Archaeological GIS Analysis of Raised Field Agriculture in the Bolivian Amazon

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ARCHAEOLOGICAL GIS ANALYSIS OF RAISED FIELD AGRICULTURE IN THE BOLIVIAN AMAZON

by

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ABSTRACT

Modern agricultural systems have been criticized for their detrimental effects on the environment and a general emphasis on crop yield rather than long-term sustainability. Traditional forms of agriculture may provide case-specific examples of sustainable alternatives for contemporary societies. In the seasonally inundated savannas of the Llanos de Mojos, pre-Columbian Native Americans piled earth into ‘large raised field platforms’ elevated high enough above the floodplain to allow crops to grow. Archaeological evidence indicates that raised field agriculture supported much larger populations than those found in the Beni today. The examination of satellite imagery has revealed more than 40,000 individual fields spread across an area of approximately 7,500 square kilometers. This study created a digitized map of large raised fields to search for spatial patterns in their distribution. A GIS analysis was conducted in which fields were distributed into organizational groups based on characteristics such as proximity and orientation to cardinal direction. These groups represent potential ‘social units’ involved in the organization of labor required to construct raised fields. This study demonstrated the consistent presence of these units throughout the entirety of the agricultural system. Patterns in the distribution of these groups allowed the study area to be divided into two distinct regions representing a larger scale of organization within a seemingly uniform system. A transitional zone between these two regions was identified on the river Omi, providing a clear area of interest to target in future archaeological excavations. Further archaeological investigations of raised field agriculture have the potential of demonstrating the overall productivity of the system as well as how it was incorporated into the social systems of those who managed it.

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CHAPTER ONE: INTRODUCTION

Anthropogenic climate change is real and has been fully recognized by the scientific community (Oreskes 2004:1686). Global climate change and continued degradation to the environment will cause the loss of ecosystem services that are critical in protecting humans from threats such as drought and famine (Myers & Patz 2009:223,227). It is now important for policy makers to identify, value and compare these services to the costs and tradeoffs that come with protecting one service at the expense of another (Brauman 2007:85). In modern agricultural systems crop yield is prioritized by the market over other services such as soil conservation, pollination, or soil diversity and ultimately the environment has suffered as a result. (Robertson & Swinton 2005:38; Renard 2012:31). For example, erosion rates on tilled land are decreasing the amount of available soil faster than it can be naturally formed and excessive nitrogen runoff can wreak havoc on other nearby ecosystems (Myers & Patz 2009:237). The use of broad-spectrum pesticides kill beneficial crop insects with important ecological roles (Robertson & Swinton 2005:38). Despite these detrimental effects to the environment, modern agricultural research focuses more on genetically modified crops than on alternative methods of agriculture or innovation which can preserve multiple ecosystem services beyond crop yield alone. There is a need for sustainable forms of agriculture that manage multiple ecosystem services while still meeting the subsistence demands of growing populations (Renard 2012:30-31). While it is important to understand agricultural systems as being ecologically complex, they are still created by humans and are subject to social forces such as markets or government policy and regulation (Robertson & Swinton 2005:38). A majority of 20th century famines were caused by poor governance rather than failure of ecological functions within an agricultural system preventing it to produce food (Myers & Patz 2009:227). The success of agricultural systems in preserving ecosystem services while still meeting the needs of society will require managing both the ecological as well as social aspects of these systems (Robertson and Swinton 2005:38).

Traditional forms of agriculture often thought to be inherently low in productivity may prove to be case-specific examples of sustainable agriculture that are relevant to modern research (Renard 2012:31). Pre-Columbian tropical rainforest culture in the Amazon basin was once thought to be limited in size and complexity due to environmental constraints that prevented intensive forms of agriculture and population growth (Meggers 1971). However, a growing body of historical, ecological and archaeological evidence supports the existence of large complex societies across the basin. In particular earthworks in the Llanos de Mojos including causeways, fish weirs, and raised agricultural fields have been associated with dense populations of pre-Columbian Native Americans (Erickson 2000; Walker 2004).

The seasonally inundated savannahs of the Llanos de Mojos provide an excellent case study for further analyzing how Pre-Columbian Native Americans engineered the landscape and domesticated an inhospitable environment in order to manage natural and agricultural resources. Indigenous peoples of the Mojos have been of academic interest since the early 1900's with the earliest excavations by Erland Nordenskiöld in 1908 and 1909 (Denevan 1966:19). Earthworks including large monumental mounds and raised causeways were documented in the region, however, it wasn't until the use of aerial photography in the 1960s that one of the largest modifications to the Mojos landscape became clear. While surveying for oil throughout South America, aerial photographs captured images of long rectangular platforms of earth, or 'large raised fields', arranged in clusters across the mojos savannah and numbering in the thousands. The variable density of grass atop the fields provides a clearer view of the ground beneath making the fields appear lighter in color than the denser and usually greener grass surrounding the platforms (Denevan, 1966). Today with readily available satellite imagery available through applications like Google Earth, a clearer picture of the extent of raised field agriculture is available and more than 40,000 large raised fields have been identified.

Today this area of Bolivia is sparsely populated and most economic activity centered on cattle ranching or swidden agriculture rather than savanna farming. However, archaeological evidence indicates it once supported a much larger population of Pre-Columbian Native Americans (Denevan 1966; Walker 2004:115). It has been proposed that raised field agriculture may be a sustainable alternative for contemporary land management practices (Renard et al. 2012;31; Erickson 1992:297). Several studies have indicated that raised field agriculture is capable of sustaining high yields of crops per unit of land (Renard et al. 2012:32). Erickson (1995) reconstructed raised fields in the Llanos de Mojos that were successful at draining ground for crops during the wet season and retained water in their canals well into the dry season. These fields produced a crop of both manioc and maize during their first year and were the first savannah crops grown in this region in living memory (Erickson 1995:93). However, long-term studies of raised field productivity are still lacking (Renard et al. 2012:32) and the system as a whole cannot be successfully replicated and maintained without further experimentation. In the Mojos raised fields were built by farmers with an established social organization and access to a body of indigenous knowledge created over many generations. Raised field agriculture cannot simply be re-introduced as an intact system but rather must be developed by contemporary farmers in the Beni and based on their own forms of social organization (Walker 2004:125).

Archaeological investigations of raised field agricultural can provide further insight into the overall sustainability of the system as well as how farmers organized themselves to manage it. Excavations of settlement sites associated with raised fields have provided estimates of population sizes involved in their organization as well as begun the process of establishing a chronology of raised field construction. Based on radiocarbon analysis of charcoal deposits, the site of Cerro was dated to the 13th and 14th centuries A.D. and excavations revealed a deposit of anthrosol created by a population of approximately 2,000 people (Walker 2009:79). This is consistent with the accounts of Padre Agustin Zapata (Walker 2009:79) who visited this region of Mojos in the late 17th century and reported numerous villages with at least 1,800 people each and one with more than 2,000 (Denevan 1966:114). The site of San Juan, located along the same river as Cerro, was dated to the 5th century A.D. but was also associated with raised agricultural fields. Raised fields were persistently used for more than 900 years in this region (Walker 2004:89) and further investigation is needed to understand the chronology of field construction and use within the larger system.

Evidence of the social organization of these populations is not so clear in the archaeological record and spatial analysis of raised field placement provides an alternative method of identifying different social units responsible for field construction. Raised field platforms were not constructed as a single and instantaneous modification to the landscape but a series of many modifications over time that are now viewable as a single image. Landscape features such as raised field groups can be viewed as snapshots of human agency that have been superimposed upon one another over time leaving behind a ‘palimpsest’ type record (Walker 2004; Erickson & Walker 2009). Satellite imagery of the Beni has become increasingly more available online and is regularly improving in quality. Student researchers with the Archaeological GIS Project of the Beni (Proyecto Arqueologico SIG del Beni/PROSIGAB) at the University of Central Florida utilize programs like Google Earth and ArcMap to identify raised fields in satellite imagery and digitize these images into a GIS database. Previous spatial analysis of raised fields using this type of spatial data identified raised field 'blocks' of contiguous fields clustered near permanent bodies of water (Boothby 2010; Garcia-Cosme, 2015). Walker (2004) identified raised field 'groups' that consisted of adjacent fields sharing similar orientations or appearing parallel (53). These 'group' units may represent the efforts of small community work parties and will be defined more clearly in the methods section.

The purpose of this study is to define and identify all raised field platforms that fall into 'block' and/or 'group' organizational units and examine the distribution of these units throughout the entire system. Patterns in the distribution of raised field blocks and groups may reveal a larger scale of organization beyond individual groups and blocks. Are these units an integral part of the system in its entirety or are there regions within the system that are not dominated by block and group units? It was hypothesized that both block and group organizational units would be dominant if not universal units found throughout the system. This is based on the previous identification of block and group units within the system and the visible dominance of these units in preliminary examinations of raised field spatial data. This is also based on the previous studies indicating raised field groups are linked to community work parties. These group social units are expected to be found anywhere labor was organized this way within the system.

CHAPTER 2: LITERATURE REVIEW

The Llanos de Mojos is a seasonally inundated savannah lying at the southwestern reach of the Amazon basin. Its roughly 90,000 square kilometers of basin is surrounded by forest and crossed by numerous rivers meandering their way north to the Rio Madeira, one of the four main tributaries of the Amazon (Denevan 1966:6; Walker 2004:19). Each year two types of seasonal water flood the Mojos. The first is local rainwater or 'water from above' which accumulates in the savannahs or any low lying area with poor drainage. The second is 'water from below' which originates as rainfall in the nearby Andes and flows into the Mojos rivers causing them to overflow their banks (Walker 2004:21). Roughly 80% of the savannah floods each season with 100% flooding occurring with above average flood levels (Denevan 1966:11). The wet season between November and April can produce anywhere from 1200mm to 3500mm of rain (Lombardo 2010:503). During the dry season from May through September, the waters recede and the flooded savannahs return to desert-like conditions with water restricted to river channels and permanent lakes (Denevan 1966:11). This changing environment is characteristic of the Mojos savannah and all life must be adapt to these varying conditions or modify the landscape to alter them.

The extensive range of this flooding is due first to the minimal variation in relief throughout the region in which elevation changes less than "one foot per mile" (Denevan 1966:8). Another factor is the presence of an impermeable layer found in savannah soils that prevents water from draining into the ground (Denevan 1966:5, 8, 11, 13). While the seasonal water regime is one of the strongest forces in the Mojos, it is most strongly influenced by the region's topography, in which small changes in elevation can result in a completely different terrain (Denevan, 1966). There are three general types of terrain in the Mojos: savannah, gallery forests, and forest islands. Savannahs are of primary interest to this study as one of the main functions of raised fields is altering the local hydrology of the savannah so that it can be cultivated.

The Savanna

The Mojos savannah is a grassland or 'pampa' spread across the flat low lying portions of the region which may be inundated for anywhere from five to ten months depending on elevation. Regions with longer hydroperiods may be dominated completely by grasses and sedges while those with shorter hydroperiods can support some savannah trees or scrub known as arboleda (Denevan 1966:15). The origin of tropical savannahs has been an issue of debate for some time and the Mojos is no exception. Carl Sauer (1958) argued that anthropogenic fire, rather than climate, was the primary force behind the creation and spread of tropical savannahs such as those in Amazonia (191). Erickson (2008) sites the presence of trees growing atop raised field platforms indicating that pre-Columbian farmers were capable of clearing forests and utilizing fire to maintain savannas (172). However, Langstroth (2011) argues that pre-Columbian earthworks and anthropogenic fires have not significantly altered the species makeup or diversity within the Mojos and the landscape is representative of an ecosystem that has been developing since long before the arrival of humans (189).

Whether or not humans are ultimately responsible for the expansion of the Mojos savannah, there is evidence of pre-Columbian Native Americans clearing forests and using fire regimes to alter and manage the landscape. Pollen taken from lake sediments near the site of Cerro indicate that trees had been cleared from the surrounding savannahs and gallery forests by the fourth century A.D. In this area, farmers were prioritizing agricultural resources over those resources provided by maintaining the forests (Whittney 2014:9).

The Savanna Tribes

The earliest accounts of the people living in the Mojos come from members of Spanish expeditions who entered the region in search of the 'Gran Mojo,' a kingdom rumored to be rich in gold but was probably based on stories about the Inca empire in Peru (Metraux 1943:3). Numerous expeditions from Peru went looking for Mojo for more than half of the 16th century but it was not until 1617 that an expedition successfully reached the Mojos. Though no gold was found, the conquistadors did report finding large populations of Native Americans who lived in dense settlements and cultivated the savannahs (Metraux 1943:3, 4).

In the early 17th century, failure to find the Gran Mojo resulted in some expeditions shifting their focus to slave raiding rather than exploring and large numbers of Native Americans were removed from the region at the same time European diseases were beginning to spread through the populations (Block, 1994). The primary source of information on this region comes from Jesuit missionaries who created missions in Mojos and remained for an entire century between 1668 and 1768 (Denevan 1966:30, 31). Despite disturbances from slavers and disease, Jesuit accounts indicate a thriving population of Native Americans (Block, 1994). Based on these accounts, Denevan (1966) estimated a minimum population of 112,000 Native Americans at the beginning of the Jesuit period (116). Large raised field platforms are found in areas associated with the Cayuvava and Movima language groups which were estimated to have a combined population of at least 30,000 Native Americans (Deneven 1966:116).

The Jesuits describe a linguistically diverse group of people with more than 30 tribes belonging to at least 10 language groups, however, many of these tribes were likely subtribes with a common language. Denevan (1966) lists six distinct groups referred to collectively as the 'savanna tribes' and include "the Arawakan Mojo and Baure and the linguistically unclassified Cayuvava, Itonama, Movima and Canichana (40)." They are described as an amphibious people who readily responded to rising floodwaters in ways such as sleeping in their canoes, elevating living and cooking platforms above floodwaters, or simply stringing up hammocks high enough to sleep above the rising water (Denevan 1966:60).

The savanna tribes organized into villages which comprised 'grandes familias' or multifamily groups that lived and worked together (Block, 1994). A village may consist of anywhere from several dozen to several hundred houses depending on the tribe (Denevan 1966:58-59) and a sub-tribe could consist of several different villages (Metraux, 1943:5-6). Houses were round with wattle and daub walls and a single center post supporting a grass roof (Denevan 1966:59). Each village would have a communal drinking house and multiple kitchen houses. Almost any ceremony or celebration was accompanied by a large drinking party and a village may have had 10 or more feasts each year as well as taking part in feasts at other villages (Metraux 1943:10, 17, 18). While many villages were placed along favorable riverfront areas, savanna sites also existed and there is evidence that these were highly mobile communities that could relocate or divide for a variety of reasons (Block, 1996).

While agricultural subsistence was important, savannah tribes also exploited aquatic resources such as fishing, hunting (deer, tapir, jaguar, birds, rabbits, fox…) or foraging for turtles and eggs (Denevan 1966:105). They also maintained trade routes with nearby regions, exchanging items like cotton cloth, colorful feathers, or traded manioc flour for highland items such as stone axes or salt (Block, 1994). Shamanism was an integral part tribal religion and there were both nature gods as well as spirits with strong ties to geographical locations. To the

Mojo, spirits permeated nature and any unexplained event or phenomenon could be explained by the actions of these spirits. There are numerous reports of the existence of a jaguar cult though it is unclear whether the jaguar was an actual jaguar god or if jaguars represented some form of spirit (Metraux 1943:9, 12).

There are several reports of powerful chiefs among some savanna tribes who could redistribute resources. The Mojo chief Yaya was said to have received tribute from multiple villages. Padre Agustin Zapata visited tribes north of the Yacuma known as the Cayuvava who were reported to live in large villages and served a single chief known as Paititi. Spaniards had entered the region a century earlier searching for the myth of Paititi and his lake filled with gold and pearls and it is possible that this chief was the base of the name in that myth though there were never any riches discovered (Denevan 1966:46, 49). Such chiefs were probably not required to work and made major decisions regarding issues such as warfare, village relocation, trade, mediating disputes or enforcing punishments, and earthwork construction. Other reports indicate more autonomous villages with their own headmen who may have held little authority and who did not inherit their position. A chief's decisions or instructions were not followed without question but rather his people would choose whether or not to comply. Charisma and personality were important factors in a chief's ability to maintain authority (Denevan 1966) (Metraux 1943:6, 7).

Agriculture

In 1617, the Solis Holguin expedition into Mojos encountered villages with hundreds of corncribs, each containing several dozen bushels of maize or other crops stored by the farmers (Denevan 1966:98). Manioc is at the forefront of the earliest accounts of Mojos agriculture and has been considered a staple over other crops such as maize (Denevan 1966:99). Bitter manioc was important because it could be processed into a bread that could be stored longer than sweet manioc. The crop is an excellent source of carbohydrates but had to be supplemented with animal or vegetable protein (Lanthrap 1970:49,51). Savanna tribes also cultivated squash, sweet potato, peanuts, papaya, red pepper, cotton, tobacco, plantains, cotton, and sugar cane (Denevan 1966:99). Phytolith analysis from excavations of agricultural fields at the site of El Cerro in Mojos indicate that maize was a staple crop and was grown in raised agricultural fields along with sweet potato (Whitney 2014:9).

There are several types of Pre-Columbian raised fields that were constructed to drain and farm the savanna including small circular mounds, ditched fields, ridged fields, and large raised fields. Each of these types involved the creation of canals or ditches separating raised sections of earth but they differ in general shape and organization and are not usually found mixed together in the same area (Denevan 1966:85). The primary focus of this study are the 'large raised fields' described earlier that appear like large rectangular platforms on the savannah.

Large raised fields are the largest and most impressive of the different types of raised fields given their size and vast numbers. Student volunteers with the Archaeological GIS Project of the Beni have mapped more than 40,000 large raised fields. In ArcMap these fields have an average platform width of approximately 20 meters and an average length of 140 meters with many fields longer than 1000 meters. The platforms are less than a meter in height and have suffered from some erosion over the years. However, they are high enough to remain above floodwaters most of the year and they still hold their general rectangular shape which is visible from aerial photographs and satellite imagery. Even today the platforms are elevated enough to provide different hydrologic and soil conditions, and it is the resulting changes in vegetation patterns across their surfaces which make them stand out from the air. Trees, shrubs, and termite mounds can often be seen in rows along the better drained soils atop the platforms (Denevan 1966:84 - 87).

Sustainability

The main criticism of raised field agriculture for modern use is the assumption that constructing fields requires high amounts of labor (Renard 2012:33). Erickson (1995) estimated "800 person-days per [hectare]" were required to construct raised fields, but argued that fields could be farmed continuously with little additional investment in labor (93). In Mojos, building raised fields took more labor than cultivating the forest, however, it only required simple wooden digging sticks as opposed to stone for axes which was rare in the region. Based on previous experiments in constructing raised fields as well as spatial analysis of field distribution, it was estimated that large raised fields in the Mojos could have been built by small groups of as few as 20 people (Walker, 2001:14; Walker, 2004:119).

The raised fields remaining in the Mojos today do not have the adequate nutrients in their soils to cultivate crops, especially nutrient intensive crops like maize (Lombardo et al. 2011). These nutrients have been leached from the soils since the fields were abandoned (Whitney 2014:8). Though modern farmers in the Beni claim the savanna soils are too poor in nutrients to farm, initial field construction may increase the fertility of the soil. The soil beneath the claypan is exposed to less leaching and in some areas contains more nutrients than the soils on the surface. Constructing a raised field would relocate these nutrients to the surface giving the field an initial boost in fertility (Denevan 1966:92). To date experimental raised field studies in the Mojos have focused on the creation of new fields and experiments involving the rehabilitation of existing pre-Columbian fields are unpublished.

Phytolith analysis from agricultural fields confirm that maize was being grown on raised fields near the site of El Cerro. The ability of raised fields to continuously produce a staple crop like maize indicates that they had much higher soil quality when they were in use than is presently visible (Whitney 2014:9). There are no early accounts of savanna tribes using fertilizer (Denevan 1966:97), however, the intervening canals between raised field platforms can be used to recycle nutrients. The water hyacinth found in the Mojos is an aggressive aquatic plant with roots that can absorb toxic chemicals from the water. Water hyacinth found in the region is an excellent source of organic matter for composting and can greatly increase microbial activity in the soil (Vidya 2014). Aquatic plants such as this along with other organic matter and nutrient sources like decomposing fish could be used to produce a 'green manure' form of compost in the canals that was then applied to the field platforms as a form of fertilizer (Erickson 1988:235; Walker 2011:289). Rodrigues et al (2015) found no evidence of geochemical changes to soils of raised fields that would be expected if the fields had been farmed continuously with the addition of 'green manure' or other fertilizer sources to their surfaces (135). While the current conditions of raised field platforms do not indicate a potential for sustainable use, the archaeological record has shown that staple crops were continuously cultivated on raised fields in the past and raised field agriculture may be a viable option for contemporary farmers in the Beni (Whitney 2011:9).

<u>Services</u>

Raised fields represent a form of 'ecological engineering' in which the landscape is modified and a mosaic of environments with different ecological functions is created (Renard, 2012:33). The alternating pattern of raised field and flooded canal provides a set of environments capable of supporting a much higher level of diversity than a flat savannah that may be dominated by fewer or even a single species of grass. Erickson (2008) argues that the creation of raised fields has resulted in large increases in biodiversity and overall vegetative biomass on the savannas (172). Many raised fields found in the Mojos are currently covered in forest. Some of these are located in areas of forested high ground where forests have regrown over both field and canal (Erickson 2008). These forests could have existed before the fields and regrew as secondary forests after the fields were abandoned. Other fields have forest restricted to their platforms with no trees being found in the canals. Fields such as these are more likely to represent field abandonment resulting in the creation of a forest on what was once savanna. Even if forests were cleared to create the fields, the secondary forest growing atop abandoned fields may be of a different makeup than the previous forest. Pre-Columbian modifications to the landscape have been shown to raise biodiversity and alter successional paths in other areas of the Mojos as well as other parts of Amazonia (Heckenberger et al. 2007:202; Erickson 2010:620; Erickson & Balee 2006:217). Whitney (2011) found an increase in pollen of Inga genus near El Cerro after the previously cleared gallery forests grew back into a secondary forest (9). Tree species in this genus are a valuable resource to Mojo Indians and have been associated with several sites (Erickson 2010). Increased levels of biodiversity is one of the most valuable services provided by raised field agriculture, especially when considering the environmental degradation associated with the contemporary practice of cattle ranching in the region.

The surfaces of raised fields can be protected from fire due to the changing relief as well as the retention of water in their canals. This may be an alternative explanation for why many fields and causeways are now covered with trees while the surrounding savanna is not (Denevan 1966:79,80). Fire control may have been a valuable function of raised fields (Walker 2012:244). Charcoal in lake sediments near Cerro indicate that fire was regularly used in conjunction with raised fields until the early fourteenth century (Whitney 2014:7). Early accounts of Mojos hunting parties noted the use of setting savanna fires to help drive game (Metraux 1943:7). Erickson & Balee (2006) noted that elevated earthworks and borrow pits holding water may have acted to protect communities from fires set on the savanna (202,218). Fire protection is a valuable service amidst an ecosystem managed primarily by fire.

Raised field platforms provide an area of safety for wild animals fleeing the rising waters or a spreading fire. Mojos savanna tribes would hunt during periods of either drought or flooding when animals were concentrated near watering holes or areas of dry high ground (Denevan 1966:106). Even today the cattle roaming the Mojos utilize raised fields as areas of high ground for refuge and travel. From satellite imagery the trails of cattle can be seen tracing across the tops of fields and ranchers dig deep borrow pits to provide drinking water for cattle in the dry season. Raised fields, especially those abandoned and covered in forest, may have provided a similar form of refuge to wild game allowing them to increase in numbers as well as creating seasonal hunting areas atop raised fields.

Social Organization

There are no eyewitness accounts of raised fields being constructed or managed, including those of early Jesuits (Denevan 1966:90, 95). Savannah farming may have already been declining at the onset of the colonial period, however, it was probably still taking place (Walker 2004; Whitney 2014:9). The best information on the social organization of raised field agriculture comes from the spatial analysis of raised fields still visible in the landscape. Raised fields are believed to have been constructed as part of community work parties in which multiple households would contribute workers to provide enough pooled labor to complete the task. Festivities and alcohol played a large part in organizing and compensating farmers for their efforts (Walker, 2001:11, 12). The fields created by these work parties are visible as discrete units on the landscape represented at the smallest scale by the individual field.

When viewing the distribution of raised fields in satellite imagery they are regularly seen organized into larger 'groups' made up of contiguous individual fields lined up in a parallel formation. Walker (2004) identified 30 field groups in the Iruyunez-Omi region of the Mojos comprised of fields with less than 10 meters of separation and less than 15 degrees of difference in orientation to cardinal direction between fields (53). These groups are parallel and situated close enough together to prevent other fields from being built between them.

The carrying capacity for an individual field in this study was found to support fewer people than would have been required to build the field. Fields comprising groups had a combined carrying capacity comparable to that required by the group of people needed to build the largest field in the group. These groups can be considered a form of 'social unit' representing the actions of the community work party involved in their creation. They are not considered representative of any actual social group but are a line of evidence indicating an intermediate scale of organization within the agricultural system that is larger than the individual field but smaller than the entire system (Walker 2004:53, 61).

Spatial analysis of these groups based on carrying capacity and labor requirements indicated that raised fields were organized by small groups of between 20 and 100 people and did not require dense populations to support their construction. However, archaeological evidence from a forest island associated with these raised field groups indicates a population numbering in the thousands may have depended on raised field agriculture (Walker 2004:119). While insightful, spatial analysis of raised field groups alone cannot be linked to specific forms of social organization. The small groups of workers constructing raised fields could have been organized at the local level by farmers or also at a larger scale by some form of centralized authority (Walker 2011).

An alternative method is to link the spatial patterns of landscape features to the communal tasks related to their creation and management. Where a landscape may be comprised of a set of related features, a set of related tasks can be combined into a 'taskscape.' While landscapes require land, taskscapes require labor and represent another means of comparing different landscapes (Ingold 1993:158). Landscape features with tasks that interfere with other features on the landscape can be assumed to require more cooperation between those constructing the features and therefor making the task more complex (Walker 2011). Farmers constructing raised fields along the Iruyañez would need to coordinate the placement of a new field to ensure enough room was left to remove the fill for the field and to maintain any hydrologic functions the intervening canals may have performed. Hunting parties would need to negotiate rites to hunt stranded wildlife crossing between fields. Intentional burning would also have to be coordinated if a connected group of fields were to be burned at one time. These tasks were found to be relatively simple when compared to the taskscape of the Apere which involved the overlap of ditched fields and causeways which could alter the hydrology of other fields in the vicinity. Along the Apere the construction of a causeway would have required the cooperation of all the farmers whose ditched fields would be affected by the changing flow of water re-directed by the new causeway feature. While this does not directly indicate the type of socio-political organization behind raised field agriculture, it is clear that any centralized authority wishing to access agricultural resources would face less political resistance from farmers using large raised field platforms along the Iruyunez than they would from those using ditched fields along the Apere (Walker, 2011).

Large raised fields are the primary focus of this study as they have been most thoroughly mapped from satellite imagery and represent one of the most extensive modifications to the landscape. Satellite imagery has improved enough that large raised fields can be mapped and analyzed as individual units throughout the extent of their use in the Mojos. The spatial analysis of 'group' social units across the entire system of large raised fields may provide the basis for regional distinctions in the social organization of raised fields. The specific objective of this analysis is to identify all raised field groups within the Mojos and identify any patterns in their distribution. This type of data can guide further archaeological research by indicating areas of interest to target for survey and excavation.

CHAPTER THREE: METHODS

Student volunteers of the Archaeological GIS Project of the Beni (Proyecto Arqueologico SIG del Beni/ProSIGAB) at the University of Central Florida have been utilizing satellite imagery available through programs like Google Earth to digitize maps of raised field platforms as well as their associated features such as rivers, lakes, and forest islands. This is an ongoing effort to create a GIS database of raised field agriculture that may guide further archaeological research in the region. Figure 1 shows how raised fields are first identified in satellite photos and mapped/digitized with an overlaying polygon that is georeferenced to that location. This digitized data can be saved and then imported into other programs such as ArcMap which are capable of further spatial analysis.

While fields may be readily identified in satellite imagery, their exact shape and outlines are not always so easy to distinguish. Picking the exact end of one field and the start of another can be quite difficult and digitizers do not always produce the exact same map of the same field when dealing with distorted imagery. For instance the constant movement of cattle from one field to another can trample down the ends of the fields making them appear to blend together into one single field. Other fields have well preserved ends that can be drawn out neatly without any question. To further complicate this problem students often overlap their work adding new fields to the database while re-mapping fields that were previously identified. The first part of this project was utilizing ArcMap to sort through the collection of maps and create a single map of all raised fields in which each field was represented by a single polygon. Figure 2 shows how a group of overlapping polygons were sorted out and removed based on the amount of individual area that overlaps with other polygons. Any polygon with more than 25% of its total area falling inside another polygon was removed until one polygon with the least amount of overlap was left.

These polygons were examined individually, however, and exceptions were made for intersecting fields that were clearly perpendicular as opposed to parallel and were clearly representations of different fields rather than the same field twice. The final part of Figure 2 shows the final stage when polygons with only small amounts of intersects were separated from their intersecting regions and those small intersecting regions were then merged back in to a polygon with which they shared a longer border. This process was guided by previous observations that raised field platforms are generally rectangular in shape and few cases of fields being built atop of one another in sequence have been recorded in this region. As part of the quality control of the file there was an analysis of the ratio of each polygon's perimeter to area in order to identify non-rectangular polygons that may represent something other than a large raised field or multiple fields digitized incorrectly as a single field. Ultimately a GIS layer of 40,472 non-intersecting polygons was produced [Figure 3]. There are many parts of the landscape which appear to contain fields however they are either poorly preserved or poorly captured in the imagery. While this file is believed to be a near complete representation of raised field distribution, more fields are still being found as satellite imagery continues to improve though the numbers are not expected to increase significantly. This file only represents large raised field platforms and does not include a variety of other raised field types such as mound fields or ditched fields.

With an analysis layer of raised field polygons, the next step was to examine the fields as a complete set. ArcMap 10.2.2. was used to measure the surface area of each field, the distance between each field and every other field, and the distance between each field and the nearest permanent body of water. The Minimum Bounding Geometry tool was used to measure the smallest rectangle which could be created to surround an individual field and then measure the orientation of a leg of the rectangle [Figure 4]. This method provides an accurate orientation for fields that conform to a rectangular shape but can be skewed if the fields curve or turn along their distance. Each field was assigned a ratio of the area of the field to the area of the minimum bounding rectangle created for that field. Non-rectangular fields result in a very low ratio allowing for most of the non-rectangular fields to be identified and the accuracy of their digitization checked against satellite imagery. In most instances the non-rectangular fields were the result of multiple fields being digitized as a single field or non-field objects such as forest islands being incorrectly identified as raised fields.

Blocks

When trying to sort fields into organized groups one of the simplest relationships that can be inferred is between two fields that are immediately adjacent to one another. When one field is built next to another field it takes up limited space available for a group of farmers to expand and build more fields next to ones currently in use. The assumption here is that building one field adjacent to another required some form of cooperation between those who had rights to access the fields. The next step in the study was assigning each field into a block based on its proximity to other nearby fields.

Preliminary analysis of the data revealed an average distance of less than 10 meters between any field and the nearest neighboring field. The average width of a field was estimated as approximately 20 meters. Field width measurements were taken with the Minimum Bounding Geometry tool but since no field is perfectly rectangular this measurement was slightly skewed towards a higher value and 20 was selected as a more accurate estimate based on manual measuring of sampled polygons. Based on these figures it was determined that 40 meters was the minimum width of an area needed to construct a raised field platform. This includes 20 meters for the platform itself and two adjacent canals each with a 10 meter width. 40 meters is consistent with methods used by Walker (2004) in creating raised field groups based on proximity. Raised fields with less than 40 meters separating them are more closely associated with one another because there is not enough room between the fields to build another field. The construction of one field has impacted the adjacent field by taking up a limited amount of space allowing fields to be constructed side by side. Fields with more than 40 meters separating them from adjacent fields are less associated as there was enough available space for more fields to have been constructed between them. Intentionally spacing fields apart from one another may have been a basic unit of organization and is the basis for the block designation here. Figure5 shows how in ArcMap fields were first united with the spatial join tool and then assigned into blocks based on shared spatial joins no greater than 40 meters. Figure 6 shows a larger selection of fields divided up into individual blocks.

In this study no field could be assigned to more than one block of fields and blocks required a minimum of two fields. Individual fields isolated from all other fields by more than 40 meters were designated as isolates and examined separately from the blocked fields. ArcMap was used to measure the average block size (surface area), number of fields per block, and distances between each block and the nearest permanent body of water. In order to examine the distribution of blocks throughout the study area, they were first assigned into Neighborhood designations based on nearest permanent river or wetlands associated with each block.

<u>Neighborhoods</u>

Previous GIS analysis of raised fields has indicated strong correlations between field placement and nearest source of permanent water. Based on these findings and the general abundance and importance of rivers in the region, ArcMap was used to divide up fields into six neighborhoods based on their proximity to six permanent bodies of water west of the Mamore river that are associated with raised field platforms [Figure 7]. In a few instances there are groups of fields spanning the midpoint between two rivers. To maintain the integrity of individual blocks, all fields in a block were assigned to the same neighborhood. The closest permanent body of water was identified for each block and all fields in a block were assigned to the corresponding neighborhood for that water system. Individual isolate fields not assigned to blocks were also assigned to a Neighborhood associated with the nearest permanent body of water to each isolate.

Within each neighborhood, both individual polygon and block characteristics could be examined for patterns that may not have been so clear in the entire set of fields. ArcMap was again used to measure the number of fields in each neighborhood as well as the smallest and largest field, average size of a field, total surface area of all fields, and the cardinal orientation of each field. The average distance between fields was also measured along each river system as well as the average distance between each field and the nearest permanent water source.

Groups

Examining the orientation of each field in the study revealed fields of every orientation with a larger proportion of fields clustered around the orientations of 85 degrees (5 degrees counterclockwise of due east) and 355 degrees (5 degrees counterclockwise from due north). 15,882 fields have an orientation ranging between 152.5 (or -27.5) and 17.5 degrees with an increasing number facing closer to north or 175 degrees. 11,600 fields have an orientation ranging from 62.5 to 107.5 with an increasing number facing east or 85 degrees. 6828 fields have an orientation between 17.5 and 62.5 degrees clustering around the northeast cardinal direction. 6162 fields have an orientation between 107.5 and 152.5 clustering around the southeast cardinal direction. There are clearly many more fields oriented to the cardinal directions North and East [Figure 8].

From these findings, four 'oriented grouping' designations were created into which each field could be distributed [Figure 9]. Every field in the study had its orientation measured and was assigned to one of these four grouping designations. From here each field could be assigned into an individual 'group' based on both the 40 meter proximity requirement as well as requiring each field in a group to share the same grouping designation [Figure 10].

Within each Neighborhood the total number of groups for each of the four oriented grouping designations was counted along with the average size and number of fields for each individual group. Fields which could not be grouped with at least one other field were identified as 'group isolates' and their size and grouping designation were recorded. The ratio of group isolates to total fields within each grouping designation was calculated to determine the likelihood that a given field orientation would be in either a group or appear as a group isolate.

CHAPTER FOUR: RESULTS

The study included a total of 40,472 individual raised field platforms spread across an area of approximately 7,419 square kilometers. The fields have a combined area of 112.1 square kilometers. The average size of a field is 2,750 +- 2,738 square meters with individual areas ranging from 15 to 44,695 square meters. The number of fields of a particular size decreases as the fields grow larger. The most common size is approximately 800 square meters with more than 3,000 fields of this general size alone [Figure 11].

Though spread across such a large geographical area the average distance between any field and its nearest neighboring field is only 9.5 +- 43 meters with a maximum distance of 2,240 meters. The fields have an average distance of 2,157 +- 1,882 meters to the nearest permanent body of water but can be found at any distance from a river up to 9,056 meters which is the midpoint between the two most widely separated bodies of water [Table 1].

Neighborhood Analysis

The distribution of fields between the rivers shows that while there are large clusters of fields located adjacent to rivers, in any neighborhood fields can be found spanning out into the savannah several thousand meters from a permanent water source [Figure 12]. It should be noted however that this methodology did not account for seasonal water sources such as small streams, canals, lakes, and flood zones. While permanent bodies of water are clearly important, other factors are involved in field placement given their dispersal across the open savanna. There are also extensions of the Tapado and Iruyani rivers which appear to intersect and a small section of the Iruyani was mistakenly assigned to the Tapado. This did not significantly alter the results, however, future analysis should more clearly define the network of canals and streams that may connect these larger river systems.

Examining the individual fields in each neighborhood revealed several patterns in the distribution of raised field characteristics such as average and total surface area per neighborhood. Results from this analysis are in Table 2. The total number of fields in each neighborhood increases from south to north with a vast majority of all raised field surface area being found in the northern portion of the study area. Of the 40,472 fields included in the study, neighborhood 1 in the south consisted of 2,507 fields while neighborhood 6 consisted of 17,280 fields. Measuring the surface area of raised fields in each neighborhood showed a similar pattern of increasing area moving from south to north. Neighborhood 1 contained 634 hectares of field area or 5.7% of the total raised field area of 11,211 hectares. While in the far north neighborhood 6 was again the largest with 3.279 hectares of raised field area or 29.2% of the total area represented by all raised fields.

The average size of an individual field along each neighborhood showed a different pattern than that seen in the larger study area. Neighborhoods 3 and 4 near the center of the study area had the largest average individual field size with 4,075 +- 3,040 square meters along Neighborhood 3 and 5,036 +- 3,588 square meters along neighborhood 4. Moving north and south from these two neighborhoods the average field size for each neighborhood gets smaller with an average of 2,529 +- 2.749 square meters along the Rapulo in neighborhood 1 and the smallest average of 1.898 +- 2.052 square meters in neighborhood 6 to the far north.

Analysis at the neighborhood level also revealed distinctions in the frequency of fields orientated to different cardinal directions. In northern Neighborhoods 4-6, there is a greater frequency of fields facing North and East with significantly fewer fields facing Northeast and Southeast. In contrast Neighborhoods 1-3 in the south have significantly more fields oriented Northeast and Southeast. However, every neighborhood still contains fields of all different orientations [Figure 13].

Block Analysis

The block analysis identified 2,761 blocks spread across the study area with an increasing number of blocks per neighborhood moving from south to north. The average total area of an individual block (The sum surface area of each polygon within a block) was just under 4 hectares for the entire study area. Block sizes ranged from less than 1 hectare to just under 500 hectares. The average total area of an individual block was similar along each neighborhood ranging between 3 and 5.6 hectares. Where Neighborhood 6 had previously shown to have on average much smaller surface area per field than other river systems, the blocks in this neighborhood contained nearly twice as many fields on average than other neighborhoods with larger individual fields [Table 3]. Despite the fluidity in average block size throughout the area, the ten largest blocks in the study area were all located along the 3 northernmost neighborhoods the smallest being over 100 hectares in size [Figure 14].

Of the 40,472 fields in the study, 1,431 fields could not be grouped into blocks due to their increased distance from other fields. These 'isolate' fields are found in each neighborhood and consistently represent a low proportion of the total fields in each neighborhood. The ratio of area devoted to isolate fields throughout each neighborhood ranged from 2.5% to 6.2% [Table 4].

Group Analysis

A total of 6151 individual groups were identified in the analysis accompanied by 5,682 'group isolates' which could not be joined to a group based on either proximity or oriented grouping [Table 5]. The initial grouping of fields revealed that overall abundance of both groups and group isolates is determined by orientation. Of the 5,057 groups identified in northern neighborhoods 4-6, 3,516 of these groups or nearly 70% belong to either the north or east oriented groups. Of the 1,094 groups in the southern neighborhoods 1-3, 789 of these groups or 72% belong to either northeast or southeast oriented groups. This pattern can be seen in the total area of groups where in the north nearly 88% of all field area is from fields that belong to either north or east oriented groups. In the south roughly 81% of all field area is devoted to fields oriented closest to either northeast or southeast. This pattern can also be seen in the average size of a group (sum surface area of all fields in a group). In each neighborhood the average size of a group is much larger for a particular set of oriented groups. In northern neighborhoods 4-6, groups are larger on average when oriented either north or east. This is the opposite in neighborhoods 1-3 in the south where larger groups are on average oriented southeast or northeast. Figures 15-20 show this distribution of oriented groups along each of the six neighborhoods.

Beyond this consistent proportioning of group size between oriented groups, there are larger differences in the average size of a group from neighborhood to neighborhood. Groups along the Omi or Neighborhood 4 have a consistently higher total area (3.4 +- 5.2 ha) than any other neighborhood. Groups along Neighborhood 6 though more numerous are consistently much smaller (1.0 +- 2.5 hectares) in total size. The average size of a group for the entire study area was 1.6 +- 3.8 hectares. This distribution of larger and small groups can be seen in Figure 21.

The ratio of the number of isolate fields to grouped fields is also a visible pattern between neighborhoods. Among all six neighborhoods, between 12% and 15% of fields could not be placed into a group and were considered group isolates. In the northern three neighborhoods, however, only 9% of all fields oriented north are isolates while 30% of all fields oriented southeast are isolates. In the northern three neighborhoods 25% of all northeast oriented fields are isolates and 12% of all east oriented fields are isolates. This emphasis on two cardinal directions is again reversed in the southern three neighborhoods where being oriented either north or east results in a higher probability that a field will be a group isolate [Table 6]**.**

CHAPTER FIVE: CONCLUSION

This study first demonstrated that proximity based blocks and orientation based groups are significant units of field organization present throughout the entire study area. 96.5% of all fields in the study were grouped into blocks, and 85.9% of all fields were also placed into oriented groups within blocks. In any area of the study it is much more likely that a field will be accompanied by other fields forming an oriented group as well as a larger block of fields with a variety of orientations. These units feed into the fluid nature of raised field agriculture in that they are readily identifiable throughout the system giving it a more unified appearance. Clustered along each major permanent body of water are blocks of fields that flow from one to another with seemingly random assortments of different oriented groups. A variety of both large and small fields can be found in every neighborhood but are still organized closely together into these basic units of organization.

The study next demonstrated that within the larger system are two distinct regions that are distinguishable in two ways. The first is in the overall abundance (both in number and surface area) of raised field platforms. The northern three neighborhoods contain 8,555 hectares of fields compared to 2,238 hectares of fields in the three neighborhoods to the south. Table 7 and Figure 22 show how a preliminary view of the data indicated this greater abundance of fields in the north. While blocks in both the northern and southern neighborhoods have the same average size, the northern neighborhoods contained the ten largest blocks in the study each ranging from 100 to just under 500 hectares in size [Figure 23]. However, without a clear chronology in field construction it is unclear how many of these fields were in use at one time and whether or not this region is distinct because it produced more food at one time or if it was simply constructed over a longer period of time.

The defining characteristic of this north/south region within the study area is the switch from a dominance of the north/east oriented groups in the northern neighborhoods to a northeast/southeast dominance in the south neighborhoods. Figure 24 shows how individual fields in the northern three neighborhoods are much more likely to be oriented north or east while the opposite is true in the southern neighborhoods. Within each region the minority groups are not congregated in a single area but rather are spread throughout each neighborhood and accompany majority oriented groups within the same block. This pattern between north and south can be seen in Table 8 as well as Figures 25 & 26. This pattern is important to interpreting this landscape because field orientation has no clear utilitarian use within the raised field system. Changing the orientation of fields is not altering the flow of water towards or away from the area and has no obvious effect on whether or not the fields could be farmed continuously. The orientation of fields to different cardinal directions had some kind of meaning to the people who constructed them and the resulting landscape was intentionally created rather than an accidental byproduct of slow and steady field building.

When viewed on the map, this shift in emphasis on different oriented groups is very clear and the study area can be divided into two distinct regions [Figure 27]. However, the exact transition between these two regions does not occur exactly between neighborhoods 3 and 4 as would be expected. While the Omi, neighborhood 4, is clearly dominated by north/east oriented groups, there is a sharp shift to northeast/southeast dominated groups at the river's southwestern extent that marks the actual transition between the two regions [Figure 28]. This area of the Omi that lies in this southern region could be an area of interest to archaeologists as it represents a clear transition from one region to another while still being located on the same river as a kind of link between the two regions [Figure 29].

An interesting aspect of the Omi that distinguished it from other neighborhoods was the consistently larger size of individual groups throughout the neighborhood. Figure 30 shows the distribution of small and large groups in the study area and the Omi lies near the center with more large groups (between approximately 15 and 30 hectares) spread along its banks. While large groups can be found in any neighborhood the Omi does not have large concentrations of small groups (less than 2 hectares) as can be seen in the other neighborhoods. While a transitional zone across the Omi has occurred in the orientation of groups, it still united to the rest of the river in that the size of the groups does not significantly decrease throughout its length. It has been previously suggested that the size of a group may represent the needs of the laborers who built the fields. Bigger work parties would need to build more fields to meet everyone's needs. Larger field groups on average could represent larger populations building or utilizing raised field agriculture in that area. Archaeological excavations have provided dates for forest island sites associated with fields in northern neighborhoods. There are no excavations or dates from this southwestern portion of the Omi identified here. Excavations of forest islands along this section of the Omi would be more likely to reveal evidence of large populations as well as aid in linking these two regions into a clearer chronology of development and interaction along the border of these two regions.

This transition in field orientation also lies conspicuously close to the same line drawn by Denevan (1966 pp 41) marking the transition between the regions associated with Cayuvava and Movima language groups. Denevan's map does not include the Omi and emphasis is placed on the Cayuvava being centered around the Iryuani (neighborhood 5) to the north and the Movima around the Rio Yacuma (neighborhood 2) in the south. With better flood and digital elevation data, future research could analyze the movement of floodwaters over raised fields and look for possible links between field placement and orientation with regional hydrologic functions. Are there other environmental factors involved in field placement and orientation such as erosion rates or thermal inputs from varying orientation to the rising and setting sun?

As noted previously, raised field groups may represent the efforts of a community work party. The dominance of group units throughout the study area supports the notion that raised fields could be reconstructed at the community level in the Mojos today. Local farmers may be capable of organizing themselves and pooling labor to construct or rehabilitate raised fields on the savannah rather than limiting it use to cattle ranching alone. Further archaeological research in the construction and maintenance of pre-Columbian raised agricultural fields has the potential to guide such efforts.

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APPENDIX A: TABLES

	Count	Total Area (ha)	Average Field Surface Area (m^2)	Largest Field Area ($m^{2)}$	Smallest Field (m^2)	Average Distance Between Fields (m)
All Fields	40472	11,129.4	2750 +- 2741	44,695	16	9.5 +- 43

Table 1: Summary of preliminary analysis of all raised field polygons in ArcMap.

	Field Count	Total Area (ha)	Average Field Size (m^2)	Largest Field (ha)	Average Distance Between Fields (m)	Average Distance to Nearest River (m)
All Fields	40,472	11,129	2750 +- 2738	4.5	9.5 +- 43	2157 +- 1882
NH1: Rapulo	2,507	634	2529 +- 2749	2.5	8.5 +- 33	1558 +- 977
NH2: Yacuma	1,031	385	3733 +- 2948	2.0	20.5 +- 109	1391 +- 949
NH3: Quinato Wetlands	2,640	1,330	5036 +- 3588	3.6	13.8 +- 70	672 +- 594
NH4: Omi	4,932	2,010	4075 +- 3040	2.8	8.2 +- 35	1183 +- 770
NH5: Iruyañez	12,082	3,492	2890 +- 2692	3.0	8.9 +- 34	1950 +- 1713
NH6 : Tapado	17,280	3,280	1898 +- 2052	4.5	9.1 +- 38	2934 +- 2118

Table 2: Summary of all raised field polygons distributed into six neighborhood units.

	Block count	Number of Fields Comprising Blocks	Max Number of Fields Per block	Average Number of Fields Per Block	Average Block Area (m^2)	Sum Block Area (ha)
NH1: Rapulo	193	2,436	209	12.6 +- 29.1	3.2 +- 9.8	625
NH2: Yacuma	98	996	180	10.1 +- 21.7	3.8 +- 6.6	374
NH3: Quinato Wetlands	321	2,448	137	7.7 +- 12	3.9 +- 7.4	1,238
NH4: Omi	379	5,203	454	13.8 +- 33.4	5.6 +- 16.7	2,137
NH5: Iruyañez	805	12,264	1,229	15.2 +- 53.1	4.4 +- 20.4	3,516
NH6: Tapado	966	15,694	1,920	16 +- 83	3.0 +- 19.3	2,901

Table 3: Summary of block distributions among the six neighborhoods.

	Number of Fields in Blocks	Isolate Fields	Sum Isolate Area (ha)	Total NH Area (ha)	Isolate Area Over Total NH Area x 100	Avg Distance Between Isolate and nearest block
NH1: Rapulo	2,436	80	16	641	2.5%	155 +- 188
NH2: Yacuma	996	70	25	399	6.2%	537 +- 605
NH3: Quinato Wetlands	2,448	147	70	1,308	5.3%	264 +- 365
NH4: Omi	5,203	152	49	2,186	2.3%	181 +- 225
NH5: Iruyañez	12,264	395	85	3,601	2.4%	181 +- 230
NH6: Tapado	15,694	586	92	2,993	3.1	171 +- 221

Table 4: Summary of block isolate distributions among the six neighborhoods.

Four Orientated Groupings Per Neighborhood	Group Count	Fields Count	Average Group Size (ha)	Average number of fields per group	Largest Group Area (ha)	Total Group Area *TGA (ha)	Grouping TGA/ NH TGA * 100
NH1: Rapulo	**368**	**2,245**	**1.6 +- 3.2**	**6.1 +- 9.1**	**28**	**592**	
North Groups	37	149	.8 +- 1.1	4 +- 2.5	5	30	5%
Southeast Groups	174	1,173	1.9 +- 3.3	6.7 +- 9.1	21	335	57%
East Groups	38	121	.5 +- .5	3.2 +- 2	2	18	3%
Northeast Groups	119	802	1.8 +- 3.8	6.7 +- 11.2	28	209	35%
NH2: Yacuma	**182**	**908**	**1.9 +- 2.6**	**5 +- 5.5**	**18**	**347**	
North Groups	18	95	1.5 +- 1.7	5.3 +- 4.6	7	28	8%
Southeast Groups	80	459	2.6 +- 3.6	5.7 +- 7.1	18	209	60%
East Groups	18	93	1.6 +- 1.3	5.2 +- 4.3	5	28	9%
Northeast Groups	66	261	1.3 +- 1.0	4 +- 2.7	4	83	24%
NH3: Q. Wetland	**546**	**2,285**	**2.2 +- 2.6**	**4.2 +- 3.5**	**28**	**1,174**	
North Groups	113	365	1.6 +- 1.7	3.2 +- 1.7	10	183	16%
Southeast Groups	207	988	2.6 +- 3.3	4.8 +- 4.1	28	546	46%
East Groups	81	265	1.5 +- 1.3	3.3 +- 1.7	7	125	11%
Northeast Groups	145	667	2.2 +- 2.4	4.6 +- 4	15	320	27%
NH4: Omi	**575**	**4,616**	**3.3 +- 5.0**	**8 +- 10.7**	**46**	**1,905**	
North Groups	234	2,636	4.6 +- 6.6	11.2 +- 14.1	46	1,072	56%
Northeast Groups	83	472	2.1 +- 2.9	5.7 +- 7.3	12	174	9%
East Groups	154	1,090	3.2 +- 4.1	7.1 +- 7.8	27	488	26%
Southeast Groups	104	418	1.7 +- 1.8	4 +- 3.4	11	172	9%
NH5: Iruyañez	**1855**	**10,363**	**1.7 +- 4.4**	**5.6 +- 8.4**	**130**	**3,158**	
North Groups	668	4,573	2.2 +- 6.7	6.8 +- 12	130	1,498	47%
Northeast Groups	215	724	.9 +- 1.1	3.4 +- 2.3	8	189	6%
East Groups	612	3,575	1.8 +- 2.9	5.8 +- 6.5	32	1,081	34%
Southeast Groups	360	1,491	1.1 +- 1.3	4.1 +- 3.4	10	390	12%
NH6: Tapado	**2678**	**14,342**	**1.1+- 2.8**	**5.4 +- 8.5**	**67**	**2,871**	
North Groups	987	6,292	1.3 +- 3.2	6.4 +- 10.3	66	1,301	45%
Northeast Groups	306	1,178	.6 +- 1.0	3.8 +- 4.5	13	197	7%
East Groups	902	5,085	1.2 +- 3.4	5.6 +- 9.2	67	1,086	38%
Southeast Groups	483	1,787	.6 +- .8	3.7 +- 3.4	9	286	10%

Table 5:The makeup of groups within each neighborhood, broken down by the four oriented groupings used to define groups [refer to Figure 9].

	Total Field Count	Isolate Count	Isolate Count / Total Field Count
NH1: Rapulo	**2,507**	**262**	**10%**
North Groups	211	62	30%
Southeast Groups	1,272	99	8%
East Groups	167	46	28%
Northeast Groups	857	55	6%
NH2: Yacuma	**1,031**	**123**	**12%**
North Groups	125	30	24%
Southeast Groups	498	39	8%
East Groups	108	15	14%
Northeast Groups	300	39	13%
NH3: Q. Wetland	**2,640**	**355**	**13%**
North Groups	443	78	18%
Southeast Groups	1,114	126	11%
East Groups	339	74	22%
Northeast Groups	744	77	10%
NH4: Omi	**4,932**	**316**	**6%**
North Groups	2,713	77	3%
Southeast Groups	526	54	10%
East Groups	1,187	97	8%
Northeast Groups	506	88	17%
NH5: Iruyañez	**12,082**	**1,719**	**14%**
North Groups	5,101	528	10%
Southeast Groups	1,045	321	31%
East Groups	4,003	428	11%
Northeast Groups	1,933	442	23%
NH6: Tapado	**17,280**	**2,938**	**17%**
North Groups	7,090	798	11%
Southeast Groups	1,780	602	34%
East Groups	5,904	819	14%
Northeast Groups	2,506	719	29%

Table 6:The proportion of isolate fields found within each oriented grouping.

	Field Count	Total Area ha	Largest Field Area (ha)	Largest Block Area (ha)	Largest Group Area (ha)
All Fields	40472	11,129	4.5	494	130
Northern Neighborhoods 4-6	34294	8,781	4.5	494	130
Southern Neighborhoods 1-3	6178	2,348	3.6	85	28

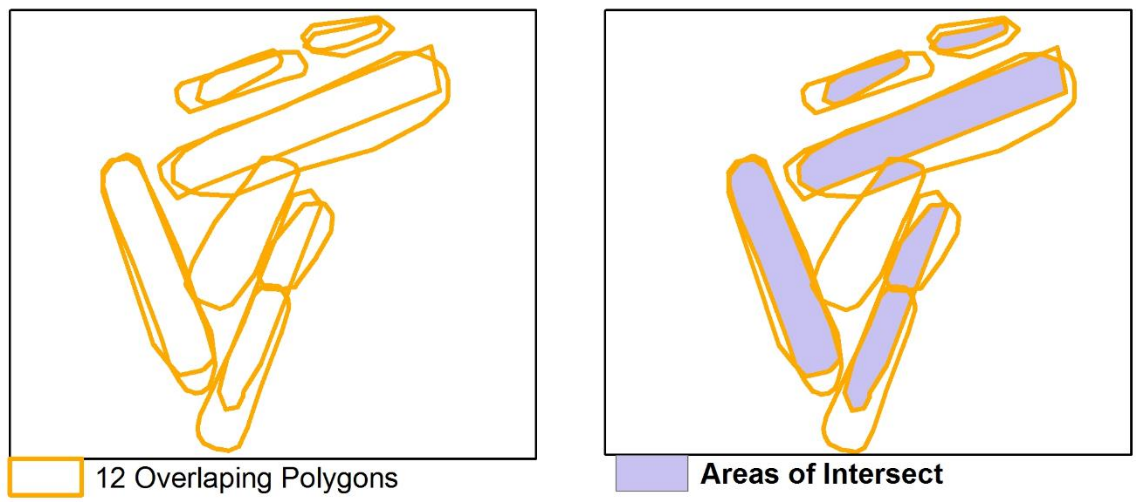
Table 7: Comparison of the number and total area of fields between the northern and southern neighborhoods.

	Group Count	Field Count	Average Group Size (ha)	Largest Group Area (ha)	Total Group Area *TGA (ha)	Group TGA / Neighborhood TGA * 100
Neighborhoods 4-6	**5,057**	**29,351**	**15.7 +- 3.9**	**130**	**7940**	
North Groups	1,868	13,704	2.1 +- 5.4	130	3,933	50%
Southeast Groups	595	2,302	.9 +- 1.4	13	531	7%
East Groups	1,648	9,654	1.6 +- 3.4	73	2,630	33%
Northeast Groups	946	3,691	.9 +- 1.2	11	845	10%
Neighborhoods 1-3	**1,094**	**5,439**	1.9 +- 2.8	**28**	**2,114**	
North Groups	168	609	1.4 +- 1.6	10	240	11%
Southeast Groups	460	2,620	2.3 +- 3.3	28	1,090	52%
East Groups	137	479	1.2 +- 1.2	7	171	8%
Northeast Groups	329	1,731	1.8 +- 2.8	28	613	29%

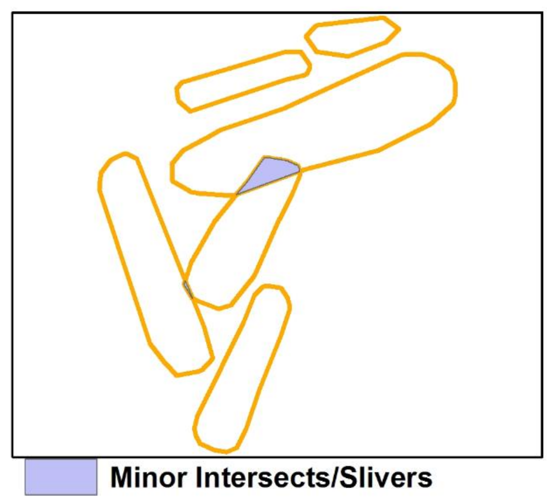
Table 8: Comparison of the distribution of oriented groups between the northern and southern neighborhoods.:

APPENDIX B: FIGURES

Figure 1: Digitizing raised fields from satellite imagery and then transfering them to ArcMap.



Field ID	Field Area (m²)	Intersect Area (m²)	Intersect Area/Field Area
1	570	265	0.46
2	880	439	0.49
3	2667	2367	0.88
4	3154	2968	0.94
5	1685	896	0.53
6	268	265	0.98
7	487	439	0.90
8	4603	2968	0.64
9	2662	2368	0.87
10	1729	896	0.51
11	2020	222	0.10
12	922	602	0.65



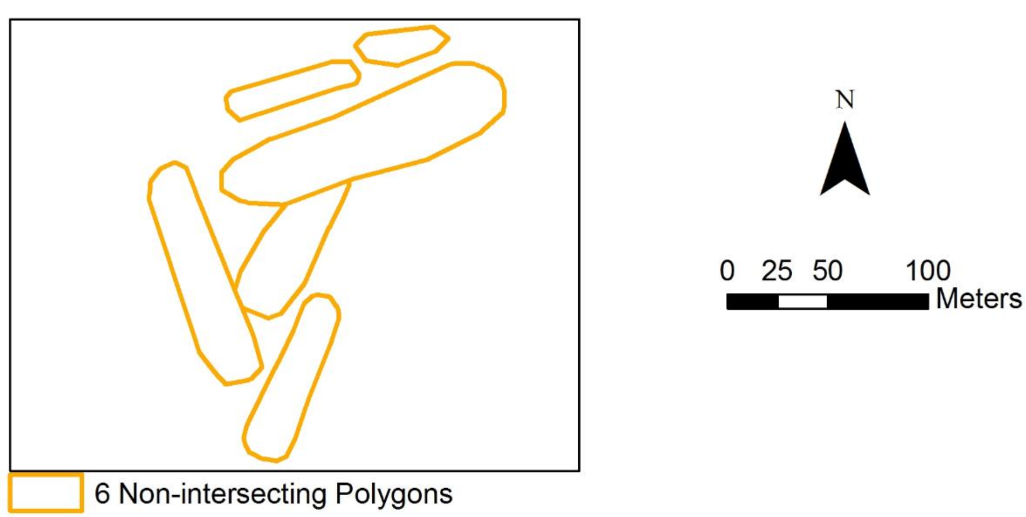


Figure 2: Creating an analysis layer of non-intersecting polygons.

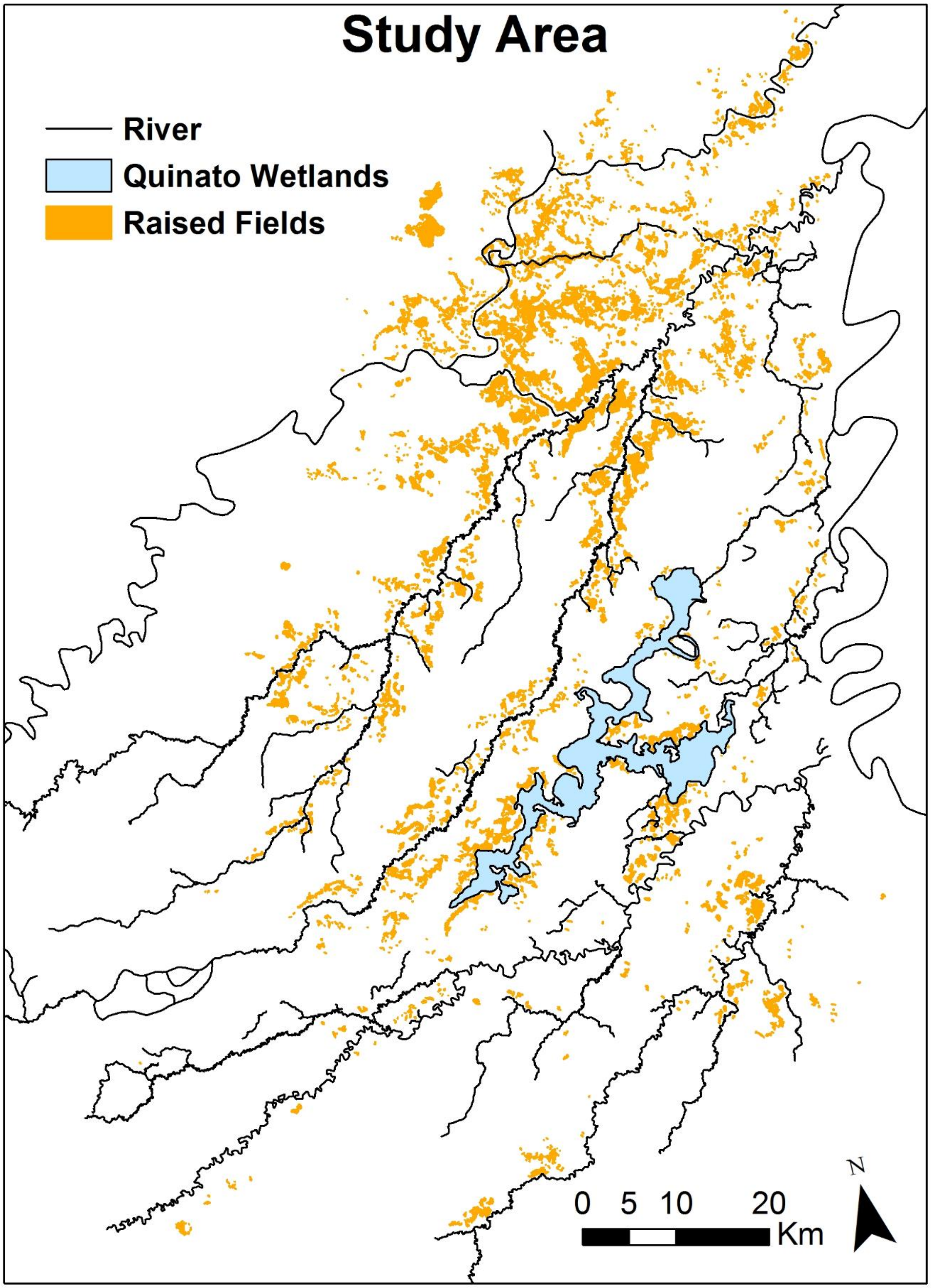


Figure 3: Analysis layer of polygons representing all large raised fields in the study area.

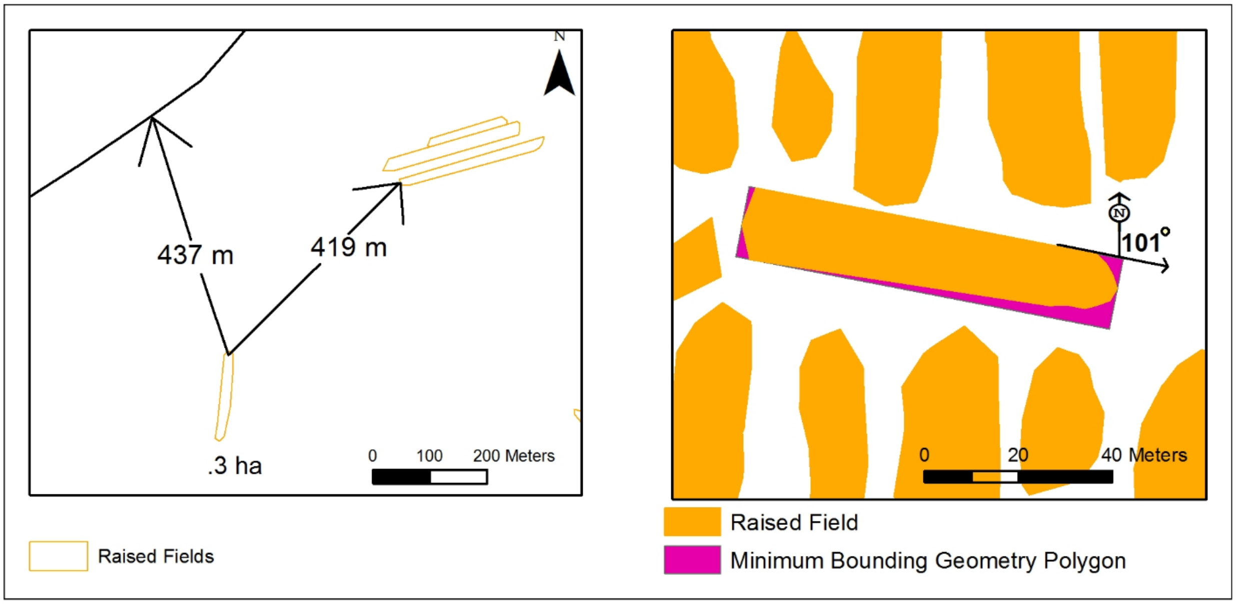


Figure 4: Measuring individual field attributes in ArcMap.

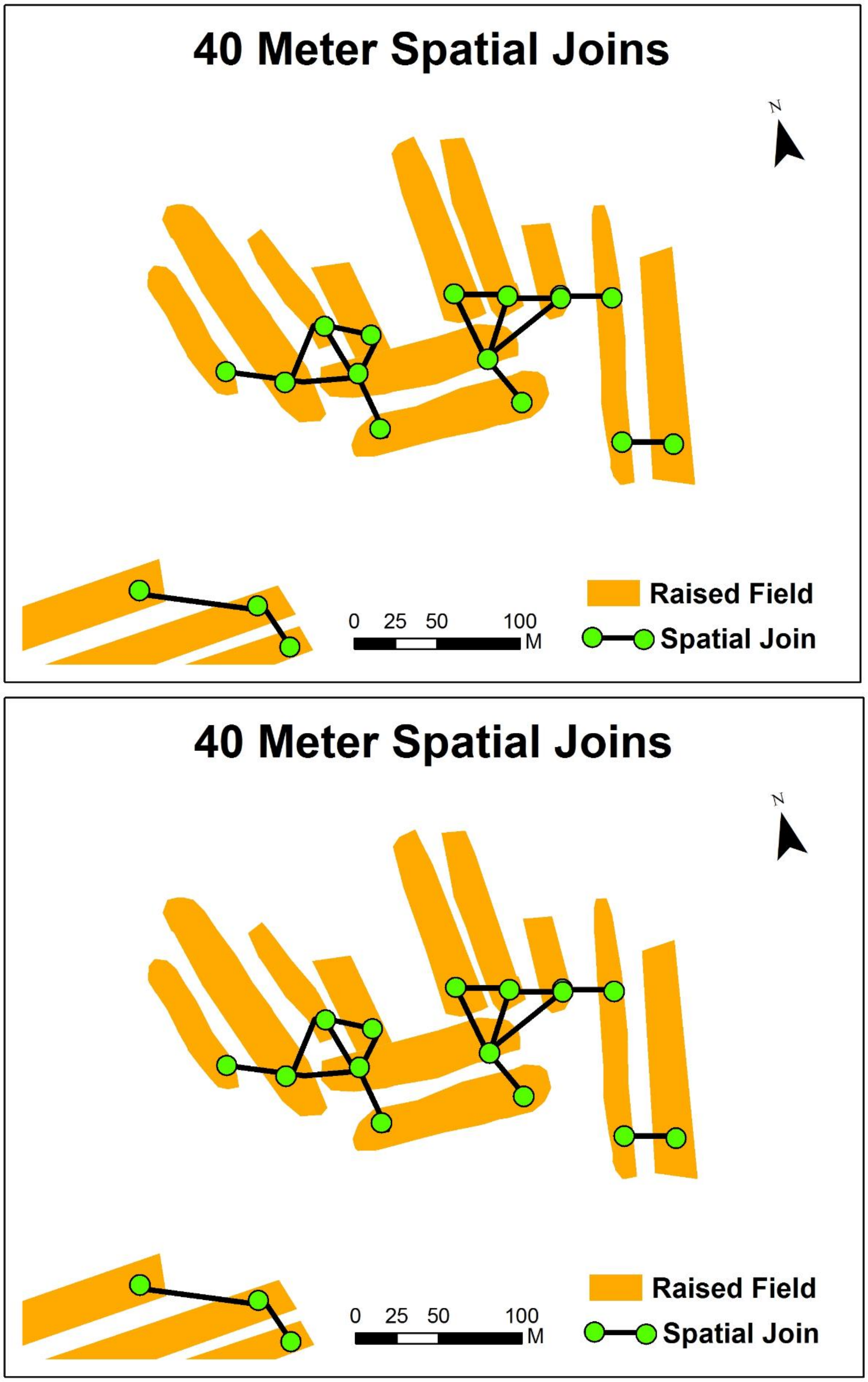


Figure 5: Using ArcMap to divide fields up into associated blocks.

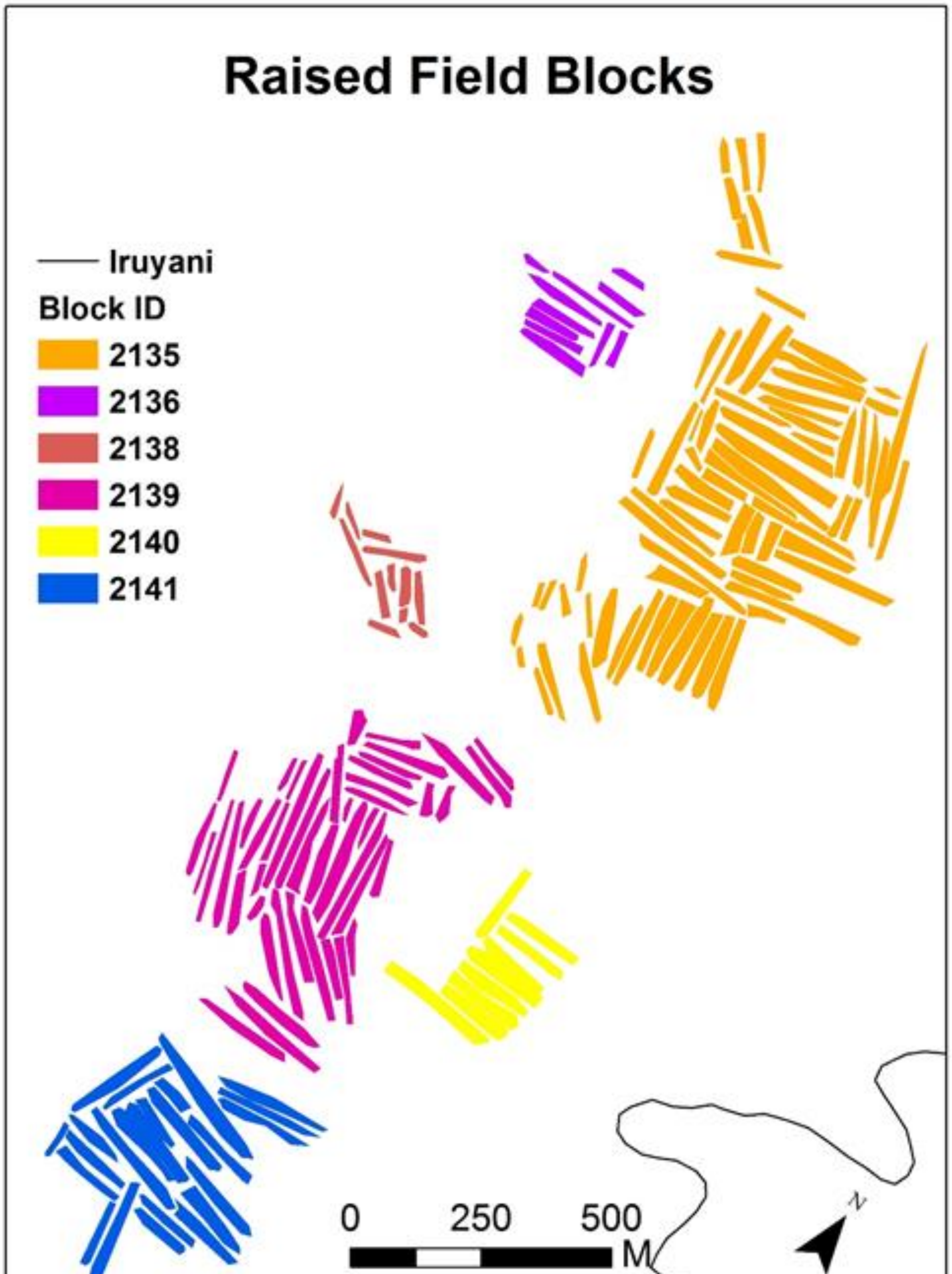


Figure 6: Example of raised field blocks along the Iruyañez.

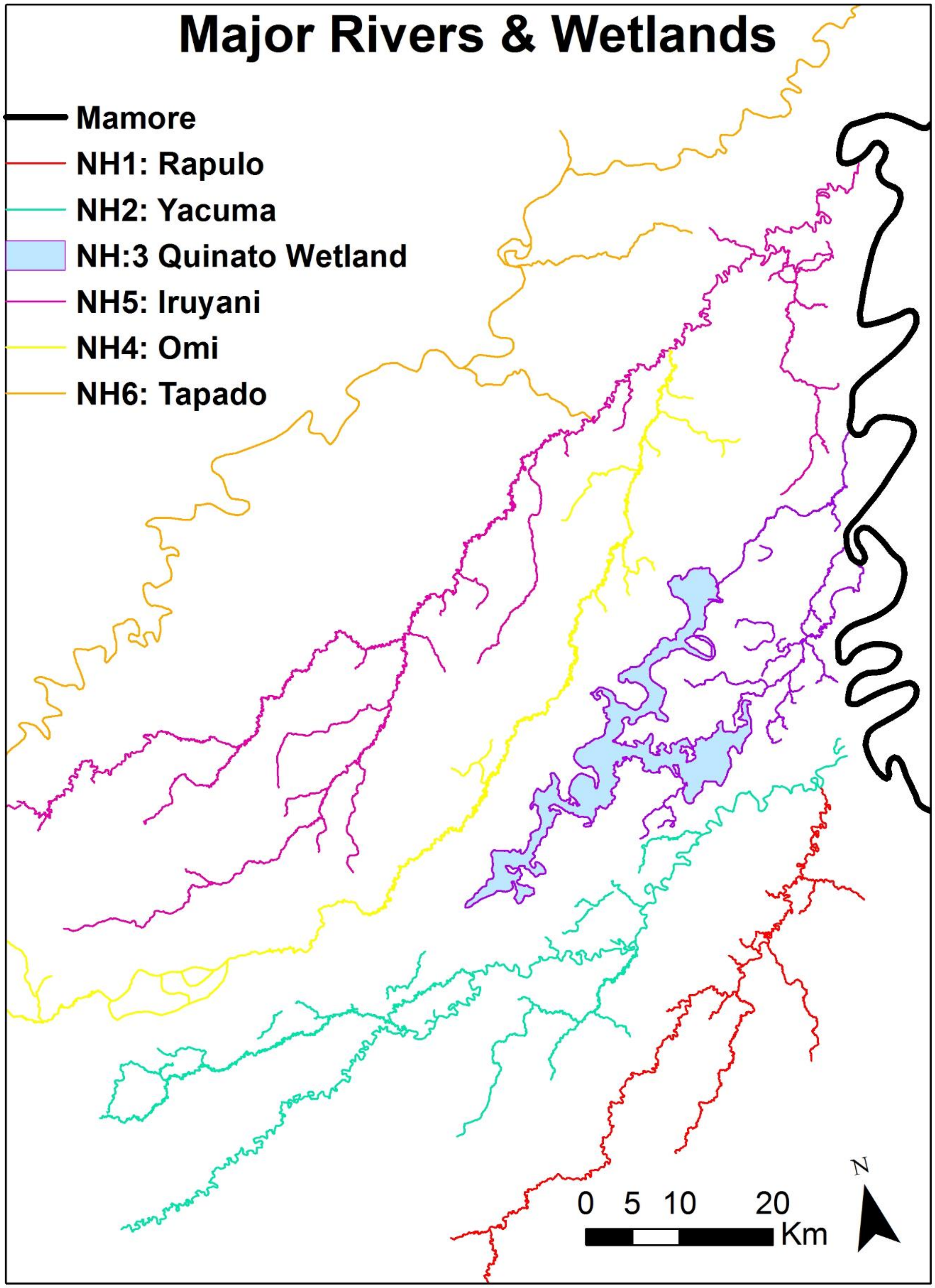


Figure 7: Six neighborhoods (NH) representing permanent bodies of associated with large raised fields.

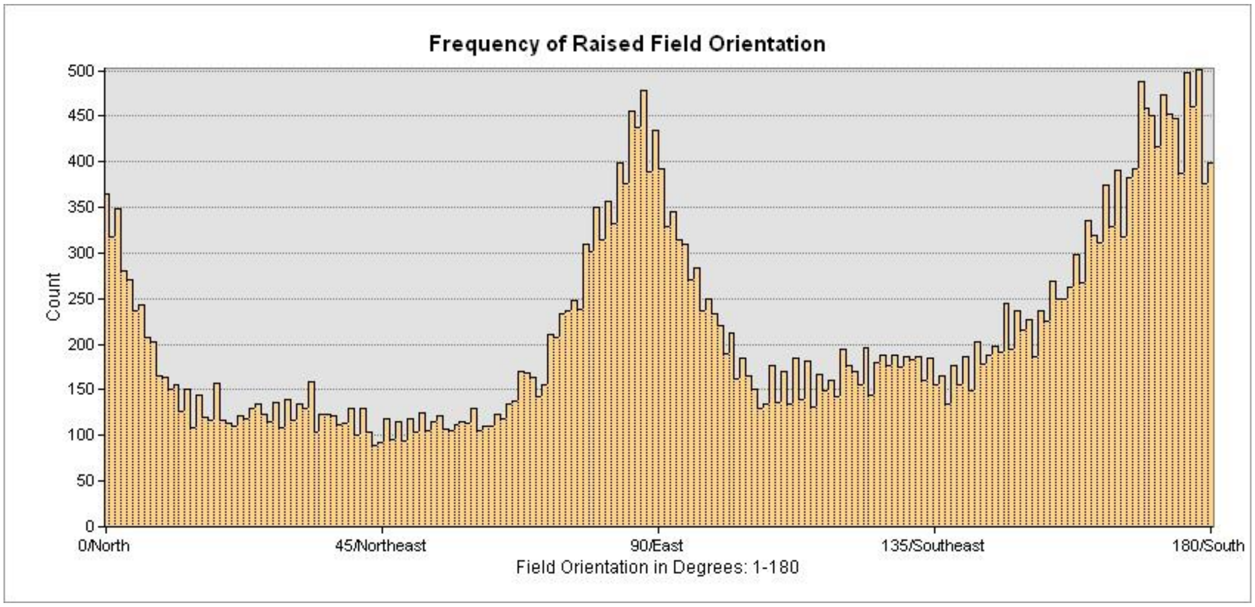


Figure 8: Frequency of individual raised fields oriented to different cardinal directions.

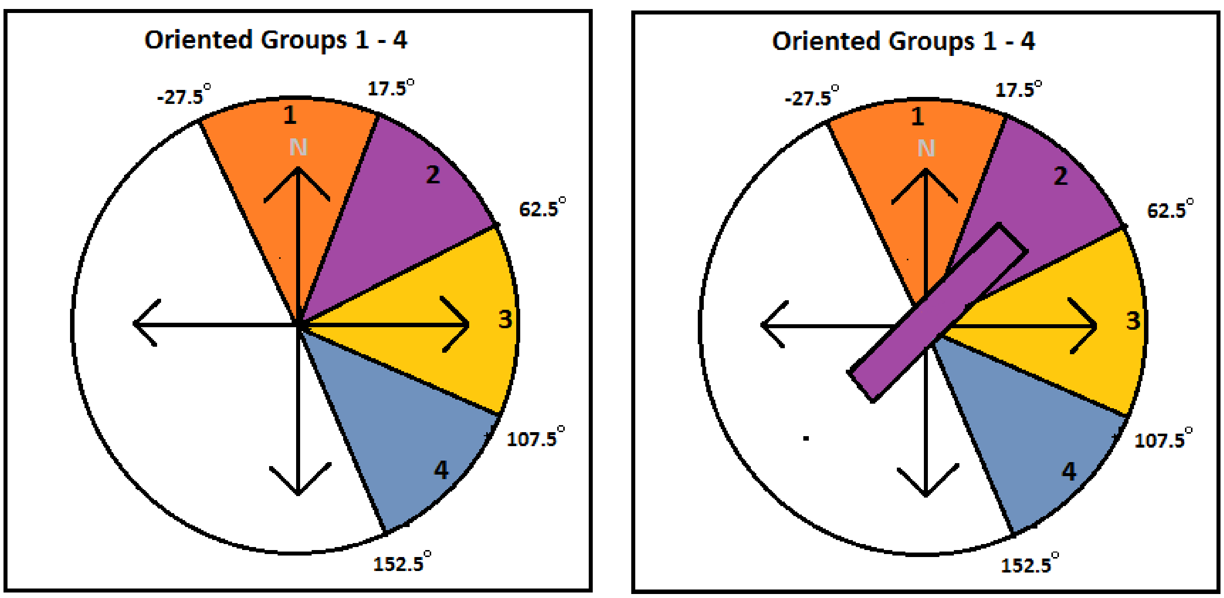


Figure 9: Each field in the study was designated in one of four oriented groups.

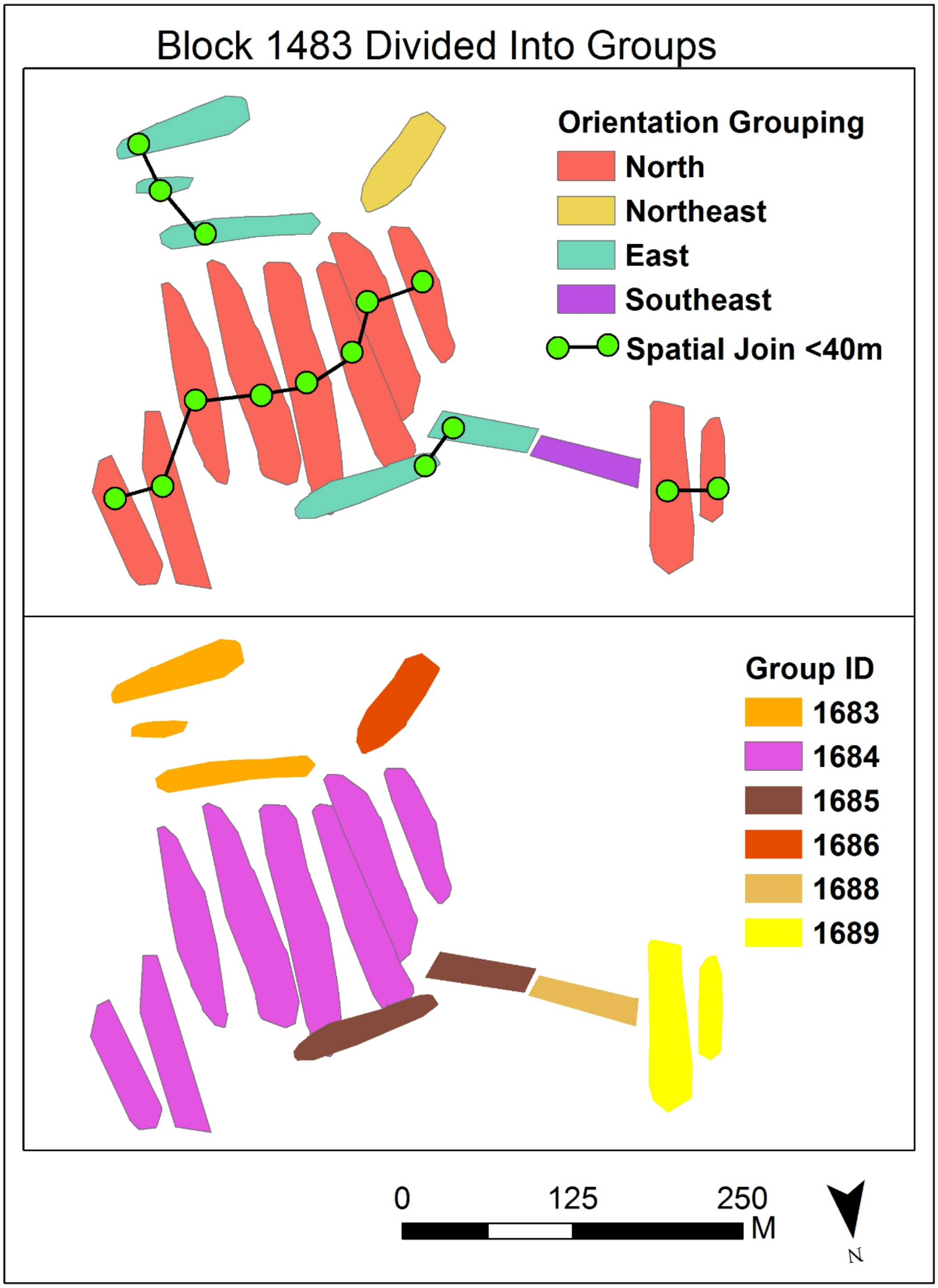


Figure 10: Individual fields are linked by 40meter spatial joins but only those joins between fields of the same orientation grouping are kept and used to create groups. Note that block 1683 & 1688 contain only a single field and are isolates rather than groups.

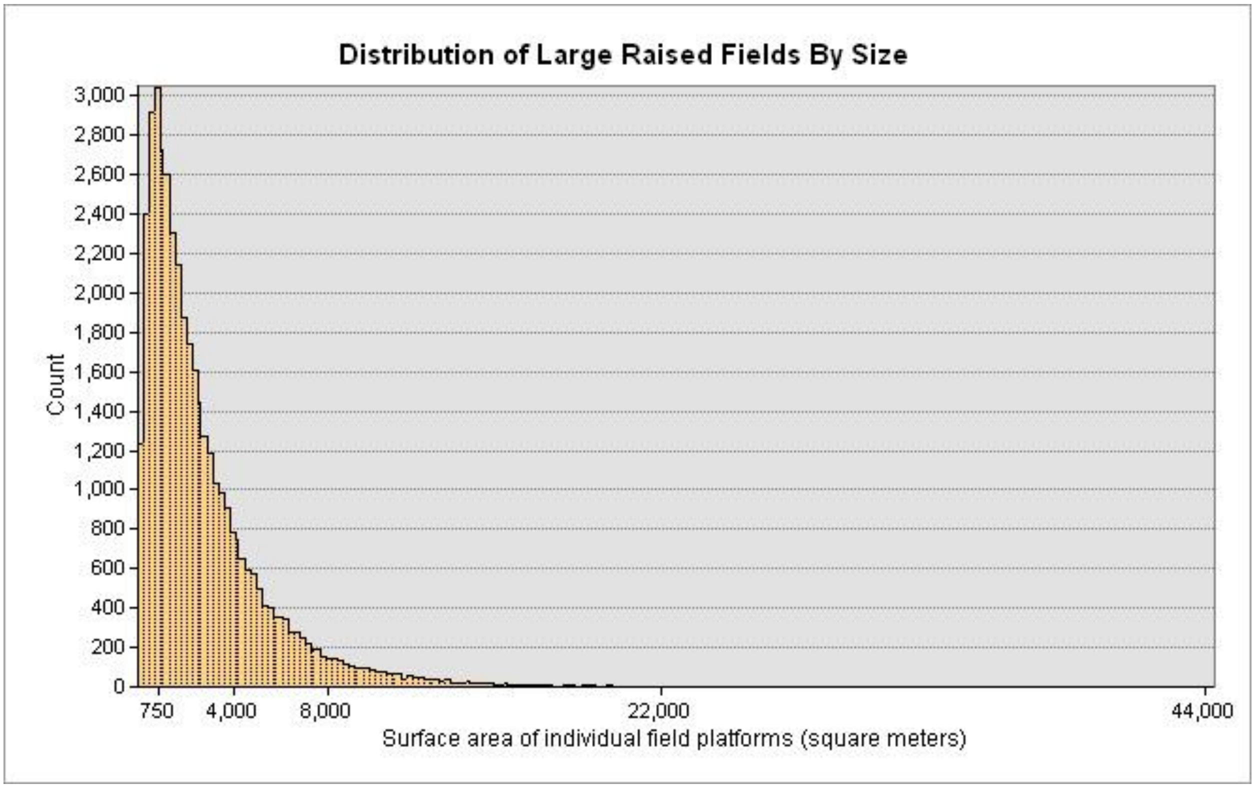


Figure 11: Frequency of individual raised fields by size.

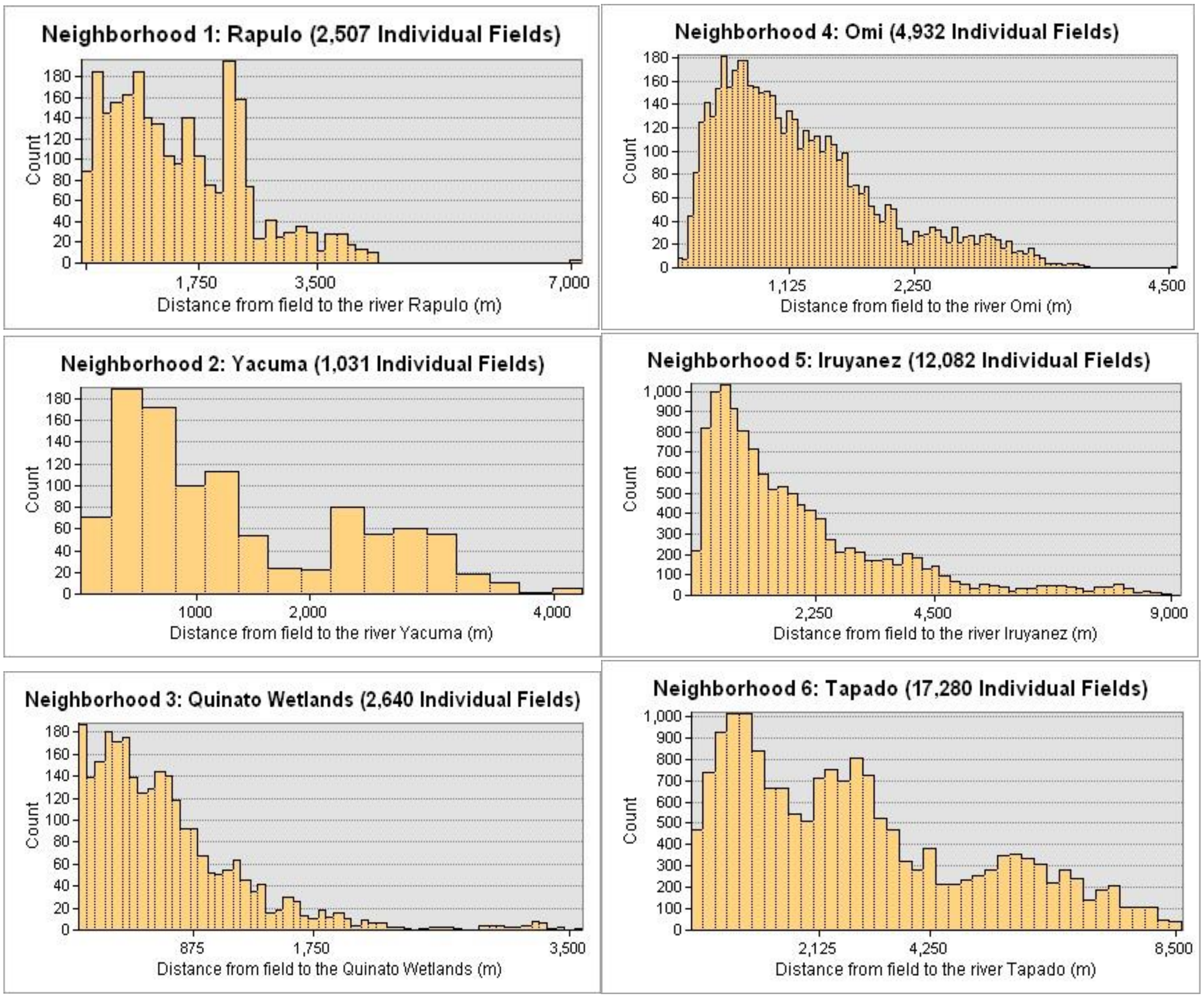


Figure 12: Distribution of fields at distances from the nearest permanent body of water.

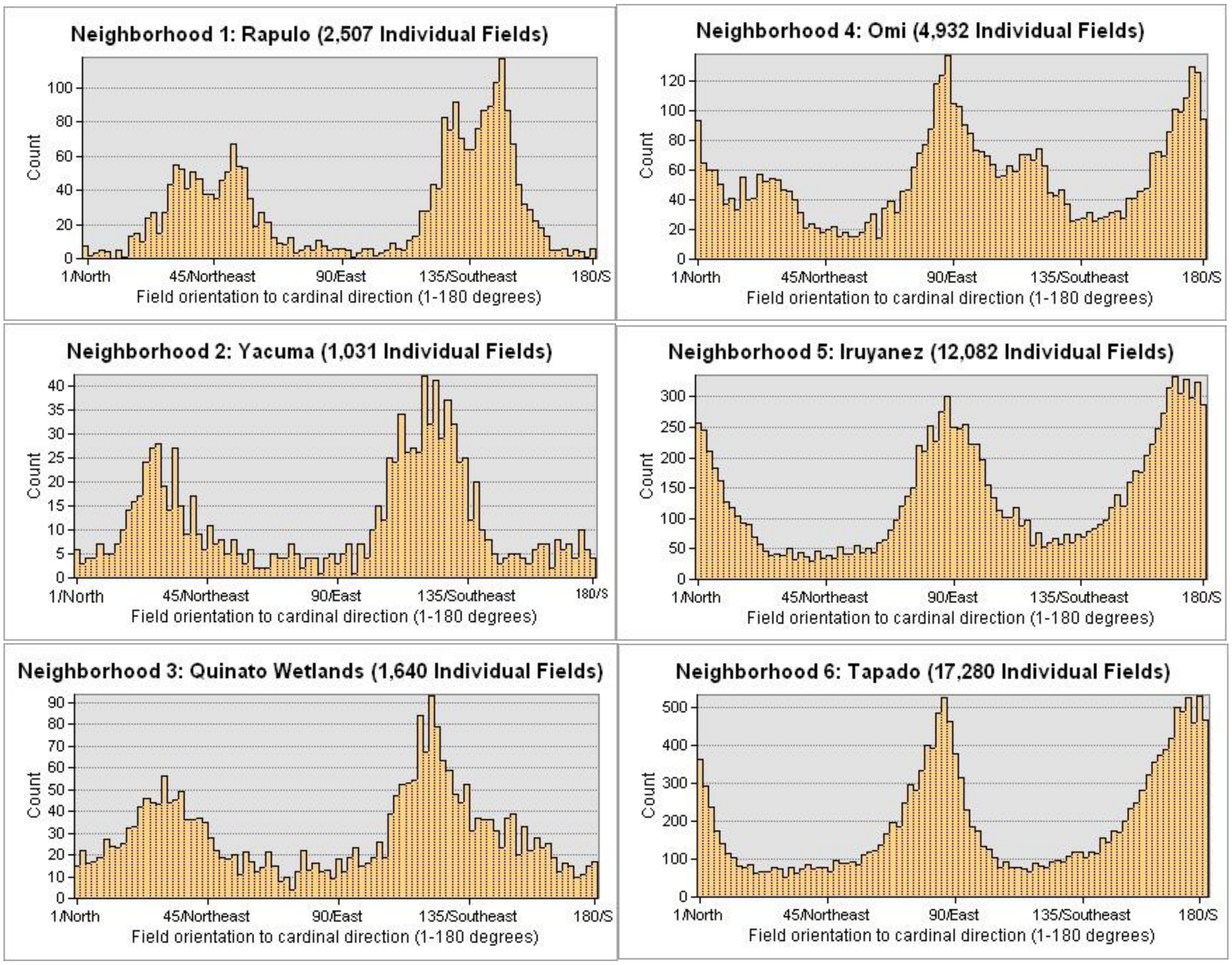


Figure 13: The distribution of oriented fields within each of the six neighborhoods.

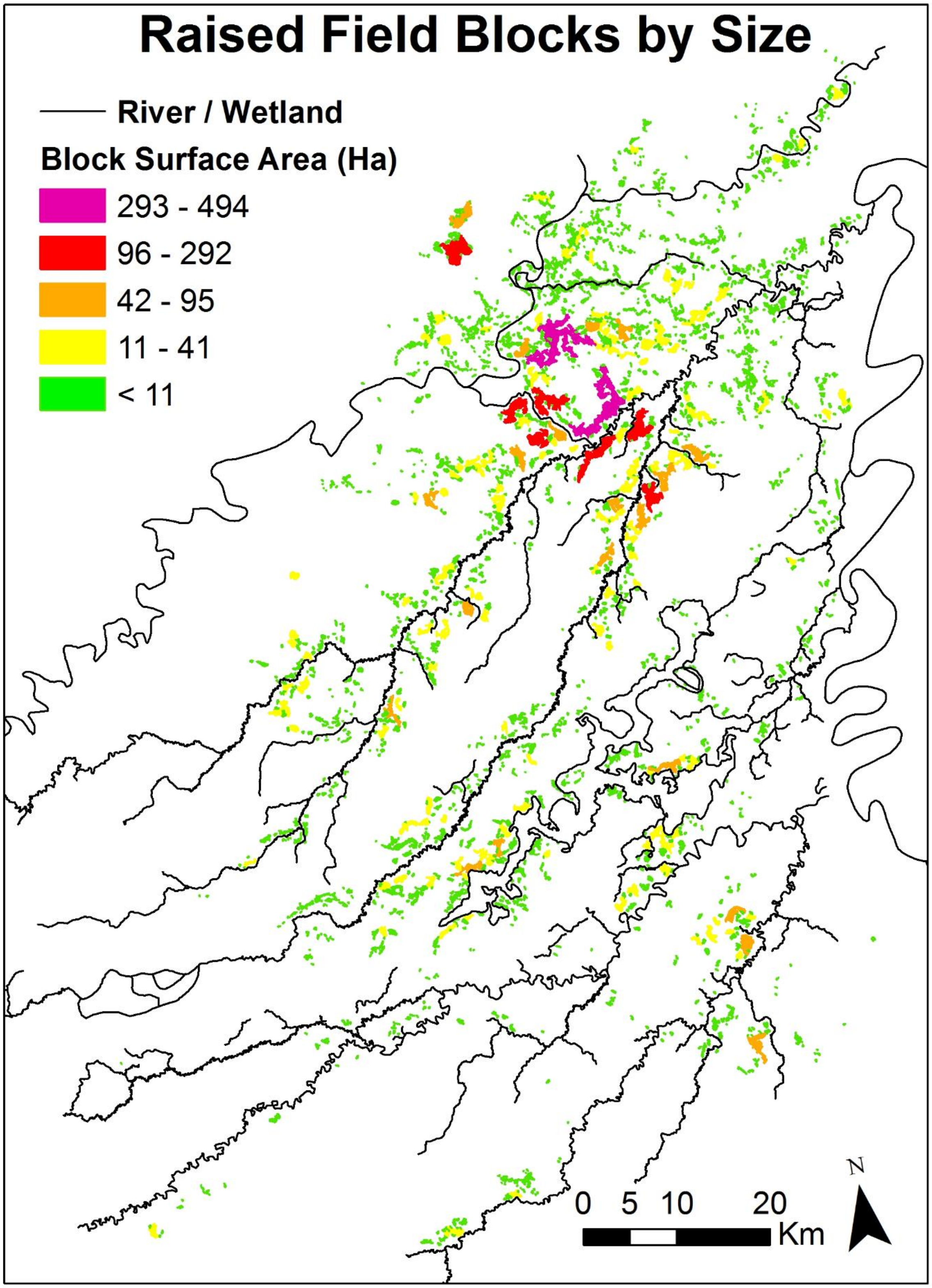
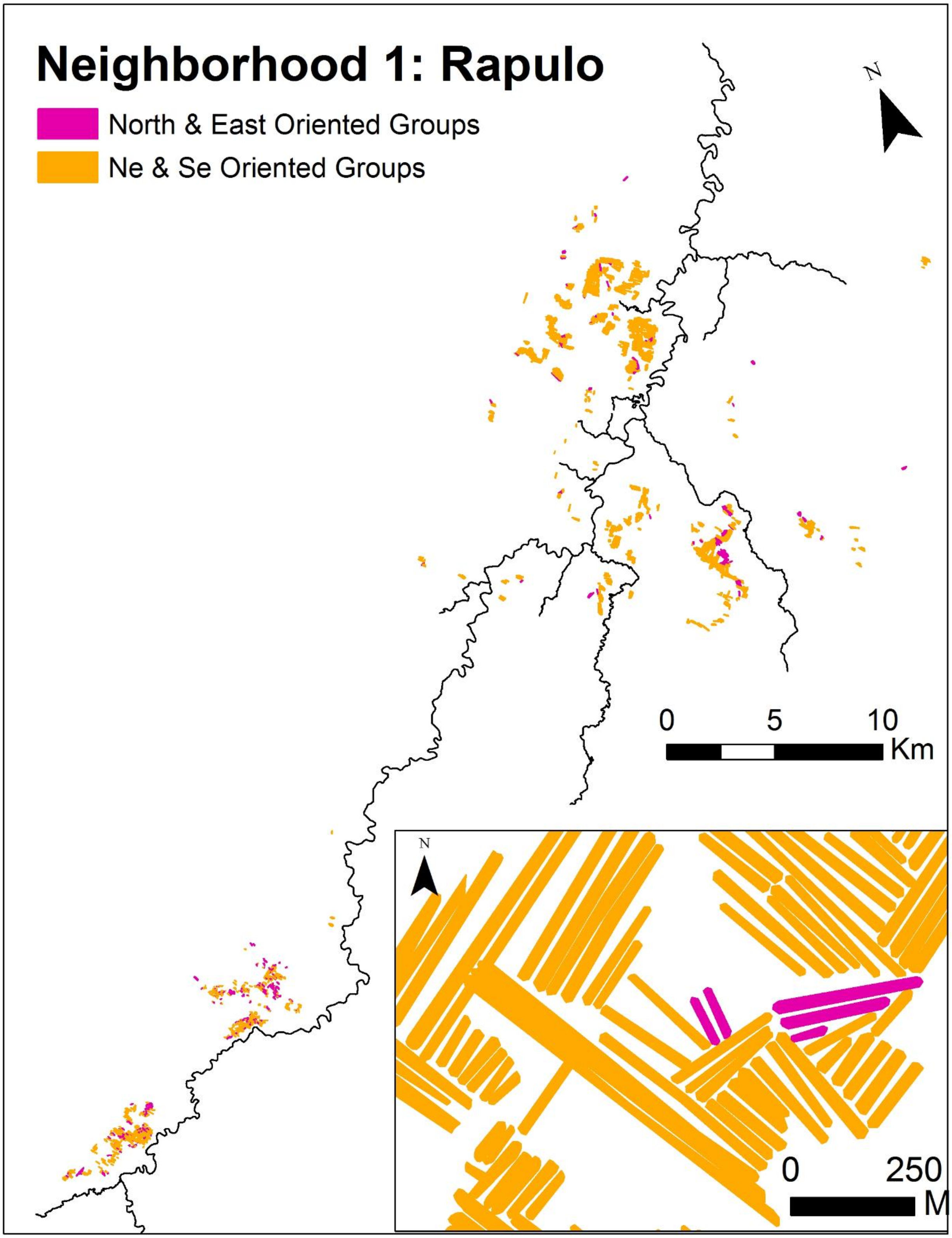


Figure 14: Raised fields blocks distributed by size (sum surface area of all fields in a block).



Neighborhood 1: Rapulo
North & East Oriented Groups
Ne & Se Oriented Groups
N
0
5
10
Km
N
0
250
M

Figure 15

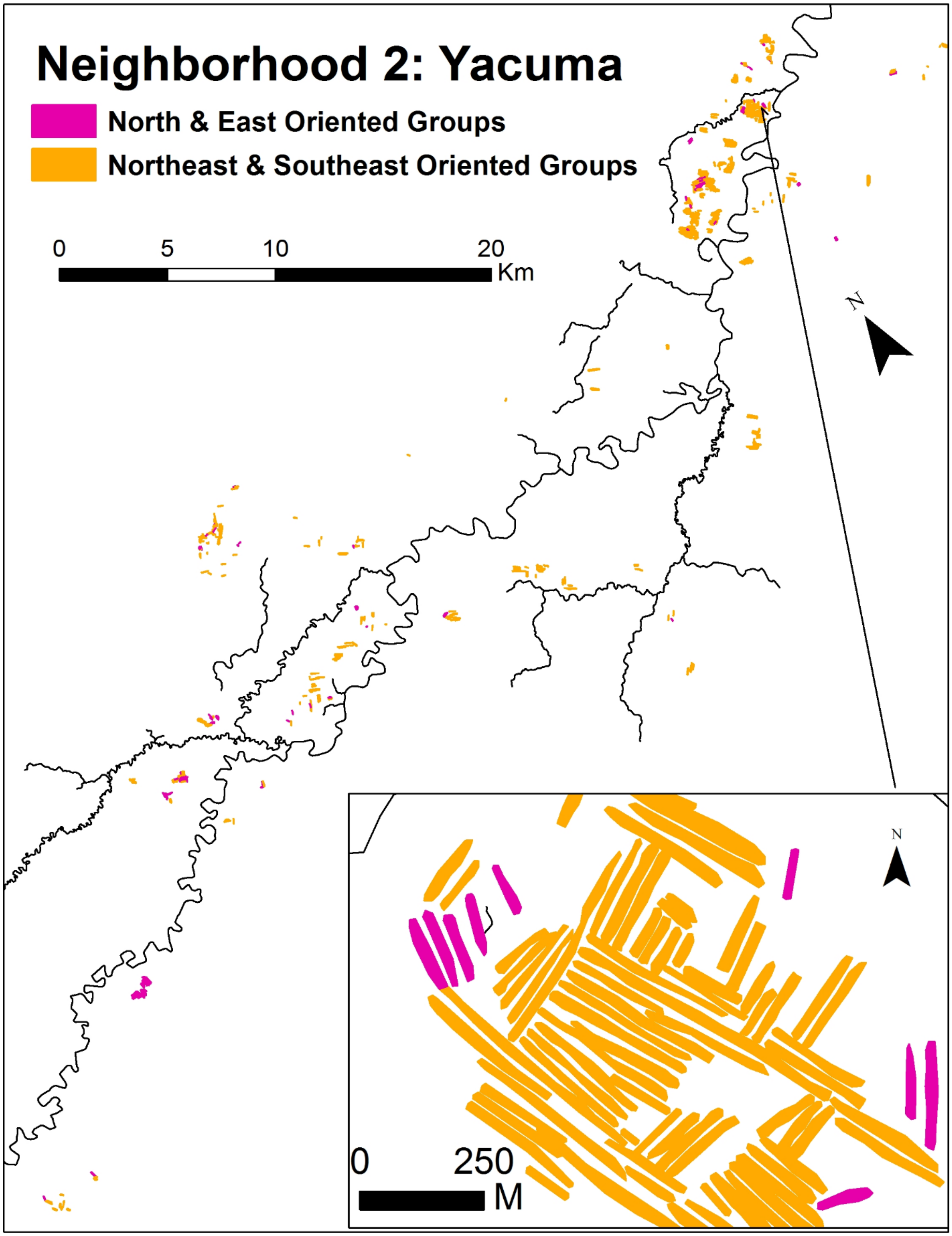

Neighborhood 2: Yacuma
North & East Oriented Groups
Northeast & Southeast Oriented Groups
0
5
10
20
Km
N
N
0
250
M

Figure 16

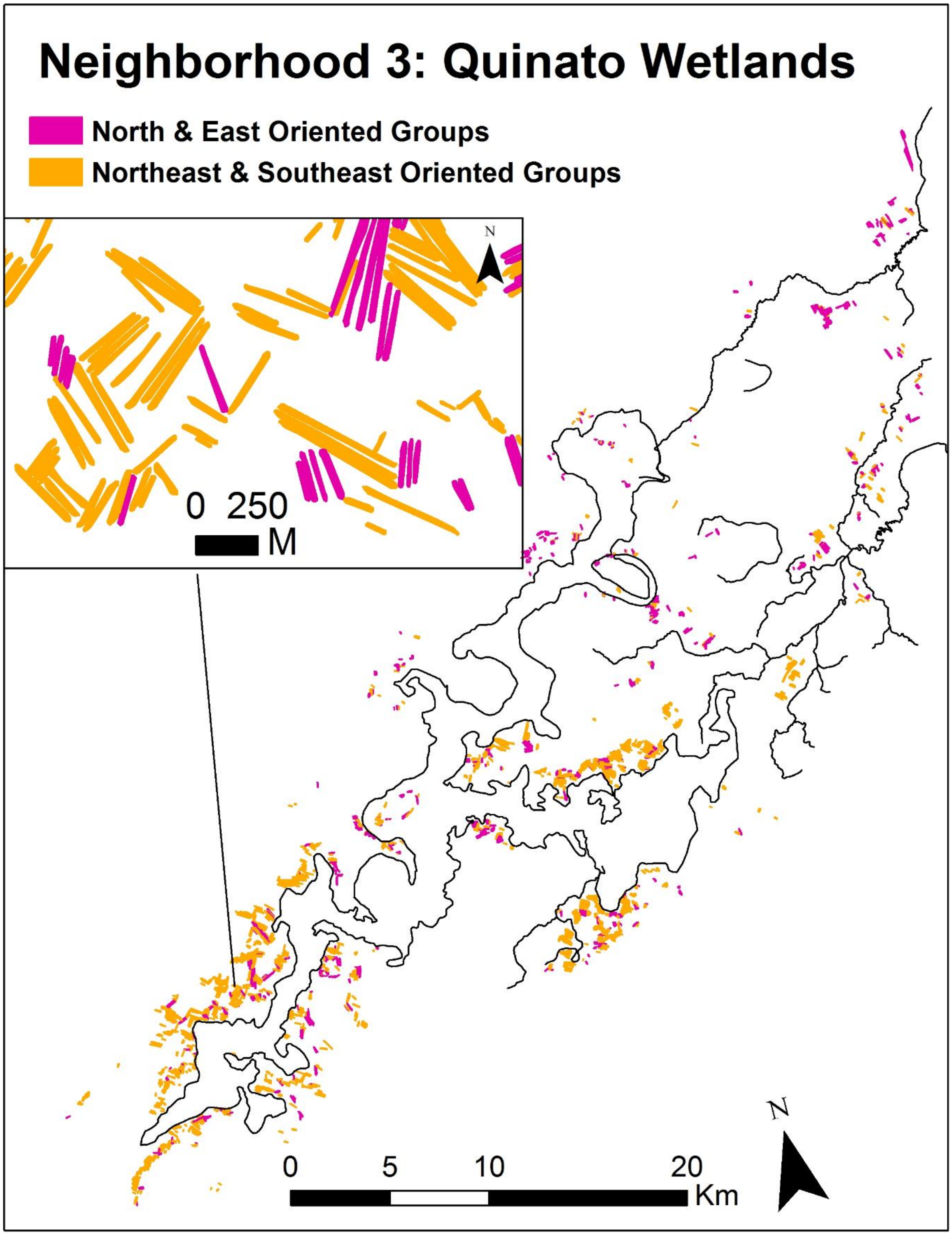
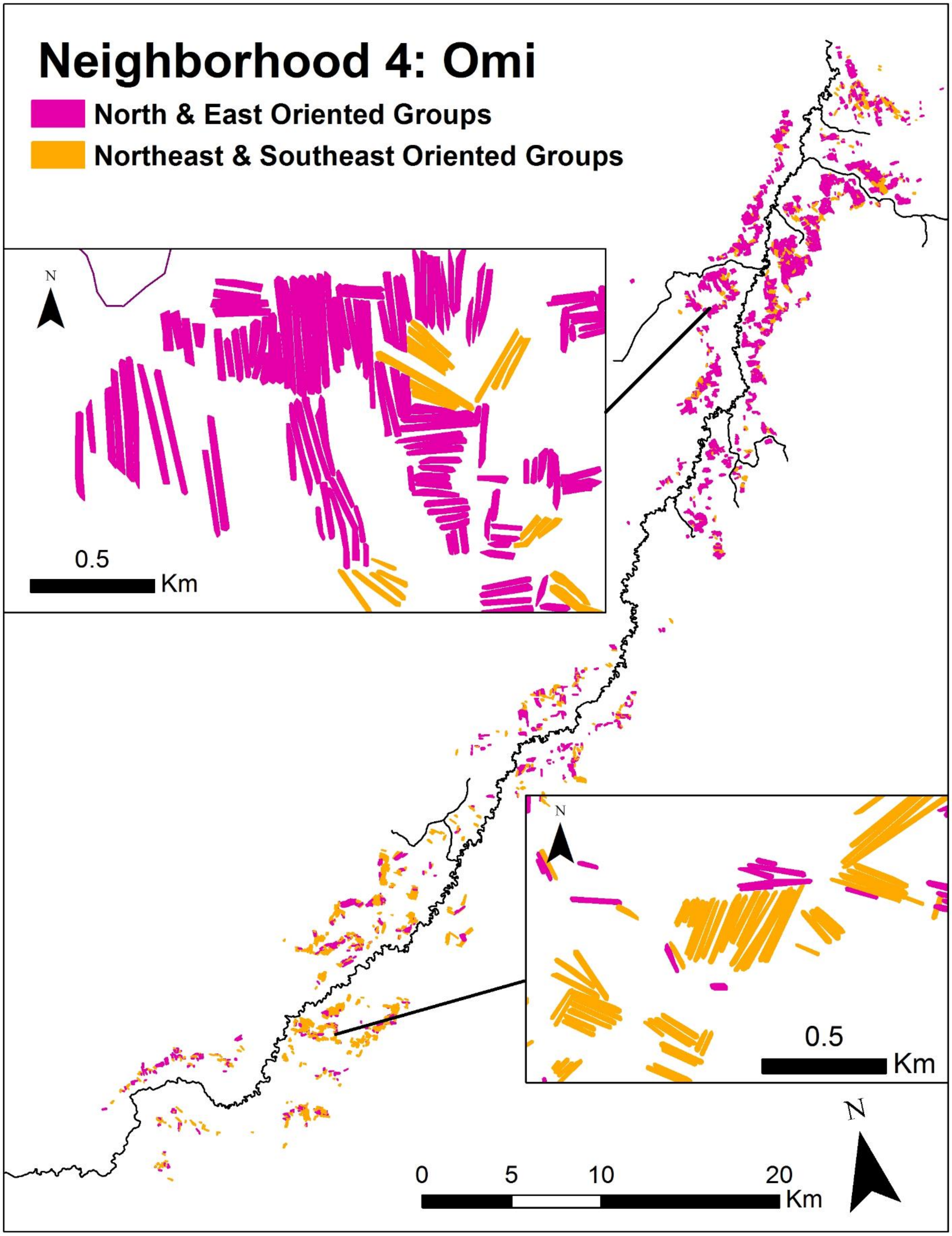

Neighborhood 3: Quinato Wetlands
North & East Oriented Groups
Northeast & Southeast Oriented Groups
N
0 250
M
0 5 10 20
Km
N

Figure 17



Neighborhood 4: Omi
North & East Oriented Groups
Northeast & Southeast Oriented Groups
N
0.5
Km
N
0.5
Km
N
0 5 10 20
Km

Figure 18

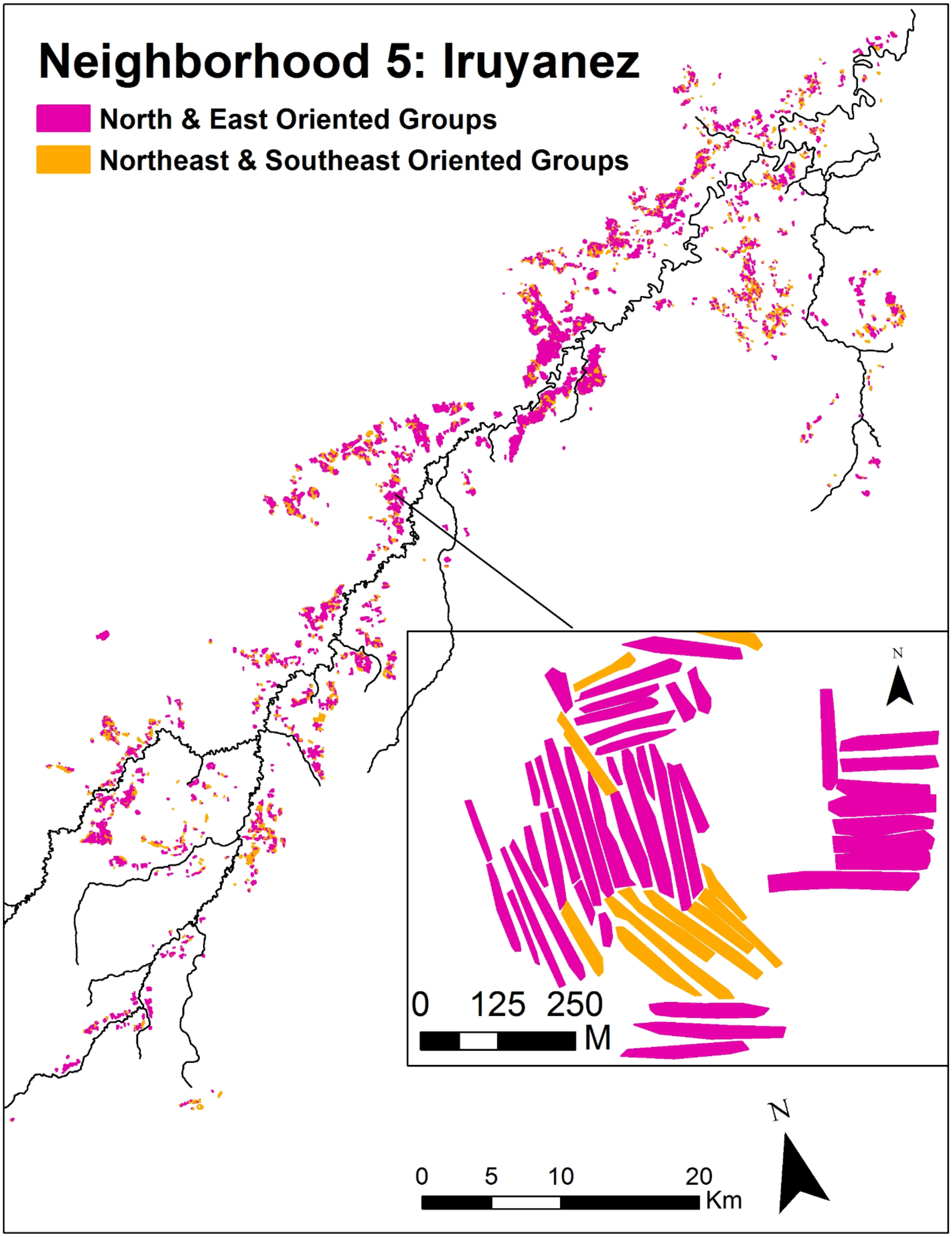
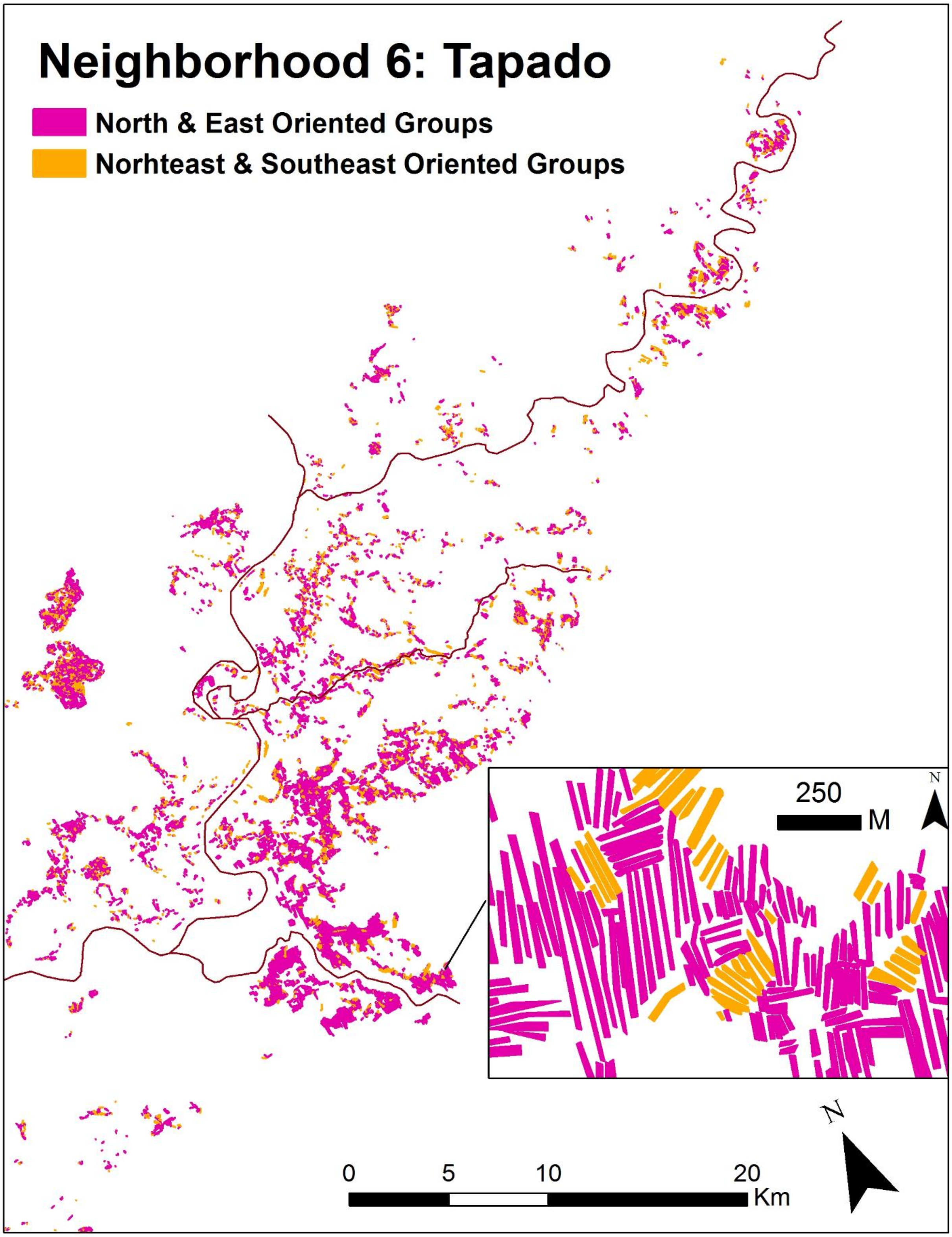

Neighborhood 5: Iruyanez
North & East Oriented Groups
Northeast & Southeast Oriented Groups
N
0 125 250
M
N
0 5 10 20
Km

Figure 19



Neighborhood 6: Tapado
North & East Oriented Groups
Norhteast & Southeast Oriented Groups
250
M
N
N
0
5
10
20
Km

Figure 20

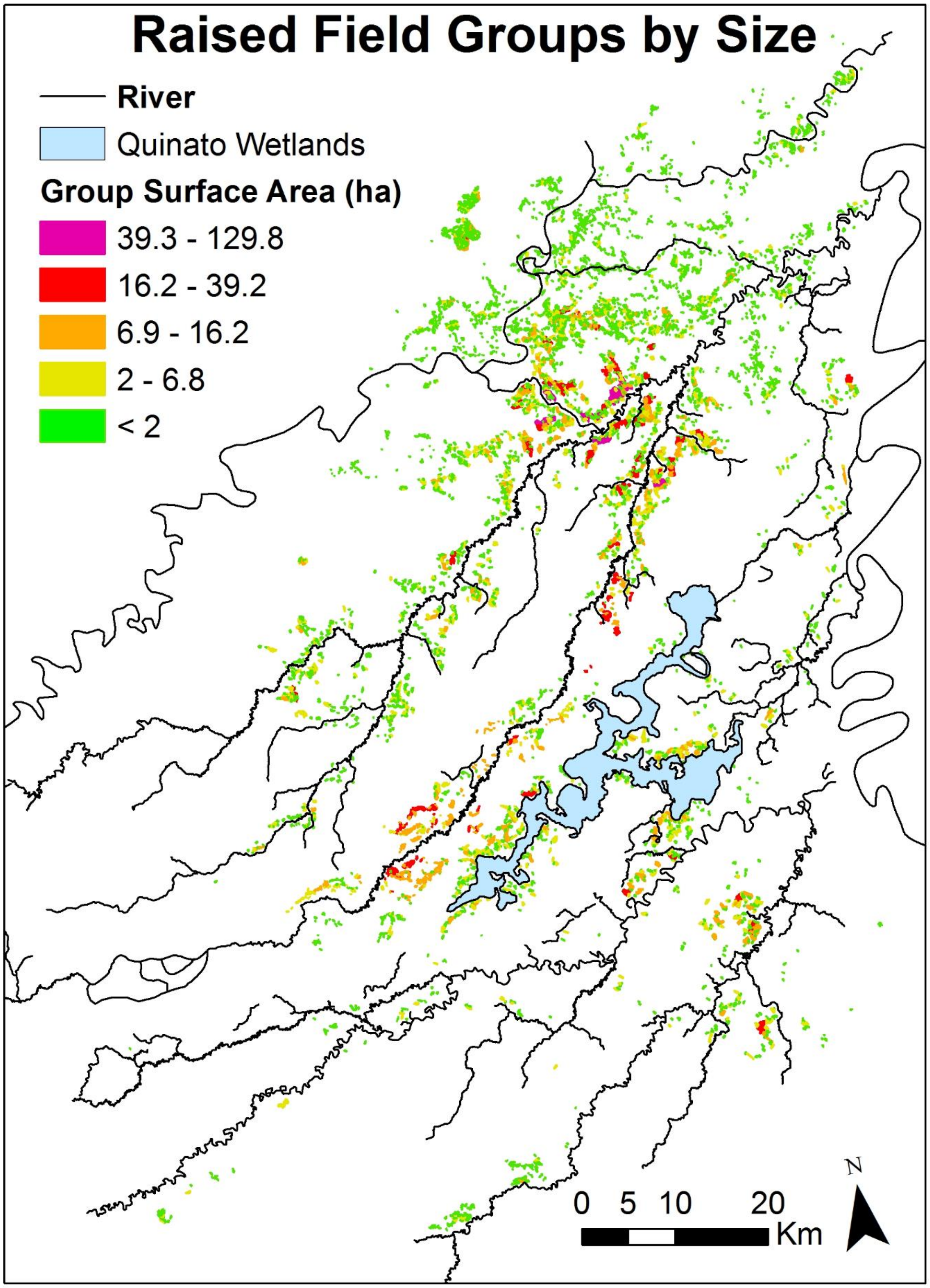

Raised Field Groups by Size
River
Quinato Wetlands
Group Surface Area (ha)
39.3 - 129.8
16.2 - 39.2
6.9 - 16.2
2 - 6.8
< 2
0 5 10 20
Km
N

Figure 21

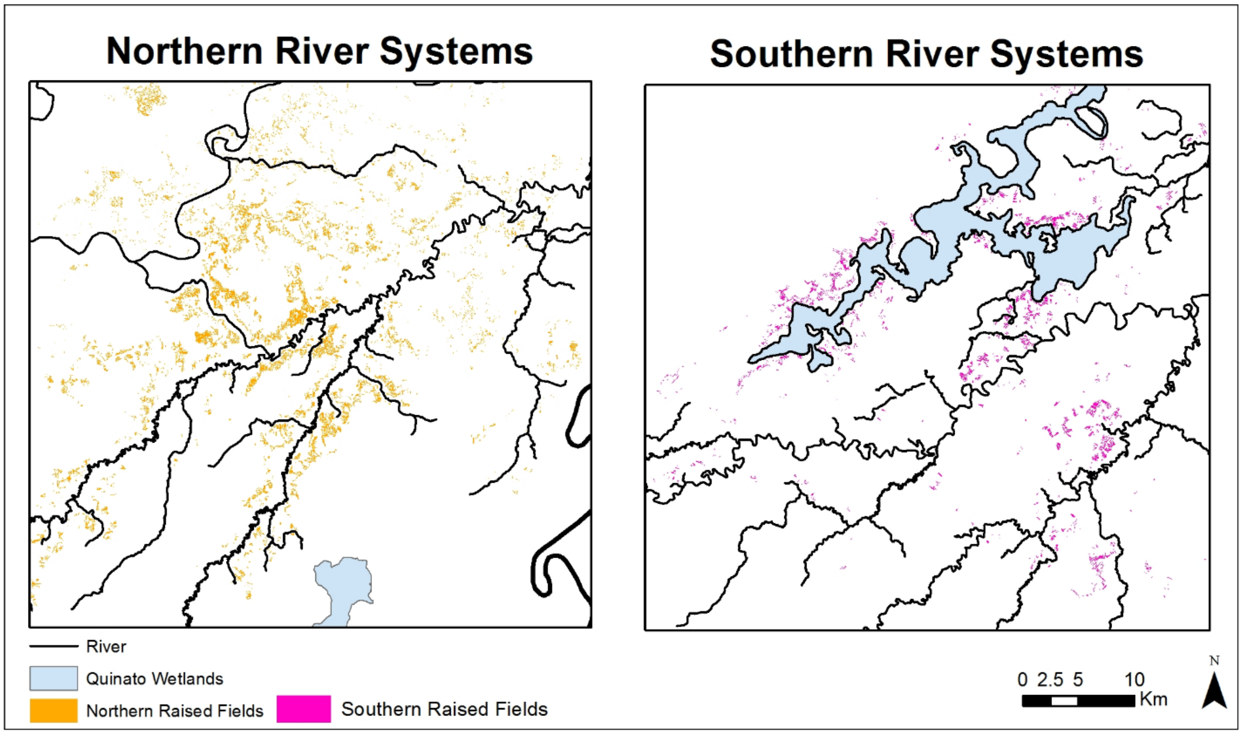


Figure 22: Comparison of the number of fields between the northern and southern neighborhoods.

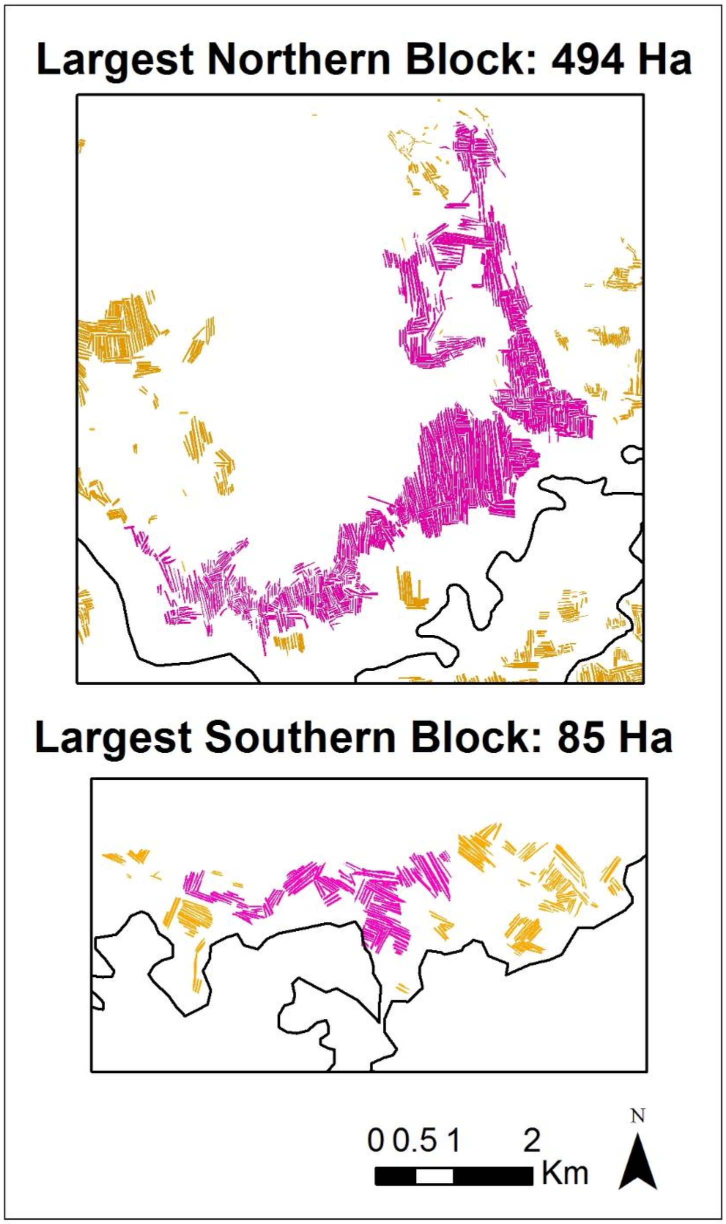


Figure 23: Comparison of the largest block in both the northern and southern neighborhoods.

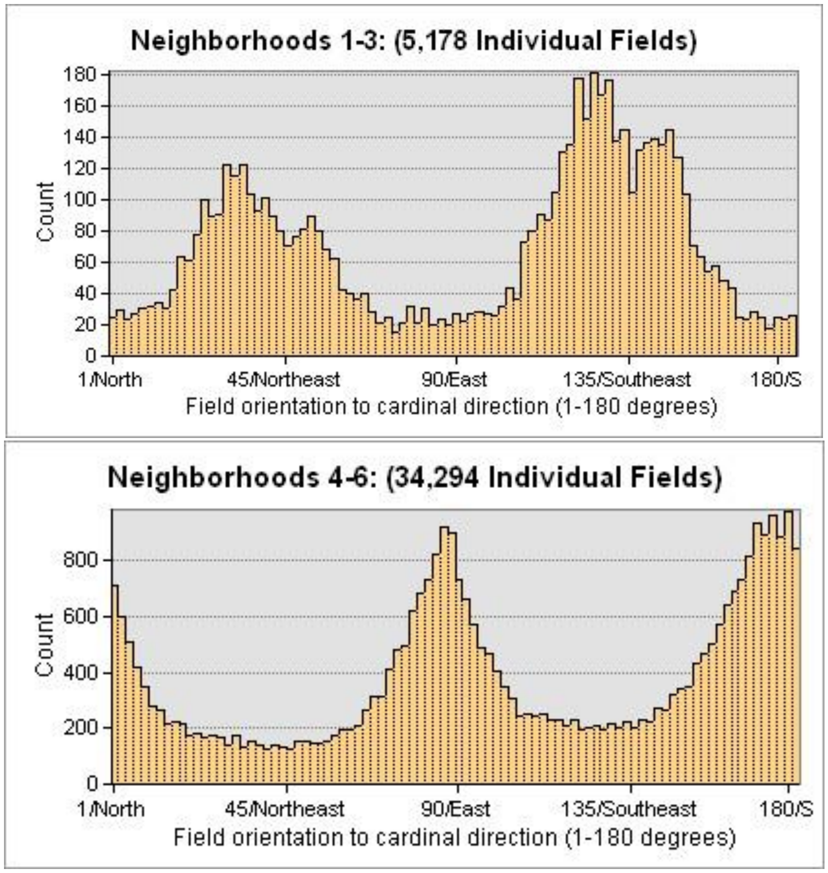


Figure 24: A comparison of the number of fields oriented to different cardinal directions in both the northern and southern three neighborhoods.

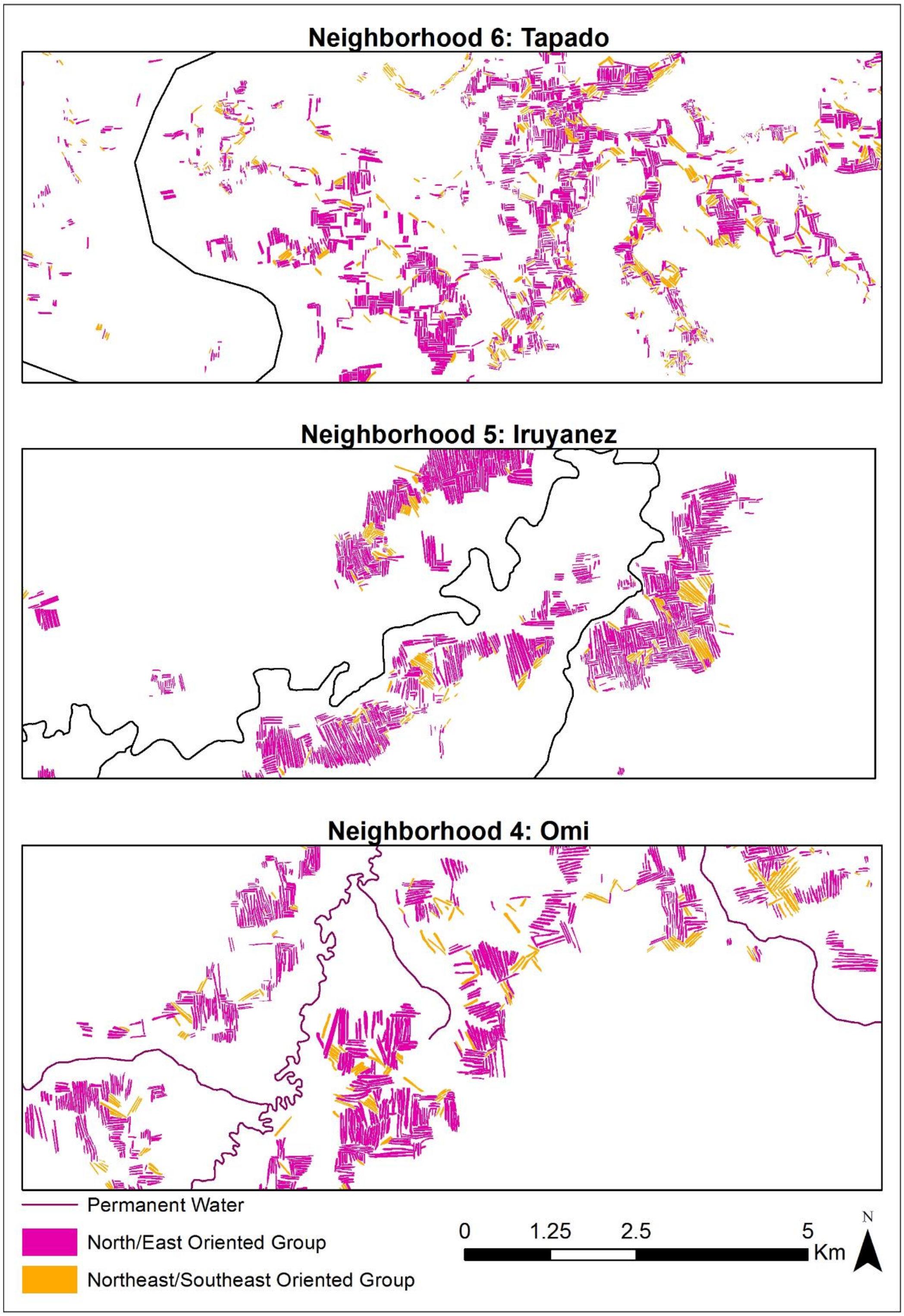


Figure 25: The dominant distribution of oriented groups along the northern 3 neighborhoods.

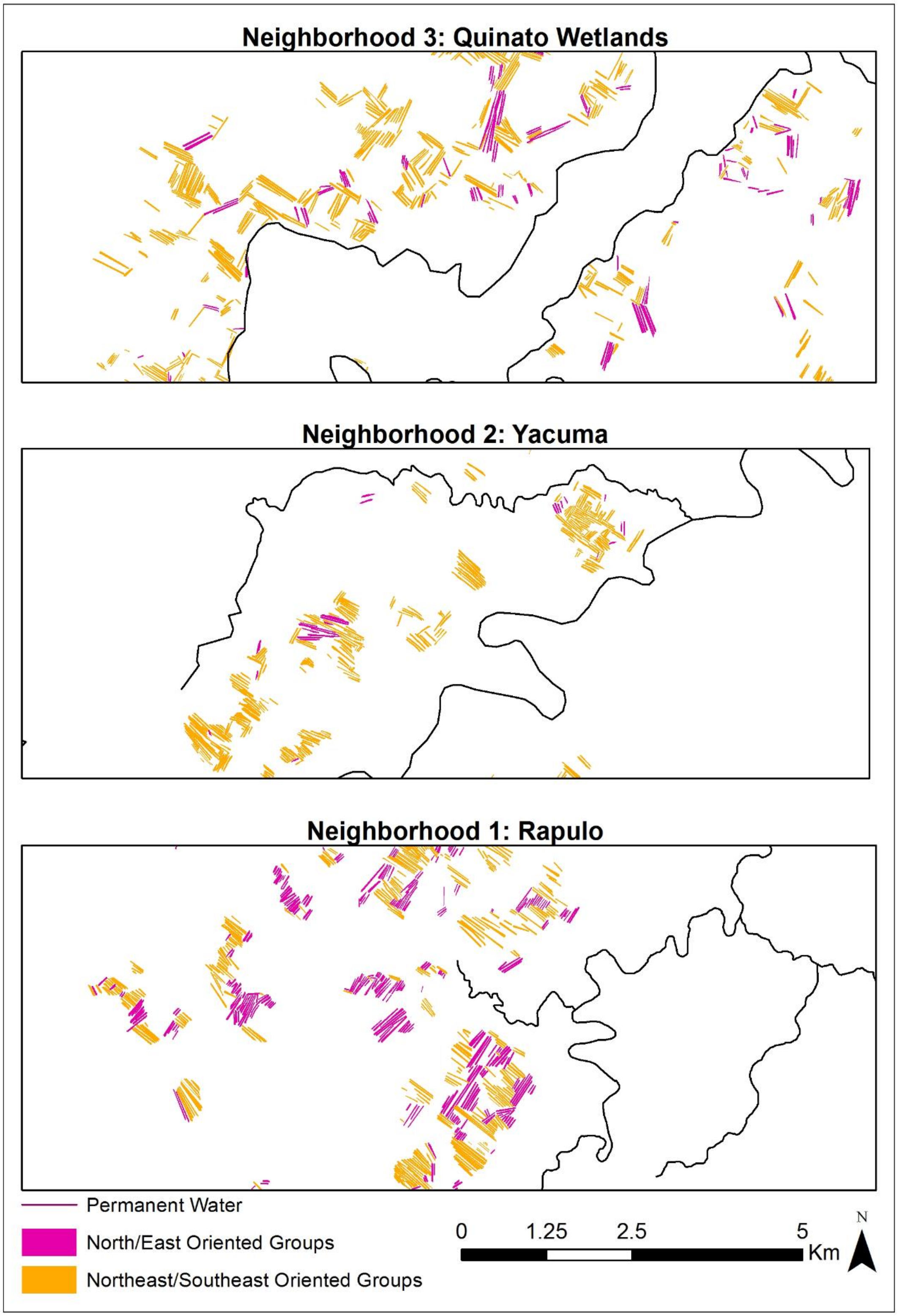


Figure 26: The dominant distribution of oriented groups along the northern 3 neighborhoods.

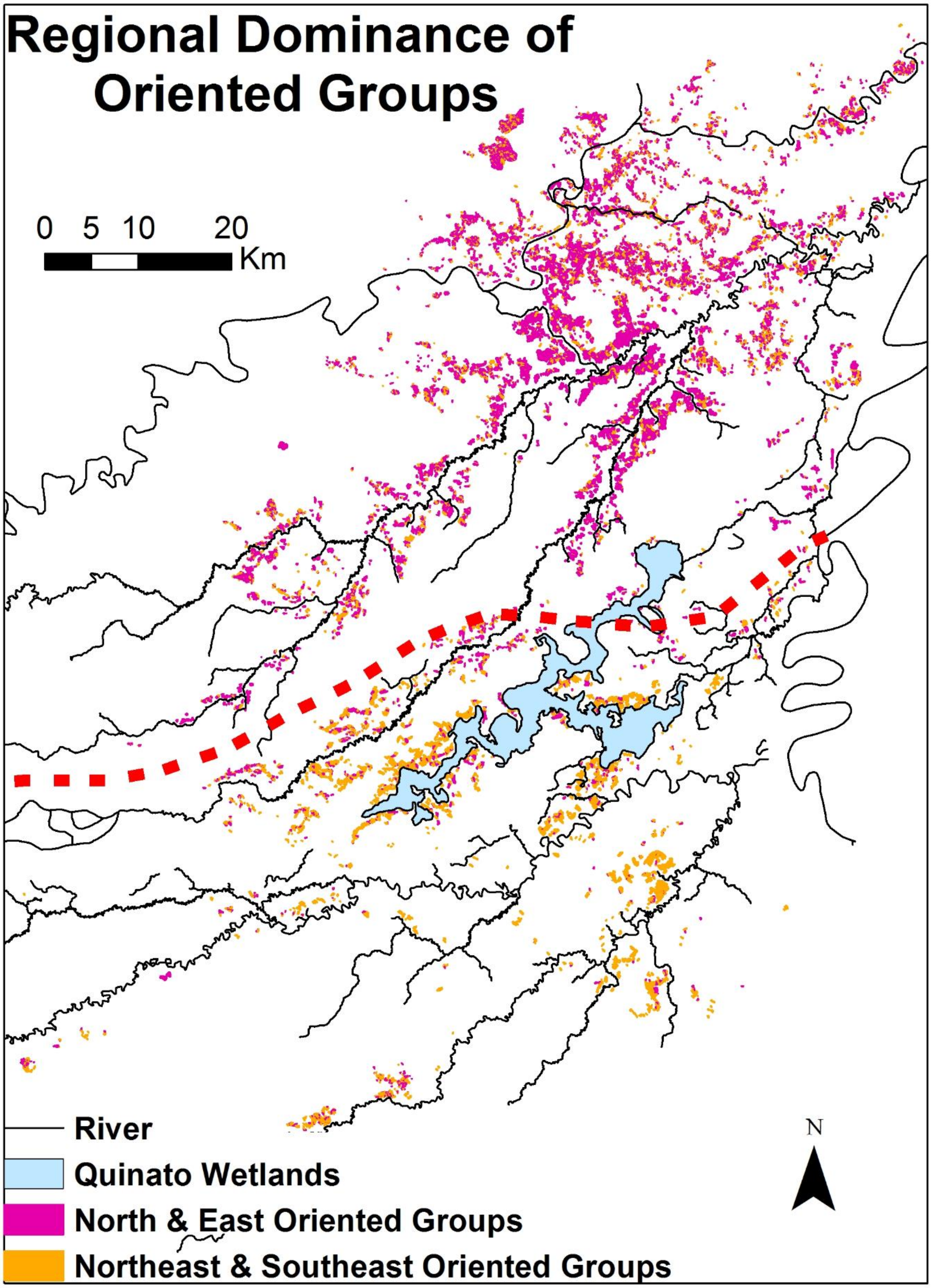


Figure 27: The study area can be divided into two distinct regions based on the alternating dominance of oriented groups.

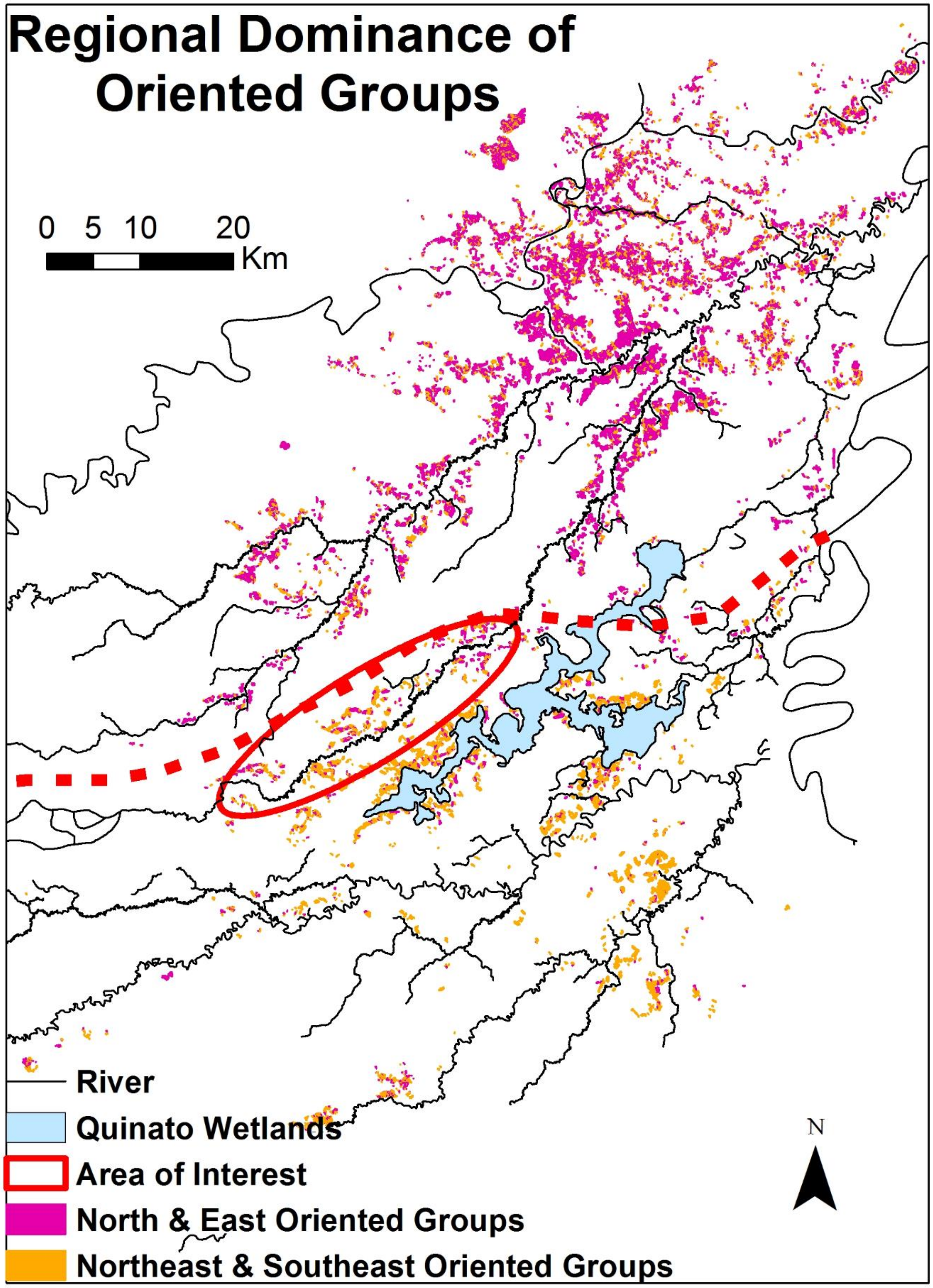


Figure 28: An area of interest can be identified where the Omi passes through the transition from one region into another, altering the dominance of oriented groups in this area.

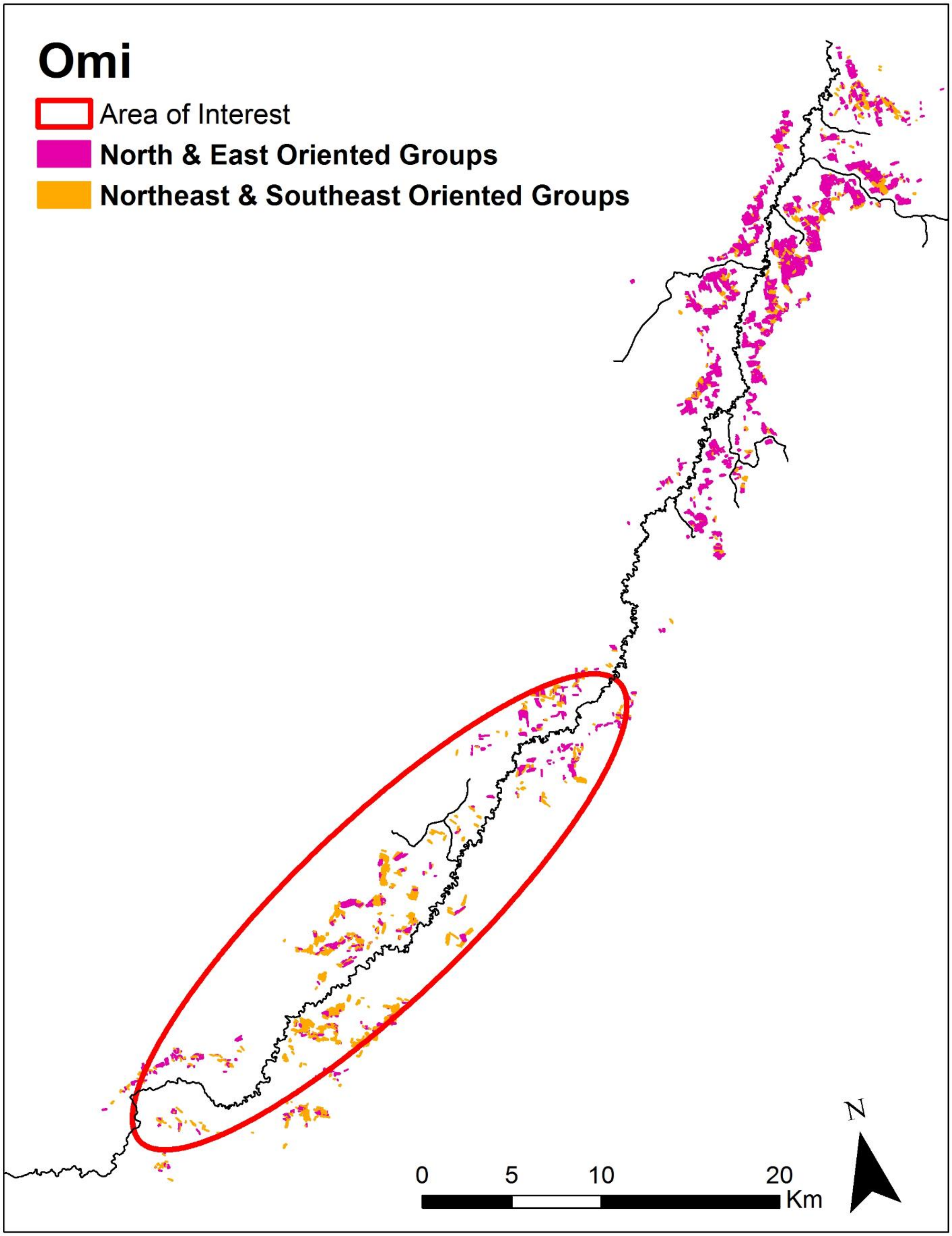


Figure 29: A closer look at the area of interest and the shift in dominance of oriented groups.

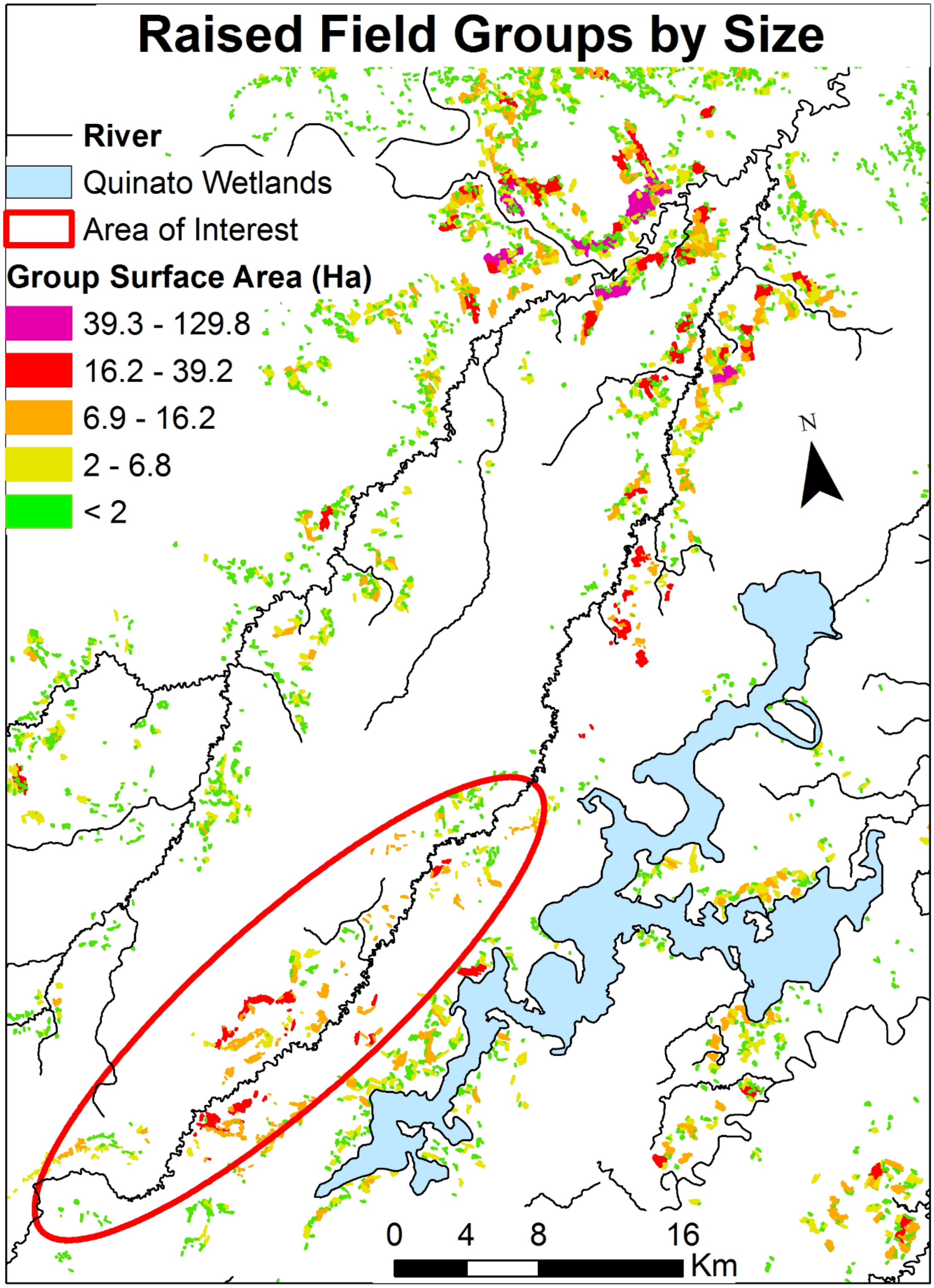


Figure 30: Revisiting groups patterns along the Omi.

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