an anthropogenic landscape in Pre-Columbian times may assist current lawmakers, activists, and inhabitants of the Amazon in making decisions regarding current land use and conservation.

CHAPTER 2
THE LLANOS DE MOJOS

History, Landscape, and Archaeology

Studies in the Amazon have historically been focused on the state of the environment and its effects on past and present human populations. For this thesis, a theoretical approach is needed that can aptly interpret the landscape as seen on satellite imagery. To understand how this remotely-sensed imagery fits in with historical events and pre-Columbian cultures, a thorough background in geographical climate, historical events, and archaeological research on pre-Columbian cultures is necessary. A framework for interpreting how the landscape is a product of these factors can be found in historical ecology.

Historical ecology developed from the need to address noticeable shortcomings in other anthropological approaches when considering the relationship between humans and the environment. Historical ecology has roots in several of these approaches, namely cultural ecology, cultural evolutionism, cultural materialism, and ecological systems theory. It is essentially an interdisciplinary approach, drawing on different paradigms and combining aspects of both social and life sciences. Historical ecology "takes the landscape to be the central unit of analysis and human beings as the principal mechanism for change in the environment" (Balée and Erickson 2006:ix-x). The Amazonian landscape is often misconceived as what Denevan (1992) terms 'the pristine myth', as natural environments untouched and untainted by mankind. In contrast, Denevan (1992) argues that there are few environments on earth that have not been influenced or changed to some degree by humankind. Denevan's concept is crucial to historical ecology because it is an anthropocentric approach, regarding humans as the “mechanism of environmental dynamics” (Balée and Erickson 2006:2) whose disturbance can either degrade or enrich an environment. The landscape is a built environment, encoded with cultural information and produced by intentional manipulation and management of natural resources, flora, and fauna. Nature and culture are not exclusive; rather, they are deeply integrated with each other. Cultural ideas and concepts are expressed through human activities and creations, which are imprinted or molded onto the landscape. Nature is not a pristine, human-free wilderness, as it is often perceived in Romantic westernized views. Rather, it is important to view the landscape as a product of human-environmental relations, and as such is open to study and interpretation regarding past cultures and their activities.

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). There are several natural elements of the Llanos de Mojos which must be taken into consideration when viewing the landscape on satellite imagery. The force of rivers and the annual flooding create a highly variable environment and their effects shape the landscape, including resulting in the formation of levees. The terrain is also variable, depending on the location and distance from water sources.

The region is drained by four rivers and their tributaries: the Rio Guapore, Rio Mamoré, Rio Beni, and the Rio Madre de Dios. All of these rivers join the Rio Madeira in the northern part of the region. There are also four large lakes: the Rogagua, Rogoaguado, Yachaja, and San Luis (Block 1994). These lakes are available year round as sources of water. Rivers in the Amazon basin are highly mobile, and can change their courses within a handful of years (Cleary 2001; Lathrap 1968). This mobility of the rivers creates a dynamic landscape that is constantly changing. The rivers of the Amazon "are not mere geographical curiosities. They formed the basis of an extensive system of trade routes prior to the sixteenth century that linked the Amazon to the Orinoco, the Caribbean, and the Andes" (Cleary 2001: 66). Waterways were the primary means of transportation, communication, and acted as a significant food source (Denevan 1966). The overflow of the rivers draining from the Andes, combined with the impervious soils, poor drainage, and the flatness of the terrain, results in the inundation of the Llanos every year. The dry season lasts from around May to September, and is characterized by much lower levels of water and the landscape stays in a state of drought. The wet season lasts from December to March. On average, seasonal floods cover up to a third of the landscape, forcing people and animals to high ground and restricting travel to the use of canoes (Denevan 1966). Depending on the month, the actual amount of land above water is variable. The flooding of Mojos creates a highly variable environment, in which the elevation of ground highly determines the vegetation growth. Minute differences in elevation can spell the difference between flooded and dry land, so knowing what kind of vegetation grows on certain land is important for the purposes of this project. Ground over one meter high is flooded on occasion, is usually forested and often consists of the remains of natural levees. Land that is over three meters high normally only consists of manmade mounds and shield outcrops that are found at the margin of the Beni Basin (and in the northern and eastern parts of the Llanos de Mojos). Due to the low difference in elevation between the base of the Andes mountains and the mouth of the Amazon, a greater amount of sediment is deposited along the river banks, and smaller amounts of the sediment is carried out to sea. The Llanos de Mojos has very little visible bedrock on its surface because of this heavy deposition of sediments, so any outcrop of rock on the savanna forms a rare hill, and all are well-known in the area (Denevan 1966).

Gallery forest occurs along rivers, is seasonally flooded, and is rich in forest resources, tropical plants and animals. This is where swidden cultivation is most often practiced. The open savanna is characterized by claypan soils, and is subjected to the annual flooding. The dry, grassy, savanna is kept clear of trees by man's repeated use of clearing and prescribed burnings (Denevan 1966, O'Brien 2001). The riverfront land, or the várzea, is noted as the best site for settlement and agriculture (Block 1994). The levees that naturally form alongside rivers (due to the deposition of sediments from the river) provide high ground that is protected from flooding and fires. Levees are naturally elevated land located along the banks of rivers. They are formed as sediments from the river are deposited along its banks, accumulating into a high ground that borders the river (Erickson 2006; Walker 2004). Older levees tend to be fragmented, surrounded by savanna and wetlands. Levees along active rivers exclude the gallery forest, which is at a lower elevation and periodically flooded. The natural high ground of levees is ideal for settlements, both ancient and modern, due to the protection from floodwaters. Levees are sometimes associated with raised fields and anthropogenic soils (Walker 2004).

Along with the natural environment, pre-Columbian and historical human activities have shaped the landscape. In order to understand how the landscape has changed since the arrival of Europeans in Mojos, it is critical to look at the history of the area. Spanish expeditions, mission establishments, slave raiding, and European settlement are all factors that have altered the way the landscape was used and viewed. Native settlement, political, and agricultural systems were fundamentally altered by the introduction of European people, goods, and ideas.

Several scholars have written on the early Spanish exploration of Mojos (Block 1994; Cleary 2001; Denevan 1966) based on historical documents. These documents come from two major sources: Spanish explorers and Jesuit missionaries, in the form of letters, surveys, and reports. These sources depict the Europeans' and Jesuits' perspective on the native cultures and landscape. The earliest records that contain information about the Llanos de Mojos come from the Spaniards who were exploring South America (Block 1994). Most of them were in pursuit of El Dorado, and some tales described the Llanos de Mojos as being the city of gold and riches (Block 1994). Although they were disappointed with the lack of gold and material riches in this region, they were impressed with the number of people that were thriving in large tribes on the savanna. While navigating downstream, the Spaniards describe the riverbanks as crowded with people and the pre-Columbian settlements extending nearly continuously down the river (Block 1994).

The next people to write about this region were the Jesuit missionaries. What Block calls the "Mission Period" was a period of Jesuit occupation that lasted from 1668 to 1767 AD. They established mission complexes, with churches, houses, and ranches.

The Jesuits learned the local languages, and sent regular reports back to their headquarters in Lima (Block 1994). In all, there were about 21 semi permanent missions in Mojos established during the Mission Period (Denevan 1966). By the 1720s, the Jesuits had extended their mission system across the entire expanse of Mojos. The newly introduced mission life fundamentally changed how the native populations lived, altering their forms of agriculture, economy, and sociopolitical systems. The Jesuits had brought with them, along with their religion, Old World pathogens. Following the Jesuits' arrival, periodic outbreaks of smallpox, measles, influenza, and other diseases decimated large proportions of the population. The change in native settlement patterns had greatly affected the way the natives were exposed to European diseases. When dispersed tribes gathered to live in one settlement (the mission), the more intimate interaction between the peoples resulted in more vulnerability to disease outbreaks. Eventually, natives living on the missions developed some immunity to European diseases, but sporadic outbreaks still continued (Block 1994). The end of the Jesuit presence in Mojos came in 1767 AD, when the clergy of the Society of Jesus were expelled from Spanish domains by order of a royal decree. In their absence, the mission systems continued; their influence can still be seen today, as all major towns in the Llanos de Mojos were previously missions (Denevan 1966).

The Bolivian Republic was created in 1825. The change in the international economy greatly affected the missions and their inhabitants. The sudden demand for products from the rubber tree resulted in thousands of people leaving for the rubber barracas of the Beni forests (Denevan 1966). Economic focus then turned to tending livestock, exporting goods, commercial agriculture, and textile manufacturing (Cleary

2001). Later, aviation had a substantial effect on Bolivia's economy (Denevan 1966). By 1952, commerce was mainly transported by air, avoiding the obstacles of traveling on the ground during the rainy season. Beef became a major export, and cattle ranching became a lifestyle that is still continued to this day. The Jesuits had introduced cattle, and the 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). It was the discovery of these aerially-viewed earthworks that first brought Mojos to archaeologists' attention.

Archaeological studies have been the primary source of information regarding pre-Columbian cultures in the Amazon, and in the Llanos de Mojos in particular. Archaeological approaches, while traditionally focused on cultural material remains, must include a broader perspective in the Amazon. As demonstrated by many archaeologists (Balée and Erickson 2006; Erickson 2006a, 2008), an approach in historical ecology incorporates an understanding of the landscape as the product of centuries of historical and pre-Columbian interaction and modification. While historical events and activities are apparent in the towns, roads, cattle ranches, and other more modern manmade features, pre-Columbian features on the landscape tend to be more subtle. As mentioned, earthworks which can be seen from aircraft tend to disappear at ground level, due to their very slight differences in elevation. Yet the study of pre-Columbian earthworks has yielded mounds of information regarding how pre-Columbian cultures shaped their landscape to cultivate agriculture, create large settlements, and to manage their environmental and aquatic resources.

One of the first archaeological studies in the Amazon was conducted by Meggers (1971), who argued that indigenous populations, both pre-Columbian and current, were restricted in their size and cultural complexity due to the limiting factors of the environment. This environmental determinism was widely promoted by scholars, who characterized indigenous Amazonian cultures as primitive hunting and gathering tribes whose agricultural potential was strictly limited to what the environment could provide (Meggers 1971). However, archaeological discoveries within the past few decades now support a theory counter to the one that has been widespread for decades. It is now believed that the rapid depopulation and abandonment of pre-Columbian settlements and earthworks at the time of European contact have led to this misleading belief involving strict environmental determinism (Denevan 1992). The earliest historical documents describe large amounts of people occupying the Amazonian basin before and at the point of Spanish Contact (Block 1994; Denevan 1966), and archaeological excavations since the 1970s have revealed evidence of extensive human habitation with a sophisticated culture (Denevan 1966; Dougherty 1984; Erickson 1995, 2006b; Heckenberger et al. 1999; Mann 2008; Neves 2006; Walker 2000, 2004, 2008a). These archaeological approaches generally integrate a historical ecological perspective, which allows scholars to view the landscape as the result of long-term interactions between humans and the environment. Rather than pre-Columbian cultures being limited by environmental constraints, they are seen as active agents in affecting and forming their environment into a culturally encoded landscape that reflects the history of cultural activities. This idea of the landscape is exemplified throughout the Amazonian region. Schaan (2010) argues that pre-Columbian societies in the Amazon, and on Marajo Island in particular, had deep impacts on their environments, "through dynamic manipulation of crops, animals and landscape…The ancient Marajoarans once built their own ecology, exploiting natural resources in sustainable ways, and leaving us lesions which are still imprinted in the landscape" (Schaan 2010:200).

Erickson (2008) addresses an issue in environmental studies that has important implications for archaeologists: forests in Amazonia. While Amazonian forests are traditionally viewed as pristine environments that are endangered by current human activities and climatic changes, Erickson explains how these forests are largely "the cultural products of human activity" (Erickson 2008:175). Tree cultivation and forest management are currently practiced, and were practiced by pre-Columbian cultures as well. While evidence for anthropogenic forests comes largely from archaeological excavations of earthworks, the evidence that Erickson presents in this study is from the analysis of pollen, opal phytolith, and sediment from lakes in the Amazon. This evidence reveals that prescribed burning, clearing, farming, and agroforestry has been occurring for thousands of years on both a local and a regional scale. Certain species which were of particular use to pre-Columbian societies were encouraged to flourish by transplanting them, fertilizing, and weeding. These domesticated or semi-domesticated plants now were increasingly dependent on humans for their survival, reproduction, and seed dispersal. While these activities sometimes lower the biodiversity of an ecosystem by focusing on particular species, Erickson states that the overall biodiversity may actually be increased in these anthropogenic forests. Not only are the biodiversity of the flora enhanced, but also of the fauna, due to the agroforestry and farming areas attracting game animals (Erickson 2008). This archaeological information is crucial when studying modern forests in the Amazon, since crops such as fruit trees still constitute a significant portion of the forests, and their extent can be attributed to the practices of pre-Columbian societies that practiced these landscape-altering farming techniques.

The constructions of mounds are one of the most common adaptations to the annual flooding in the region of the Llanos de Mojos (Denevan 1966; Erickson 2000; Erickson 2006; Erickson and Balée 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. 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 mound sites that he studied contained pottery, which are clear indicators of human activity. Among Amazonian archaeologists, however, there are still debates about the origin, purpose, construction and artificiality of the mounds (Erickson 2000). While people were occupying the mound, there was likely 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 as well as the abandoned raised agricultural fields. These elevated areas were ideal, as the plants were supported by anthropogenic and artificially enriched soils and protected from fires by the water-filled pits surrounding the mounds. The forest-covered mounds are today called ‘forest islands’, due to their appearance as isolated patches of forest throughout the savanna. Balée 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.

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 (Denevan 1966). After his initial work, it wasn’t until the 1960s that further research was conducted in the region (Denevan 1966). His excavations were among the first, and proved the existence of sophisticated cultures thriving in Mojos prior to European arrival and constructing these large earthworks. Further excavations in Mojos would not take place until Denevan’s (1966) groundbreaking work.

Since the 1960s scholars have conducted archaeological excavations on mounds present in the Llanos de Mojos, demonstrating that the frequent presence of ceramics and altered soils indicate human presence, habitation, and modification (Arnold et al. 1988; Calandra et al. 2004; Denevan 1963, 1970; Dougherty 1981; Erickson 2000; Neves 2006; Nordenskiöld 2009; Plafker 1963; Walker 2000, 2004, 2008a, 2008b). Other places of archaeological interest on the landscape include mounds, forest islands, and agricultural fields. During excavations at these features, several scholars have discovered the presence of *terra preta*, an anthropogenic soil that indicates human habitation and modification of the soils (Glaser and Woods 2004; Walker 2004).

Ring ditches are an archaeological feature have been researched, surveyed, and excavated in order to demonstrate their functions as defensive structures surrounding mounds (Erickson 2010; Walker 2008b). For the most part, these ring ditches have been excavated as stand-alone excavations, or noted as a feature during surveys of mounds (Erickson 2010; Walker 2008b). Erickson "located an additional 15 unsurveyed ring ditch sites in recently deforested areas"(Erickson 2010:625) using Google Earth™, demonstrating the practicality and productivity of utilizing satellite imagery to remotely identify archaeological sites. Although this study, and several others like it, employs Google Earth™ to some extent, few studies put a major emphasis on utilizing Google Earth™ in conjunction with archaeological excavations. It is critical for archaeologists to take advantage of modern technologies, especially of advances in satellite imagery and GIS programs. Using these tools contributes a unique approach to archaeology: by viewing and analyzing archaeological features and landscapes from the air, rather than from the dirt. From this aerial perspective, archaeologists can include spatial information in with the temporal data that is collected from archaeological excavations, allowing them to see how archaeological features have changed not only through time, but over a landscape as well. In the Amazon, it has been well documented that space is a fundamental medium in which societies express and define cultural characteristics such as identity, political structure and social organization.

Raised fields are a distinctive type of agriculture that is specifically adapted to the annual flooding of the savannas, and are found throughout Mojos. 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). The first extensive studies of the raised fields were conducted by Denevan (1966) who photographed and mapped them during aerial reconnaissance. The realization that prehistoric earthworks covered the majority of the region launched archaeological excavations that ultimately proved the popular notion of the Amazon wrong; that this region was not sparsely populated by simple tribes, but home to large and complex societies capable of large scale landscape renovations. 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. Population estimates have been proposed, based on the extent of raised fields and the potential amount of labor required for their construction as well as the potential amount of food that could have been produced (Denevan 1966).While there are a large variety of raised fields, it is currently unknown how they relate to specific settlements or cultural groups.

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.

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) has noted 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.

Previous research conducted by the author, and consulted for this thesis, includes a preliminary survey and mapping of geographical features within a specified area in the Llanos de Mojos using Google Earth™. These files, which include the geographic information for forest islands, rivers, and ranches, are useful as a base for which to continue mapping a much larger area. This initial work was done as part of The Archaeological GIS Project of the Beni, which is conducted by Walker (2010), and it aims to map all significant natural, artificial, ancient and modern geographical and structural features in the Llanos de Mojos region using Google Earth™, in combination with archaeological excavations conducted in the region (Walker 2010). The summer 2010 field season focused on excavating an archaeological site in the forest island, Isla Estancita, located along the Yacuma River just north of the town of Santa Ana in the Beni Department of Bolivia. Preliminary surveys revealed a ring ditch, terra preta, carbon (currently undated) and ceramics within the forest island, all evidence of Pre-Columbian landscape modification, occupation, and extended use. Further excavation at this location will provide temporal and contextual information about the construction, function, and role of ring ditches in Pre-Columbian societies (Walker 2011).

Summary

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 ArcGIS™ (which uploads Google Earth™ files, converts them to vector data, and conducts spatial analyses), several types of specific natural and man-made features within a study area will be mapped and analyzed. The locations of these features will be compared to one another, to determine if this spatial analysis can support or refute patterns of settlement proposed by scholars (Erickson 2000).

If earthworks were being purposely located, altered, and cultivated by native populations 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 people arranged themselves physically and socially. It is possible that forest islands and raised fields may be located in relation to resources such as water, to accessible areas for transportation, or to other sociopolitical groups. The goal of this project is to analyze how the distribution and spatial patterns of landscape features and constructed earthworks reflect sociopolitical variances, regional boundaries, or regional networks. Among the objectives are: to define how a landscape can be utilized, shaped, and reflective of intangible social features; to investigate how the altered landscape affected the mobility of people through the region; to shed light on the pristine/anthropogenic debate; to present an interdisciplinary approach to studying archaeological sites, which combines archaeological data, satellite imagery, and GIS programs; and to construct a database of digitized features, based on the landscape seen in satellite imagery.

It is hypothesized that the political and social relations of Pre-Columbian societies will be visible through the imprints they have left on the landscape. Similar to how other Amazonian societies arrange themselves spatially in strict and cardinally oriented ways, the societies of the Llanos de Mojos will be shown to have settlements and constructed earthworks which reveal insight into their social and political systems.

CHAPTER 3
GOOGLE EARTH™

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 computer program that uses satellite imagery to create a detailed projection of the Earth. This thesis used the free version of Google Earth™, which is available to the public to download at their website.[1] The satellite imagery available for the region of the Llanos de Mojos was last updated October 31, 2011, covering the region with Spot Image imagery.[2] Google Earth™ is a convenient program for archaeologists to use because it provides tools for digitizing and creating digital spatial data based on the satellite images. This program is also helpful for a variety of other fields of study, as remote sensing has many benefits over other means of gathering geographical data.

While Google Earth™ has several features which are useful, this project only required the tools used for creating digital shapefiles over the pre-Columbian and manmade features visible on the satellite imagery. The Google Earth™ program includes 3 major tools that enable 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.

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[1] http://earth.google.com/

[2] http://www.astrium-geo.com/en/143-spot-satellite-imagery

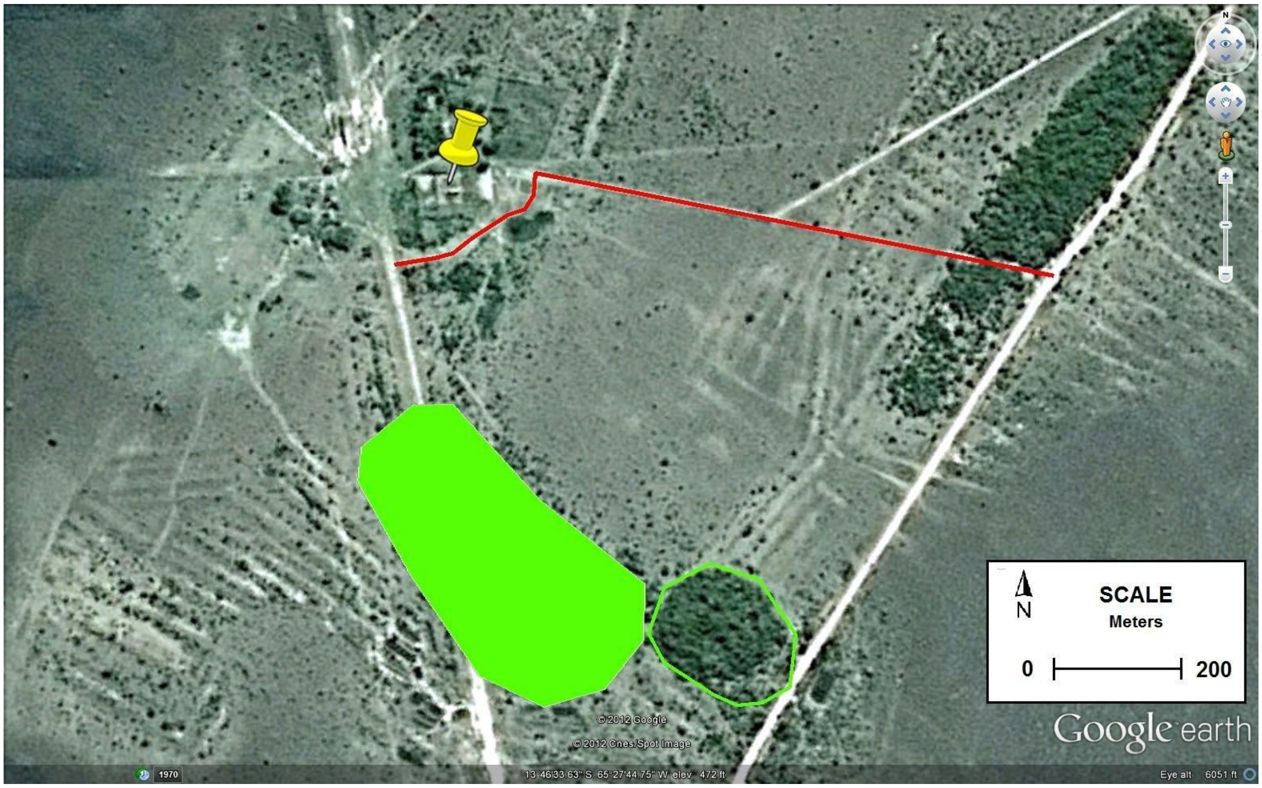

Figure 3-1. An example of Google Earth™ tools.

This snapshot (Figure 3-1) displays the three types of tools usable in Google Earth™: placemark, polygon, and path. The yellow thumbtack is one of the many symbols available for the Placemark tool. The two green Polygons at the bottom of the image show how polygons can be customized as filled in, or as just an outline. The red line across the center of the image is an example of the Path tool, which can be used to trace lines that are either curvy or straight.

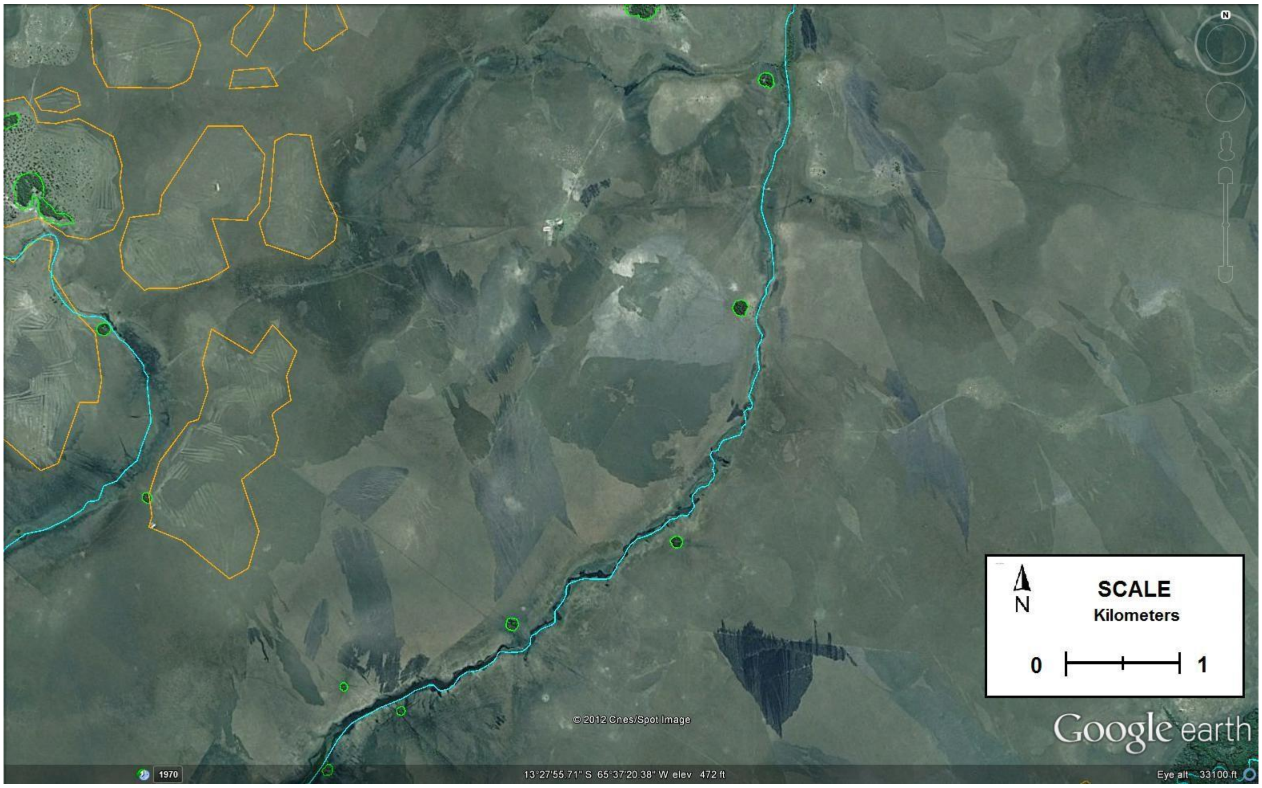

Figure 3-2. Examples of polygon and line files.

This image in Figure 3-2 depicts the polygon and line shapefiles that were created to map the streams, forest islands, and raised fields that are visible in this image. Here, it is easier to see where the small round forest islands are located along the stream. The forest islands are outlined in green. The raised fields are outlined in orange, in the upper left side of the image. Two blue streams run through this image. The rest of the savanna has slightly irregular color changes, due to a variety of factors not directly relevant to the study of the Pre-Columbian settlements (current land use by ranchers, differences in vegetation growth, and the use of controlled fire by ranchers to maintain the savanna).

Methods

A key component to this thesis was the application of satellite imagery analysis, using the imagery available in Google Earth™. Google Earth™'s imagery of this region clearly shows the pre-Columbian earthworks as contrasted against the landscape. This enables the mapping and digitizing of both pre-Columbian and modern features.

The first feature mapped was the Study Area.

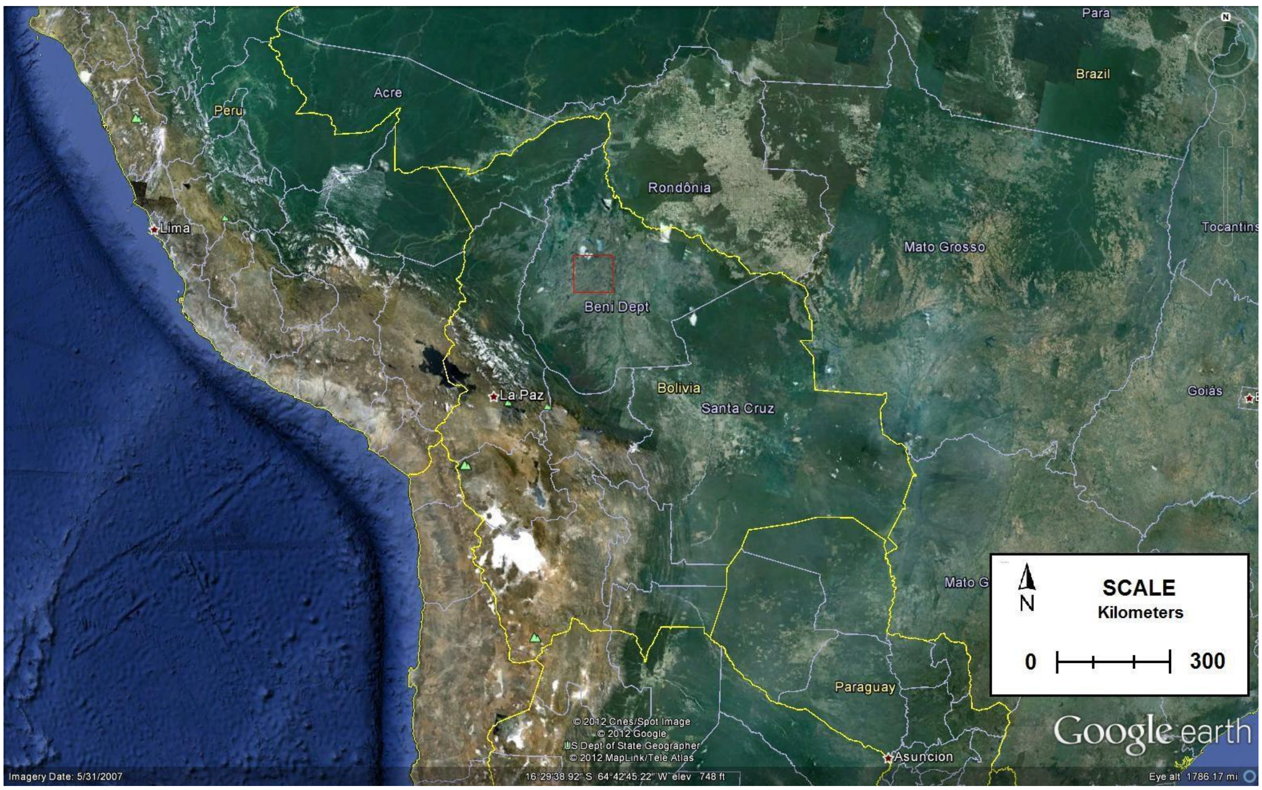

Figure 3-3. A screenshot of the satellite imagery in the Google Earth™ program, focusing on the country of Bolivia. The study area for this thesis is the red square, located in the northeast region of Bolivia.

The study area, as seen in Figure 3-3, is located in the region of the Llanos de Mojos, in northeastern Bolivia. The perimeter of the Study Area is 404 km. The sides of the rectangular study area are the following in length: the northern side is 103 km, the western side is 99 km, the southern side is 103 km, and the eastern side is 99 km. The area of the Study Area is 10,197 km². While not a perfect square, attempts were made to keep the study area as regulated as possible. The boundaries of the study area were not determined in any way by geographical features, though the area was chosen because of the known archaeological excavations conducted in the area, giving support to archaeological interpretations made regarding the geographical landscape.

The coordinates of the four corners of the study area are as follows:

NW: 13°08’36.52” S, 66°09’28.73” W

NE: 13°08’36.52” S, 65°11’54.62” W

SE: 14°02’12.02” S, 65°11’54.62” W

SE: 14°02’12.02” S, 66°09’28.73” W

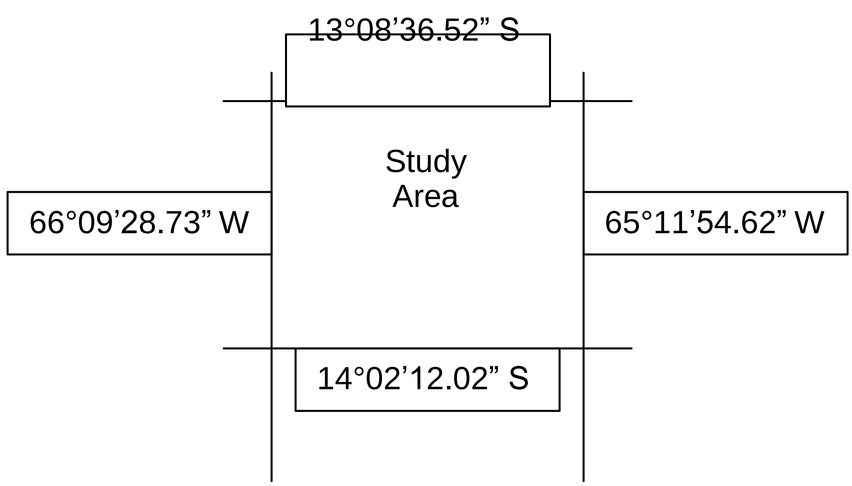

Figure 3-4. The latitudinal and longitudinal boundaries of the study area.

The Study Area lies within these latitudinal and longitudinal lines. This was intentional, to keep it a rectangular shape for calculating the area of the Study Area.

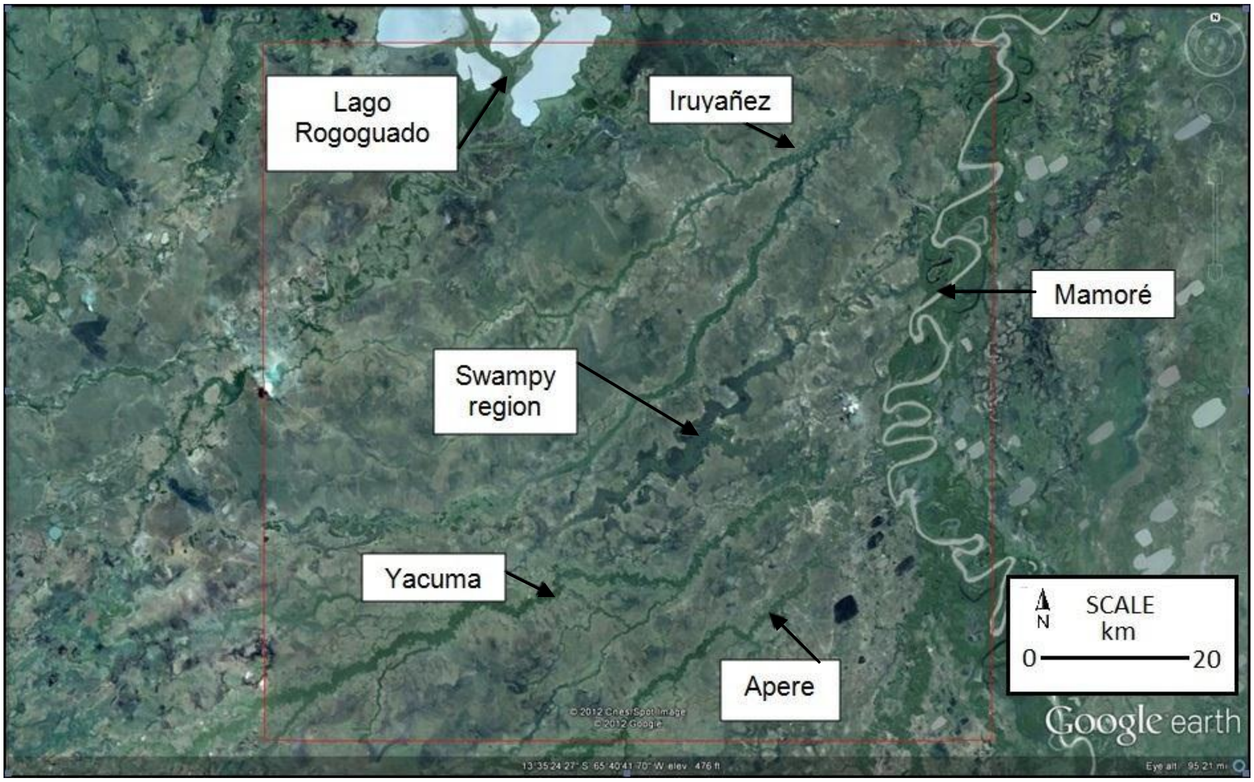

Figure 3-5. The Study Area and major geographical features. The Study Area is the area outlined by the red polygon. The following images will show the mapped shapefiles in this area, categorized by types of features.

Once the Study Area was in place, the rest of the digitizing could begin. A handful of digitized files were already available from previous work in the same region, and therefore could be reused. There are 3 types of features mapped: Pre-Columbian, Modern, and Landscape features. Pre-Columbian features include Ring Ditches and Raised Fields. Modern features include Roads, Ranches, and Archaeological Excavations. Landscape features include Lakes, Rivers, Forest Islands and Gallery Forest.

The Study Area is characterized by several major rivers running through it. The Mamoré river runs North-South along the right side of the Study Area. The Rogoaguado lakes are present in the northern part, and the Iruyañez, Yacuma, and Apere rivers run through the study area. In the center of the study area is a swampy region, that tends to stay wetter during the dry season compared to the savanna, and fills with water during the wet season. This swampy region has been mapped as a blue polygon, and is categorized with the lakes.

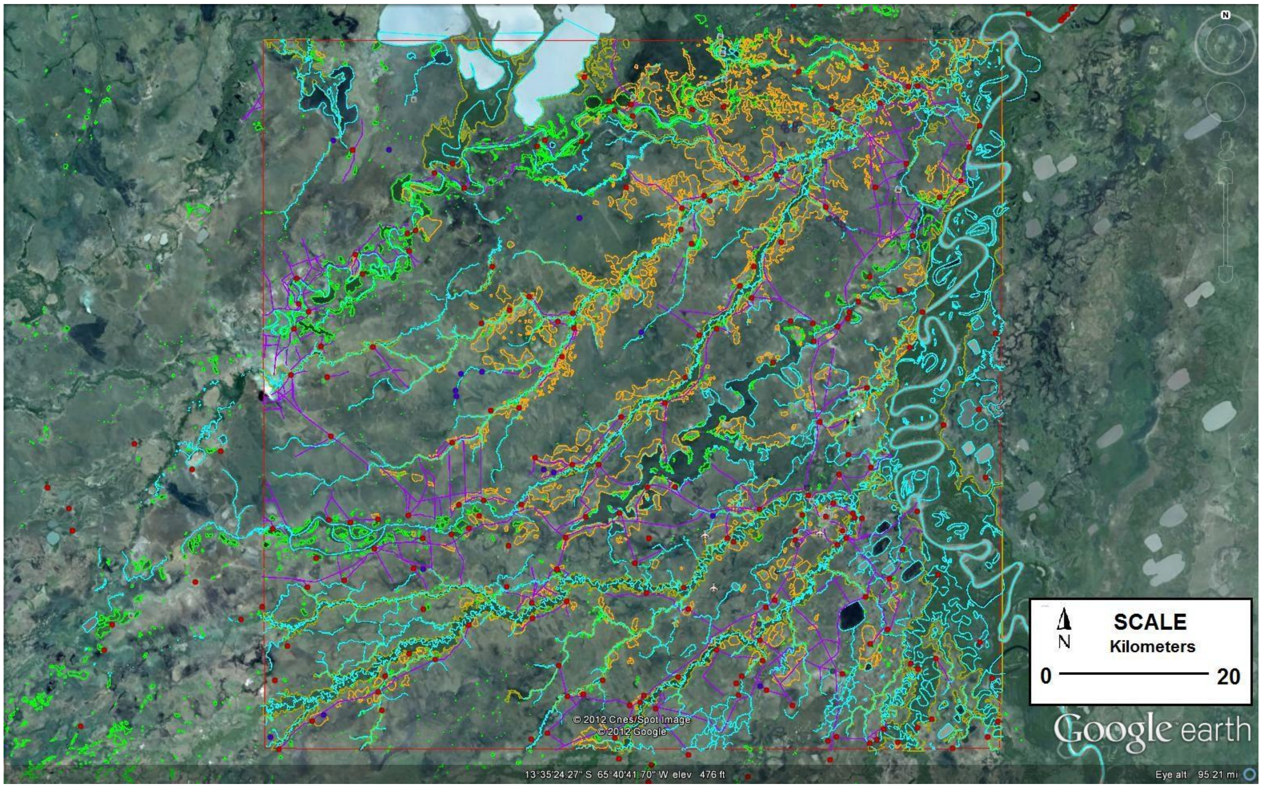

Figure 3-6. All features mapped. This screenshot depicts all of the features that were mapped.

Figure 3-6 displays all of the mapped features. They are each a different color, in order to easily differentiate between them. Ranches are red placemarks, Archaeological Excavations are dark purple placemarks, Ring Ditches are dark blue placemarks, Roads are light purple paths, Rivers are light blue paths, Lakes are light blue polygons, Raised Fields are orange polygons, Forest Islands are bright green polygons, Gallery Forest are olive green polygons, and the Study Area is a red polygon.

Table 3-1. Information about the Features.

Feature Class	# of Files	Type of Files	Total Length (km)	Total Area (km²)
Archaeological Excavations	27	Point	n/a	**n/a**
Ring Ditches	16	Point	n/a	**n/a**
Ranches	201	Point	n/a	**n/a**
Roads	304	Path	1484.42	**n/a**
Rivers	455	Path	3454.452	**n/a**
Raised Fields	653	Polygon	n/a	**678.12**
Forest Islands	2217	Polygon	n/a	**211.31**
Lakes	422	Polygon	n/a	**446.54**
Gallery Forest	48	Polygon	n/a	**1539.41**
Study Area	1	Polygon	n/a	**10286.49**

Table 3-1 shows the data for each feature class that was mapped in Google Earth™ and subsequently used in ArcGIS™. The data includes the number of number of files in each feature class, the type of file, and the total length or area for each feature class. For point files, like the ones in the feature classes Archaeological Excavations, Ring Ditches, and Ranches, there are no length or area measurements available. Line files, for the feature classes of Roads and Rivers, have measurements for only length. Polygon files, for feature classes of Raised Fields, Forest Islands, Lakes, Gallery Forest, and Study Area have measurements for area.

Figure 3-7. Forest island Isla San Pablo and ring ditch.

This ring ditch is known from previous archaeological excavations (Walker 2008b). The next image depicts a red polygon, over the visible ring ditch in this image. The ring ditch can be seen as the curved line of trees extending out from the southern side of the forest island, reflecting the elevation change in the depressions of the ditch and elevated areas alongside where excavated earth was piled. This is an example of how other ring ditches can be identified on the satellite imagery throughout the region.

Figure 3-8. Forest island Isla San Pablo with mapped ring ditch. The red polygon maps the ring ditch that is visible on the satellite imagery. This is an example of how once identified, ring ditches and other features are mapped.

Figure 3-9. Isla Estancita.

The forest island located in the center of Figure 3-9 is the forest island Estancita. It was excavated by Walker (2010, 2011), and found to be a Pre-Columbian sites with evidence of habitation (ceramics, charcoal) and a ring ditch. It is located north of the town of Santa Ana del Yacuma, and the Yacuma river. By including this site in the Study Area, there is now the archaeological data to back up interpretations of the forest islands as settlement mounds. It also assists in locating other similar forest islands for predicting settlement sites. The ring ditch, though not visible in the satellite imagery, is known to be located within the forested boundaries of the forest island. Other ring ditches were identified and marked on the satellite imagery, to note any patterns in their spatial locations. With the data from Isla Estancita, it can be claimed that where ring ditches are located, there is likely also evidence of a settlement mound.

Figure 3-10. Raised fields and forest islands.

Some forest islands are known to be located on raised fields, rather than elevated mounds. 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, then the forests that grow atop them will be irregular-shaped as well. This image shows how trees and vegetation growing on raised fields become clumped together to form forest islands; however, they have an irregular shape due to the irregular patterns of the raised fields. Based on this image and other known examples, it can be inferred that forest islands growing in irregular patterns with linear characteristics are most likely located on ancient raised fields. This assumption could help researchers locate raised fields, even if they are not visible under the tree cover on the satellite imagery. This method of identifying raised fields, based on the irregular shape of the forest, is especially handy when examining satellite imagery that is not as detailed as this imagery available for the Mojos region. This image also infers that not all forested areas in Mojos are settlement mounds; it would be very convenient for researchers to be able to differentiate between settlement mounds and covered raised fields based solely on shape.

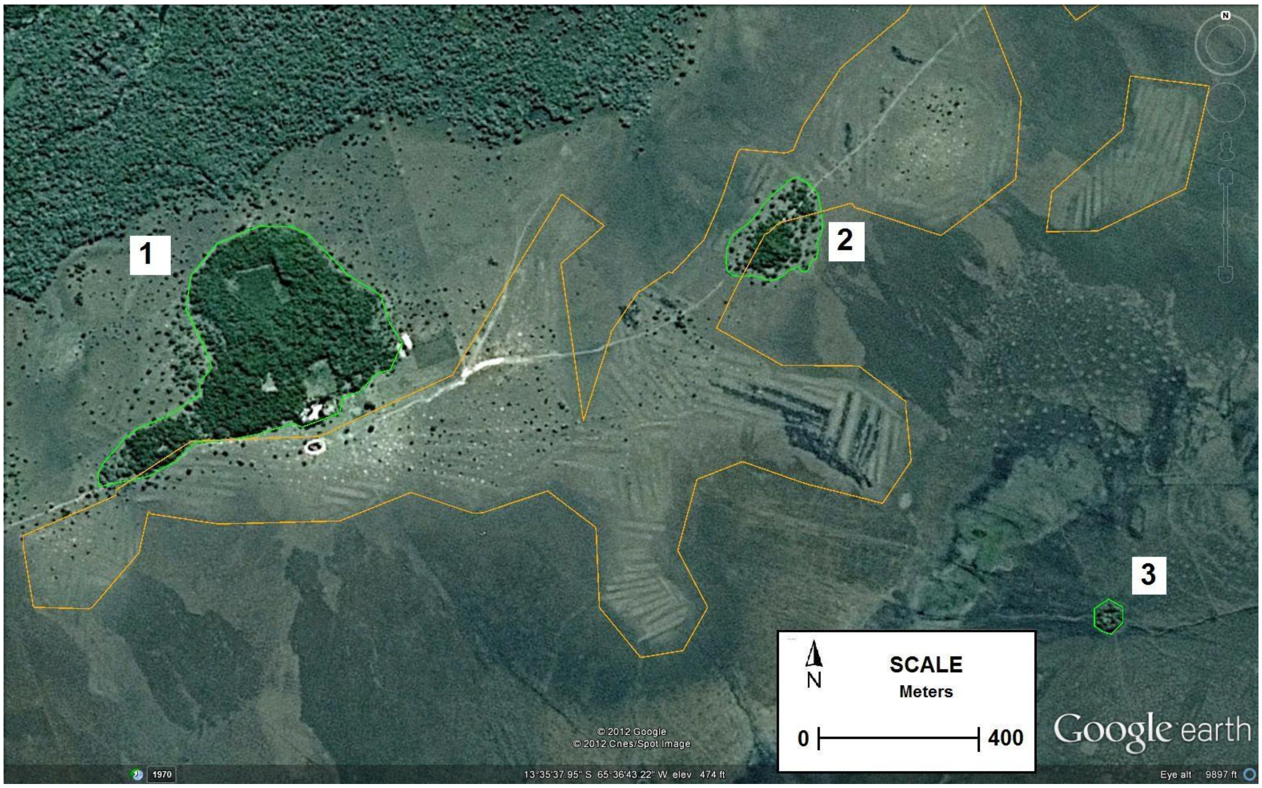

Figure 3-11. Raised fields (orange polygon) and forest islands (green polygons).

Based on the previous observations about the differences in forest islands, tentative classifications can be made to differentiate between different types of forest islands. Figure 3-11 displays the three main types of forest islands encountered while mapping features in Google Earth™. These types were noticed while mapping, but the files were not categorized separately due to too many files having an ambiguous appearance that were not clearly one type. Pre-Columbian settlement mounds, which are overgrown with secondary vegetation, often appear like Forest Island 1 (Figure 3-

11). The forest is darker than the gallery forest, and the island has a more clearly defined boundary. It can be a circular, oval, or slightly irregular shape (but is most often a rounded shape). Forest that grows on top of raised fields appears like Forest Island 2, with a more dispersed shape (Figure 3-11). These forested areas range in size from a few trees to very large areas, and do not have clearly defined boundaries, making them difficult to accurately map as a shapefile. Forest Island 3 in Figure 3-11 is an example of the small, circular forest islands. These nearly perfect circles of forest are clearly defined, and often occur along smaller streams or in the middle of the savanna. They are rarely located along gallery forest or the larger rivers. The significance of the types, along with their spatial organization, is analyzed in Chapter 5.

Figure 3-12. Bodies of water.

The image in Figure 3-12 depicts several types of bodies of water found in the region of Mojos. Semi-rectangular lakes are located on the left side of the image. A river runs north to south on the right side, with smaller rivers and streams emptying into it. In the top right corner, oxbow lakes are found throughout the floodplain adjacent to the major rivers. For digitizing these natural features, polygons were used for the lakes and paths were used for the rivers. Although they were mapped as separate features in Google Earth™, they are combined using a “Buffer” tool in ArcGIS™ to analyze the geographic location of water sources in general (see Chapter 4).

Figure 3-13. Roads and forest islands.

Modern day roads are visible on the satellite imagery in Figure 3-13 as white lines crossing across the landscape. In this image, roads transect two forest islands and are surrounded by raised fields. This occurs often throughout the region. Since forest islands and raised fields are often the highest ground on the savanna, it would make sense to construct roads across these elevated areas to avoid the low-lying flooded portions of the savanna. This is good news for archaeologists, in that access to forest islands will be facilitated by the proximity of the forest islands to the main roads. It is also useful to know the difference in appearance between roads, raised fields, and trails (made by either cows or humans), as they all have linear shapes and a pale color on the satellite imagery. In Figure 3-13 especially, the differences between the roads and raised fields can be subtle.

Figure 3-14. Forest, river, and savanna on the Mojos landscape.

This image in Figure 3-14 depicts a large area of the landscape. It shows a major river running from left to right, and the forest and floodplain adjacent to it. This particular area of the study area became more difficult to map and categorize. Most of these forested areas do not seem to be singular coherent sections of forest; rather, this image suggests that the forested areas are a result of the erosion of river levees, which were originally all covered in forest.

Figure 3-15. Small forest islands along a river.

Along many of the smaller streams in the study area, small forest islands occur at regular intervals. Differences between these small round forest islands and the larger ones would suggest a difference in construction, use, and function.

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. 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.

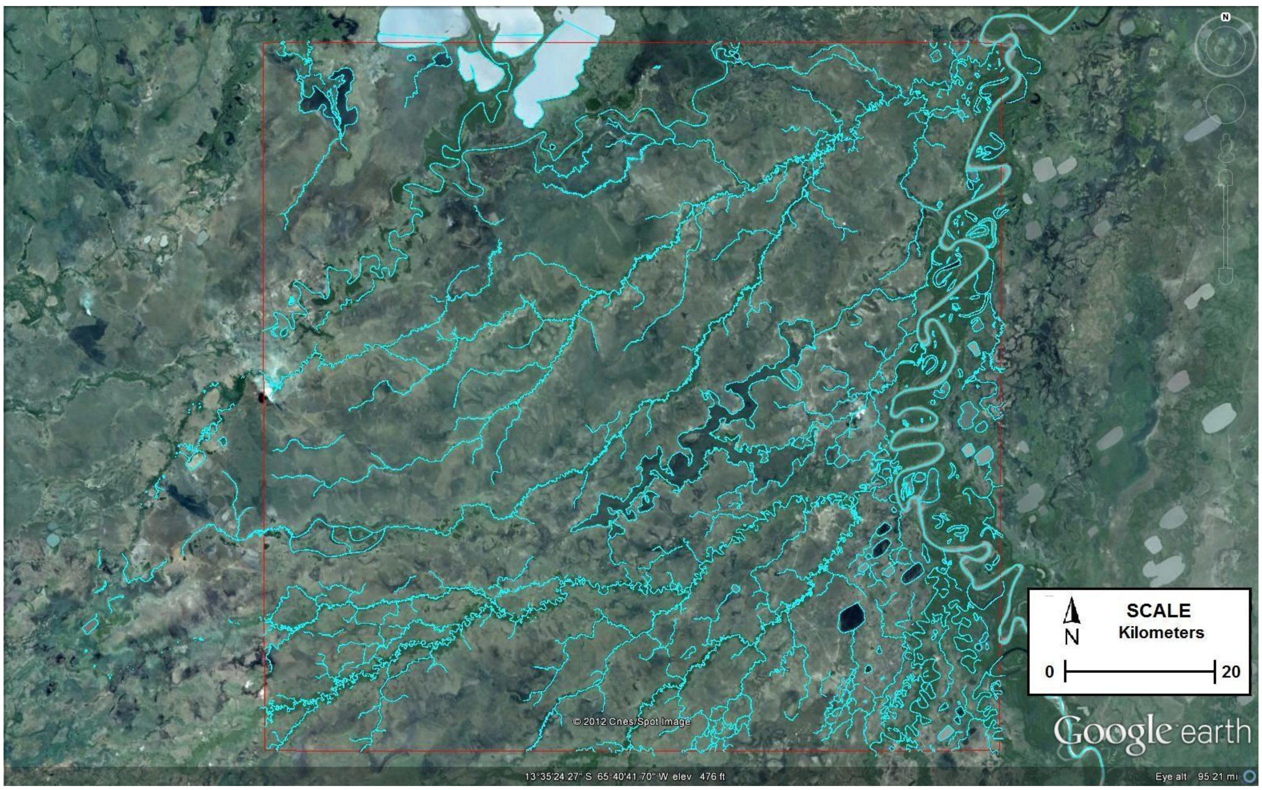

Figure 3-16. Bodies of water in the Study Area.

Figure 3-16 shows the Study Area (red outline polygon) and sources of water (blue polygons for lakes, blue lines for rivers and streams). The Rio Mamoré flows northward along the right side of the image. The smaller rivers flow eastward, from the left side of the image towards the right. In the center of the image is a swampy area, identifiable by its darker color. The lakes in this region mostly occur in the northwest (top left) portion of the image, in the southeast (bottom right) portion, and along rivers as oxbow lakes.

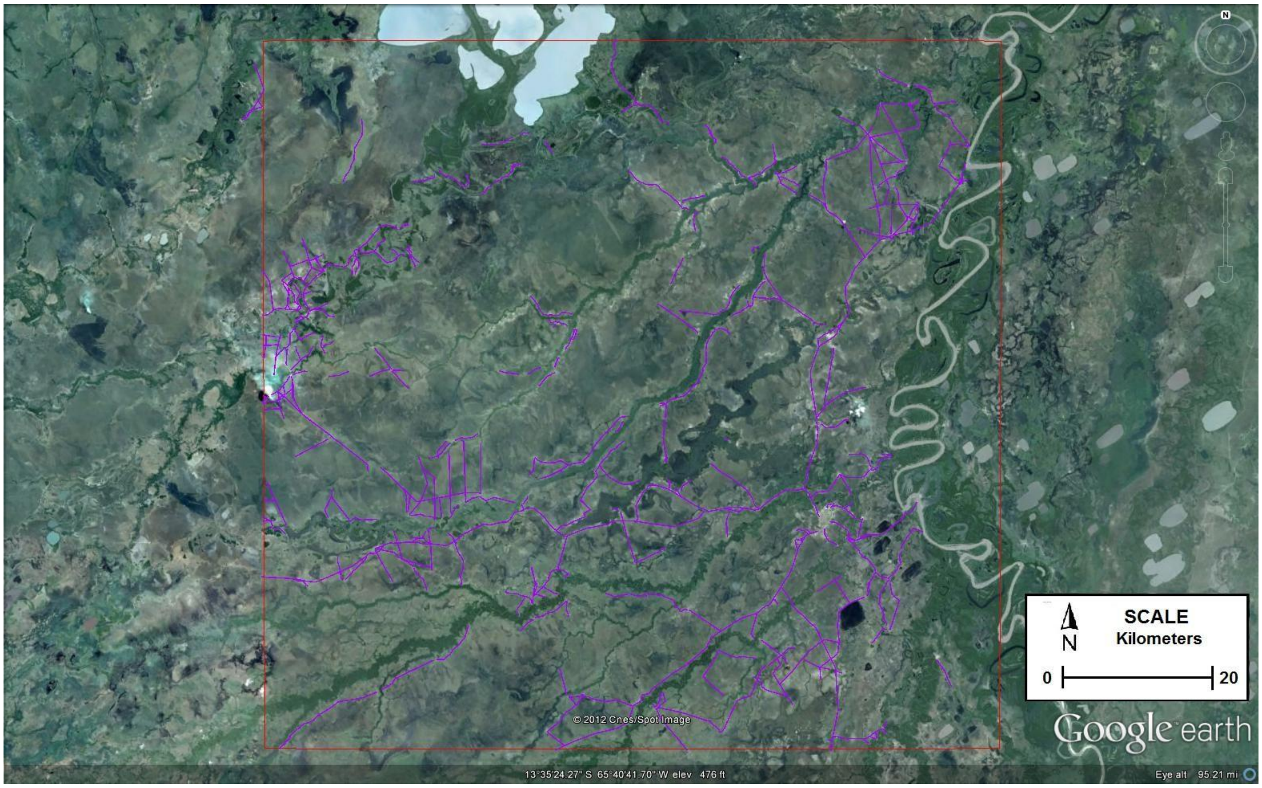

Figure 3-17. Roads in the Study Area.

Figure 3-17 displays the Study Area (red outlined polygon) and modern day constructed roads (purple line features). These represent only the roads that were clearly visible on the satellite imagery. It's probable that many more roads exist besides these, but if these are the only ones visible then they are most likely the roads that are used most often (and kept clear and elevated). Most of the roads connect major towns and many lead to ranches. There are sections of the savanna that seem to lack any roads or construction whatsoever. This may be due to the low-lying region being too swampy, or just due to the distance and isolation from the towns and rivers.

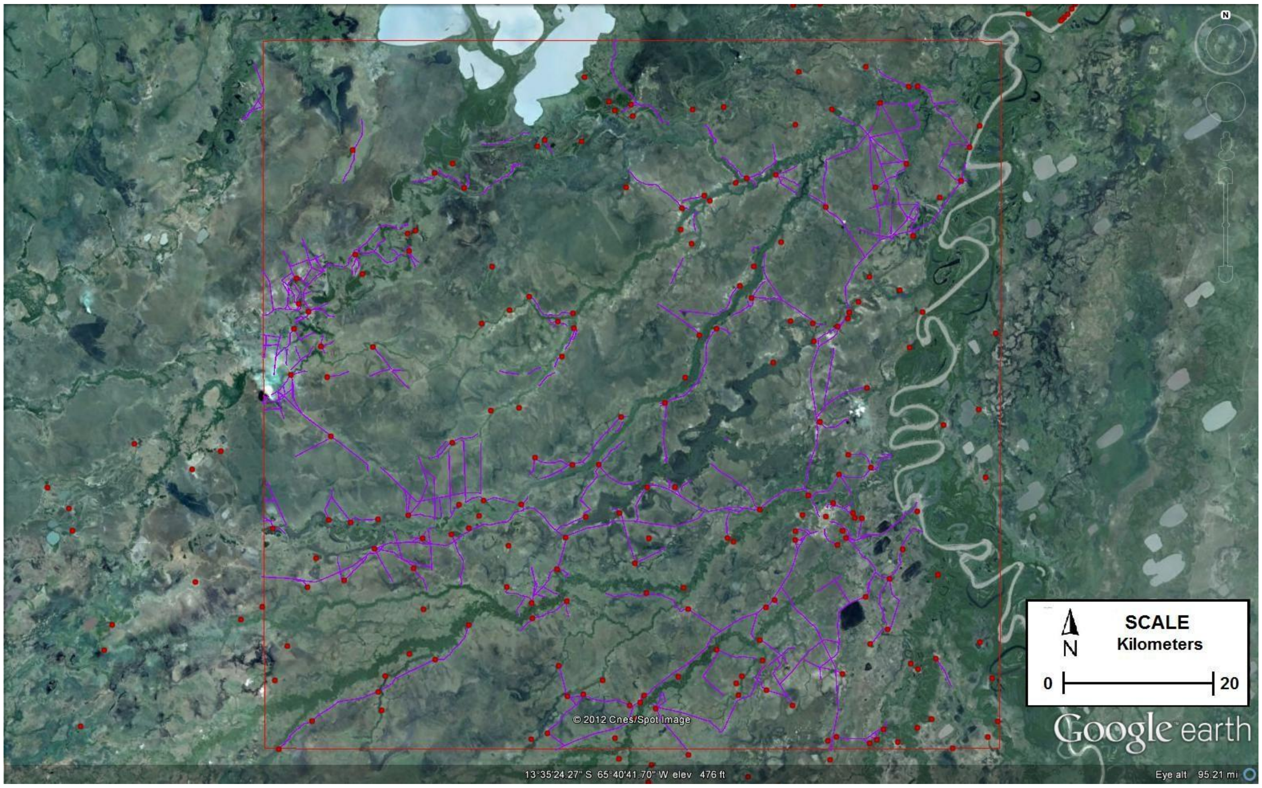

Figure 3-18. Modern roads and ranches in the Study Area.

Figure 3-18 shows the Study Area (red outlined polygon), modern day constructed roads (purple lines), and modern ranches (red points). This image shows how ranches are connected by major roads. These modern day features are important for archaeologists planning to visit the region and coordinate transportation to towns and excavation sites. It is also important to identify land ownership to inquire about permissions to survey and/or excavate.

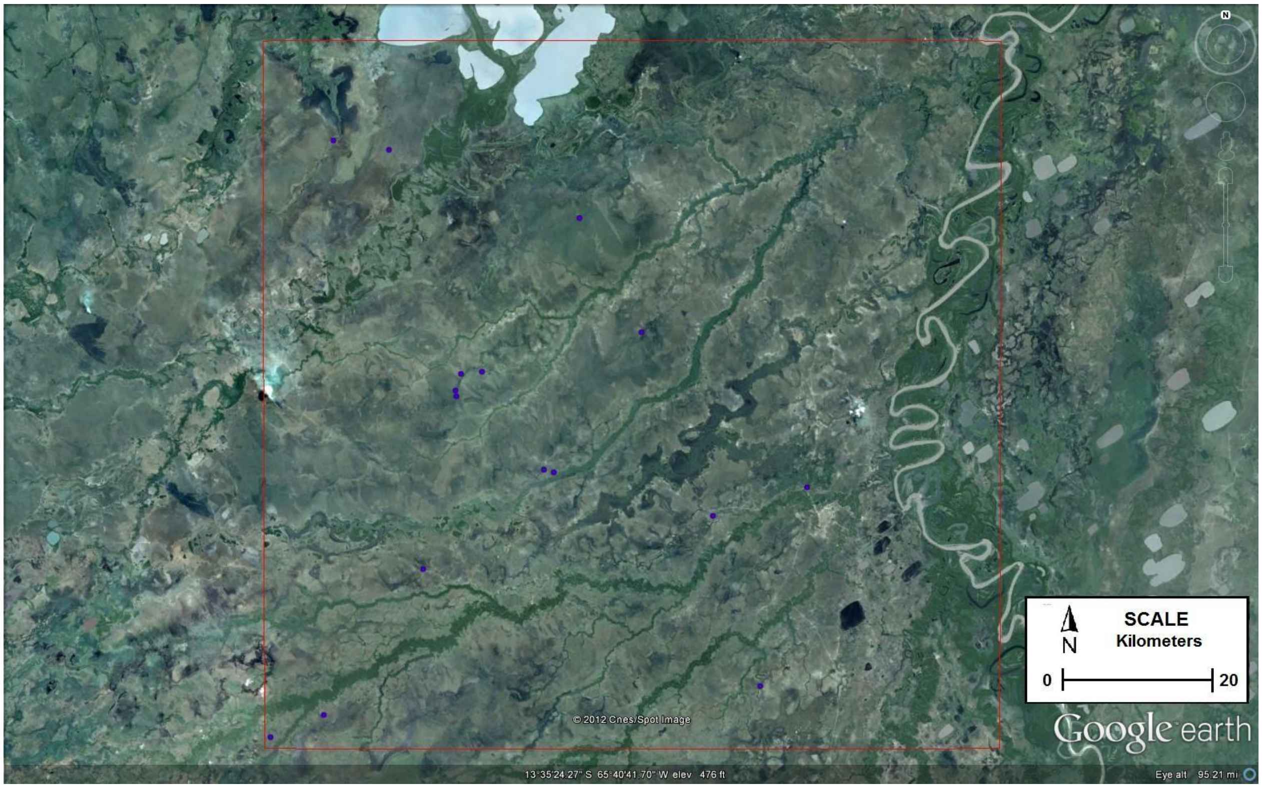

Figure 3-19. Ring ditches in the Study Area.

Figure 3-19 shows the Study Area (red outlined polygon) and Ring Ditches (dark purple points). The ring ditches are dispersed over the study area, and only seem to cluster in one or two areas. There does not seem to be a consistent pattern, just based on a visual analysis of this image. These are only the ring ditches visible on the satellite imagery; it is possible that there are many more ring ditches that are covered by forest and vegetation, and therefore not visible. Although these ring ditches are identified based on the characteristics of known ring ditches (Walker 2011a), ground-truthing will be required to verify if these are in fact pre-Columbian built ring ditches.

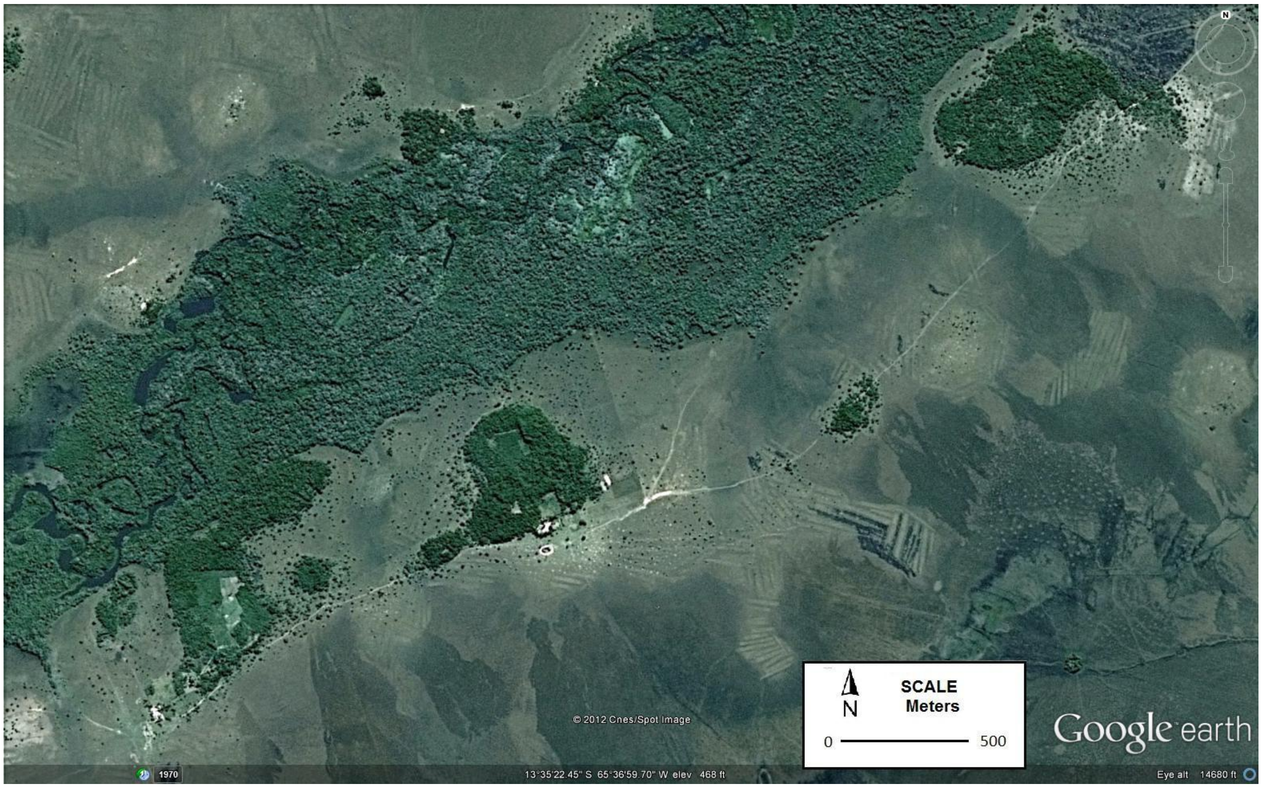

Figure 3-20. Forest islands and ranches.

Ranches have been found to be situated on forest islands that reveal Pre-Columbian occupation. In Figure 3-20, the forest island located in the center is home to a ranch, as visible by the small white items (buildings and constructions), and the square ‘chunks’ taken out of the forest island are areas cleared by the rancher. This forest island is located just south of a river. A road runs from bottom left to upper right in this image (the white line), transecting or closely passing several forest islands. There are several reasons why a ranch may be constructed on a forest island. The elevation would provide relief from the annual flooding, as it did for Pre-Columbian populations. The soils in a forest island are often found to be composed of *terra preta*, a rich anthropogenic soil characterized by a dark color, broken ceramics, and charcoal (Glaser and Woods 2004). These soils are rich in nutrients and used by modern people for local agriculture.

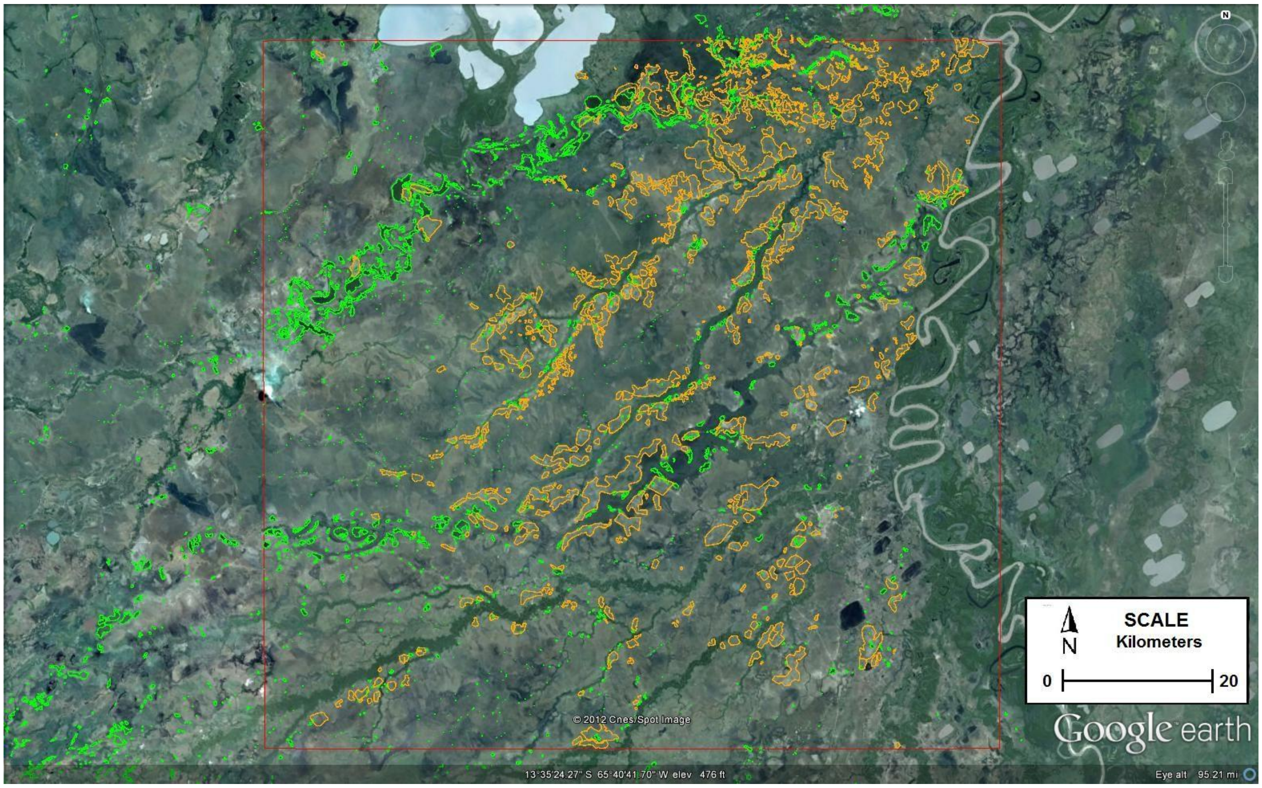

Figure 3-21. Raised fields and forest in the Study Area.

This image in Figure 3-21 depicts two types of features, raised fields and forest. The Study Area is the red outlined polygon, the areas of raised fields are the orange polygons, and the forested areas are outlined by the green polygon. It would be sensible if raised fields, used for agriculture, were located within a reasonable distance from the forest islands on which the Pre-Columbian society lived. According to an initial visual analysis of this image, it appears that both forest and raised fields occur along major rivers that run from west to east. However, their spatial relationship is not clear in this image, as it appears that they are not directly geographically dependent on each other.

Summary

Google Earth™ has proven itself useful as a remote sensing technique for identifying and mapping both environmental and cultural features on satellite imagery. A fairly straightforward method, this approach to mapping features has many benefits but a few drawbacks. It is time consuming to map all the features in a wide area. It is normally up to the discretion of the user to identify features and determine their boundaries, and this could change from user to user. If multiple researchers were interested in the same region or same method of digitizing, then a standardized method of identifying features and mapping them could be arranged so as to promote continuity.

While the digitized files provide interesting visual interpretations, Google Earth™ does not have tools for spatial analyses. These files must be exported, then, to another computer program. The program chosen for this project was ArcGIS™. The next chapter discusses the methods, results, and summary of the analyses of ArcGIS™.

CHAPTER 4
GEOGRAPHIC INFORMATION SYSTEMS (GIS)

ArcGIS™

Once the digitizing in Google Earth™ is complete, the next step is to analyze the data in ArcGIS™.[1] This program is an example of GIS, or Geographic Information Systems, which are computer programs that provide tools for spatially analyzing digital files. ArcGIS™ was accessed through the University of Florida, although it is purchasable for download from the website. There are other GIS programs available for download online that are free, if users do not have access to purchase ArcGIS™. Both vector (shapefiles) and raster (images) data can be analyzed in GIS programs, but for the purpose of this project only vector shapefiles were used.

Methods

In the Google Earth™ program, the digitized files are saved in KML format. The files were saved in groups, according to each category of feature mapped (example: Raised Fields, Forest Islands, Lakes, Rivers). This means that while a user cannot access the individual files within each group (for example, a certain forest island within the Forest Island group file), it saves a tremendous amount of time when the user does not need to individually save and export thousands of files.

In ArcMap™, the KML files were added to a blank map. Each group was added as a single file. The projected coordinate system used was WGS 1984. The UTM Zone is 19 S. Each file category was uploaded as a feature class. Since many files overlapped outside of the study area, these files had to be ‘clipped’ so that only the files

[1] http://www.esri.com/software/arcgis

mapped within the study area were used for analysis. Figure 4- 1shows the files after the clip tool was used. Each feature class is represented with a different color, and Figure 4-1 includes a key on the left side for identifying features based on color and feature type. When the files were imported, they retained their type- as point, line, or polygon.

While analyzing files and applying the ArcGIS™ tools, it was necessary to organize them into three folders: Original Files, Clipped Files, and Analysis Files. The Original Files were the ones first uploaded into ArcGIS™. They overlapped the Study Area, and needed to be ‘clipped’ before analysis. After running the “Clip” tool to isolate only the features that were located within the study area, the result is the files in the “Clipped Files” folder. These were the files used for running analyses. Several tools were used on these files, including Buffer, Select by Location, and Intersect. Using these tools creates new files, and these new files were saved under the folder “Analysis Files”. For example, the Buffer tool was used to create a 1 kilometer ‘buffer’ around the Rivers line feature (Figure 4-2). The resulting file, a polygon that overlay the rivers with 1 km on either side of the River line, could later be used for finding what forest islands lay within 1 kilometer of rivers.

There were several questions in mind while analyzing the ArcGIS™ files.

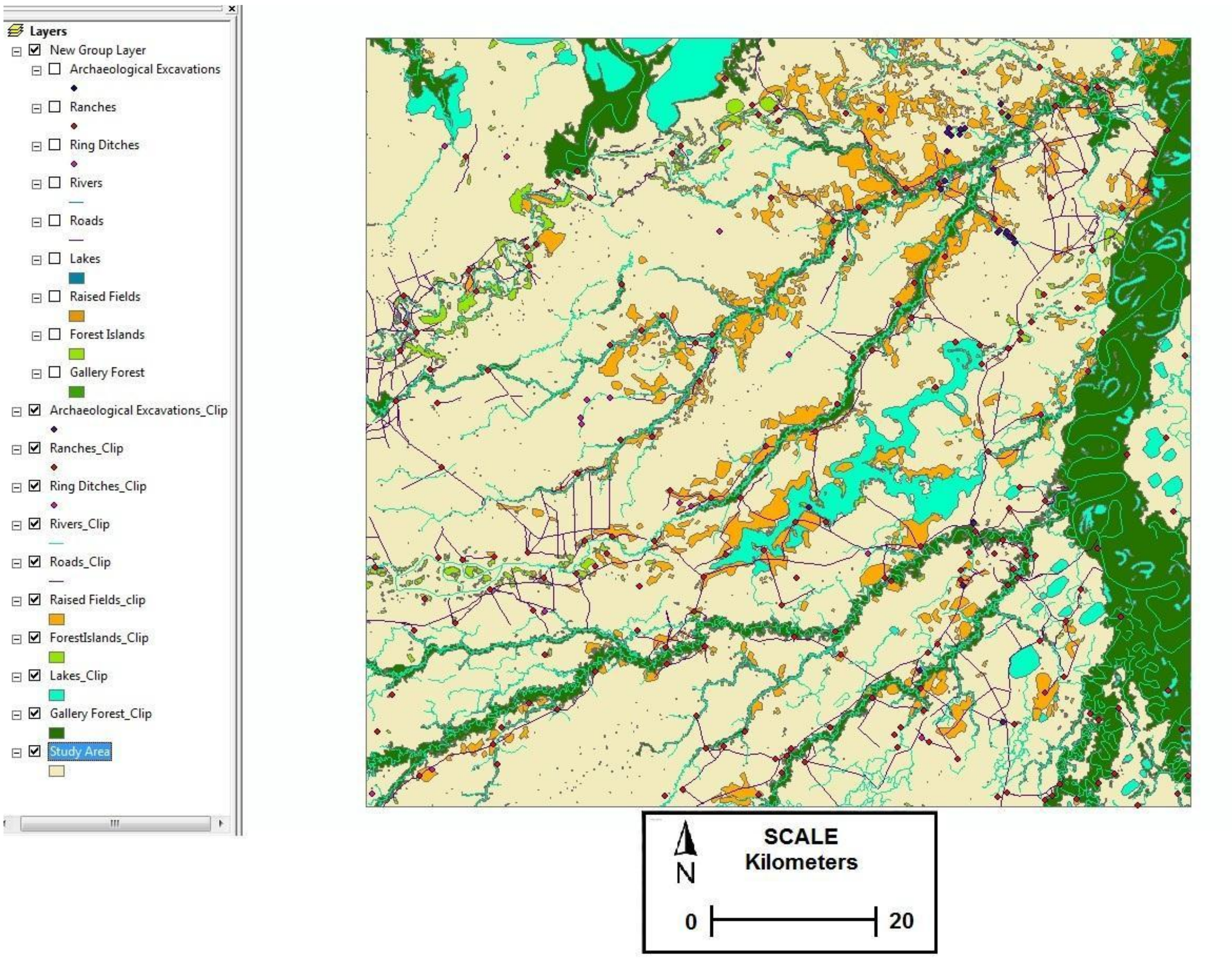

Figure 4-1. ArcGIS™ "clipped" features. This image displays all of the feature classes after using the "Clip" tool to focus only on the files that are contained within the study area (the yellow box).

After the original files imported into ArcGIS™ were 'clipped', analyses could begin with the files as seen in Figure 4-1. The key on the left of the image identifies the features by their color and file type. The three point features are archaeological excavations (purple), ranches (red), and ring ditches (pink). The two line features are rivers (light blue) and roads (dark purple). The five polygon features are raised fields (orange), forest islands (light green), lakes (light blue), gallery forest (dark green), and the study area (light tan).

An advantage of viewing the landscape in ArcGIS™, as opposed to Google Earth™, is that by removing the satellite imagery in the background, the map has become clearer and focused on the features of interest. Now the files are clearly defined and visible, and each feature is color-coded for quick and efficient interpretation. Maps such as these are invaluable resources for scholars in many fields of study, not just archaeology.

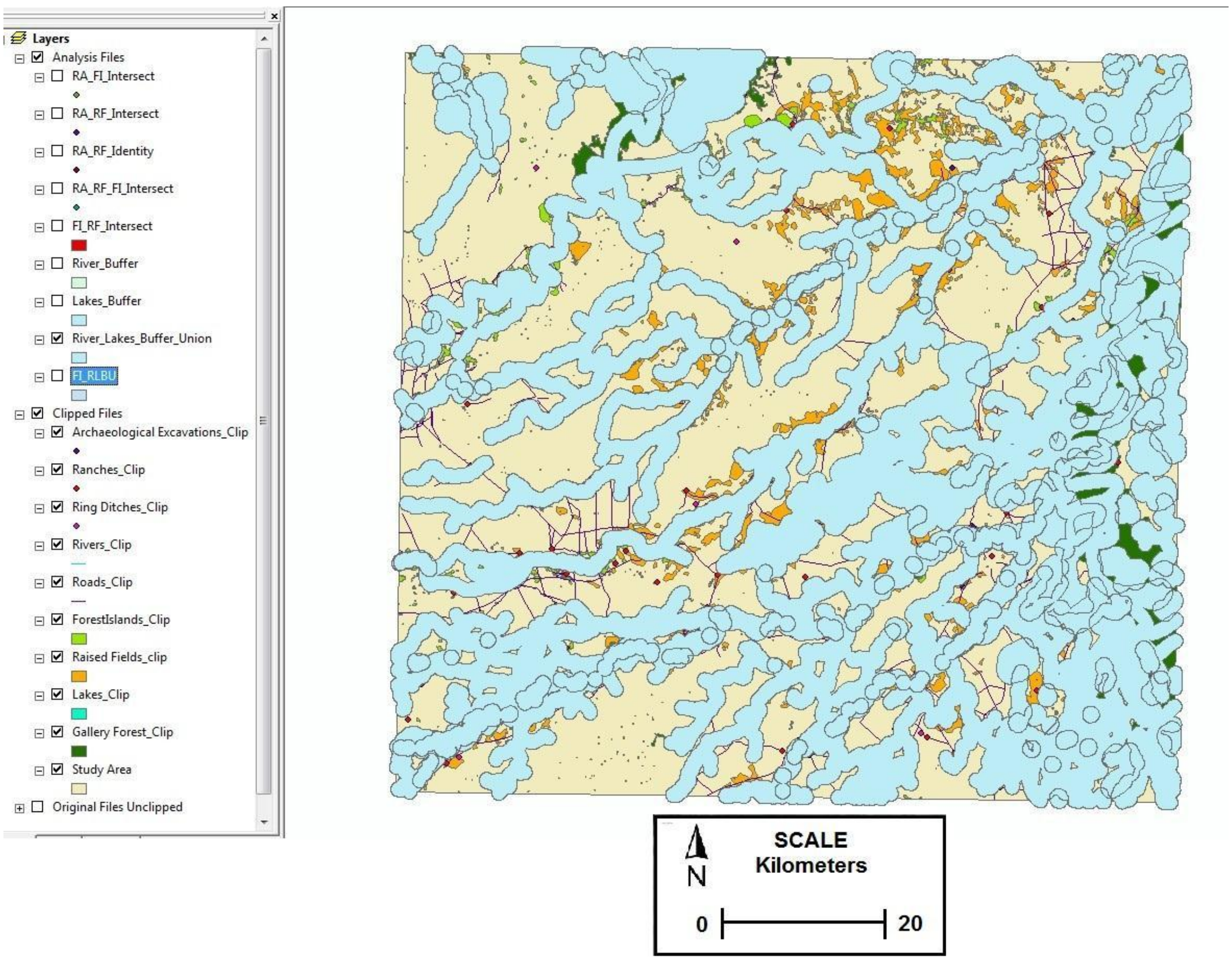

Figure 4-2. The Union tool in ArcGIS™.

The screenshot in Figure 4-2 displays the result of using the “Union” tool to combine the Buffers of both the River and Lake files. This is to create a single file, for doing analyses in which the interest is in water sources in general (and not rivers or lakes in particular). The Intersect tool is then used to see where other files, such as Forest Islands, Ranches, or Ring Ditches, overlap with the water file. The result is all of the files found within 1 kilometer (the Buffer) of water sources (Rivers and Lakes).

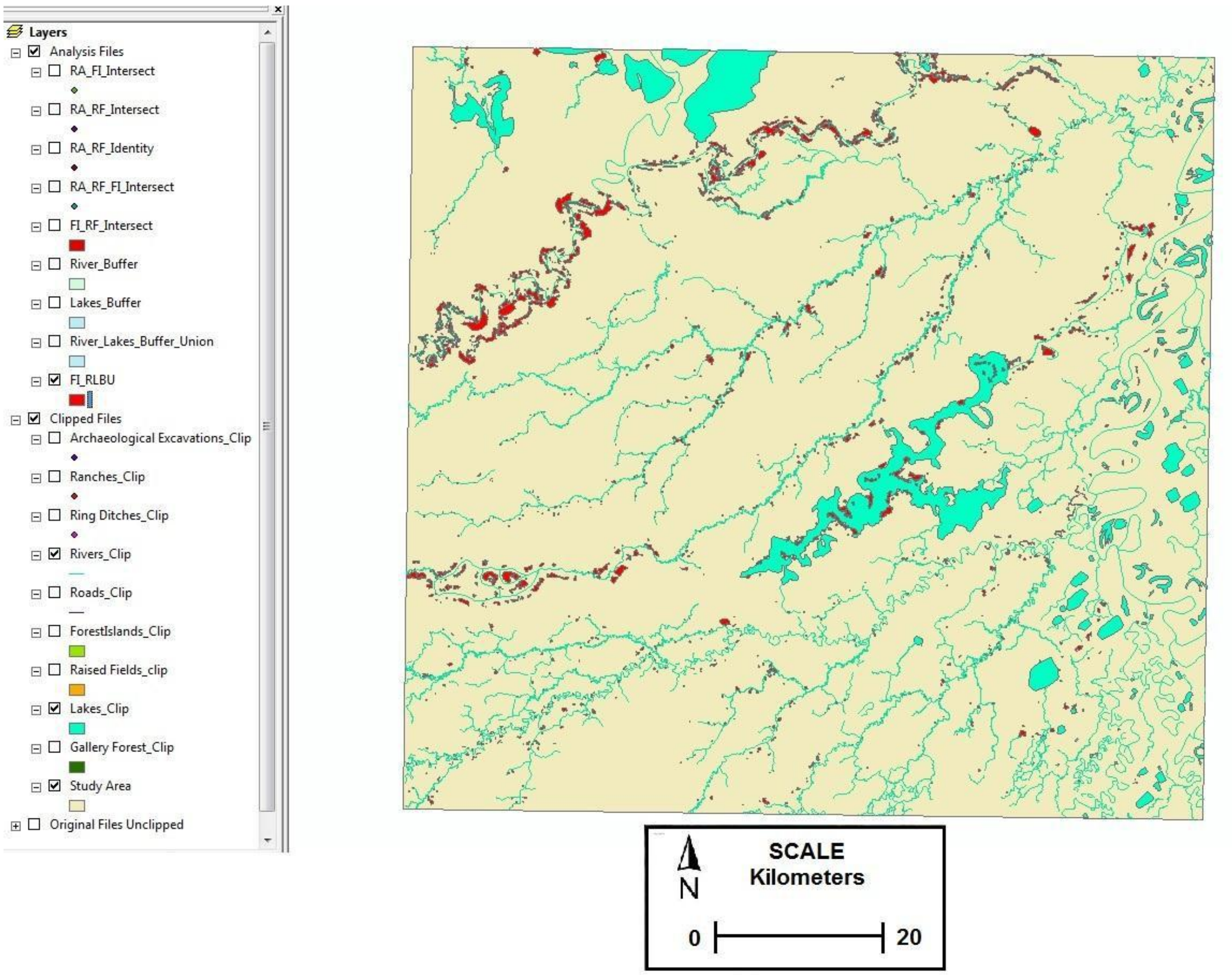

Figure 4-3. Forest islands and bodies of water in ArcGIS™.

The screenshot in Figure 4-3 shows only Rivers, Lakes, and the Forest Islands which are within 1 km of those water sources. The Rivers and Lakes are in blue, and those select Forest Islands are red. There are 1610 Forest Islands that are within 1 km of water. This is a large majority (72.6%) of the forest islands. The significance of this correlation is discussed in Chapter 5: Findings and Analyses.

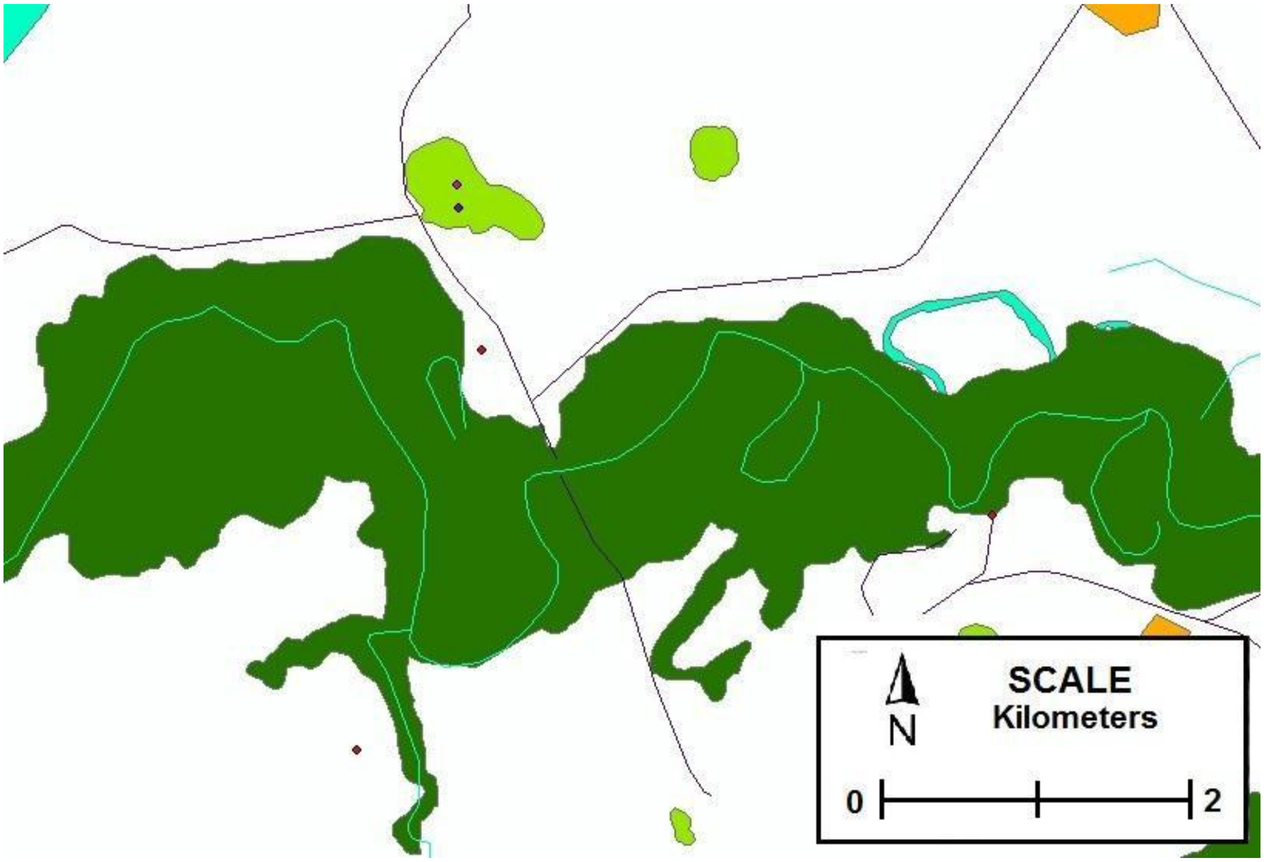

Figure 4-4. A close-up of Isla Estancita in ArcGIS™.

Isla Estancita (Figure 4-4) is approximately 200 meters from the edge of the gallery forest (dark green polygon), and 900 meters from the Rivers line (blue line), which represents the center of the river. The rivers are not a consistent width throughout the year, as the annual flooding results from the snow melting in the Andean highlands and the runoff causes the overflow of the rivers in the Bolivian Mojos. Since gallery forest, as opposed to forest islands, are perceptible to this annual flooding, it can be estimated that the rivers' width can be estimated to be between the River line and the extent of the gallery forest that grows along the rivers. The red points in Figure 4-4 represent the locations of ranches, and the purple point represents the ring ditch known to be located in Isla Estancita. The blue polygons, representing lakes, sometimes appear as curvy “U”’s along rivers. These types of lakes are called oxbow lakes, and they are the remnants from where the river used to run. Over time, the river can gradually close off a loop when changing its course across the landscape. These closed-off loops of river will still retain water, and can be seen throughout the gallery forest along rivers.

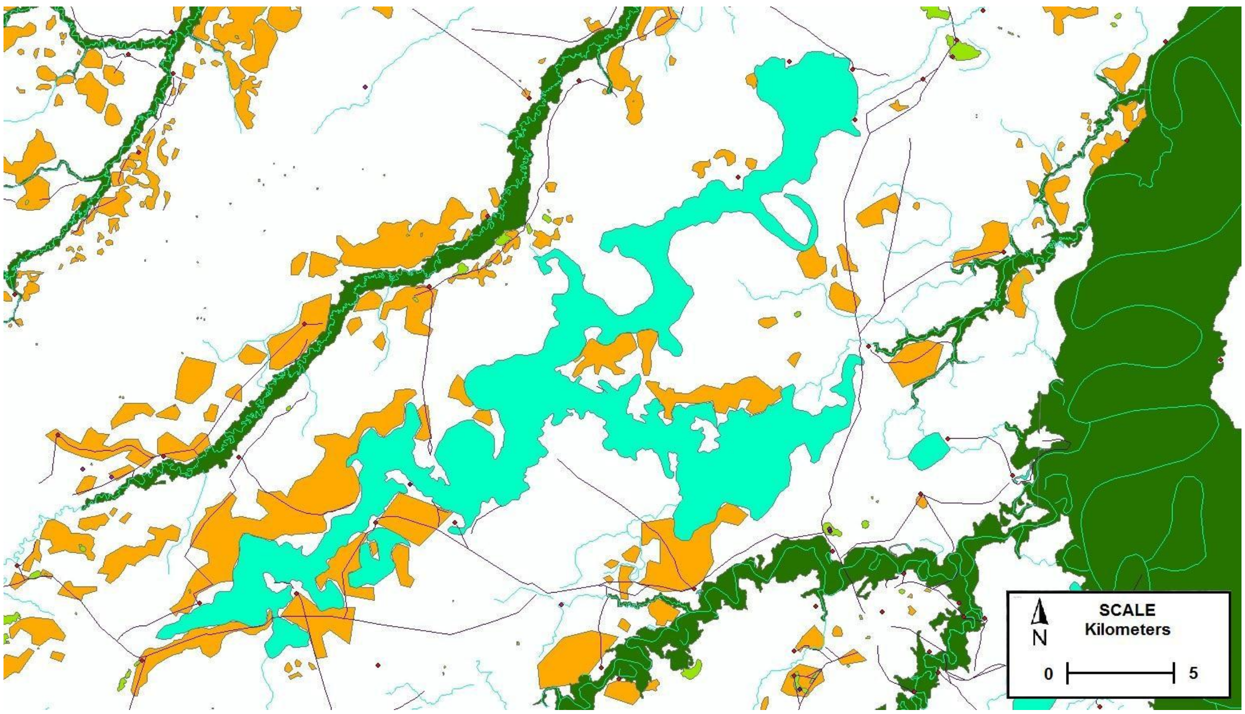

Figure 4-5. Swampy region in ArcGIS™.

Other significant features in the study area include a large swampy area. It was mapped as a lake. Although it is not entirely full of water year round, it remains swampy even during the dry season. Isla Estancita can be seen (Figure 4-5) bordering the Gallery Forest in the lower right corner.

The orange polygons, representing the areas where raised fields are visible on the satellite imagery, can be seen in Figure 4-5 along the swampy area and along rivers. The initial visual analysis of the spatial patterns of these raised fields, that they appear to be concentrated along waterways rather than in the open savanna, can be confirmed through analyses using the ArcGIS™ tools.

Summary

ArcGIS™ provides the necessary tools for conducting spatial analyses on digital files. With its ability to open Google Earth™ KML files, ArcGIS™ is very adaptable and does not require a conversion program. The variety of tools and ease of use make this program ideal for researchers studying spatially-related issues. While a larger amount of archaeologists are learning and using ArcGIS™, there are more that can benefit from its applications. While this chapter is a modest overview of how ArcGIS™ can be used to analyze shapefiles, tutorials on the other functions of ArcGIS™ are available at the ESRI website.[2] The tools available in this GIS program are used for conducting spatial analyses in order to determine geographical correlations and patterns between the mapped features in the study area. The results of these analyses are discussed in the following chapter.

[2] http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=tutorials

CHAPTER 5
FINDINGS AND ANALYSIS

Analysis of Raised Fields and Forest Islands

While other features in the study area will be discussed, a major focus is on the raised fields. Forest islands are still debated as being anthropogenic in origin; although evidence of habitation is often found, the nature of the mounds is still debated between being a natural occurrence, intentional construction, or unintentional compilation. Raised fields, on the other hand, are clearly manmade, and clearly ancient. While archaeology of raised fields reveal a long or interrupted history of use during pre-Columbian times (Walker 2004), historical and ethnographic accounts indicate that these fields have not been constructed or maintained since at least the arrival of the Jesuit missionaries. It is also argued that these fields may have been abandoned before Europeans even arrived (Walker 2000), but the introduction of metal tools by Europeans instigated a fundamental change in the way pre-Columbian cultures practiced agriculture. With the more efficient metal tools, the primary method of agricultural cultivation turned from raised fields to slash-and-burn, a method which allowed them to clear plots of land quickly and is still commonly seen today.

Figure 5-1. Raised fields and forest islands bordering gallery forest.

The Raised Fields do not have a consistent size, shape, or orientation throughout the region. There appear to be different ‘styles’ of raised field throughout the study area. These differences were not reflected in the mapped polygons, but a visual analysis on Google Earth™ can approximate the locations of different groups of ‘styles’. These differences have been noted by previous researchers (Denevan 1966).

Denevan distinguishes “large raised fields” as a distinctive type of earthwork found in the Llanos de Mojos (1966), stating that they “30 to 80 feet in width and some are over 1,000 feet long…[They] occur in clusters of up to several hundred; some are in parallel alignments and others angle off obliquely” (Denevan 1966:85-86). Most of the raised fields mapped in the study area seem to match this description. However, in areas of greater erosion, it can be difficult to tell on the satellite imagery if raised fields are smaller, have been eroded away, or simply do not show up well on the imagery.

While the general areas of prominent styles have been described by Denevan (1966), future research may entail using GIS to create a map of where different styled fields are located. During this project, the fields were not mapped or differentiated according to their apparent styles, so that spatial information is not currently available.

Figure 5-2. Raised Fields by rivers.

Orientation of the raised fields, when located next to a river, seems to be influenced by the shapes and curves of the river. In many cases, the raised fields are eroded close to the river bank or jut up close to other sources of water such as in the swampy area around the center of the study area. In some instances, the raised fields are visible up to the river bank, showing that their construction seems to fan out from the river. This indicates that the construction of the raised fields were intentionally located along these major waterways.

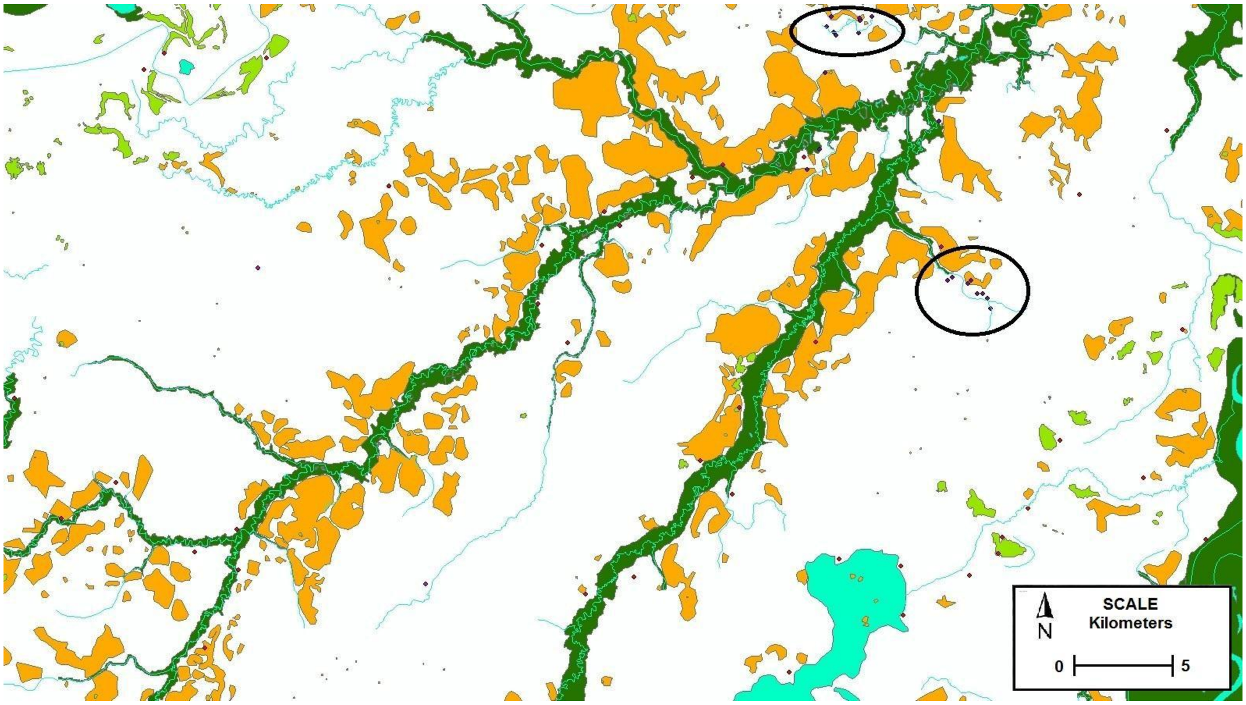

Figure 5-3. Raised fields along rivers and gallery forest in ArcGIS™. The raised fields are represented by orange polygons, the rivers by blue lines, and the gallery forest by dark green polygons. The two circled areas are where archaeological excavations have been conducted by Walker (2004, 2008a).

When the polygons representing the raised fields (orange) are viewed in ArcGIS™, it becomes apparent that the spatial pattern seen in Google Earth™ is reinforced by the correlation between raised fields and rivers in ArcGIS™. As can be seen in Figure 5-3, the results of archaeological excavations by Walker (2004, 2008a) can be applied to the results of GIS analysis because they are from the same location.

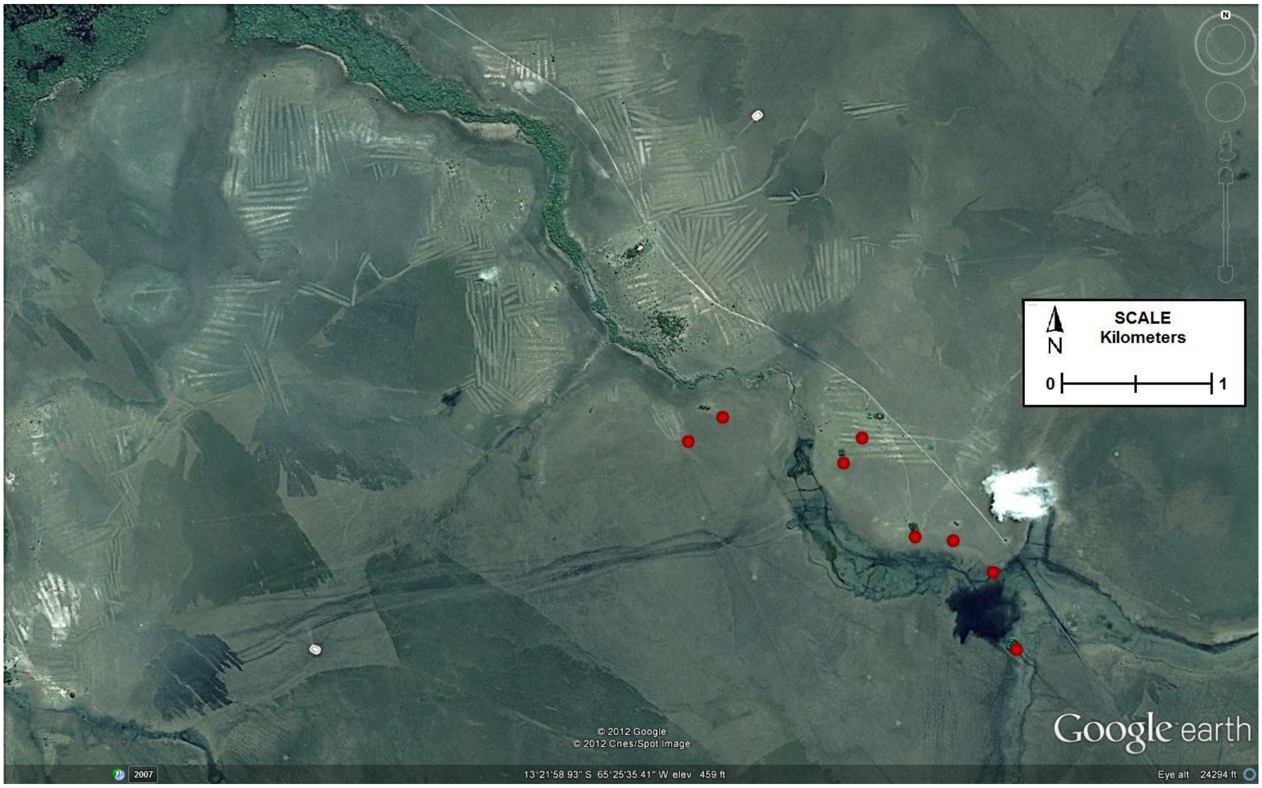

Figure 5-4. Raised fields along river, with locations of archaeological excavations by Walker (2004).

Raised fields were clearly located purposefully adjacent to sources of water. There is a clear preference for the secondary or smaller rivers, rather than the Mamoré river or the lakes in the region. While there is a high concentration of raised fields in the upper right corner of the study area, there are practically no raised fields in other sections of the study area, other than a few sections of raised fields (see Figure 5-5). The upper left corner of the Study Area, by the large lakes, and the entire western side of the study area lack raised fields (Figure 5-4).

Figure 5-5. Raised fields located near the Mamoré river.

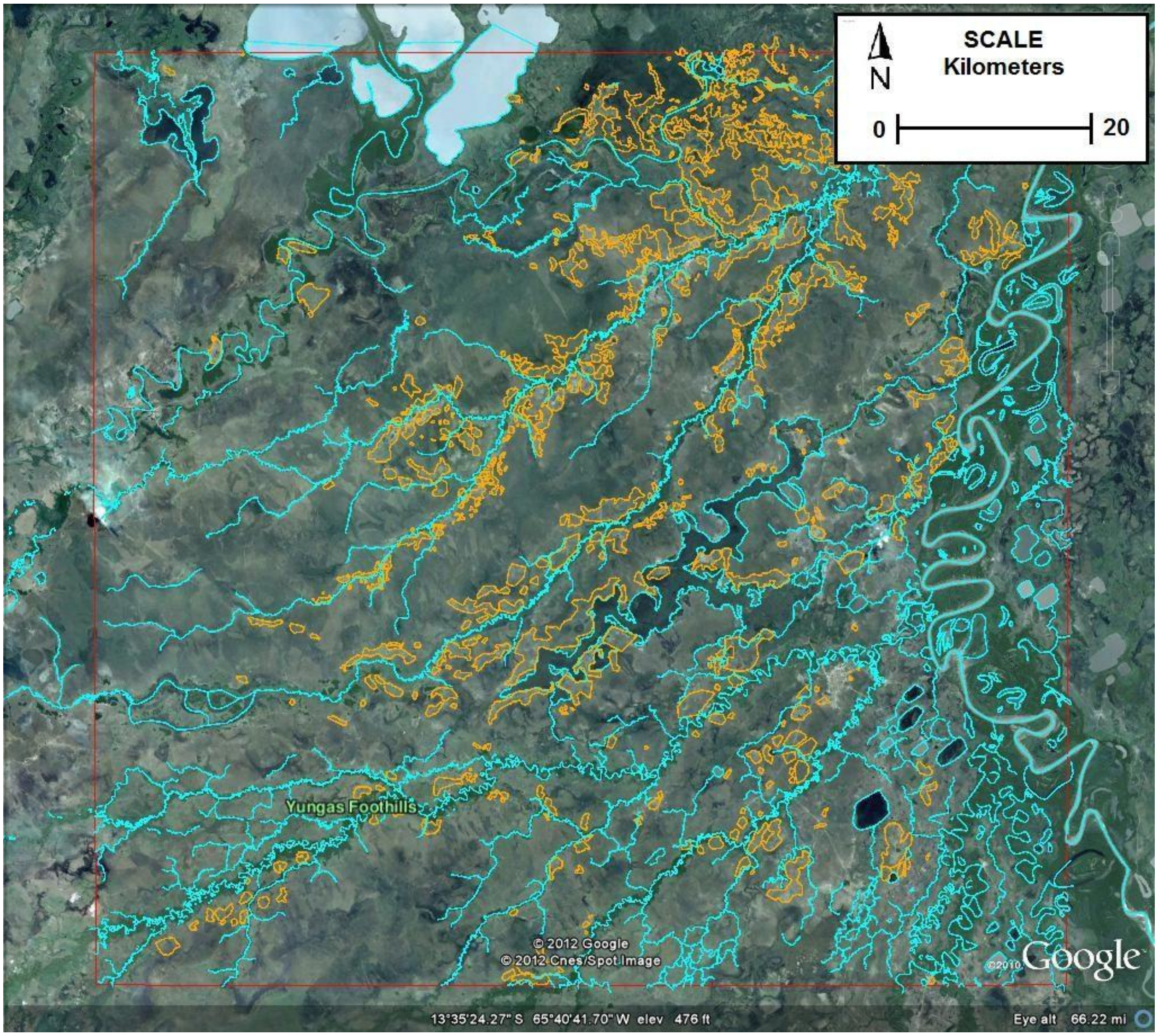

Figure 5-6. Raised fields (orange) and sources of water (blue).

Figure 5-6 shows only the raised fields (the orange polygons), sources of water (the blue polygons), and the study area (the red polygon). While it is not known if many archaeological surveys have been conducted in the western half of the study area (most archaeology has focused closer to the Mamoré, or on the eastern side of the Mamoré River), it seems to be a fair guess that perhaps not as many archaeological sites will be found there. The concentration of raised fields closer to the Mamoré suggests that pre-Columbian societies lived along the secondary rivers, benefitting from the use of water transportation and resources. Why weren't raised fields constructed mainly along the Mamoré itself? Although some raised fields are visible in the upper right corner of the study area as bordering the gallery forest along the Mamoré, there do not seem to be raised fields along the Mamoré besides those.

Figure 5-7. Raised fields near the swampy area.

Due to the erosion of the raised fields, it is often difficult to identify the boundary of the area they cover. This image in Figure 5-7 shows the raised fields that are located along the swampy region of the study area. To efficiently map these features, liberties were taken in suggesting possible boundaries. When mapping features in Google Earth™, it must be kept in mind that each user will likely have different ideas about the boundaries of objects and map them differently from other users. Promoting a standardized method of identifying and mapping features would help solve this problem. In this image, the orange polygon suggests the general area of raised fields. The specific boundary of the group of forest islands is not defined, because in this case it is too vague to say for certain where the boundary is between the raised fields and the swampy savanna. Other areas where the raised fields are not so eroded have a highly visible boundary where the colors and textures on the satellite imagery clearly define where the vegetation and elevation are markedly different. This image (Figure 5- 7) is also another example of how the raised fields tend to be aligned closely with water sources.

There are 279 forest islands are located within 1 km of raised fields. There are 442 intersections of Forest Islands and Raised Fields, 19 of which are from the same forest island. This indicates two things: that these forest islands are either forest vegetation growing on the elevated sections of raised fields, or that raised fields are constructed right up to the forested mounds where settlements once thrived. As demonstrated in Figure 3-11, the differences between those types are visible and it is possible to distinguish between the two.

If forested mounds, which have been excavated and proven to have been habitation sites, have raised fields located adjacent to them, is it possible to predict where other pre-Columbian settlement sites are located?

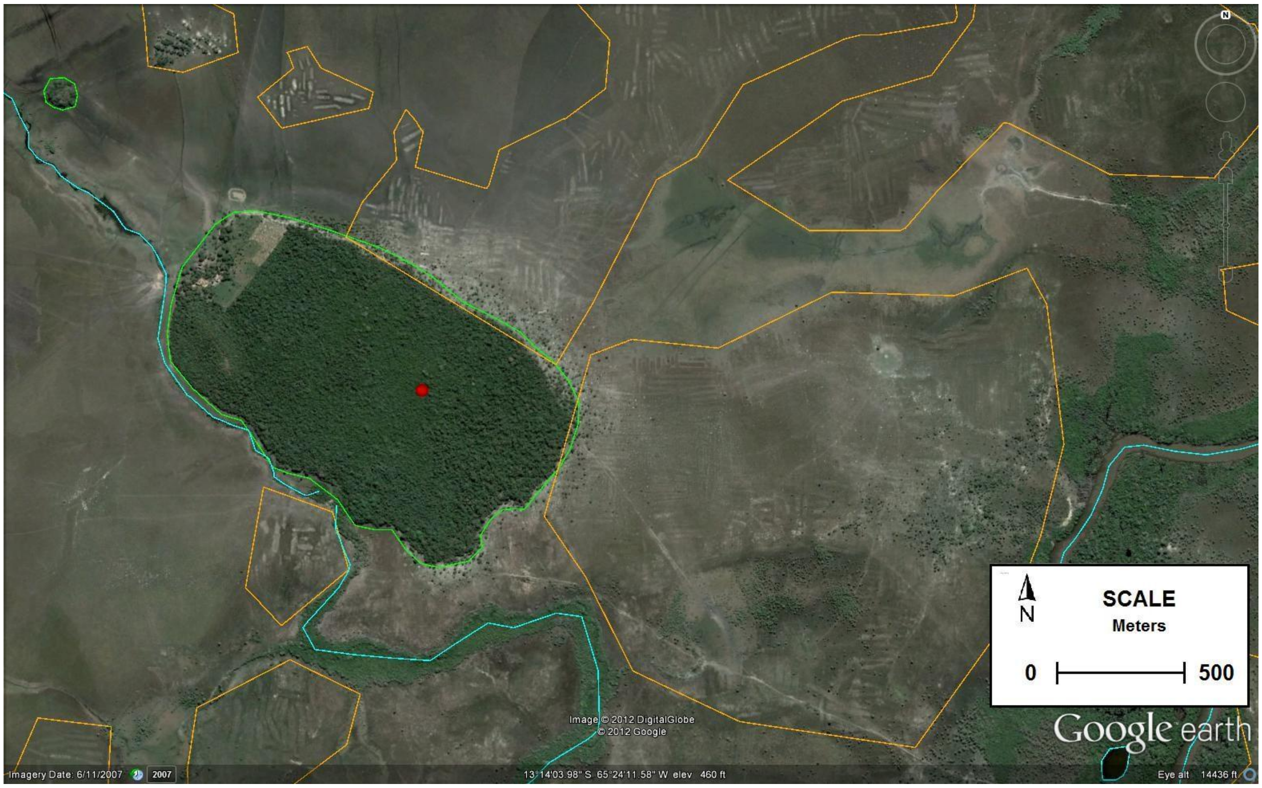

Figure 5-8. Forest Island, Cerro, excavated by Walker (2004) with raised fields.

This forest island, named Cerro, was excavated by Walker (2004). Excavations revealed evidence of habitation, in the form of sherds, wood charcoal, and burned clay. These are the components of anthrosols, or *terra preta*, which indicate the pre-Columbian occupation of a location in the past (Walker 2004). This forested mound is located along the Iruyañez River, and both the excavations and satellite imagery show raised fields surrounding the mound. When these shapefiles were opened in ArcGIS™, they appeared as shown in Figure 5-9.

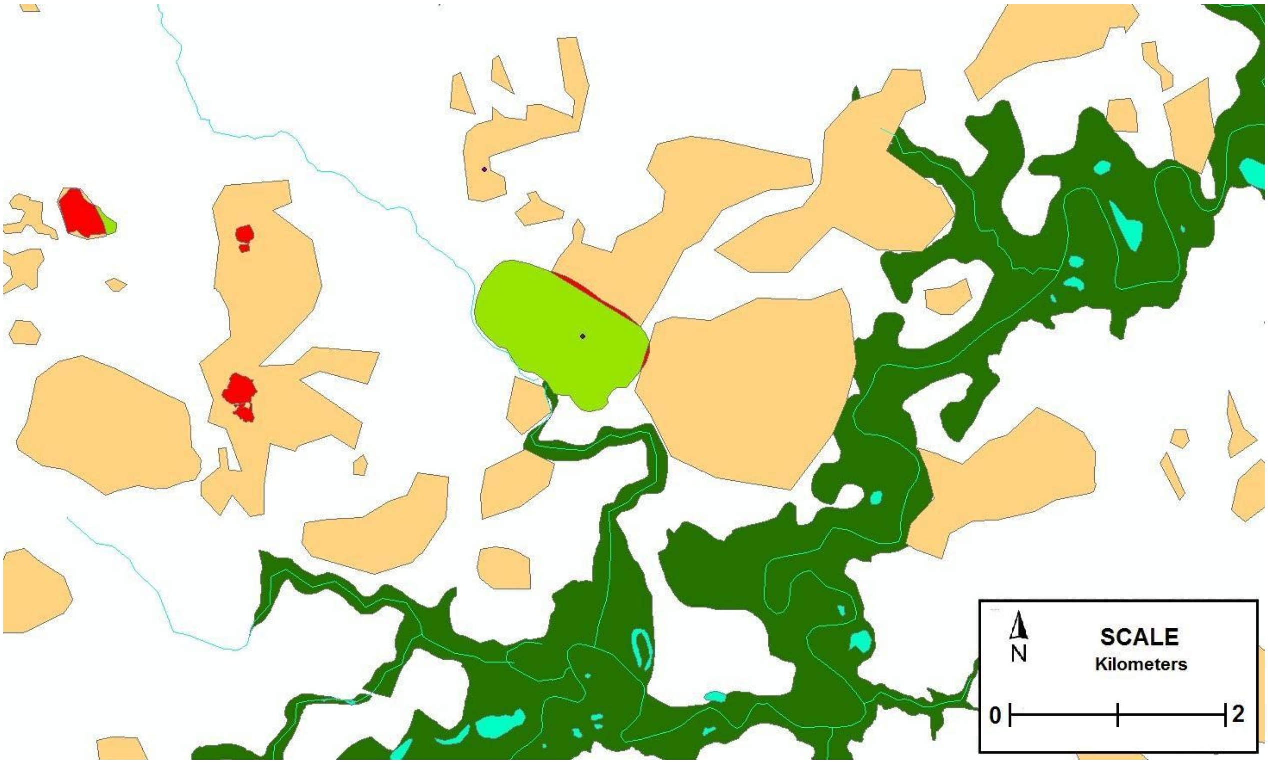

Figure 5-9. Forest island Cerro with raised fields. Cerro is the light green polygon in the center of the image. The yellow polygons are raised fields. The red polygons are the forest islands (or portions) that overlap with raised fields. The dark green polygon is gallery forest, which follows the Iruyañez River (light blue line, and light blue polygons are oxbow lakes).

Figure 5-9 is a snapshot of ArcGIS™, after employing the Intersect tool using the raised fields shapefiles and the forest island shapefiles. This tool identifies where these two sets of shapefiles overlap, or intersect. The results reveal where raised fields are located adjacent to forest islands, surrounding them, or where forest is growing on top of raised fields. The forest islands Cerro was among the forest islands that intersected with raised fields. In Figure 5-9, other forest islands show up as red polygons where they overlap with the raised fields, which are represented as light yellow in this image.

It could be assumed the fields were constructed so close to the Cerro mound because the settlement was located there. If this is true, then are other forest islands, which have raised fields located right next to them, also settlement sites? Can it be predicted that excavations will reveal evidence of habitation at these types of forest islands with raised fields around them?

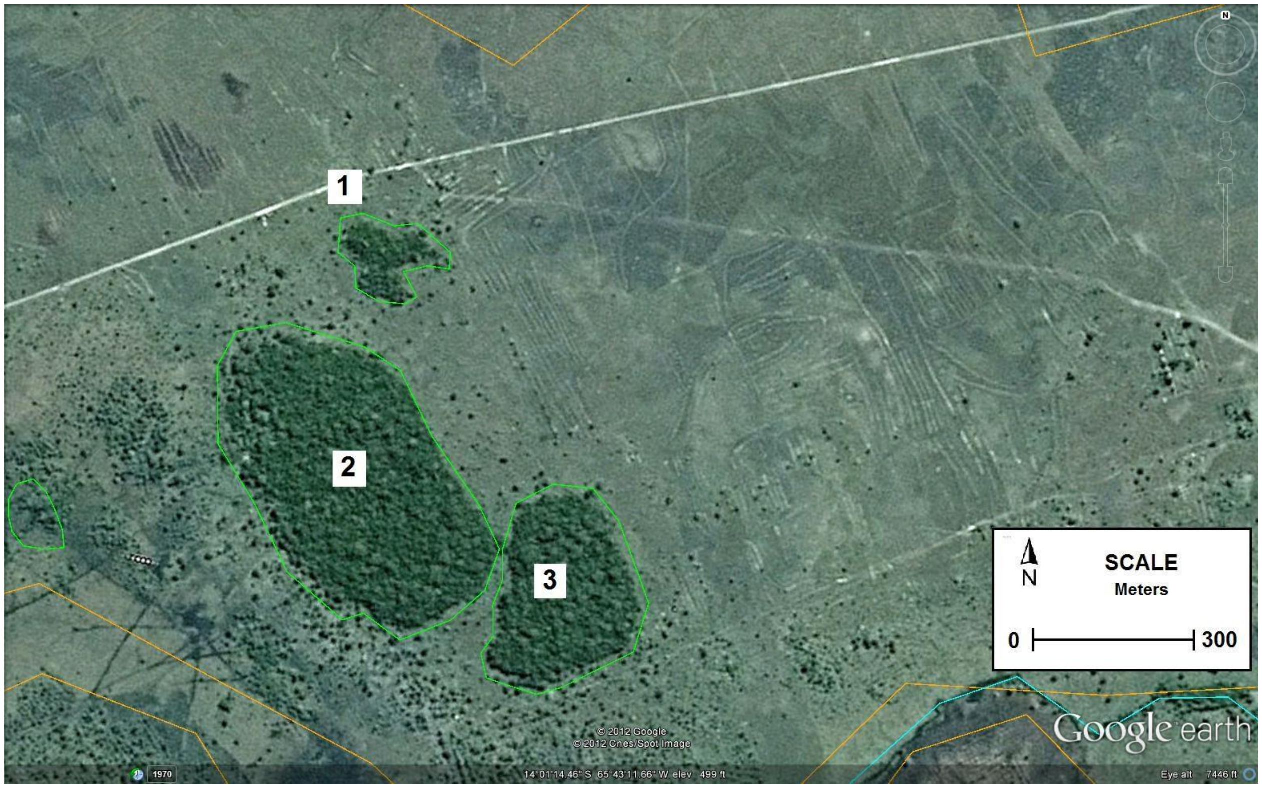

Figure 5-10. Forest islands surrounded by raised fields.

There are two types of forest islands in Figure 5-11. The forest island labeled 1 appears to be a grouping of forest that has grown over the raised fields that surround forest islands 2 and 3. Forest island 1 has an irregular shape and seems to follow the linear pattern of the raised fields, while forest islands 2 and 3 are rounded. Forest island 1 appears to just be vegetative growth on the elevated parts of the raised fields, opposed to the other two forest islands which appear to be forested mounds according to their shape and texture. No archaeological excavations have been conducted at this site, and it is unknown whether forest islands 2 and 3 are separate mounds or part of the same mound. What is known is that raised fields are visible in this image, surrounding forest islands 2 and 3 and jutting up right to the boundary of the forest islands. If this image is compared to the forest island Cerro and raised fields in Figure 5-8, it appears to be very similar. It can be suggested that forest islands like 2 and 3 in Figure 5-11 may reveal archaeological materials indicating a pre-Columbian settlement.

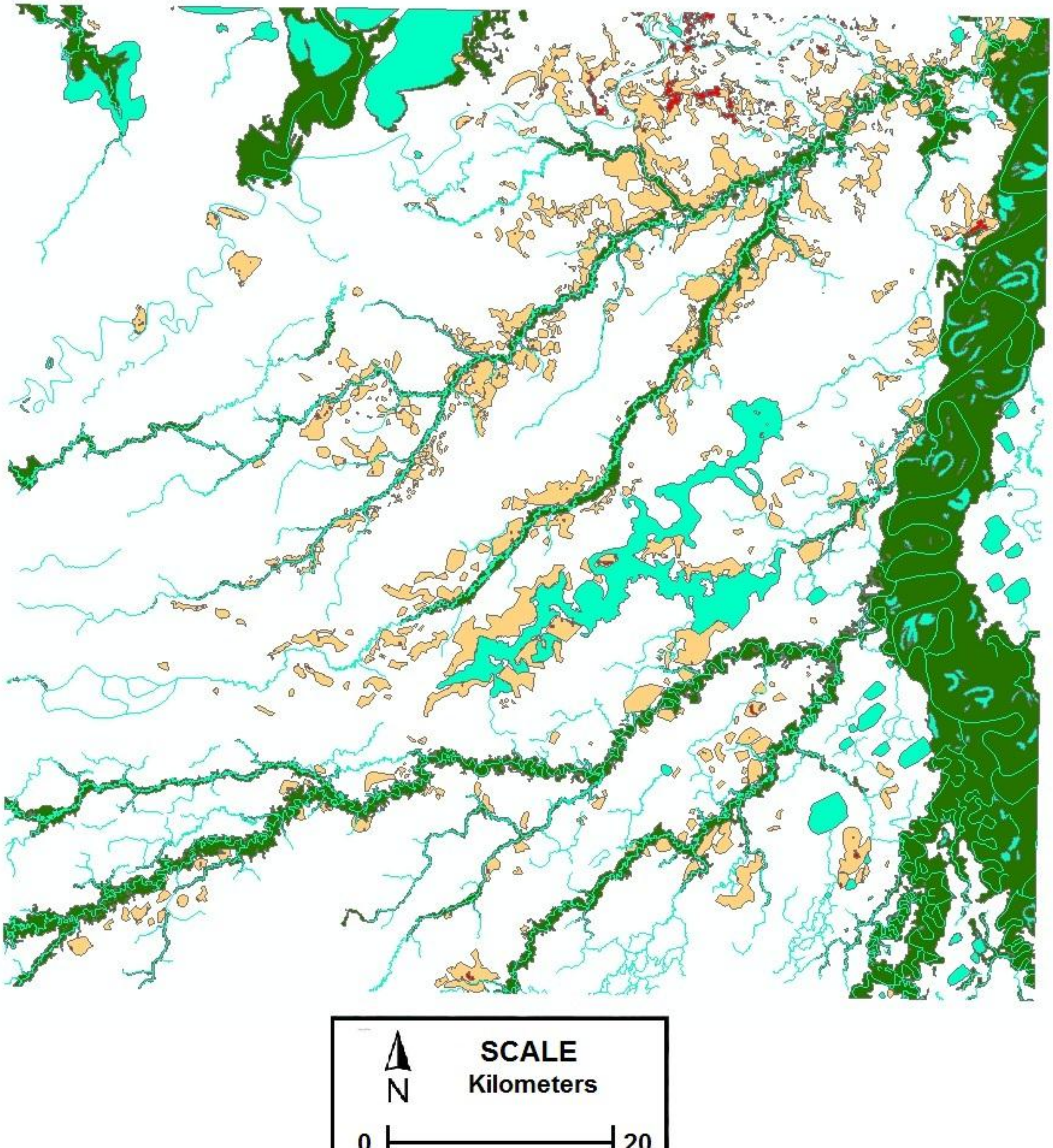

Figure 5-11. Study Area, showing the Intersect of raised fields and forest islands. Raised fields are yellow polygons, gallery forest are dark green polygons, rivers and lakes are blue lines and polygons, and the sections of forest

island that intersect with raised fields are red polygons.

When observing the entire Study Area after applying the intersect tool using the raised fields and the forest islands, 442 intersections are shown. These are represented by the red polygons in Figure 5-12. To understand more about the significance of these results, a closer look is taken at two areas in Figure 5-13 and Figure 5-14.

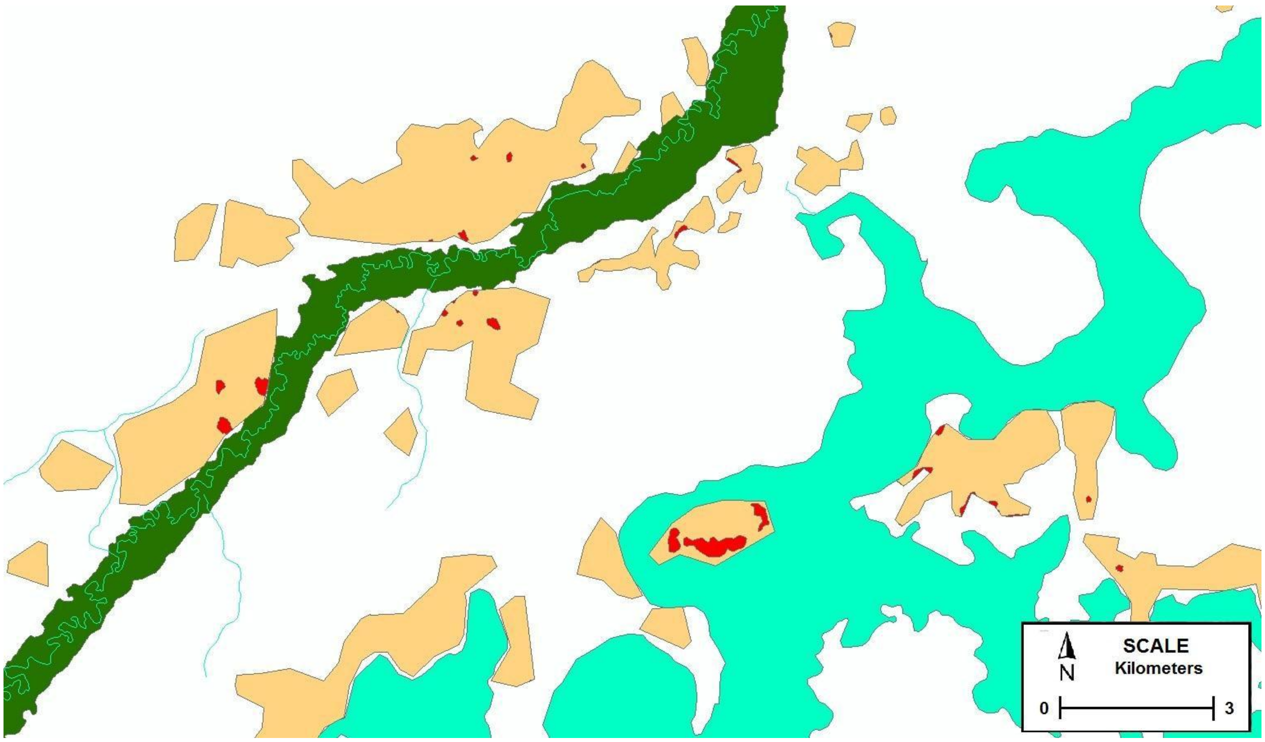

Figure 5-12. Central Study Area showing the results of the Intersect tool using raised fields and forest islands. Same representations as Figure 5-12.

In Figure 5-13, forest islands intersecting with raised fields are seen along the gallery forest and along the swampy areas of the savanna. Most of these forest islands are rounded, indicating that they are located on mounded or elevated land. Although it is not known for certain if these forested mounds have evidence of pre-Columbian habitation, their location adjacent to raised fields, their rounded shape, and their location close to water sources are strong indicators that they are possibly pre-Columbian settlement sites.

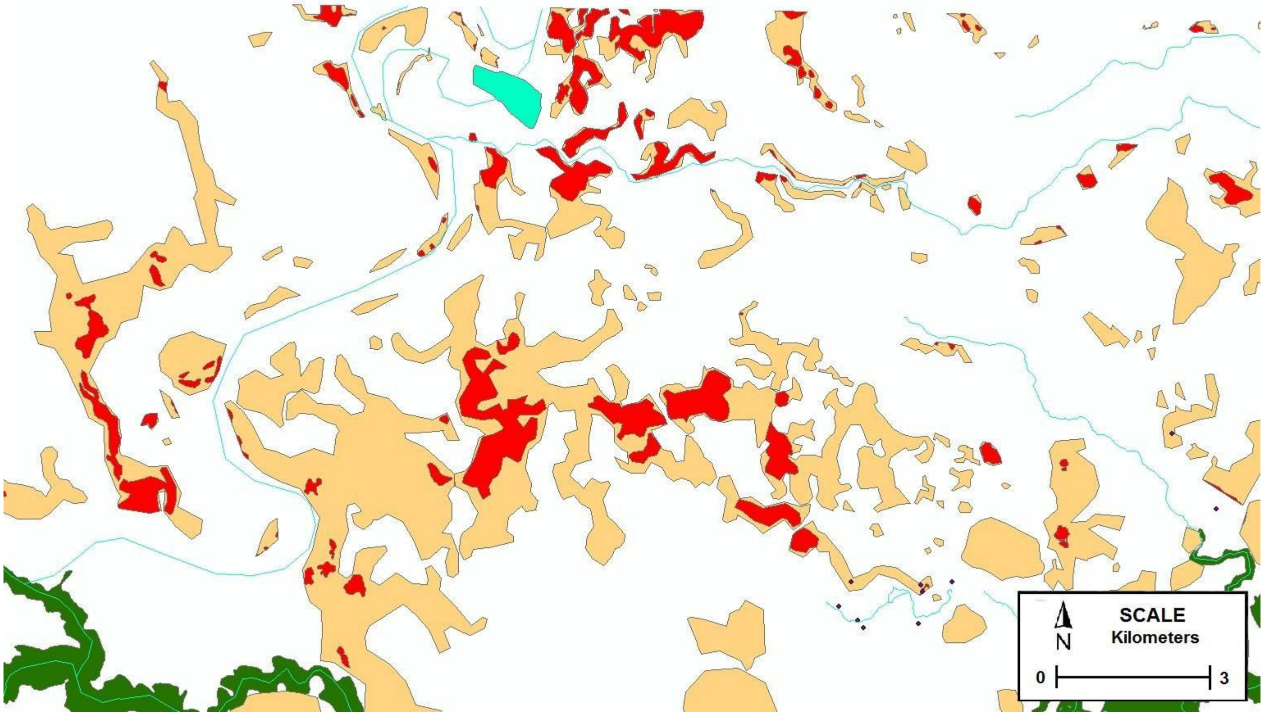

Figure 5-13. Northeast Study Area showing the results of the Intersect tool using raised fields and forest islands. Same representations as Figure 5-12.

In Figure 5-14, there appears to be a different type of forest islands intersecting with raised fields. The intersect tool identified these red polygons as forest islands. However, they have very irregular shapes that closely follow the shapes of the groups of raised fields. They are not closely associated with water sources such as the rivers. This region, located in the northeast section of the study area, is characterized by large swathes of raised fields spread across open savanna. These raised fields are not located closely along rivers or gallery forest. While it is possible that some of these red polygons may represent pre-Columbian settlements on mounds, it is more likely that the majority of these irregular forest islands just represent vegetation growing on the elevated surfaces of the raised fields. If that is the case, then it is less likely that much archaeological evidence of pre-Columbian habitation will be found in these forests.

Figure 5-14. Raised fields in the Northeast corner of Study Area.

In Figure 5-15, the forest island Cerro is located in the central right portion of the image. While the raised fields are mostly concentrated along rivers for the entire study area, in this region the raised fields are found across the savanna. This is the largest expanse of raised fields in the study area, and may indicate a longer habitation by pre-Columbian societies, a more intensive agricultural production, or the continual construction and abandonment of fields.

There are 1610 Forest Islands that are within 1 km of water (that includes both Rivers and Lakes). This is a large majority (72.6%) of the forest islands, indicating a correlation between forest islands and sources of water. If this is a significant correlation, then there needs to be a closer look at the previously described types of forest islands and how they are organized on the landscape.

The size of the larger forest islands along the river may not accurately reflect a single settlement at one point in time. A settlement may have grown and shrunk over time, or may have started off smaller and migrated in one direction gradually. Therefore, the total size of the large forest islands cannot be used for assuming it as a single settlement for purposes of population size. They can be used to see how large of a population could potentially live on that mound, but that does not necessarily mean that that was the size of the population at any given point in time.

The stretches of savanna that occupy the space between rivers are dotted with small forest islands. Many of these islands are nearly circular in shape, suggesting either meticulous eroding or ancient artificial construction. Assuming artificial construction or Pre-Columbian use, the function and purpose of these mounds is not entirely clear. These dispersed mounds are considerably smaller than the relatively larger mounds located along the major rivers are known settlement sites.

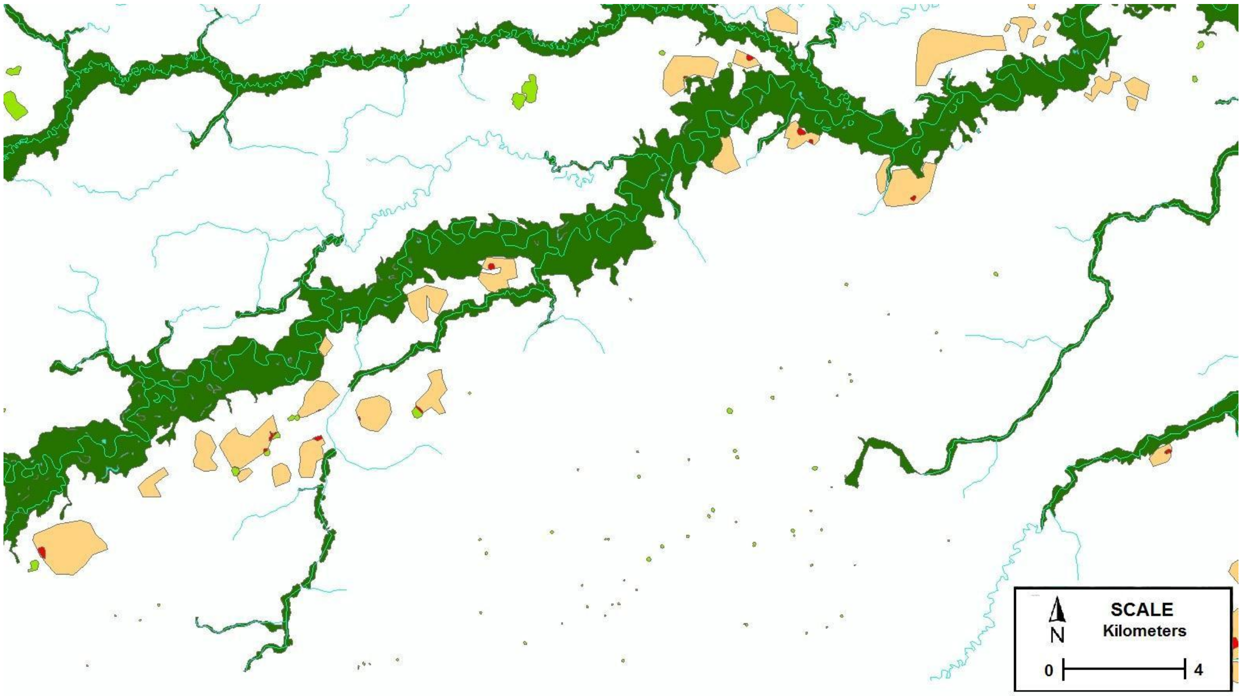

Figure 5-15. ArcGIS™ image of forest islands and raised fields in southern region of Study Area.

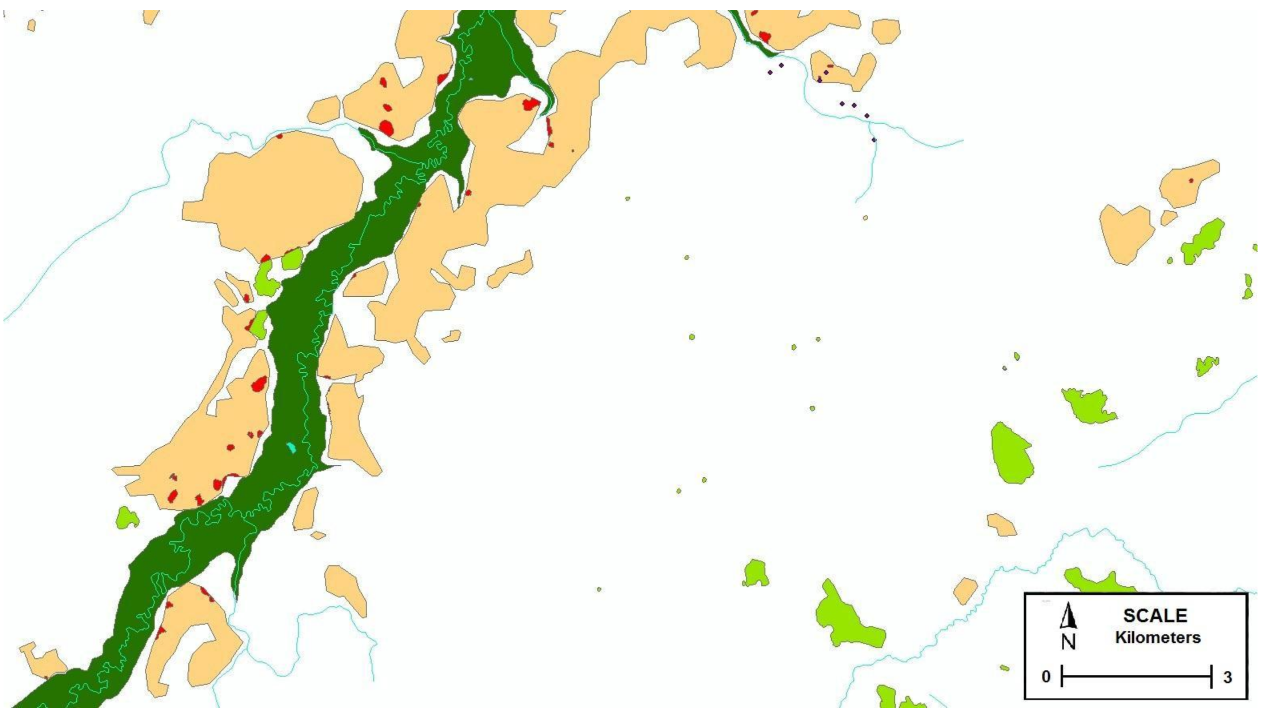

Figure 5-16. ArcGIS™ image of forest islands and raised fields near center of Study Area.

Figure 5-16 and Figure 5-17 display the hypothesized spatial organization of different types of forest islands and raised fields in the study area. The forest islands are represented by green polygons, and the red polygons are sections of the forest islands which intersect raised fields. Raised fields are represented by the light yellow polygons, the gallery forest is the dark green polygons, and rivers are the blue lines. In each of these images, the forest islands are distinguishable between two types: larger forested mounds which were once pre-Columbian settlements, and smaller round forested mounds. The large forest islands occur along the gallery forest and river, and are often located on or near raised fields. As discussed, even though these forest islands in these images have not been excavated, their location near a river and on raised fields is similar to the forest islands which have been archaeologically excavated and found to be pre-Columbian settlements. The small, round forest islands dotting the savanna have also been the focus of archaeological research (Erickson 2000a). They also have evidence of human presence, though not always the evidence of long-term or intense occupation. These two types of forest islands are markedly different in their size, shape, and location, which suggest that they were constructed and used for different functions.

These GIS results lead to an informed hypothesis regarding the spatial relationships of the pre-Columbian settlements and agricultural fields in the Llanos de Mojos. The main settlements were founded and maintained on large mounds along the riverbank, serving as the major hub of activity and habitation. They are located both adjacent to the river (which has benefits such as transportation, food, water, and aquatic resources) and to the wide expanse of savanna on which they constructed raised fields. While some fields were constructed directly adjacent to the settlements, many of the fields stretch across the land into the open savanna. The construction, maintenance, and use of these fields would have required both a means of transportation to the fields and a location for temporary camps. The temporary camps could have been smaller (rural) settlements or simply a designated place for shelter. These areas would have required the construction of small mounds (for same reasons as the settlement mounds, for the annual flooding).

Ring Ditches

A total of 16 ring ditches have been tentatively identified on the satellite imagery. Verification that these are indeed earthworks constructed by Pre-Columbian cultures would require ground-truthing, with either surveying or test pits. This method of using Google Earth™'s satellite imagery to locate and identify ring ditches has been practiced by other Bolivian archaeologists (Erickson 2010) with success. Although Google Earth™ has been proved useful as a tool for mapping data post-excavation, this proactive method of first identifying sites on satellite imagery has important benefits.

Ring Ditches can be indicative of several things. As a functional structure, they can be used to preserve water during a dry season. During the construction of a ring ditch, the excavated soils can be built into the middle to raise a mound. The elevated mounds in the Llanos de Mojos are raised above the annual floodwaters, providing a dry and secure location for settlements.

Besides their functional aspect, ring ditches have also been suggested as defensive mechanisms, sometimes accompanied by a palisade wall (Erickson 2006c, 2008). While archaeologists state that such rings and walls were used defensively in Mojos, it is not the clear case in this region around the town of Santa Ana del Yacuma, on the western side of the Mamoré river. In the 2012 excavations at the forest island of

Isla Estancita, located just north of Santa Ana del Yacuma, there was no clear evidence of a palisade construction (Walker 2011c), though the fact that the excavations did not find evidence does not mean that a palisade was never there. If the ring ditches were constructed as defensive structures, there would be political implications that correspond with the settlement patterns identified in this GIS project. The ring ditch would encompass a settlement that identifies itself as a political unit, at war or having political tensions with other settlements that lead to violence. The next step would be an attempt to identify political and cultural boundaries. While these were certainly dynamic and fluctuated through time, the addition of archaeological information and radiocarbon dating could place settlements in time. An increasing amount of archaeological data is becoming available, but there is insufficient information on the dates of these sites to begin a chronology and place them in time.

Summary

Remote sensing has revolutionized aspects of archaeology related to spatial data. Questions regarding large scale monumentality can now be addressed using remote sensing methods, using techniques such as satellite imagery to identify, compare, and analyze earthworks all over the world. In particular, this technique has been used in the Llanos de Mojos region of Bolivia to research the extent, categorization, construction, and spatial organization of pre-Columbian earthworks (Walker 2011d). These monumental earthen constructions are found across the region, and include canals, causeways, fish weirs, settlement mounds, ring ditches, and various types of agricultural fields (Denevan 1966). Erickson (1995) utilized several techniques of remote sensing in his research. Due to the lack of reliable and accurate maps needed for guiding archaeological surveys and locating sites, Erickson relied on other forms of navigation. Erickson studied aerial photographs from the archives of the Instituto Geográfico Militar and the Bolivian Air Force's Oficina de Aerofotogramía. Then, using a GIS and remote sensing software package (IDRISI) to prepare computer-generated classifications of key zones from digital LANDSAT imagery, Erickson was able to produce a series of large-scale environmental base maps for guiding ground reconnaissance and for locating earthworks. This computer program was used to produce maps of vegetation communities, land use, forest and savanna boundaries, river courses, and roads over large areas. IDRISI was used to scan and digitize aerial photographs, and then manipulated to increase contrast, emphasize certain features of the landscape, identify earthworks, and to produce field maps. These remote sensing methods were combined with ground surveys, topographic mapping, and archaeological excavations to integrate traditional methods of archaeological research with new technological techniques (Erickson 1995). Lombardo et al. (2012) analyzed the spatial distribution of raised fields (including platform, ridged, and ditched fields), canals, ditched fields, ring ditches, and monumental mounds to "compare different kinds of archaeological landscapes and the links between environmental settings and the development of complex societies" (Lombardo et al. 2012:123). They looked at two regions in the Llanos de Mojos to compare the distribution of earthworks: the platform fields region in the northwest and the monumental mounds region in the southeast. Satellite imagery was acquired from Google Earth™, and topographic profiles were based on the original Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM). What was discerned from these remote sensing methods was that there was a significant difference in the types of earthworks constructed between the two regions, and these distribution differences were a result of local geo-ecology (Lombardo et al. 2012). Heckenberger et al. (2003) discuss the research conducted in the Upper Xingu in southern Brazilian Amazon which utilizes satellite images acquired through Landsat, aerial photography, archaeological and ethnographic fieldwork, geographic information systems, the participation of indigenous Kuikuro societies. The landscape in the Upper Xingu is shown as the result of interaction between the natural environment, large pre-Columbian societies, and historical colonialism. The built environment produced by pre-Columbian societies is characterized by public constructions such as plazas, roads, moats, bridges, cultivated areas, and large settlements linked together as “galactic clusters” (Heckenberger et al. 2003:1711). The identification and mapping of these earthworks was possible through the remote sensing techniques, and their interpretation was guided by archaeological and ethnographic information. These regionally integrated galactic clusters and the system of constructed earthworks in and around them “can be characterized as saturated anthropogenic landscapes…carefully engineered and managed” (Heckenberger et al. 2003:1711), as is seen elsewhere in the Amazon. In the Baures region in northeastern Bolivia, Erickson and Walker (2009) focuses on pre-Columbian causeways and canals as part of the built environment demonstrating the agency of past cultures, Erickson describes the Geographic Information System (GIS) of the Baures Region project, which integrated Digital Elevation Models, Landsat ETM scenes, CORONA images, aerial photographs, topographic maps, and vector maps detailing the spatial information for cultural features, classified vegetation, and land use. Through the integration of these methods and archaeological excavations, Erickson and Walker (2009) discovered that although the canals and causeways serve the basic functions of transportation and communication of people, goods, and information, the shape and structure of these earthworks "suggest the agency of individuals, families, hamlets, and communities who agreed to create a local and regional infrastructure of direct communication based on a shared aesthetic of intense social interaction, straightness, and order" (Erickson and Walker 2009:220). These characteristics of the earthworks were discerned through the large-scale analysis of remote sensing, which would not have been possible through archaeological endeavors alone. Remote sensing techniques provide the needed methods to study the "landscapes of movement" (Erickson and Walker 2009) not only in the Baures region of Bolivia, but worldwide.

Nearly all archaeological studies in the Amazon utilize remote sensing to a degree, whether it's consulting aerial photographs or conducting analyses with satellite imagery and GIS. Computer programs and satellite imagery, when in conjunction with historical research, lead to exciting new ways of interpreting archaeological evidence and cultural landscapes. The progression of technology allows archaeologists to analyze information in new and 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.

An important note, and a potential problem, regarding the use of satellite imagery in mapping the earthworks is that sometimes they do not show up on the satellite imagery. While the satellite imagery normally reveals the contrast between the differences in vegetation and elevation for most of the constructed mounds, fields, canals, and ring ditches, this is not always the case. After hundreds, and perhaps thousands, of years, many of the earthworks have eroded to the point where they are not distinguishable from the surrounding landscape on the imagery. Forest cover on the islands and in the gallery forest also obscures earthworks. Therefore, while this map of digitized features represents the general spatial layout of pre-Columbian features in the study area, it is not always accurate. For example, ground surveys at the site of Isla Estancita revealed the presence of raised fields to the north of the forest island (Walker 2010). However, these raised fields are not visible on the satellite imagery in Google Earth™. Ground-truthing the location of earthworks will be necessary in order to confirm their location and extent.

CHAPTER 6
CONCLUSIONS AND FUTURE RESEARCH

Conclusions

This project is meant to demonstrate the methodologies made possible by using satellite imagery and ArcGIS™. While this thesis poses more questions than it answers, it acts as an example of how archaeologists could be combining their archaeological data with spatial analyses for a more complete understanding of their data. Hopefully, the questions proposed in this thesis will guide future research towards implementing such methods. GIS is increasingly being utilized in a variety of fields, including archaeology. However, many research projects still do not include the addition of GIS-based analyses, and could greatly benefit from it. Archaeologists who have learned how to use GIS and apply it to their research will have the upper hand in being able to envision the bigger picture, to locate their research within a larger framework of geographical and spatial analyses. While Google Earth™ has many recreational uses, the program's benefits as a research tool seems to have been greatly understood in archaeology. Google Earth™ has a promising future in archaeological research and GIS applications. The program is free, user-friendly, and already provides mapping tools which can be saved and uploaded into other programs including ArcGIS™. By combining these two programs, this thesis presents a methodology that can be replicated and used by other archaeologists who have questions regarding geographical and spatial organization and patterns. Other archaeologists have demonstrated the utility of these programs (Erickson 1995; Lombardo et al. 2012; Heckenberger et al. 2003).

While the landscape is often describes as anthropogenic, this project can estimate just how much of the environment in the Study Area consists of pre-Columbian earthworks and sculpted landscape. Referring to Table 3-1 in Chapter 3, the total area of the raised fields was found to be 678.12 km². When divided by the total area of the Study Area, the raised fields make up 6.59% of the entire environment. This would be the low end estimate, for the total percentage of human-modified land in the Study Area. Since forest islands represent areas of altered landscape as well (either growing on top of raised fields, or growing on top of settlement mounds), if the total area of those (211.31km²) is added to the raised fields, then the combination of raised fields and forest islands occupy 8.65% of the entire landscape. This percentage is a high end estimate, with a likely real value lying somewhere between 6.59-8.65%, because not all forest islands may actually represent human-modified or occupied areas. While this does not seem like a large percentage, the actual amount of available land must be taken into account. The Study Area also consists of lakes, rivers, and gallery forest. While the path feature used to map rivers does not reflect area, only length, the percentage of the Study Area occupied by lakes can be subtracted from the overall area of the Study Area to more accurately represent how much of the actual land that pre-Columbian people were altering. The lakes (446.54 square kilometers) constitute 4.34% of the Study Area. Gallery forest (1539.41 km²) occupies 14.96% of the total Study Area. When looking at how much of the savanna was modified, the area of the forest islands and raised fields can be divided by the study area (minus the lakes and gallery forest). This equation (889.43/8300.54) yields a percentage of 10.72%. Compared to the total Study Area, this percentage may be a much more accurate representation of how much of the accessible environment was altered by pre-Columbian cultures through earthwork construction and agricultural fields. However, this result must also take into consideration the environmental issues with this region: seasonality and annual flooding.

As discussed in Chapter 2, the Llanos de Mojos experiences drastic changes between the annual flooding and subsequent drought-like conditions. During the wet season, floodwaters can cover up to a third of the landscape (Denevan 1966), though this level varies on a yearly and regional basis. This means that the rivers overflow, the lakes fill, and low-lying areas become inundated. The Spot Imagery provided by Google Earth™ was taken during the dry season. Had the satellite imagery been taken during the wet season, the results of digitizing features may have been markedly different. So, the waterways (lakes and rivers) that have been mapped in this project represent the more permanent sources of water in this region of Mojos. However, this mapping does not reflect the seasonal changes and the locations of seasonally-flooded areas of the landscape that would have also provided a means of transportation via canoe and aquatic resources. If future studies have access to imagery from both seasons, it would make an interesting comparison to map the two separately and compare how drastic the changes are, and how different the pre-Columbian earthworks are represented for each one.

This project used Google Earth™ to identify and map environmental and cultural features, but there are other methods that could have been used. Supervised classification is a Land Classification method that assigns pixels in a raster image to user-defined land cover types. As opposed to unsupervised classification, knowledge regarding class types is already acquired. To do this, pixels typical of each type of land cover type (forest island, river, gallery forest, raised field, road, ranch, etc) are selected and used to identify where similar pixels occur in the image. Since sections of the Llanos de Mojos have already been ground-truthed through excavation, survey, and general travel, these well-known areas can be used as training regions to ensure that the classification method is more accurate. The computer program ENVI uses Landsat TM data to conduct various supervised classification methods. This approach was not used in this project for several reasons, but mainly due to the author having a more thorough knowledge and background in manually digitizing in Google Earth™ and using ArcGIS™ tools. However, applying a supervised classification method to satellite imagery raster data of the Llanos de Mojos region could prove significantly informative in future research.

Already knowing the location of ranches and roads would be useful for archaeologists in planning their expeditions and determining which sites would be the most efficient, reasonable, prudent, and within their budget of time and money. This may not be an issue often discussed in academic papers, but the budget of a project often determines the extent of work that can be completed, and it is important to make the most of it. These factors can be accounted for in the GIS map of the digitized features. An archaeologist can define the maximum amount of distance from the road or from a town that a site should be located. They can define the type of terrain that a site is located in. They can input information about the properties in the region, map each property separately, and note which property owners give permission for digging. With all of these definitions given, the GIS map and give an output of the most ideal sites. This type of approach could save time and money while in the field.

As the debates on climate change and carbon emissions continue, many ecologists have turned their attention to the Amazon. Issues on appropriate land-use practices could be informed by investigating how Pre-Columbian people interacted with the landscape long before Western societies arrived in the Amazon. Prescribed burnings are used by modern cattle ranches to keep the savannas clear and the forests contained, but this is not a new practice by any means. The historical context of these actions is critical when examining satellite imagery, in order to truly understand how a landscape has been shaped not only recently, but over millennia of human habitation and interaction. In addition, archaeology is highly tied to the issue of indigenous people's land rights in the Amazon. Certain land use practices by natives, deemed 'destructive' by Westerners, may have actually been practiced for thousands of years. Archaeology can show how these land use practices have affected and shaped the Amazonian environment through time. This investigation would also shed light on the question of what parts of the Amazon are pristine, or affected or influenced by mankind. An environment that is traditionally thought of as 'pristine' may have actually been shaped or influenced by anthropogenic land use practices, as is being continuously shown in archaeological excavations.

The importance of higher resolution satellite imagery and further archaeological excavations has been demonstrated through the explanation of how they can enhance our knowledge of Amazonian Pre-Columbian societies. While research has been conducted about the Pre-Columbian earthworks in the Llanos de Mojos in the Bolivian

Amazon, there are still a lot of questions about the sociopolitical organization of the different people who lived there. With the use of satellite imagery and archaeology, this question can be answered by further identifying, mapping, and analyzing the spatial and temporal relationships of the earthworks and other landscape features.

Future Research

I would recommend that all researchers from every field of study make themselves familiar with Google Earth™ and its mapping tools. Digital mapping and examination of satellite imagery appears to be useful in every aspect of academia, even if it has not been utilized yet. For researchers on a budget, this approach to spatial analysis is extremely economical. Google Earth™ is a free program that can be downloaded from their website[1], and there are free GIS programs available online. No other fancy expensive programming or equipment is needed to conduct these analyses and obtain spatial information. That makes this approach very economical and feasible.

The study area chosen for this project represents only a small section of the Llanos de Mojos, but a map that included the entire region is possible. Further work on identifying and mapping pre-Columbian features, modern features, and landscape features within the entire Llanos de Mojos region would reveal a larger picture about how cultures interacted with each other and the landscape.

Estimations regarding pre-Columbian economical production and carrying capacity have been previously proposed (Denevan 1966), based on the survey of raised fields from aerial photographs. An alternative estimation could now be conducted based on the visual images of satellite photographs. There are some differences in the

[1] http://www.google.com/earth/index.html

methods of the two approaches, and it would be informative to see how the results differ.

The GIS information could be used to create a model for predicting the locations of ideal archaeological sites. While not often discussed in articles, choosing which site to dig at is often influenced by several factors. An archaeologist makes decisions based on: convenience of located (including whether there is a navigable road to the site, the type of terrain, and its distance from a town with supplies), the permission to dig from the property owner, and certain indicators that would mark the presence of an archaeological site. For this region, the forest islands and the raised fields are the best indicators of archaeological materials. By creating preferences on the locations of certain files, the ideal spots to survey or excavate could be quickly calculated using ArcGIS™ tools.

I envision a public source of geographical information, where archaeologists can access a map such as the one created in this project. Archaeologists can contribute their own information, with geographical locations of sites to pin onto the map with the corresponding archaeological information. Although some sites of archaeological excavations are identifiable on the Google Earth™ imagery (Walker 2008a, 2008b), not all published results of excavations reveal their geographical information. I acknowledge that there are a number of factors involved in a publically-accessible source of archaeological information. Revealing the exact locations of archaeological sites could lead to increased looting, and if the sites are located on private property there is the issue of privacy. However, the benefits of creating an open source of information in which Amazonian scholars can share information have promising advantages.

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BIOGRAPHICAL SKETCH

Stephanie Boothby completed her undergraduate work at the University of Central Florida, graduating with honors and a bachelor's degree in anthropology in 2010. That same year, she was accepted into the University of Florida's graduate program and began coursework and research for the master's degree. During the summer field seasons of 2010 and 2011, she accompanied Dr. John Walker to the town of Santa Ana del Yacuma in the Llanos de Mojos, Bolivia to assist in archaeological surveys and excavations in the forest island Estancita. This thesis project is the product of those field seasons and exploration using Google Earth™ and ArcGIS™ as remote sensing tools. She completed this thesis and received a Master of Arts degree in the fall of 2012.