Fish Weirs Et Alia: A GIS Based Use-Analysis of Artificial, Pre-Columbian Earthworks in West Central Llanos de Mojos, Bolivia

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FISH WEIRS ET ALIA: A GIS BASED USE-ANALYSIS OF ARTIFICIAL, PRE-COLUMBIAN EARTHWORKS IN WEST CENTRAL LLANOS DE MOJOS, BOLIVIA

by

CHARLOTTE A. ROBINSON

A thesis submitted in partial fulfillment of the requirements for the Honors in the Major Program in Anthropology in the College of Sciences and in The Burnett Honors College at the University of Central Florida Orlando, Florida

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Thesis Chair: John Walker, PhD
ABSTRACT

This study employed a GIS-based use-analysis on a network of recently mapped pre-Columbian earthworks lying on the west side of a Bolivian floodplain. This wetland region, called Llanos de Mojos, is home to many different types of artificial mounds that served different roles for the ancient communities who constructed them thousands of years ago. This new set of features, which was mapped by volunteers of the Proyecto Sistemas Informaticas Geograficas y Arqueologicas del Beni (ProSIGAB) was purported to be a network of fish weirs, linear earthworks built in rivers or floodplains that are designed to trap fish by exploiting seasonal floodwaters. This identification was based on their similarities with the Baures Hydraulic Complex on the east side of Mojos (Erickson 2000; McKey et al. 2016; Blatrix et al. 2018). Classification procedures made use of the features’ physical attributes and relationships with other landscape features to identify them not just as fish weirs, but multi-use structures that connected infrastructure, impounded water, and trapped fish. When understood together with nearby forest island settlements, neighborhoods of agricultural fields, and drainage features, it is argued these earthworks played a substantial role in the lives of past inhabitants, demonstrating their ingenuity by fulfilling multiple functions in a complex anthropogenic landscape.
DEDICATIONS

To my cat, Pancake, who likes to step on my keyboard.

flkajlhggggasd//gfjgcg
ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to my committee chair, Dr. John Walker for advising me for almost two years, first as a ProSIGAB volunteer and now as a student researching the earthworks of Llanos de Mojos. I also appreciate the trust placed in me to manage and curate the West Central Mojos feature layer. Finally, I would like to thank Dr. Neil Duncan and Dr. Scott Branting for being part of my committee and providing valuable feedback on my manuscript.
# TABLE OF CONTENTS

**CHAPTER ONE: INTRODUCTION** ........................................................................................................ 1

**CHAPTER TWO: BACKGROUND** .................................................................................................... 3

- Physical Landscape of Llanos de Mojos ......................................................................................... 3
- Cultural Landscape of Llanos de Mojos ......................................................................................... 5
- Fish Weirs in the Bolivian Amazon ............................................................................................... 8

**CHAPTER THREE: THEORETICAL FOUNDATIONS** ............................................................ 14

**CHAPTER FOUR: THE WEST CENTRAL MOJOS DATASET** ........................................ 17

- Public Mapping with ArcGIS Online ......................................................................................... 17
- Variation in the West Central Mojos Dataset ............................................................................. 21

**CHAPTER FIVE: METHODOLOGY** .......................................................................................... 24

- Feature Verification .................................................................................................................. 24
- Feature Classification ............................................................................................................... 24
- Weighted Attributes and Functional Profiles ........................................................................... 26

**CHAPTER SIX: RESULTS** ....................................................................................................... 31

- Results for Individual Attributes ............................................................................................ 31
- Earthworks as Causeways ...................................................................................................... 32
- Earthworks as Dams .............................................................................................................. 33
- Earthworks as Fish Weirs .................................................................................................... 33
- Multi-Functional Weir Groups in West Central Mojos ........................................................... 34
  - Case Study 1: Mamoré Area of Interest (Far Northeast Group) ......................................... 35
  - Case Study 2: Southwest Area of Interest ......................................................................... 35

**CHAPTER SEVEN: DISCUSSION** .......................................................................................... 37

**APPENDIX A: FIGURES** ........................................................................................................ 41

**APPENDIX B: TABLES** ........................................................................................................... 69

**APPENDIX C: WRITTEN PERMISSIONS** ............................................................................... 77

**LIST OF REFERENCES** ............................................................................................................ 79
LIST OF FIGURES

Figure 1. An aerial view of the West Central Mojos linear feature dataset. Inset is magnified in Figure 2 ........................................................................................................................................ 42

Figure 2. Inset from Figure 1 of individual digitized earthworks lying across a riverbed in West Central Mojos dataset. Forest islands are represented by the patches of bright green on either side of the drainage (see Figure 6 for a visual of non-delineated features) ......................................................................................................................... 42

Figure 3. Figures 1-3 from Erickson (2000:191-192) showing (a) a map of the Baures Hydraulic Complex; (b) the northern and southern survey blocks encompassing zigzag structures and ponds; and (c) an oblique photograph of a fish weir running from bottom left to top right and scattered pond depressions ........................................................................................................... 43

Figure 4. Map of Erickson’s (2000:192; Figure 4) purported study area, depicting fish weirs (irregular lines) and causeways (straight lines) in Baures based upon aerial photographs. McKey et al. (2016) mention an error in the scale bar ............................................................................................................................... 44

Figure 5. Three plan drawings of fish weirs in Baures, showing small parallel openings every 50-200 m (Erickson 2000:193; Figure 5). McKey et al. (2016) find weirs with larger “V-shapes” nearby; however, these lack the parallel openings shown here ............................................................................................................................... 45

Figure 6. Maps of Llanos de Mojos and West Central Mojos from left to right located within the Madeira River and Amazon basins (reprinted with permission from Walker (2018:2; Figure 1.1). ....................................................................................................................................................... 46

Figure 7. Inset from Figure 1, displaying forest islands and the non-delineated features running perpendicularly between them ....................................................................................................................................................... 47

Figure 8. Original zigzag feature of the West Central Mojos dataset. Located next to the forest island Isla Flores in the Kinato Wetland ....................................................................................................................................................... 47

Figure 9a-b. A single zigzag feature crosses an inactive river channel (a and b). The delineated feature is shown on the left; only the larger zigzags are digitized. The non-delineated feature is shown on the right. Cattle trails can be seen below, above, and left of the feature. These are non-beveled dirt pathways used by herds to reach water reservoirs and ranches (out of frame on right). They are straighter in appearance and overlap as they near the destination .............................................................................. 48

Figure 10. Feature from Figure 9 shown at a larger scale. No other earthworks detected around it despite its location along a river channel. Other features shown include a ranch (immediate right of earthwork) and cattle trails (as seen around elevated land to lower right on image). Elevated pieces of land may have once been forest islands; however, modern development has significantly altered the pre-existing landscape and makes feature digitization a complex task. 48

Figure 11a-b. Network of delineated features, intersecting one another in a perpendicular manner (above). This complex is an interesting collection of features, which seem to arrange themselves in an almost grid-like pattern. Non-delineated versions of the features are shown at greater magnification below. Here, they cross the saturated savanna and connect a forest island to
a neighborhood of raised fields. Barbell-shaped patch of earth in both images represents a modern feature associated with cattle ranching. ................................................................. 49

**Figure 12a-b.** Network of delineated features, intersecting one another at various angles (above). Compared to Figure 11a, this network is more abstract and appears web-like in its design. A non-delineated subset of these features from the northeast corner of Figure 12a is shown at great magnification below in Figure 12b. Again, features cross over flooded terrain and intersect several forest islands. ............................................................................................................................. 50

**Figure 13.** Histogram displaying length of feature polylines in the West Central Mojos dataset as well as measures of central tendency and variance. Y-axis represents the frequency of features in each class. Classes are displayed on the X-axis and represent length in meters of each feature. The distribution is skewed to the right, indicating that most of the features in the region tend to be shorter than 1,000 m; however, there are several exceptionally long ones that skew the graph. Approximately, 300 features range between 230-300 m, which is significant as this frequency approaches almost half of the total earthworks. The minimum length for an earthwork is 31 m and the maximum is 3,013 m, or three kilometers. In regard to the first, second, and third quartile values, 25% of the dataset falls below 194 m, 50% of the features are shorter than 333 m, and 75% have values lower than 557 m. Hence, three-quarters of the dataset barely hits half a kilometer. Lastly, the average length for a zigzag earthwork is about 430 m, but this must be considered alongside a relatively high standard deviation. Standard length is influenced by several outliers. ................................................................................................................................... 51

**Figure 14.** Screen capture of the West Central Mojos dataset attribute table. Shown are the first several hundred entries of the mapped features. Each entry contains identifier and administrative information and is coded for all eight attributes listed in Table 1 (right). .................................................................................................................................. 52

**Figure 15.** A split feature crosses an active river channel. In cases like these, features on opposite sides of drainage feature are obvious halves of the same feature; however, their connection is obscured either by erosion, excessive vegetation, or water in this case. All three cases fulfill the Code_SAD attribute. ................................................................................................................................... 53

**Figure 16.** Distribution of causeways in West Central Mojos dataset. Selection highlighted in blue. Outlier features not shown. .................................................................................................................................. 54

**Figure 17.** Distribution of causeways in northeast group. ..................................................................................................................................... 55

**Figure 18.** Distribution of causeways in southwestern group. .................................................................................................................................. 56

**Figure 19.** Distribution of dams in West Central Mojos dataset. Outlier features not shown. ................................................................................................................................. 57

**Figure 20.** Distribution of dams intersecting other dams in southwest group. .................................................................................................................................. 58

**Figure 21.** Aerial view of a neighborhood of agricultural earthworks next to dams. ...................................................................................................................................... 59

**Figure 22.** Distribution of fish weirs in West Central Mojos dataset. Some outliers shown. .................................................................................................................................. 60

**Figure 23.** Distribution of "stacked" fish weirs in West Central Mojos. .................................................................................................................................. 61

**Figure 24.** Venn diagram depicting the distribution of West Central Mojos earthworks in each of the functional profiles. For example, there are 343 earthworks that have all of the primary attributes of a fish weir, causeway, and dam. Additionally, because every fish weir impounds water, there are no weirs or weir/causeways that do not function as dams. Most causeways also function as both dams and fish weirs. .................................................................................................................................. 62
Figure 25. Locations and boundaries of the Mamoré and Southwest feature concentrations. .... 63

Figure 26. Cultural components and boundaries of northeastern Mamoré group. ..................... 64

Figure 27. Distribution of multi-functional features in northeastern group. Each highlighted earthwork fulfills the primary attributes for the three functional profiles: connecting infrastructure, impounding water, and trapping fish................................................................. 65

Figure 28. Distribution of multi-functional features in northeastern group. Each highlighted earthwork fulfills the primary attributes for the three functional profiles: connecting infrastructure, impounding water, and trapping fish................................................................. 66

Figure 29. Cultural components and boundaries of Southwest group........................................ 67

Figure 30. Distribution of multi-functional features in northeastern group. Each highlighted earthwork fulfills the primary attributes for the three functional profiles: connecting infrastructure, impounding water, and trapping fish................................................................. 68
LIST OF TABLES

Table 1. Classification Procedure and Definitions Table: Describes how West Central Mojos features were classified in ArcMap. The first column denotes the kind of qualification as well as its attribute table field name. Second column refers to the way in which an entry can be coded for each qualification, including yes, no, one, both, and N/A. The final column describes exactly how an entry can qualify for a code based on its physical shape, appearance, or relationship with nearby features. ................................................................. 70

Table 2. Functional Profiles Table: Describes the attributes that qualify features for specific roles in West Central Mojos. Depending on its physical or relational properties, an attribute may be essential to a feature’s classification or it may provide secondary or even tertiary support for that classification. ......................................................................................................................... 73

Table 3. Quantitative Results for Individual Attributes: Reports the number of features out of 831 that satisfy each, individual attribute. Depending on the attribute, features could be classified under two or three different codes. .......................................................................................................................... 74

Table 4. Results for Attribute Combinations: Reports the number of features that satisfied the primary, secondary, and tertiary attributes of each functional profile as well as results for the non-exclusive combinations of different attributes. Primary + Secondary, for example, provides the number of features that satisfied secondary attributes as well as primary ones for each functional profile. Only combinations of interest are elaborated in the text. ........................................ 75

Table 5. Results for West Central Mojos Areas of Interest: Reports the number of earthworks within the northeast and southwest areas of interest (AOIs) that are designated causeways, dams, fish weirs, or multi-functional features based on the primary attributes they possess. Also states the percentage they make up of the total dataset. ........................................................................................................ 76
CHAPTER ONE: INTRODUCTION

Using satellite imagery of the Bolivian Amazon, in 2019 a new network of pre-Columbian earthworks was identified in the floodplain region of Llanos de Mojos. These features lie west of the Mamoré River, near two of its tributaries, the Yacuma and Omi Rivers (see Figures 1 and 2 in Appendix A). Currently, this network of structures is being mapped by research volunteers of the Proyecto Sistemas Informaticas Geograficas y Arqueologicas del Beni (ProSIGAB), and they have been tentatively classified as fish weirs—linear earthworks built in rivers or deltas, designed to trap fish by exploiting seasonal floodwaters.

This preliminary identification stems from the similarities they share with the hydraulic earthworks that were studied in the nearby region of Baures by archaeologist C.L. Erickson in the late 1990s (Erickson 2000; McKey et al. 2016; Blatrix et al. 2018; Figures 3-5). Both complexes present structures that cross low-lying wet savannas, often connecting adjacent forest islands. They also appear zigzag in shape and are easily distinguished from the straight causeways that run across the landscape. Interestingly, however, digitization of these linear features within the ESRI platform ArcGIS Online resulted in a varied dataset. In other words, they do not all appear to be the fish weirs that Erickson (2000) identified. This introduces the possibility that this set of earthen features has other functions that have not been identified.

Of great importance is the fact that these features do not exist in isolation just like many other artificial earthworks in Mojos (Walker 2018). In fact, groups of these earthworks can be found in direct association with raised and mounded agricultural fields discussed by Walker (2018), Lee (2017), Martin (2018), and Denevan (1966). This raises other questions about the
role of these earthworks within a wider anthropogenic environment. Why were they constructed? How did they function for the peoples living in Western Mojos?

The Cayuvava and Movima linguistic groups, specifically, are noted as occupying West Central Mojos; however, archaeological data is not yet precise enough to confirm if these were the pre-Columbian groups responsible for constructing the newly identified landscape features (Walker 2018:158-159). Additionally, there are no ethnohistorical sources that mention fish weir use within this area. Populations along the rivers such as the Mojo, Baure, and Canichana relied on fishing more than hunting, but the Mojo was the only group documented using weirs, which have not been located or studied since then (Denevan 1966:109; Block 1994:24; Metraux 1943). Nevertheless, if the same riverine environments existed in the Cayuvava and Movima regions, these groups might have depended on fishing and erected similar weirs that were not located by ethnohistorians.

Thus, it is apparent that these features have not been identified before (much less studied) by the archaeological community. As a result, this study conducts a GIS-based analysis of these earthworks using feature classification. The guiding objective is to use the dataset digitized by ProSIGAB to discover how these zigzag features functioned for populations living in the Bolivian Amazon. Are there discrete, identifiable types? What kinds of patterns do they demonstrate that relate to their hydrological or transportive role? How did pre-Columbian inhabitants manipulate the complex environment of Western Mojos into a functional taskscape that produces food, allows for transportation, and manages water?
CHAPTER TWO: BACKGROUND

Physical Landscape of Llanos de Mojos

Llanos de Mojos is a humid, savanna region spanning approximately 110,000 km² in the Bolivian Amazon (Figure 6). This environment features a stable, hot and humid climate and is characterized by strong, predictable cycles of drought and flooding (Walker 2008:927-928). Mojos receives this flooding due to its position within the Madeira River basin, a large drainage system that sits between the Andes mountain range and the uplands of the Brazilian Shield (Denevan 1966:6). As a major tributary of the Amazon River, the Río Madeira receives approximately 15% of its discharge, and the Mamoré tributary, the central river in Mojos, receives 4% (Wildlife Conservation Society 2020). Consequently, the Madeira River basin produces a wet landscape in Mojos that is scarred with active and abandoned river channels in addition to many other hydrological features such as lakes and swamps. For example, it is estimated that there are over several thousand lakes within the basin, ranging up to 200 mi² in size (Denevan 1966:8).

Despite the humid climate, the region is subjected to seasonal changes in precipitation. Droughts are a common occurrence from May to September; however, starting in November, rains begin to fill the rivers of Mojos, such as the centrally located Mamoré. With anywhere from 1,500 to 1,800 mm of precipitation annually, tributaries quickly back up and flood much of the surrounding savanna by December (Denevan 1966:8-9). In addition, poorly draining clay loam soils and minor topographic relief cause this flooding to become semi-permanent standing water.
Elevations in the region only vary between 150 and 170 masl, so even relatively higher terrains can still see 20 to 30 cm of overflow (Walker 2008:928-929). The unique combination of topography and hydrology leads local inhabitants to describe the wet season as a mixture of “water from above” and “water from below”—inundation from all around (Walker 2018:117).

About 80% of Mojos floods each year, meaning that every aspect of the physical landscape is affected from soils to vegetation, wildlife, and human habitation (Denevan 1966:11-13). For example, there are several distinct environments in Mojos that range from wet forests and savannas to dry forests and savannas (Walker 2008:929). Wet savannas are relatively low and poorly draining areas that are underwater half the year. As a result, they produce grassland, or *pampa*, vegetation as few tree species can tolerate the extremes of flooding and drought. Wet forests are found along the sloping banks of rivers in *galerías*. These contain economically useful trees such as Brazil-nut and wild rubber and remain submerged for a significant part of the year. Typically, dry savannas are found in elevated and well-drained areas such as river levees and forest islands and are susceptible to burning during the dry season (Denevan 1966:15-16; Walker 2008:929).

The final component of this complex landscape are the islands of dry forests, which are easily recognized on satellite imagery as concentrations of trees in an otherwise open landscape (Figure 7). Langstroth (1999:6-8) finds that these *islas* are formed through multiple natural and artificial means, including the fragmentation and erosion of ancient levees and anthropogenic mounding. These landforms, which total several thousand in West Central Mojos alone and average 7 ha, have provided refuge and resources to both modern and prehistoric inhabitants since the Mojos was first occupied 10,000 years ago (Lombardo et al. 2013). Reconnaissance
studies conducted by Walker (2018:41-43) found that 75% of the surveyed islands showed evidence of permanent pre-Columbian habitation, evidenced by thick layers of anthropogenic soils and ceramic deposits. Based on these estimates, seasonal flooding has implications for the cultural landscape within Mojos, and populations living in this wetland savanna for thousands of years were likely active participants in the environment.

Cultural Landscape of Llanos de Mojos

The first ethnographic accounts of prehistoric peoples in Mojos were written by Spanish explorers, soldiers, and missionaries, beginning in the late sixteenth century (Denevan 1966:2). Spanish interest in the Bolivian Amazon initially developed because of a desire to locate the legendary city of gold known as El Dorado, which was likely founded on anecdotes of the Inca empire located in the Andes (Metraux 1943:3). However, these early expeditions were quickly abandoned because of un navigable terrain, mosquitos, and ‘savage Indian chiefdoms’ (Denevan 1966:1). Eventually, exploitation and conversion of these large indigenous populations became the focus of Spanish involvement in Mojos (Block 1994:31-33). From 1631 to 1667, Denevan (1966:30, 116, 1) found that slave-raiding missions originating from Santa Cruz became a prominent risk for the estimated 112,000 Native Americans living on the savanna. By the time the region fell under the administration of the Jesuit Order in 1668, enslavement was a very real threat. Jesuit missionaries proceeded to round up the dispersed indigenous villages and established 21 mission towns where native cultures were repressed and replaced with dominant languages, new political and settlement patterns, new crops, new crafts, and new traditions (Denevan 1966:31; Metraux 1994:41-42). This process, along with the epidemics brought by
Europeans, contributed to a major depopulation of the savanna (Metraux 1943:1-2). Jesuit missionaries of the time remain the primary source of information on this region and its peoples during the contact period (Metraux 1943:4-5).

In his review of these missionary accounts, Denevan (1966:40) identified six distinct linguistic groups that were encountered by the Spanish in the floodplains: the Arawakan Mojo, Baure, Cayuvava, Movima, Itonama, and Canichana. According to Jesuit sources, these savanna groups were multiethnic and multilingual and were organized into small but densely populated political units that occupied, farmed, and fished Mojos (Denevan 1966; Block 1994; Metraux 1943; Walker 2018). Europeans also noted during contact that these groups were remarkably well-adapted to the complex, semiaquatic environment they lived in. During the wet season, for instance, these indigenous societies utilized canoes for all transportation, built elevated barbeque pits, and slept in hammocks hung above the floodwaters (Block 1994:23). However, ethnohistoric accounts are limited in that they cannot describe the pre-Columbian peoples of Mojos, or Mojeño, that occupied the region for thousands of years prior (Walker 2018:2).

The hallmark of these groups and their predecessors was their participation in major community drainage projects that made settlement, agriculture, transportation, and water management possible within the seasonally flooding savanna (Denevan 1966:45). This resulted in the creation of permanent earthworks across the extent of the floodplains. Interestingly, however, explorers and Jesuits do not mention savanna farming or artificial features in their accounts (Denevan 1966:95). Thus, interpretation of these features requires archaeological research.
Archaeological literature on the prehistoric anthropogenic landscape in Mojos began in the early twentieth century with Erland Nordenskiöld, who excavated several large mounds outside of Trinidad and studied material culture from across Mojos (Nordenskiöld 1913). Of primary interest to this project is the monograph published by William Denevan in 1966, which analyzed pre-Columbian Mojos in relation to its artificial earthworks. His work was attempted to understand how such large populations were sustained in a seasonally flooding savanna environment. This book had a profound impact on the kind of work being conducted in Mojos and drew attention to the role of artificial earthworks in pre-Columbian life. As a result, many recent archaeological studies have focused on shape, purpose, extent, and patterning with respect to raised, mounded, and ditched fields, canals, causeways, ring ditches, and fish weirs (Blatrix et al. 2018; Denevan 1966; Dougherty and Calandry 1981; Erickson 1980, 1995, 2000, 2006, 2010; Erickson and Walker 2009; Lee 2017; Lombardo 2010; Lombardo, Canal-Beeby, Fehr, and Veit 2011; Martin 2018; McKey et al. 2014; McKey et al. 2016; Prümers et al. 2006; Rapoport 1990; Walker 2008, 2011a, 2011b, 2018; Whitney et al. 2014).

One of these studies, for example, notes that these types of earthworks are never found in isolation. Walker (2018:123-126) identifies seven patterns of pre-Columbian structures in Llanos de Mojos, which equate to cultural landscapes that were produced by unique histories and ecologies and that encouraged different kinds of community activity. In the southwestern region of Mojos, for instance, there is a collection of raised fields, causeways, and canals covering about 50,000 km² of savanna (Dougherty and Calandra 1981; Erickson 1980). These raised fields, which can be found in groups called neighborhoods, are approximately 5 m wide, 50 m long, and 1 m in height. They demonstrate the creativity of the prehistoric populations and the
productive potential of the landscape because they allowed communities to participate in intensive agriculture while minimizing the risk of crop failure caused by floodwaters. Their solution raised planting beds and navigated floodwaters into nearby ditches (Walker 2018:123; Walker 2008:930-931; Martin 2018). Adjacent ditches, or canals, permitted water management and transportation via canoe, and associated causeways acted as ancient roadways, which run for more than 10 km and connect forest island settlements (Walker 2018:123; Denevan 1966:89).

Thus, within this landscape, groups were able to cultivate crop surpluses despite seasonal flooding and use canals and causeways to efficiently navigate between settlements, fields, and other resources (Erickson and Walker 2009). This description demonstrates not only how earthworks were used in the Bolivian Amazon, but it also exemplifies how pre-Columbian populations transformed a complex landscape into a multi-faceted and life-sustaining, built environment. Additionally, environments like these vary across Mojos; hence, not everyone will contain the same types of features. For example, the landscape currently under investigation in West Central Mojos consists of mounded and raised fields and what may be fish weirs.

Fish Weirs in the Bolivian Amazon

Of the different earthworks present in Mojos, this project focuses on fish weirs, which are traditionally defined as “any structure constructed in water and acting as a funnel or barrier to direct fish into a trap or enclosure or to entrap fish behind it, where they can be easily harvested (Connaway 2007:5). Prehistorically and historically, indigenous communities all over the world have employed these structures as valuable pieces of localized infrastructure capable of
providing a stable source of dietary protein (Beveridge and Little 2002; Connaway 2007; McKey et al. 2016; Greene et al. 2015; Huchzermyer 2012; McNiven et al. 2010). How weirs are built depends on the hydrological, geographic, and topographical setting, intended function, the kinds of fish to be harvested, and the construction materials available. These can include stone, cane and rushes, logs, brush, wooden stakes, and earth (Connaway 2007:5-8; Erickson 2000). A complete review of the various weir networks discernable in the world today is outside the scope of this thesis (for a detailed assessment see Connaway 2007); nevertheless, the weirs of the Baures Hydraulic Complex, an immense system of earthworks between the San Joaquin and San Martin rivers (Lee 1995; Erickson 2000; McKey et al. 2016; Blatrix et al. 2018), must be considered as they predict how other weirs in Mojos might appear and function. Below is an overview of the relevant literature.

C.L. Erickson was the first to conduct research on fish weirs within Baures and the wider Mojos, and a synopsis of this work was published in 2000. He identifies this earthwork in a northern and southern block of savanna (measuring 447 km² and 77 km², respectively) “on the basis of form, orientation, location, association with other hydraulic works and ethnographic analogy” (Erickson 2000; Figure 3b). Excavations were not carried out on the weirs themselves but on an associated causeway (Erickson et al. 1997). Within a smaller, 16.76 km² zone (Figure 4), Erickson defines the linear earthworks as 1-2 m wide and 20-50 cm tall, stating that they zigzag across the savanna connecting adjacent forest islands with some stretching as far as 3.5 km. The hallmark of these features is their shape. Zigzags are created by V-like contours that interrupt the lengths of the earthworks. These occur every 50-200 m and are approximately 1-3
m long and 1-2 m wide with small funnel-like openings at the points of the V-shapes (Erickson 2000; Figure 5).

With no evidence of agriculture and seemingly inefficient for transportation, Erickson argues that the earthworks were suited for managing and harvesting fish, especially when understood in the ecology and hydrology of the Baures environment. Heavy rains of the wet season give fish wide mobility over the savanna, however, as water levels begin to drop after May and fish begin to migrate toward deeper areas, they become trapped between the earthworks and are funneled into V-shapes where they are caught, presumably in basketry or netting (Erickson 2000; Figure 7). Erickson also purports that nearby ponds (10-30 m in diameter; Figure 3c) may have been used to retain water, keep fish alive, and raise snails. *Mauritia flexuosa* palms, which favor the elevated earthworks, may also have been cultivated for their fruits and fibers. Ethnographic accounts and radiocarbon dates of charcoal from the associated causeway suggest that this enhancement and management of seasonal aquatic resources was built and maintained by small kin groups and communities prior to the arrival of the Spanish around AD 1700 (Erickson et al. 1997; Erickson 2000).

Erickson’s work was later revisited by McKey et al. (2016) who endeavored to prove that a modern analogue to the Baures Hydraulic Complex does exist despite Erickson’s inference that no comparable present-day system is both permanent and used in seasonal bodies of water. However, this disagreement likely stems from the fact that Erickson’s interpretation of the Baures features is based more on ethnohistoric information than that of McKey and colleagues whose work is more ecological in nature and, thus, searches for such ecological analogues.
In their paper, McKey et al. (2016) discuss ethnographic work done by C.F. Huchzermyer (2012; 2013) on a network of fish weirs lying within the Bangweulu floodplain in Zambia (see Figure S3 in McKey et al. 2016), an environment almost identical to the one found in Bolivia but 13 times larger (15,000 km). By comparing the two networks using GIS and Erickson’s study from 2000, the project finds that they share similarities pertaining to their exploited environments, the dimensions of the weirs, the materials used in their erection, and the type of labor that was responsible for modifying the landscape. Based on Huchzermyer’s (2012) productivity estimates, these fisheries are shown to be highly productive yet also sustainable due to the fact the juvenile fish caught in the weirs would not have survived the competition and predation of their first dry season; therefore, the fisheries have no negative effect on the population. This results in long-term use and inheritance of these structures across generations, and it is what makes their construction in this environment a valuable investment. By identifying considerable parallels in the ecology and cultural significance of each, McKey and colleagues (2016) provide a much-needed ethnographic analogy to support Erickson’s conclusions that the zigzag earthworks in Baures are indeed fish weirs.

While McKey and others focused exclusively on comparing Erickson and Huchzermyer’s work, Blatrix et al. (2018) was the only other paper to conduct an independent investigation on fish weirs in Llanos de Mojos. This analysis focused on the large-scale spatial organization of a sample of weirs in Baures in order to discern their functional role within the pre-Columbian landscape. After conducting fieldwork in two sub-basins within Erickson’s northern block, they were able to determine the existence of a different type of fish weir within Baures. Weirs with V-shapes much larger and wider than those Erickson (2000) studied (approx. 30 m long and 39 m
wide) were found to be significantly associated with ponds placed just upstream of their V-features. In addition, because 90% of the weirs studied did not have openings in these V-shapes, the authors argue that bottom-hugging fish would migrate downstream as the dry season carried on and would concentrate and become trapped in these strategically placed ponds where they would remain until needed instead of being initially caught by baskets and manually moved elsewhere (Blatrix et al. 2018). Their work reveals new insights into how Mojeño peoples made productive use of a niche environment.

Research conducted at pre-Columbian fisheries in Loma Salvatierra excavated species characteristic of shallow and stagnant, dry-season water, suggesting what kind of fish remains might be found at West Central Mojos (Prestes-Carneiro et al. 2019). More than 17,000 fish remains and 35 taxa were discovered in a network of walled ponds and canals, which were associated with fishing activities from AD 500 to 1400. Dominant fish include swamp eels (*Synbranchus* spp.), armored catfishes (*Hoplosternum* spp.), lungfish (*Lepidosiren paradoxa*), and tigerfish (*Hoplias malabaricus*). Additionally, excavations conducted by Blatrix et al. (2018) within one of the Baures ponds revealed a burrowed swamp eel about 1 m below the ground surface. Remains of these species are the most abundantly found fish at archaeological residences in Baures despite not being consumed by locals today. Like the other species noted above, these eels survive the dry season in moist soils. Put into a fishing context, they become the next logical resource as ponds dry up and fish die (Prestes-Carneiro et al. 2017). A more recent study in Loma Salvatierra used sclerochronology (season of capture) to investigate when the marbled swamp eel (*Synbranchus marmoratus*) was harvested by pre-Columbian inhabitants (Prestes-Carneiro et al. 2021). By analyzing the growth rings in their vertebrae, they found that
eels were collected all-year-round, suggesting that they were not just a seasonally exploited resource and that the fishing complex was used year-round.
CHAPTER THREE: THEORETICAL FOUNDATIONS

The modern theoretical approaches to Amazonian archaeology contrast the previous perspectives that dictated how researchers viewed life in the Amazon. Betty Meggers, a prominent Amazonian archaeologist, employed a Malthusian perspective of nature wherein nature limits the size and complexity of the populations that occupy it. Over time, societies in this region could reach a precarious balance with a harsh environment but only because of their in-depth understanding of it, which allows them to survive and adapt (Meggers 1954, 1971). Her perspective was rooted in Leslie White’s (1951) thermodynamic law of culture where energy times technology yields cultural product. However, in contrast to Lathrap (1970), Erickson (2008), and Balée (1998), Meggers perceived a disparate relationship between humankind and the natural world where inhabitants were always fighting against the harsh realities of climate, hydrology, and plant and animal life.

Meggers’ perspectives did not take into account the gradual and robust interrelationships between pre-Columbian populations and their environments. For example, generations of work and experience in West Central Mojos produced not only productive landscapes but also dense populations. Small forest islands were estimated to be home to 50-100 people and large islands could have held as many as 1,000-2,000 (Walker 2018:120-121). Walker also estimates that 75% of the 2,000 islands were occupied; thus, a quick calculation this project makes using his statistics estimates a total population of half a million.
A perspective that better aligns with the pre-Columbian evidence is held by Robert Netting (1993) who analyzed the agricultural efficiency and conservation of resources practiced around the world by smallholders, farmers who practice intensive, permanent, and diversified agriculture on relatively small farms in areas of dense population. These smallholders tended to produce more per unit area than large farms in the same region, and they did so with greater efficiency and less environmental degradation. The larger unit of smallholders is the household, which coordinates labor, regulates consumption, produces most of its own subsistence, and participates in a marketplace. Applied to Llanos de Mojos’ anthropogenic landscapes, we can see how dispersed villages could not only create their own landscapes but also how they could produce surpluses and increase populations. Elinor Ostrom (1990) points to multiple ethnographic and historical case studies of communities managing common-pool resources over multiple generations, which disproves the prevalence of Garett Hardin’s (1968) infamous concept “Tragedy of the Commons” where individual households are said to act selfishly, increasing their own productivity by overusing or damaging the commons. Common resource management would be an important component of societies whose lifeways relied on the productivity of their commons.

The intensive aquaculture described by Erickson (2000), McKey et al. (2016), and Blatrix et al. (2018) is an example of common-pool resource management. It is a complex of infrastructure that was built and managed by a community of people, and its operation was made possible through seasonal flooding. After the initial labor investment was made through recurring work parties, the landscape could be sustainably managed for generations as long as it was regularly maintained (Erickson 1988; Netting 1993; Walker 2001). This would include
dredging, reshaping, cleaning, and repairing the fisheries where and when necessary (Connaway 2007). The Mojeño altered the terrain in such an intensive way that it made it easier for them to subsist off their land, showing that productivity is not limited by the complex Amazonian environment. In fact, under the right kind of management, populations can make it more productive than before (Balée 2002). Balée and Erickson (2006) make this argument in relation to agriculture, and Erickson and Walker (2009) apply the same ideas to causeways and canals. The term landesque capital has come to represent these human phenomena (Brookfield 2001:55). It refers to developments in earthly infrastructure that endure beyond the season and allow populations to thrive in environments that Old World Europeans considered hostile.

Over time and through the work of many generations, the unique combinations of landesque capital produced anthropogenic landscapes. To Ingold (1993), the precise term is taskscape, and it represents the connection between a series of landscape features, a community, and the tasks they undertake together, which are afforded by and create the built environment (Walker 2018). Within Mojos, Walker (2011b) interprets these tasks as being divided into six types: farming, construction, hunting, water control, fire control, and transportation. Therefore, the patterns of earthworks discussed by Walker (2018) make up intricate taskscapes where their existence results from and allows for community activities and subsistence. Such a taskscape might also be found in Western Mojos with the recently identified features playing an inextricable part.
CHAPTER FOUR: THE WEST CENTRAL MOJOS DATASET

This project identifies the multi-functional nature of a series of pre-Columbian earthworks that were recently identified in Western Mojos. The first feature to be identified was located on the outskirts of a forest island called Isla Flores in the Kinato Wetland (Figure 8) and presented as a relatively linear earthwork that changed direction multiple times at a sharp angle. After further investigation, many more features were found and ProSIGAB volunteers began mapping them on ESRI’s ArcGIS Online suite. Currently, the shapefile covers roughly 4,000 km² of floodplain and contains over 1,000 polylines mapped on multi-banded satellite scenes with resolution up to 0.5 m in some areas. Significant variation in the dataset results from ProSIGAB’s public mapping efforts, a fluctuating floodplain environment, and physical differences between weirs.

Public Mapping with ArcGIS Online

Twenty years ago, the main means of surveying and mapping artificial earthworks in Mojos was by using a series of aerial photographs and Xeroxing them to magnify earthworks (Erickson 1995). Researchers in Mojos lacked the gathering, managing, and analyzing powers of a modern geographic information system (GIS). While these systems still leave room for error, they enable today’s researchers to conduct a substantial amount of work while remaining organized. Today, ProSIGAB volunteers utilize ArcGIS Online to map earthworks in Llanos de Mojos. This web-based GIS confers both advantages and disadvantages.
Because ProSIGAB is a public mapping effort, the large datasets of Mojos can be digitized with relative efficiency (Goodchild 2007; Cohn 2008; Silvertown 2009; Haklay 2013). However, each volunteer must have access to the dataset they are communally working to create. ArcGIS Online allows for user collaboration, meaning that several people can edit one shapefile at the same time. The platform is still relatively new, however, which means that some functionalities are limited, but updates are likely already on the way. For example, shapefiles that are actively being edited are not automatically refreshed every several seconds, leading volunteers to accidentally map the same areas. Other parts of the platform could benefit from streamlining. For instance, in order to place a point over an earthwork, a volunteer must click the ‘Add Point’ button on the side of the screen each time they wish to do so. Nevertheless, it is still a faster process than before, especially when the target dataset is several hundred thousand earthworks.

Furthermore, features are mapped against the ESRI-managed World Imagery Layer. This basemap represents a mosaic of high-quality satellite imagery with minimal cloud cover. Satellite imagery is picked based on the percentage of cloud cover and color, and then it is subsequently stitched together. Unfortunately, this is not a seamless process. Good imagery is available at different points in time and the state of the environment is always in flux, meaning that landscape features vary from patch to patch of the World Imagery quilt. Furthermore, this basemap is corporately managed, and it takes a dedicated search to find which satellites and dates imagery was taken from or in. Interestingly, ESRI mentions the use of SRTM data in its description of the South American portion of the basemap, but to find the correct metadata of any specific scene, users must access the Wayback Imagery service, a digital archive for the
World Imagery basemap. Here, users can view every version of the basemap, and by clicking on the scene of a precise area, the imagery company and satellite information is provided along with the resolution and accuracy. The majority of the West Central Mojos dataset appears to have been digitized on the 2019-04-03 version of the basemap, which was assembled with satellite imagery taken in 2015-2016 by the Worldview-2 (not SRTM). This satellite provides ESRI with high resolution (up to 0.5 meters), 8-band multi-spectral imagery and it was launched in October of 2009 by Digital Globe. Unfortunately, the World Imagery basemap is updated without notice. Updated imagery allows volunteers to find new features that previous versions did not reveal, but it makes systematic mapping of any one region impossible as volunteers do not know which sections have been updated and when unless they check the Wayback archive before digitizing every feature. This also implies that the task of mapping an area is never finished because there is always the possibility of finding new earthworks.

Along with these technical disadvantages, there are a few, inevitable limitations that accompany volunteer-based GIS mapping projects. First, the imagery is never as perfect, and its resolution is never as high as would be preferred. Where fieldwork is not possible, there will be a disconnect between what is seen on the imagery and what exists down on the ground. This has especially been the case while digitizing the novel features of West Central Mojos. The savanna terrain is complex, and sometimes it is difficult to distinguish where a linear feature ends, especially when the basemap in this region cannot magnify past the scale of 1 cm per 40 m. For features no more than a meter wide and zigzags just as small, this resolution renders them invisible.
A second limitation that public mapping projects withstand is that each digitizer perceives features differently (Haklay 2010). Depending on their background and experience with GIS, the region under study, or other public mapping campaigns, a person may miss earthworks that appear obvious to others. This makes consistency difficult; however, it opens the possibility that a volunteer will locate a feature that would have otherwise been missed. Furthermore, the savanna comprises substantial modern activity. Cattle ranches, roads, and fence lines are familiar to ProSIGAB volunteers (Figures 9a-b and 10); however, cattle trails are occasionally mistaken for the zigzag features by new recruits. In fact, these branching pathways often cross over the features that intersect lowlands, likely because the earthworks provide enough elevation to prevent cattle hooves from getting wet. Hence, this landscape represents an often-confusing mixture of modern and pre-Columbian features. It is important that volunteers build familiarity with it in order to best interpret what they see.

Public mapping campaigns, thus, have their advantages and disadvantages. ProSIGAB makes good use out of the advances in online geographic information systems and satellite imagery, but in the same token, the project is at the mercy of ESRI in terms of the software’s online workflow and basemap construction. Similarly, each volunteer’s perspective is an asset; however, it is important to keep the team on the same page while working. Otherwise, the range in physical variation of the dataset may be too great to discern meaningful patterns. Nevertheless, it is because of both benefits and drawbacks that the contents of the dataset do not necessarily match the original feature found in the Kinato Wetland.
A third reason for variation in the dataset comes from the fact that these features are distinct from other features in Llanos de Mojos. They stand apart from the rectangular and circular shapes of raised and mounded fields. They do not possess the blatant linearity of causeways. Indeed, few characteristics reveal their artificial nature: patterned relationships with other features; zigzags (or V-shapes), and a propensity toward clustering in groups. It is unsurprising that these features sat undetected for so long. Mojos is large enough when researchers are not combing grainy imagery of its terrain. When they are, the traditional technique has been to look for straight lines and circles, indictors of manmade structures.

The discovery of the Kinato earthwork would have been incidental to ProSIGAB’s mound field campaign had it not been for its resemblance to the fish weirs mapped by Erickson (2000) in Baures. However, the two complexes are located on opposite sides of the Bolivian floodplain and cannot be directly associated with each other. Consequently, even if they serve the same function, this project does not assume that the earthworks will look the same or display similar spatial organization, especially since the West Central features cover a much larger area than the Baures weirs. Erickson’s study blocks cover only 524 km², but the features themselves span approximately 1,000 km². As a result of these prominent differences, search parameters were intentionally non-specific; the project’s task was to map noticeably non-linear features (with discrete zigzags if possible) that were distinct from the raised and mounded agricultural fields. Because of this, the physical range in this dataset is impressive, even if most objects tend to resemble the Baures weirs in key ways.
In terms of distribution, features are found both as individual occurrences and in groups. For example, the feature shown in Figure 9 is the only one of its kind mapped for 5 kilometers. There are no nearby forest islands or other features such as agricultural earthworks, but it is near a river channel. In contrast, concentrations of earthworks have been regularly found intersecting low-lying depressions, connecting forest islands and neighborhoods of previously mapped raised and mounded fields. Within these clusters, physical relationships between features vary. One concentration immediately west of the Mamoré displays features that intersect both low-lying areas and other features, creating an interconnected grid (Figure 11a-b). Southwest of this group is another collection where features lay strictly parallel to one another as they intersect low-lying areas (Figures 2 and 7). Less than three kilometers away lies another group of earthworks that intersect, but not at ninety-degree angles (Figure 12a-b). Instead, the features create a more abstract web of connections.

Finally, individual appearance varies across West Central Mojos; not only do these features vary in shape because of the wide search parameters but elevation, moisture, vegetation, and soil color are also constantly changing as one moves across the landscape, causing features to look vastly different from place to place. Thus, it is difficult to give a comprehensive report on the dataset’s variation (see Figures 2; 7-11 for examples of dissimilarity), leading to the project’s need to classify them in a more concrete manner.

Regardless of shape or appearance, there is one quantitative attribute that can be reliably measured from feature to feature. This descriptive statistic is length, and it is included in this summary to give the reader an idea of how these earthworks vary in size across West Central Mojos. Figure 13 presents a histogram of feature length in the dataset as well as measures of
central tendency and variance. The y-axis represents the frequency of features in each class, which are displayed along the x-axis and represent the length in meters of each feature. The graph displays a skewed distribution. Out of 831 features in the region, 779 are shorter than 1,000 m; however, there are several exceptionally long earthworks that skew the histogram to the right. Approximately, 300 features range between 230-300 m, which is significant as it is almost half of the total earthworks. The minimum length for an earthwork is 31 m and the maximum is 3,013 m, or three kilometers. Regarding the first, second, and third quartile values, 25% of the dataset falls below 194 m, 50% of the features are shorter than 333 m, and 75% have values lower than 557 m. Hence, three-quarters of the dataset barely reach half a kilometer. Lastly, the average length for a zigzag earthwork is about 430 m, but this must be considered alongside a relatively high standard deviation. Standard length is influenced by several outliers.
CHAPTER FIVE: METHODOLOGY

Feature Verification

An arbitrary stopping point of 1,050 features was selected to begin the classification procedures. First, however, it was necessary to conduct a simplified quality check of the dataset due to the discrepancies in volunteer mapping techniques. Feature entries were reviewed one at a time in their physical contexts. Any structures that were identified as objects other than earthworks were labeled “Low Probability” and not included in the next step of the analysis. Linear features designated as “Medium Probability” and “High Probability” were those most likely or extremely likely to represent novel, earthen features such as, but not limited to, fish weirs like those identified by the Baures studies (Erickson 2000; McKey et al. 2018; Blatrix et al. 2018). These medium and high probability earthworks were then exported to a new shapefile where the methodology occurred. The total features present when classification began was 831.

This step of narrowing down the dataset in addition to the subsequent classification procedures took place within ESRI’s desktop version of ArcMap due to the limited functionality of ArcGIS Online. Despite the strides the platform has made in creating a collaborative workspace for mapping teams, it falls behind in the type and number of analyses that it supports.

Feature Classification

In order to understand the role of these earthworks in Mojeño lives, this project conducted a classification-based use-analysis of the features in ArcMap. Each medium and high
probability earthwork was examined in its surrounding environment and then coded based on its possession or partial possession of eight attributes: intersecting a forest island, intersecting another weir, intersecting a drainage feature, lying stacked against another weir, intersecting a neighborhood of agricultural earthworks, containing zigzags, being associated with a pond-like depression, and splitting across a drainage feature (see Table 1 in Appendix B). These attributes were chosen either because volunteers noticed that they occurred frequently in the dataset or because they would have allowed earthworks to benefit human habitation in the wetland savanna. Furthermore, the attributes were divided into a series of three functional profiles where they demonstrated an earthwork’s purpose(s) in the landscape based on their significance. Functional profiles include connecting infrastructure, impounding water, and trapping fish. The attributes’ weight in each of these profiles is outlined in Table 2 and explained in the next section.

Classification procedures took place within the attribute table of the earthwork map layer (Figure 14). This table contains columns of information, or fields, for each entry: Object ID, Creation Date, Shape Length, level of verification, or notes. The eight traits used in this methodology were also represented by fields. Table 1 reviews each attribute, including field names, field codes, and operational definitions, which permit the replicability of this methodology. Quantitative definitions were used sparingly in defining the attributes. Any arbitrary number produced for the purposes of classification risked separating the earthworks where natural categories did not exist. Definitions were also left nonspecific to compensate for ever-changing earthwork endpoints as well as boundaries among forest islands and drainage areas. This is an effect of erosion and the occasionally bad satellite imagery.
During the classification procedure, mapped entries were reviewed one at a time, and if an earthwork met the criteria of the attribute, the field code or data value of the cell was “Yes” and if it did not meet it, the code was “No”. Attributes that an earthwork partially met received an additional data value (e.g. Q: Is the feature touching a forest island? A: Only one side touches) and some characteristics were non-applicable to certain earthworks (e.g. Q: Is the feature split across a drainage area? A: Not applicable to earthworks that do not intersect river channels).

Weighted Attributes and Functional Profiles

Each observable characteristic of a West Central Mojos feature related something about its intended function(s), whether it was a physical component of the earthwork itself or a relationship with another environmental or manmade feature. In the case of this dataset, attributes of differing weight demonstrated that earthworks functioned to connect infrastructure (forest island settlements, agricultural fields, et cetera.), impound water, and trap fish (Walker 2018:97-100; Table 2).

In support of any one of these functions, a trait’s level of significance was listed as primary, secondary, or tertiary. Primary attributes were considered essential to a feature’s classification as they were foundational to the functional profiles. Depending on the attribute, their presence alone could have proved that an earthwork was used in a certain way; however, their absence would have completely undermined the feature’s ability to perform that function. Secondary attributes provided further evidence to support the function in question; however, each had a reason for not necessarily being present in all earthworks with primary attributes; thus, their absence did not impact job performance. Finally, tertiary attributes provide marginal
support for a feature’s classification under a functional profile; however, these traits are
distanced from the roles they support. Either they were a side effect of the function or only
existed under specific circumstances.

For example, Code_IFI and Code_TNM are the primary attributes for connecting
infrastructure. They represent “intersecting a forest island” and “touching a neighborhood of
agricultural earthworks”, respectively. According to the attribute definitions, when one or both
the endpoints of an earthwork were found intersecting or pointed toward a nearby forest island or
neighborhood of agricultural earthworks, the code for the entry was “One” or “Both” in the
applicable fields. Features that were coded this way are defined as causeways. This is because
both attributes alone could indicate an earthwork’s ability to connect different locations in a
landscape. Moreover, in a floodplain environment where forest island settlements and fields are
separated by drainage channels, causeways would not simply connect places, they would make them accessible via elevated pathways. Additionally, because taphonomical processes could have
deteriorated a cultural feature on the other side of a causeway, an earthwork only needed to
provide access to one visible element of the anthropogenic landscape to meet the requirements.
This functional profile also includes one tertiary attribute, Code_IOW or “intersecting other
weirs”. If a causeway was interconnected with other earthworks, it would strengthen its case for
being an extended road; however, an earthwork is not a causeway by virtue of its position in a
network. The feature must be able to take a commuter to a destination.

A second function for an earthwork was that of a dam or levee. Preventing the flow of
water is a reasonable need in seasonally flooding environments. When the dry season begins,
life-sustaining reservoirs or pools evaporate more slowly. Similarly, barriers placed in strategic
locations can incur the flooding of agricultural fields (Erickson 2006). In either case, the key to this role was a feature’s construction across seasonally inundated terrain such as a riverbed or large expanse of floodplain. In the attribute table, this primary trait is referred to as Code_IDF or “intersecting a drainage feature”. A secondary attribute in this profile is Code_SAD, which refers to a feature that is visibly disconnected from its counterpart on the other side of a channel (Figure 15). During classification, the midsections of these features were not visible for one of three reasons. Either increased vegetation or standing water obscured them or they eroded completely after not being maintained for several thousand years. Either way, this characteristic provides direct evidence that the structure was involved with water; however, not all hydraulic earthworks may have suffered from erosion or vegetative overgrowth. The direction of water flow changes frequently in flat landscapes, so some levees or dams may have been spared. Additionally, a distinction was made between features with a second digitized half and features without a second digitized half (see Table 1). For entries that were designated as dams or levees, the final total had to be divided in half to avoid an overestimation of water-impounding features. In the same token, keeping track of which entries did not have counterparts prevented their total from being needlessly reduced. Lastly, Code_IOW was included in this profile as a secondary attribute. Again, barriers control water flow, but larger spaces would have needed additional, overlapping features to close the area off completely. This trait directly supports the function of a dam, but its presence fluctuates based on where dams were being placed.

The third functional profile was a suite of six fish weir attributes. Several of these traits are derived from the Baures studies (Erickson 2000; McKey et al. 2016; Blatrix et al. 2018). Zigzags or V-shapes were noted as being the key components of these fisheries, despite some
differences in their operation. High water levels during the wet season allowed fish to travel over these weirs unabated, but as these levels began to drop in May, they were forced to swim through the V-shaped gaps into baskets, nets, or even large ponds (where they could also be stored). Because of this, earthworks in West Central Mojos were coded for containing zigzags (Code_CZ) or being associated with nearby ponds (Code_APLD). In fact, zigzags are such a unique trait that any feature possessing them is a designated fish weir. Additionally, because volunteers were specifically hunting for and digitizing weirs with zigzags, it is predicted that nearly the entire database consists of fish weirs. The presence of ponds, however, is a secondary attribute because weir types differ in their dependency on them. If weirs are placed close enough together, fish could be caught and stored in the weirs year-round. This relationship between multiple, parallel features is another secondary attribute of a fish weir (Code_SW). Fishing communities would want to maximize the productivity of high-catch areas, and if the design of the fishing complex does not include ponds for storage, the alternative is to build several features close enough together so that they retain standing water all year.

These three weir-specific traits are supported by the abovementioned hydraulic characteristics, Code_IDF, Code_IOW, and Code_SAD. A fish weir’s location within a river channel or low-lying floodplains is vital to its fish-trapping capabilities; thus, Code_IDF is a primary attribute. Code_IOW; however, is only a tertiary attribute because it is loosely associated with maximizing the productivity of large, seasonally flooding areas. More intersecting weirs means more barriers to retain fish. In addition, the existence of a split earthwork demonstrates a feature’s hydraulic nature, but it only supports the fish weir interpretation if the earthwork possesses the primary characteristics as well.
An earthwork with these six attributes demonstrates not only water control but one that is also oriented toward fishing. Indeed, if groups of these earthworks were identified in conjunction with forest islands and neighborhoods of agricultural earthworks, it would indicate their role as multi-use features. Not every earthwork has necessarily demonstrated each of these functions; nonetheless, when they are taken together, they could present as a new type of anthropogenic landscape not dissimilar from those documented by Walker (2018).
CHAPTER SIX: RESULTS

Results for Individual Attributes

Table 3 presents the quantitative results of the classification procedures. The number of earthworks found intersecting others of the same kind (Code_IOW) was 249 out of 831 classified features. Exactly 582 did not meet the criteria for this attribute. The number of earthworks that intersected drainage features (Code_IDF) was well over half of the dataset; 697 converged with floodplains and river channels while 134 did not. Roughly proportional to this attribute was the number of features found lying parallel to other in groups (Code_SW). Exactly 602 features existed in stacks and 229 did not. The number of features with zigzags or V-shapes (Code_CZ) like those noted by the Baures studies was 788. Only 43 earthworks did not present a chevron pattern or multiple changes in direction. Additionally, 131 were associated with pond-like depressions (Code_APLD) compared to the 700 that were not. Thirty of the features converged with forest islands (Code_IFI) at both endpoints and 193 intersected only one isla; 608 features did not approach or point toward any islands. The sister attribute, convergence with neighborhoods of agricultural earthworks (Code_TNM) found 95 earthworks that connected two fields and 166 that only intersected one neighborhood. Five hundred seventy earthworks were not associated with any agricultural fields. Finally, 130 separate entries had digitized counterparts on the opposite side of their channels (Code_SAD), indicating that 65 different earthworks were divided in half. Ninety-five split features were found without a second digitized
half. Either these halves were not digitized or were not visible on the imagery. Precisely 606 features were not split across drainage zones.

Earthworks as Causeways

This functional profile was centered on two primary attributes that classified features based on whether they provided access to different kinds of community infrastructure. An earthwork could be designated as a causeway for providing access to even one cultural feature; thus, earthworks that did not fulfill both Code_TNM and Code_IFI were causeways. Table 4 displays the numeric results for each of the functional profiles and their various attribute combinations. In it, 416 features intersected either forest islands or neighborhoods of agricultural fields; thus, exactly half of the dataset fulfills the causeway criteria (see Figure 16 for the distribution of causeways in West Central Mojos). Only 68 earthworks connected both types of landscape features. Furthermore, few causeways appeared in remote locations across the survey area. Instead, they existed at a higher frequency in concentrated areas of earthworks, forest islands, and neighborhoods of agricultural fields, specifically the far northeast and southwest groups mentioned in chapter four (Figures 2, 11a-b, 17, 18). The number of causeways that intersected other features (Code_IOW) was 116. Of that amount, only 15 extended causeways connected both fields and settlements.
Earthworks as Dams

Six hundred ninety-seven features met the primary criteria for a dam, crossing a drainage feature. This means that over 80% of the digitized features in West Central Mojos have a hydraulic function (Figure 19). Of that 697, 160 features also met the secondary attribute, Code_SAD, indicating that they were damaged over time or completely overgrown by vegetation. Two hundred thirteen earthworks intersected other features (Code_IOW), allowing for larger areas to be dammed up. Most of these features belonged to the abstract web-like network in the southwest part of the region (Figures 12a-b and 20). Finally, only 56 earthworks met the primary attribute and fulfilled both secondary attributes. Interestingly, about a quarter of the dataset (220 dams) is found intersecting drainage features and neighborhoods of agricultural earthworks. This is suggestive of their use as reservoirs to retain water for crops in the dry season (Figure 21).

Earthworks as Fish Weirs

The two essential traits of a fish weir were possessing zigzags (Code_CZ) and intersecting a drainage feature (Code_IDF). Unlike the requirements for a causeway, features had to fulfill both criteria to trap fish in the manner noted by the Baures studies. The selection tool in ArcMap discovered 668 features with both primary attributes; thus, approximately 80% of the features mapped by ProSIGAB volunteers are defined as fish weirs (Figure 22). Within this percentage, 510 were found stacked together in groups of parallel weirs (Code_SW), which makes up a total of 62% of the database (Figure 23). Only 103 weirs were associated with ponds
(Code_APLD), however. The number of weirs fulfilling both the primary and secondary attributes was limited to 91, barely over a tenth of the dataset. As for the number of features with both primary and tertiary attributes, 214 fish weirs were found split across drainages areas (Code_SAD) and 200 overlapped with other weirs (Code_IOW). Only 51 fish weirs had both tertiary attributes, however, and only nine of those also contained the secondary attributes (see Table 4 for more specific combinations).

**Multi-Functional Weir Groups in West Central Mojos**

Due to the way that functional profiles were designed in this study, there is considerable overlap between features that functioned as dams and fish weirs. Both earthwork types are hydraulic in nature, so this is not a surprising find. Only 29 hydraulic features do not possess zigzags and only 120 zigzag features do not exist within river channels. Thus, if the majority of the West Central Mojos dataset (668 weirs) can be understood to impound both water and fish, the last role these features could have is that of a causeway. Figure 24 displays a Venn diagram that shows the frequency at which earthworks fulfilled multiple functions. It is shown that the majority of causeways in West Central Mojos were also fish weirs and dams. This means that important destinations in Mojeño landscapes were often separated by drainage channels. Furthermore, there are 0 earthworks that only functioned to trap fish because a mound in a drainage channel is also going to impound water. Hence, every classified fish weir is also a dam. However, what is interesting is that there are very few cases (17) where water controlling features, or dams, did not trap fish. Finally, there are 343 earthworks in Mojos that fulfill every
profile. They make up 41% of the dataset. There are two concentrations of weirs in West Central Mojos where the overlap in earthwork function is significant (Figure 25).

Case Study 1: Mamoré Area of Interest (Far Northeast Group)

Less than 10 km west of the Mamoré River lies a dense concentration of cultural features. This includes forest islands, raised fields, and features from the West Central Mojos dataset. Figure 26 depicts the contents as well as the arbitrarily defined boundaries for this area of interest, which covers approximately 30 km² of terrain. As noted previously, this area of interest was noted before classification methods were applied. This is due to the unique relationship between many of the features, which intersect each other, often at perpendicular angles. There are 80 features within the area, and interestingly, the results of the classification analysis show that the number of earthworks fulfilling the primary attributes of each functional profile is approximately 11% of their respective totals even though the area of interest only has 10% of the total weirs in the region (Table 5). For example, the Mamoré area of interest contains 47 of the 416 causeways in West Central Mojos. Additionally, 76 earthworks cross drainage features as dams, and 74 of those also contain zigzags, designating them as fish weirs. Furthermore, there are 45 features in the area of interest that meet the primary attributes of all three functional profiles, demonstrating that they fulfill the roles of causeways, dams, and fish weirs (Figure 27). This is about 13% of the total number of multi-functional features (Figure 28).

Case Study 2: Southwest Area of Interest

The second and far larger concentration of features sits on the extreme southwestern edge of the West Central Mojos dataset. This area of interest contains forest islands, mounded fields,
and 285 digitized features within 297 km² (Figure 29). As a result, this is the largest concentration of these earthworks within West Central Mojos, and it consists of both southwestern groups discussed within chapter four: an extended “stack” of earthworks intersecting the main drainage channel as well as the web-like network of intersecting features to the southwest. Despite these two areas representing distinct networks, they are close enough to have been used by the same groups as there is less than a kilometer of distance between the closest features.

Within the area of interest, there are 113 causeways, 270 dams, and 258 fish weirs (Table 5). These numbers are significant in comparison to the percentage of features the Southwest has from the dataset. The study area has 34% of the total features, but almost 40% of the total dams and fish weirs and 41% of the causeways. Furthermore, there are 154 earthworks in the Southwest area of interest that fulfill all three functional roles: about 45% of the total multi-functional features in the dataset (Figure 30).

Taken together with the statistics from the Mamoré area of interest, these two zones, which cover only 330 km² of the West Central Mojos study region, contain 44% of the total earthworks, 39% of the total causeways, and 50% of the total dams and fish weirs. These proportions are higher for multi-functional features. Together, the areas of interest possess 58% of the total multi-functional features in West Central Mojos, demonstrating that they are hotspots for different kinds of human activity.
CHAPTER SEVEN: DISCUSSION

This project aimed to discern the function(s) of a new set of pre-Columbian earthworks in West Central Llanos de Mojos. Similarities drawn between these features and the Baures Hydraulic Complex on the eastern side of the Mamoré River led ProSIGAB mapping teams to conclude that they were fish weirs, however, enough variation existed between the datasets to require a thorough analysis of the features, their physical attributes as well as their relationships to other natural and cultural features. A classification-based analysis relied on these observable attributes to classify the earthworks into functional profiles ranging from connecting infrastructure to impounding water and trapping fish. The level of significance that each attribute carried dictated how a feature would be classified. The results of this methodology show that all three functional profiles are represented in some form or another on the ground. Occasions where earthworks demonstrated multi-functional identities as causeways, dams, and fish weirs were concentrated into two groups on either side of the region, a northeastern group dubbed the Mamoré concentration, and a southwestern group called the Southwest concentration. These areas possessed a higher-than-expected number of multi-functional features for the number of features they contained in the space they had, suggesting that they represent pieces of landesque capital in an anthropogenic landscape or taskscape.

Interestingly, the number of ponds that occurred alongside weirs in the dataset was far lower than expected. Both Erickson (2000) and Blatrix et al. (2018) describe Baures fishing complexes where ponds are essential to their design; either they provided a means of storage for the caught fish or they were part of the trapping process. However, the Southwest concentration
was the only location the ponds reliably appeared in, suggesting that they were less important to the design and function of these weirs in this region. It is possible that the distance between weirs or their density impacts whether ponds are a necessary component of their design; however, more research is required. Weirs that are stacked closely together would likely not only increase productivity, but they would also increase water retention between weirs. This would still allow fish to be stored until needed, and depending on the size of the area, it would also sustain canoe travel several months into the dry season. Especially in places where weirs intersected many times, such as the southwestern portion of the Southwest group, dams could keep seasonally inundated areas flooded for a longer period of the year. In fact, the features in the area of interest in Figure 20 are oriented in such a way that they do not directly block the passage south, which happens to link to a permanent river; thus, connecting this anthropogenic landscape to farther locations, perhaps for the purposes of trade. Hence, in a region where canoe travel is still important means of getting around, these weirs are more involved with transportation than simply as causeways.

Exploring the nuanced ways that these earthworks could have functioned for pre-Columbian inhabitants aids in the understanding that these populations had robust and complex relationships with the floodplain environment. Betty Meggers saw a disparate relationship between Amazonian communities and nature wherein populations could only survive the harsh tropical settings by creatively adapting to them; however, her theoretical perspective contrasts this study’s findings (Meggers 1954, 1971). Instead of being limited by high temperatures and seasonal flooding, these groups utilized the unique hydrology to adapt the landscape to meet
their own needs. This is shown through the various types of earthworks that fulfill productive roles: fish weirs, dams, and causeways.

Furthermore, these populations were not simply surviving in an inhospitable floodplain, they were thriving. Fish weirs, dams, and causeways in West Central Mojos acted as landesque capital for inhabitants. They represent labor invested into the landscape, which made it more productive and useful for future generations (Brookfield 2001). Recurring work parties pooled labor from multiple households to produce and maintain artificial common-pool resources (Erickson 1988; Olstrom 1990; Netting 1993; Walker 2001). Then, later generations benefited from the access provided by causeways and the surpluses of fish, crops, and water supplied by weirs, fields, and dams. Descendants participated in the inherited anthropogenic landscapes while using relatively little energy to maintain and manage them (Balée 2002; Balée and Erickson 2006; Erickson and Walker 2009). For example, shallow bodies of water in the tropical savanna have been recorded as yielding 1,000 kg of fish per hectare per year, and abandoned river channels can produce anywhere from 100,000 to 400,000 fish (Erickson 2000). As long as seasonal flooding did not erode the earthworks, features in West Central Mojos were permanent pieces of capital capable of providing fish, water control, and transportation to any number of generations that continued to rebuild, reshape, and utilize them.

Taskscapes are also relevant to the findings of this study. They represent the community, the terrain, and the activities or tasks that they undertook together not only to produce such landesque capital but also to reap the benefits of such earthworks for generations (Ingold 1993). This study demonstrates how just one feature can allow for multiple tasks based not only on its physical attributes but also on the relationships it has with other cultural features. Fish weirs in
West Central Mojos, for instance, are not always just fish weirs. Their zigzag patterning and locations in drainage channels impound fish, but when they are placed close enough together in stacks, they can also dam enough water to store fish throughout the dry season when such ponds are not located nearby (McKey et al. 2016; Blatrix et al. 2018). A nearby association with a neighborhood of agricultural fields allows features to water crops by damming up the surrounding area and flooding nearby fields (Erickson 2006). Finally, they can provide access to and from a number of locations: forest island settlements, fisheries, neighborhoods of agricultural fields. As more feature types are found existing in areas such as the northeastern and southwestern groups, the opportunity for unique relationships between features grows and so does the complexity of the taskscape. Every intersecting fish weir or nearby pond layers tasks on top of one another, especially when the earthworks themselves are multi-functional. Consequently, any one square kilometer of land could be capable of catching and storing fish, extending the length of canoe routes, growing and watering crops, and likely more. Furthermore, these areas of interest identified by this project are novel in Mojos and not identified in Walker (2018) alongside other unique combinations of causeways, canals, ring ditches, and forest islands. They represent anthropogenic landscapes whose full potential has yet to be explored by archaeologists and other researchers. The scope of this project was limited to methods that could be successfully carried out using GIS; however, much remains unknown about these multi-functional fish weirs, especially in regard to their design and construction. Comprehensive comparisons could then be made between these features and the Baures studies. Until then, there are always more features to digitize.
APPENDIX A: FIGURES
Figure 1. An aerial view of the West Central Mojos linear feature dataset. Inset is magnified in Figure 2.

Figure 2. Inset from Figure 1 of individual digitized earthworks lying across a riverbed in West Central Mojos dataset. Forest islands are represented by the patches of bright green on either side of the drainage (see Figure 6 for a visual of non-delineated features).
Figure 3. Figures 1-3 from Erickson (2000:191-192) showing (a) a map of the Baures Hydraulic Complex; (b) the northern and southern survey blocks encompassing zigzag structures and ponds; and (c) an oblique photograph of a fish weir running from bottom left to top right and scattered pond depressions.
Figure 4. Map of Erickson’s (2000:192; Figure 4) purported study area, depicting fish weirs (irregular lines) and causeways (straight lines) in Baures based upon aerial photographs. McKey et al. (2016) mention an error in the scale bar.
Figure 5. Three plan drawings of fish weirs in Baures, showing small parallel openings every 50-200 m (Erickson 2000:193; Figure 5). McKey et al. (2016) find weirs with larger “V-shapes” nearby; however, these lack the parallel openings shown here.
Figure 6. Maps of Llanos de Mojos and West Central Mojos from left to right located within the Madeira River and Amazon basins (reprinted with permission from Walker (2018:2; Figure 1.1).
Figure 7. Inset from Figure 1, displaying forest islands and the non-delineated features running perpendicularly between them.

Figure 8. Original zigzag feature of the West Central Mojos dataset. Located next to the forest island Isla Flores in the Kinato Wetland.
Figure 9a-b. A single zigzag feature crosses an inactive river channel (a and b). The delineated feature is shown on the left; only the larger zigzags are digitized. The non-delineated feature is shown on the right. Cattle trails can be seen below, above, and left of the feature. These are non-beveled dirt pathways used by herds to reach water reservoirs and ranches (out of frame on right). They are straighter in appearance and overlap as they near the destination.

Figure 10. Feature from Figure 9 shown at a larger scale. No other earthworks detected around it despite its location along a river channel. Other features shown include a ranch (immediate right of earthwork) and cattle trails (as seen around elevated land to lower right on image). Elevated pieces of land may have once been forest islands; however, modern development has significantly altered the pre-existing landscape and makes feature digitization a complex task.
Figure 11a-b. Network of delineated features, intersecting one another in a perpendicular manner (above). This complex is an interesting collection of features, which seem to arrange themselves in an almost grid-like pattern. Non-delineated versions of the features are shown at greater magnification below. Here, they cross the saturated savanna and connect a forest island to a neighborhood of raised fields. Barbell-shaped patch of earth in both images represents a modern feature associated with cattle ranching.
Figure 12a-b. Network of delineated features, intersecting one another at various angles (above). Compared to Figure 11a, this network is more abstract and appears web-like in its design. A non-delineated subset of these features from the northeast corner of Figure 12a is shown at great magnification below in Figure 12b. Again, features cross over flooded terrain and intersect several forest islands.
Figure 13. Histogram displaying length of feature polylines in the West Central Mojos dataset as well as measures of central tendency and variance. Y-axis represents the frequency of features in each class. Classes are displayed on the X-axis and represent length in meters of each feature. The distribution is skewed to the right, indicating that most of the features in the region tend to be shorter than 1,000 m; however, there are several exceptionally long ones that skew the graph. Approximately, 300 features range between 230-300 m, which is significant as this frequency approaches almost half of the total earthworks. The minimum length for an earthwork is 31 m and the maximum is 3,013 m, or three kilometers. In regard to the first, second, and third quartile values, 25% of the dataset falls below 194 m, 50% of the features are shorter than 333 m, and 75% have values lower than 557 m. Hence, three-quarters of the dataset barely hits half a kilometer. Lastly, the average length for a zigzag earthwork is about 430 m, but this must be considered alongside a relatively high standard deviation. Standard length is influenced by several outliers.
Figure 14. Screen capture of the West Central Mojos dataset attribute table. Shown are the first several hundred entries of the mapped features. Each entry contains identifier and administrative information and is coded for all eight attributes listed in Table 1 (right).
Figure 15. A split feature crosses an active river channel. In cases like these, features on opposite sides of drainage feature are obvious halves of the same feature; however, their connection is obscured either by erosion, excessive vegetation, or water in this case. All three cases fulfill the Code_SAD attribute.
Figure 16. Distribution of causeways in West Central Mojos dataset. Selection highlighted in blue. Outlier features not shown.
Figure 17. Distribution of causeways in northeast group.
Figure 18. Distribution of causeways in southwestern group.
Figure 19. Distribution of dams in West Central Mojos dataset. Outlier features not shown.
Figure 20. Distribution of dams intersecting other dams in southwest group.
Figure 21. Aerial view of a neighborhood of agricultural earthworks next to dams.
Figure 22. Distribution of fish weirs in West Central Mojos dataset. Some outliers shown.
Figure 23. Distribution of "stacked" fish weirs in West Central Mojos.
Figure 24. Venn diagram depicting the distribution of West Central Mojos earthworks in each of the functional profiles. For example, there are 343 earthworks that have all of the primary attributes of a fish weir, causeway, and dam. Additionally, because every fish weir impounds water, there are no weirs or weir/causeways that do not function as dams. Most causeways also function as both dams and fish weirs.
Figure 25. Locations and boundaries of the Mamoré and Southwest feature concentrations.
Figure 26. Cultural components and boundaries of northeastern Mamoré group.
Figure 27. Distribution of multi-functional features in northeastern group. Each highlighted earthwork fulfills the primary attributes for the three functional profiles: connecting infrastructure, impounding water, and trapping fish.
Figure 28. Distribution of multi-functional features in northeastern group. Each highlighted earthwork fulfills the primary attributes for the three functional profiles: connecting infrastructure, impounding water, and trapping fish.
Figure 29. Cultural components and boundaries of Southwest group.
Figure 30. Distribution of multi-functional features in northeastern group. Each highlighted earthwork fulfills the primary attributes for the three functional profiles: connecting infrastructure, impounding water, and trapping fish.
Table 1. Classification Procedure and Definitions Table: Describes how West Central Mojos features were classified in ArcMap. The first column denotes the kind of qualification as well as its attribute table field name. Second column refers to the way in which an entry can be coded for each qualification, including yes, no, one, both, and N/A. The final column describes exactly how an entry can qualify for a code based on its physical shape, appearance, or relationship with nearby features.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Field Codes</th>
<th>Operational Definition of Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersecting a forest island (Code_IFI)</td>
<td>No</td>
<td>One or both ends of the weir is pointed toward the nearby forest island, which should still be visible while display is at maximum magnification. The estimated azimuth of the weir is essential. Although its exact endpoints may change over time due to erosion, its direction should remain the same. Forest island presence is assumed from a concentration of trees that contrast the pampas and is elevated above nearby drainage.</td>
</tr>
<tr>
<td>Intersecting other weir (Code_IOW)</td>
<td>Yes</td>
<td>A weir crosses or converges with the endpoint of another weir. The intersection can be perpendicular or oblique in nature. A weir will still be codified as ‘yes’ if it approaches another weir but does not totally intersect it at maximum magnification. Both of the intersecting weirs will receive a ‘yes’ designation.</td>
</tr>
<tr>
<td>Intersecting drainage feature (Code_IDF)</td>
<td>Yes</td>
<td>A weir approaches, intersects, or lies completely within an identifiable river channel (active or inactive), the gap between two elevated forest islands, or a presumed drainage area that is visibly darker than the surrounding terrain. Noticeably dark areas are assumed to be saturated pampas where water would drain to. Weirs can intersect a drainage feature at any angle.</td>
</tr>
<tr>
<td>Stacked weirs (Code_SW)</td>
<td>Yes</td>
<td>A weir is ‘stacked’ when it lies roughly parallel to another weir positioned on either side. Only two weirs are needed in sequence to be stacked, but there is no limit to how many can be in the sequence. If there are more than two, the stack should display regular spacing, and weirs should be roughly equidistant from any weir lying between them.</td>
</tr>
<tr>
<td>Attribute</td>
<td>Field Codes</td>
<td>Operational Definition of Attribute</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>----------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Intersecting neighborhood of agricultural earthworks (Code_TNM)</td>
<td>No</td>
<td>Because drainage areas often follow meandering routes, a weir is also stacked if it and another weir are positioned radially around a bend such as an oxbow.</td>
</tr>
<tr>
<td></td>
<td>One</td>
<td>One or both endpoints of a weir approach or intersect a neighborhood of agricultural earthworks, including raised and mounded fields. If a weir lies totally within the field, it will be codified as ‘both’; however, these cases are rare.</td>
</tr>
<tr>
<td></td>
<td>Both</td>
<td>Less leeway was given to weirs that were not directly converging with the neighborhood. Field boundaries tend to be more precise than those of forest islands, so weirs need to be within approximately 100 m to qualify.</td>
</tr>
<tr>
<td>Contains zigzags (Code_CZ)</td>
<td>Yes</td>
<td>The relatively low resolution of the basemap prohibits a detailed understanding of each individual weir. In addition, fish weir researchers from Baures note a number of different construction styles. As a result, there are multiple ways a weir can meet the qualification.</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>The feature changes direction multiple times, producing a chevron pattern (Erickson 2000; McKey et al. 2016). The weir is relatively linear but contains at least one V-shape like those noted by Blatrix and others (2018). The weir contains minute zigzags or V-shapes that are visible to the eye but not large enough to be mapped at maximum resolution.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weirs can contain curves but must have sharper angles present.</td>
</tr>
<tr>
<td>Associated with pond-like depression (Code_APLD)</td>
<td>Yes</td>
<td>Weir crosses, intersects, or is closest to a circular, pond-like depression not larger than 100 m.</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>If the weir does not directly cross it, the depression must be visible in the surrounding area when the full weir is displayed on screen.</td>
</tr>
<tr>
<td>Split across drainage (Code_SAD)</td>
<td>Yes; 1 side</td>
<td>Weir is split across drainage when erosion, the presence of water, or excess vegetation in the drainage channel prevents the two corresponding parts from touching. In order to be considered a split weir, both parts must be oriented along the same azimuth and must converge with the drainage channel.</td>
</tr>
<tr>
<td></td>
<td>Yes; 2 sides</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No; N/A</td>
<td></td>
</tr>
<tr>
<td>Attribute</td>
<td>Field Codes</td>
<td>Operational Definition of Attribute</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>When both halves or parts of the weir have been digitized and exist in the database, the designation is ‘yes; 2 sides’. The individual database entries of both parts will receive this designation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>When only one half of the split weir has been digitized, the designation is ‘yes; 1 side’. The other end must either be present and not mapped or the weir’s presence in a stack/along a river channel indicates that there should be another half.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Each half or part is considered a separate entry in the database, and each has two endpoints. For example, if one half intersects an agricultural neighborhood with one of its endpoints, the other half does not receive the Code_TNM designation.</td>
</tr>
</tbody>
</table>
Table 2. Functional Profiles Table: Describes the attributes that qualify features for specific roles in West Central Mojos. Depending on its physical or relational properties, an attribute may be essential to a feature’s classification or it may provide secondary or even tertiary support for that classification.

<table>
<thead>
<tr>
<th>Function</th>
<th>Functional Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Connecting Infrastructure</strong></td>
<td></td>
</tr>
<tr>
<td>(Causeway)</td>
<td></td>
</tr>
<tr>
<td>Intersects a forest island.</td>
<td></td>
</tr>
<tr>
<td>AND/OR</td>
<td></td>
</tr>
<tr>
<td>Touches a neighborhood of</td>
<td></td>
</tr>
<tr>
<td>agricultural earthworks.</td>
<td></td>
</tr>
<tr>
<td>Intersects another weir.</td>
<td>(Tert)</td>
</tr>
<tr>
<td><strong>Impounds Water</strong></td>
<td></td>
</tr>
<tr>
<td>(Dam or Levee)</td>
<td></td>
</tr>
<tr>
<td>Crosses a drainage feature.</td>
<td></td>
</tr>
<tr>
<td>Split across drainage feature.</td>
<td>(Sec)</td>
</tr>
<tr>
<td>Intersecting another weir.</td>
<td>(Sec)</td>
</tr>
<tr>
<td><strong>Traps Fish</strong></td>
<td></td>
</tr>
<tr>
<td>(Fish Weir)</td>
<td></td>
</tr>
<tr>
<td>Contains zigzags.</td>
<td></td>
</tr>
<tr>
<td>AND</td>
<td></td>
</tr>
<tr>
<td>Crosses a drainage feature.</td>
<td></td>
</tr>
<tr>
<td>Lies parallel to other features in stacks.</td>
<td>(Sec)</td>
</tr>
<tr>
<td>Associated with pond-like depression.</td>
<td>(Sec)</td>
</tr>
<tr>
<td>Split across drainage feature.</td>
<td>(Tert)</td>
</tr>
<tr>
<td>Intersecting another weir.</td>
<td>(Tert)</td>
</tr>
</tbody>
</table>
Table 3. Quantitative Results for Individual Attributes: Reports the number of features out of 831 that satisfy each, individual attribute. Depending on the attribute, features could be classified under two or three different codes.

<table>
<thead>
<tr>
<th>Field</th>
<th>Number of Features Classified for Each Code</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Code_IOW</td>
<td>249</td>
</tr>
<tr>
<td>Code_IDF</td>
<td>697</td>
</tr>
<tr>
<td>Code_SW</td>
<td>602</td>
</tr>
<tr>
<td>Code_CZ</td>
<td>788</td>
</tr>
<tr>
<td>Code_APLD</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>Both</td>
</tr>
<tr>
<td>Code_IFI</td>
<td>30</td>
</tr>
<tr>
<td>Code_TNM</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>Yes; 2 sides</td>
</tr>
<tr>
<td>Code_SAD</td>
<td>130</td>
</tr>
</tbody>
</table>
Table 4. Results for Attribute Combinations: Reports the number of features that satisfied the primary, secondary, and tertiary attributes of each functional profile as well as results for the non-exclusive combinations of different attributes. Primary + Secondary, for example, provides the number of features that satisfied secondary attributes as well as primary ones for each functional profile. Only combinations of interest are elaborated in the text.

<table>
<thead>
<tr>
<th></th>
<th>Primary</th>
<th>Primary + Secondary</th>
<th>Primary + Tertiary</th>
<th>Primary + Secondary + Tertiary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Causeway</strong></td>
<td>IFI or TNM 416</td>
<td>IFI + IOW 45</td>
<td>TNM + IOW 86</td>
<td>IFI or TNM + IOW 116</td>
</tr>
<tr>
<td></td>
<td>IFI + TNM 68</td>
<td>IFI + IOW 45</td>
<td>IFI or TNM + IOW 116</td>
<td>IFI + TNM + IOW 15</td>
</tr>
<tr>
<td><strong>Dam</strong></td>
<td>IDF 697</td>
<td>IDF + IOW 213</td>
<td>IDF + SAD 160</td>
<td>IDF + IOW + SAD 56</td>
</tr>
<tr>
<td><strong>Fish Weir</strong></td>
<td>CZ + IDF 668</td>
<td>CZ + IDF + SW 510</td>
<td>CZ + IDF + IOW 200</td>
<td>CZ + IDF + SW + IOW 146</td>
</tr>
<tr>
<td></td>
<td>CZ + IDF + APLD 103</td>
<td>CZ + IDF + SAD 214</td>
<td>CZ + IDF + SW + SAD 183</td>
<td>CZ + IDF + APLD + IOW 26</td>
</tr>
<tr>
<td></td>
<td>CZ + IDF + SW + APLD 91</td>
<td>CZ + IDF + IOW + SAD 51</td>
<td>CZ + IDF + APLD + IOW 26</td>
<td>CZ + IDF + APLD + SW + SAD 46</td>
</tr>
</tbody>
</table>


Table 5. Results for West Central Mojos Areas of Interest: Reports the number of earthworks within the northeast and southwest areas of interest (AOIs) that are designated causeways, dams, fish weirs, or multi-functional features based on the primary attributes they possess. Also states the percentage they make up of the total dataset.

<table>
<thead>
<tr>
<th>Function</th>
<th>Features in the Mamoré AOI</th>
<th>Features in the Southwest AOI</th>
<th>Features in Total Dataset</th>
<th>Percentage from the Mamoré AOI</th>
<th>Percentage from the Southwest AOI</th>
<th>Percentage from Both AOIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Causeways</td>
<td>47</td>
<td>172</td>
<td>416</td>
<td>11.3%</td>
<td>41.3%</td>
<td>52.6%</td>
</tr>
<tr>
<td>Dams</td>
<td>76</td>
<td>270</td>
<td>697</td>
<td>10.9%</td>
<td>38.7%</td>
<td>49.6%</td>
</tr>
<tr>
<td>Fish Weirs</td>
<td>74</td>
<td>258</td>
<td>668</td>
<td>11.1%</td>
<td>38.6%</td>
<td>49.7%</td>
</tr>
<tr>
<td>Multi-Functional</td>
<td>45</td>
<td>154</td>
<td>343</td>
<td>13.1%</td>
<td>44.9%</td>
<td>58.0%</td>
</tr>
</tbody>
</table>
APPENDIX C: WRITTEN PERMISSIONS
3/17/2021
Dear Dr. Walker:

I am completing an undergraduate thesis at the University of Central Florida entitled "Fish Weirs Et Al. A GIS Based Use-Analysis of Novel, Manmade Features in Western Llanos de Mojos, Bolivia." I would like your permission to reprint in my thesis excerpts from the following:

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