ON THE BACK OF THE CROCODILE: EXTENT, ENERGETICS, AND PRODUCTIVITY IN WETLAND AGRICULTURAL SYSTEMS, NORTHERN BELIZE

by:

SHANE MATTHEW MONTGOMERY
B.A. University of New Mexico, 2010

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Arts
in the Department of Anthropology
in the College of Sciences
at the University of Central Florida
Orlando, Florida

Summer Term
2016

ABSTRACT

Ancient populations across the globe successfully employed wetland agricultural techniques in a variety of environmentally and climatically diverse landscapes throughout prehistory. Within the Maya Lowlands, these agricultural features figure prominently in the region comprised of northern Belize and southern Quintana Roo, an area supporting low-outflow rivers, large lagoons, and numerous *bajo* (swamp) features. Along the banks of the Hondo and New Rivers, the Maya effectively utilized wetland agricultural practices from the Middle Preclassic to the Terminal Classic Periods (1000 B.C.—A.D. 950). A number of past archaeological projects have thoroughly examined the construction and impact of these swampland modifications. After four decades of study, a more precise picture has formed in relation to the roles that these ditched field systems played in the regional development of the area. However, a detailed record of the full spatial extent, combined construction costs, and potential agricultural productivity has not been attempted on a larger scale. This thesis highlights these avenues of interest through data obtained from high- and medium-resolution satellite imagery and manipulated through geographic information systems (GIS) technology. The research explores environmental factors and topographic elements dictating the distribution of such entities, the energetic involvement required to construct and maintain the systems, and the efficiency of wetland techniques as compared to traditional *milpa* agriculture. Spatial analyses reveal a total of 254 distinct wetland field systems within the 6560 square kilometer area of interest, clustered along navigable waterways, seasonal lagoons, and upland landscapes separating the Hondo and New Rivers. Energetic estimates illustrate substantial investment in wetland field construction, spanning several generations based on a locally available workforce. However, productivity calculations associated with the ditched field systems commonly exceed those attributed to *milpa* techniques, suggesting agricultural surplus far beyond the immediate need. These combined data indicate the potential export of maize and other agricultural commodities to regional centers in northern Belize and further abroad during the Late Preclassic and Late to Terminal Classic Periods through riverine trade networks. Additionally, these data help illustrate participation trends and patterns of connectivity relating to tiered sites within the area of interest. This research contributes to the overall understanding of wetland agriculture within Mesoamerica as well as provides insight into the political management of intensive agricultural production during Maya prehistory.

Dedicated to my grandfather, Dr. Richard Phillips

ACKNOWLEDGMENTS

I would first and foremost like to recognize the support of my committee chair, Dr. Arlen Chase, who provided valuable input and advice at all stages of this undertaking. I appreciate the guidance and feedback of my thesis committee, Dr. Diane Chase and Dr. John Walker. Dr. Walker's own work regarding prehistoric agriculture and GIS technology inspired my initial report on the subject of northern Belize wetland systems from which this thesis was constructed. I would like to thank all those involved in the creative and editorial processes: Kelsey Sullivan, Dr. Rebecca Phillips, and George Micheletti. Gratitude must also be extended to Dr. Holley Moyes and Dr. Terry Powis, who both provided me with ample support and field opportunities throughout my time at the University of Central Florida. I also would like to acknowledge Dr. Jaime Awe, Dr. John Morris, and the Institute of Archaeology for continuing the tradition of Maya Studies within the country of Belize.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

Thesis Overview and Research Questions

Intensive agriculture has often been argued as a prerequisite for the development of prehistoric complex societies throughout the globe (Morgan 1907; Wittfogel 1955). This is especially true for groups situated within tropical environments, which commonly necessitate innovative management of sporadic soil and water resources. The Spanish encountered Maya populations practicing simple swidden agricultural techniques upon arrival in Mesoamerica during the early sixteenth century (de Landa 1978: 38 [1566]). The swidden method, accomplished by burning and felling individual swaths of jungle prior to planting, required an extended fallow period after only several years of field use (Harrison 1978: 11; Dalle and de Blois 2006: 3). Archaeological evidence gathered throughout the Maya Lowlands, however, indicates that population densities were far greater in the previous two millennia than traditionally allowed by slash-and-burn farming alone (Palerm and Wolf 1957; Denevan 1970: 647; Culbert and Rice 1990). These combined data suggest that the Maya utilized more advanced agricultural techniques in the periods prior to European contact to support the extensive populations.

Within a prehistoric context, researchers characterize agriculture as any technique that positively affects the production, propagation, and survival of a particular plant species within a created microenvironment (Bronson 1975: 56). While swidden agriculture is effective in regions of the world with arable, nutrient rich land, the thin soils and karstic geology prominent throughout much of modern day Belize, lowland Guatemala, and southern Mexico combine for limited crop production without additional human intervention. Prehistoric populations within

Mesoamerica accomplished the task of agricultural intensification through a variety of means, including irrigation, terracing, and the addition of natural fertilizers (Beach et al. 2009: 1712). Archaeologists have identified flood-recessional farming as the precursor to intensive agriculture in many portions of Central America (Sluyter 1994: 576), taking advantage of annual deluge cycles along substantially productive alluvial river banks. The Maya practiced these techniques in northern Belize, southern Quintana Roo, southern Campeche, and the Rio San Juan region of Veracruz. By the Middle Preclassic Period (1000—400 B.C.), these systems progressed towards more formal raised and channelized field systems still visible along the riparian wetlands and closed system *bajos* (swamps) of the Maya Lowlands (Pohl et al. 1990: 189).

Table 1: Chronological periods in the Maya area (after Sharer and Traxler 2006).

Period	**Estimated Dates**	**Major Cultural Developments**
Paleoindian	12,000/20,000—8000 B.C.	Initial Settlement of the Americas
Archaic	8000—2000 B.C.	Settled Communities and Agriculture
Early Preclassic	2000—1000 B.C.	Initial Complex Societies
Middle Preclassic	1000—400 B.C.	Growth in Socioeconomic Complexity
Late Preclassic	400 B.C.—A.D. 100	Initial States
Terminal Preclassic	A.D. 100—250	Decline and Transformation of States
Early Classic	A.D. 250—600	Expansion of Lowland States
Late Classic	A.D. 600—800	Apogee of Lowland States
Terminal Classic	A.D. 800—900/1100	Decline and Transformation of States
Postclassic	A.D. 900/1100—1500	Reformulation and Revival of States

The connection between the rise of ceremonial centers and potential surplus generated by intensively managed agricultural features is intriguing. Several researchers (Hammond 1985; Pohl et al. 1990: 407) working in these regions propose that the labor investment and crop productivity created wealth differentials within certain communities and ultimately led to emergence of elite individuals. Settlements situated adjacent to agriculturally viable wetlands may have been directly or indirectly influenced to construct formal field systems to produce valuable agricultural produce for supply into the local and regional trade economies first established during the Late Preclassic Period (400 B.C.—A.D. 100).

Resource control—specifically, regulation related to water and to surplus of agricultural commodities—has long been promoted as a force of social stratification in the Maya Lowlands (Ford 1996: 299; Scarborough 1996: 314; Lucero 1999: 43). The regulation and management of water resources is commonly attributed to infrastructure associated with potable water storage and irrigation systems. While neither massive reservoirs nor large-scale irrigation features were crucial to the development of the Maya within the area of interest, the wetland agricultural systems still represent a significant investment in hydraulic manipulation and are relevant to the overall application of resource control.

The problem with the water-resource control hypothesis as applied to wetland agriculture is that it does not relate to the political mechanisms at work but instead the presumed spatial extent of these systems. Past archaeological reconnaissance along the Hondo and New Rivers has failed to adequately identify the complete distribution of these fields for the entire region. Instead, researchers have approximated the extent of the fields based on limited aerial identification or ecological maps of wetland vegetation; however, recent aerial reconnaissance (Guderjan and Krause 2011: 131) has incrementally increased knowledge of the spatial distribution along the Rio Hondo drainage. These remote techniques have led to both under- and over-representations of the prehistoric field systems across northern Belize and southern Quintana Roo, creating a wide range of estimates and competing theories. If solid arguments are to be constructed concerning the surplus potential and positive economic impact of these systems, effort must be spent to identify the exact range of relic Maya fields. Only then can archaeologists generate estimates regarding construction-related energy expenditure, crop yields, and carrying capacity in the area of interest during important periods of development and transition.

Data derived from spatial analyses, demonstrating higher densities of wetland agricultural systems in association with well-documented ceremonial centers such as Nohmul, Cerros, Lamanai, and Aventura, support a hypothesis of elite agricultural management. For the sake of simplicity, these major centers are defined based on plaza count, quality of architecture (vaulted rooms, formal benches, etc.), and density of non-residential monumental constructions (Hammond 1975: 42—43). The model expects wetland agricultural features to be situated within adequate pedestrian distance of these sites; an estimate of seven kilometers (4.3 miles) would represent the maximum one-way distance to a given field. This figure denotes the greatest distance observed for communal field cultivation among the modern Maya of the Yucatán Peninsula (Alexander 2006: 455).

In addition, energy expenditure can be analyzed in relation to presumed elite management theories. An environment especially suited for elite oversight of wetland field systems would favor agricultural features that: 1) are complicated and physically demanding to construct, beyond the means assumed by the immediate population, or 2) are relatively simple to construct but difficult to maintain for an extended amount of time and require widespread cooperation or specialized engineering knowledge. If construction/maintenance models reveal wetland agricultural systems that involve only moderate effort to build and sustain on a local level, then elite management would appear unnecessary and less probable.

Finally, this thesis will combine spatial, energetic, and environmental data to examine agricultural productivity of wetland field systems in contrast to typical *milpa* techniques. The specialized microenvironments of wetland areas will be taken into account to determine average annual yields per acre. High crop surplus may be indicative of possible export to other, less agriculturally productive parts of the Maya Lowlands. Participation in such an economy could have required a level of elite management for the procurement or distribution of agricultural products. If crop yields do not significantly outperform the previously established yields from *milpa* systems, then perhaps the Maya constructed these wetland systems to support specialized crops or serve as fallback fields in time of prolonged drought, as proposed by Luzzadder-Beach and colleagues (2012: 3650).

Through the combination of these three facets of research—spatial extent, construction/maintenance costs, and agricultural productivity—the phenomena of Maya wetland systems will emerge on individual, regional, and interregional levels. Analysis of spatial distribution will reveal the relationship between known Maya sites in the area and participation in wetland agricultural production. Distributional data analyses will indicate what types of environments and soil characteristics the Maya targeted for wetland use. Energetic models will elucidate the costs and benefits of wetland agricultural techniques in relation to more extensive crop production methods. Finally, updated productivity indices will help to clarify the yield potential and possible economic participation within the ancient Maya economy.

Organization and Chapter Focus

The bulk of this research is organized into seven chapters, each describing a portion of the investigation conducted in the area of interest. Chapter 1 provides a preliminary outline of the contemporary issues and potential hypotheses attached to the current examination of Maya wetland systems. Chapter 2 discusses the environmental background and positions the area of interest within the larger landscape of the Maya Lowlands. Cultural developments within the region and the evolution of ancient wetland agriculture across Mesoamerica are explored in Chapter 3. Chapter 4 details the methods and results of spatial analysis of wetland agricultural systems within the project area, providing associations between river systems, soils, vegetation, and site participation. Chapter 5 highlights the subject of field construction energetics and establishes timeframe estimates for the creation of the systems based on spatial data obtained in the previous section. Potential agricultural production associated with the relic field systems will be elucidated in Chapter 6, providing crop estimations and values established through previous research. Chapter 7 synthesizes the results from the previous three chapters and discusses how the combined data relate to existing theories on agricultural production, field usage, site influence, and participation in regional trade networks. Additional tables, figures, and other relevant data are located in the supplementary appendix.

CHAPTER 2: ENVIRONMENTAL BACKGROUND

Introduction

A complete understanding of Maya wetland agriculture cannot be generated without first distinguishing the regional environment in which these developments took place. The portion of the Maya Lowlands under investigation separates the drier Yucatán Peninsula from the steep slopes and canyons of the Maya Mountains to the south. The wide, lazy rivers of northern Belize provide straightforward access to the more rugged upland areas of the country along the Guatemala border. These same river systems and the numerous associated wetlands attracted prehistoric populations during the Late Archaic Period (3000—2000 B.C.) and provided numerous valuable resources to the ancient Maya across millennia (Lohse 2010; Rosenswig et al. 2014). This chapter will explore the physical setting of the region and discuss the various climatic, hydrological, and pedological factors that made the area so conductive for the practice of wetland agriculture.

Area of Interest Overview

The current area of interest encompasses approximately 6560 square kilometers within the greater portion of northern Belize (Corozal, Orange Walk, and Belize Districts) and southern Quintana Roo, Mexico. This area stretches from the Mennonite settlement of Blue Creek to the Caribbean coast and from the modern city of Chetumal, Mexico south to Belize City. The complete study region contains major river systems (Hondo and New Rivers, as well as a portion of the Belize River), minor riverine networks (Booth's, Bravo, and Northern Rivers; Black and Irish Creeks), lagoons (New River, Western, Northern, and Progresso Lagoons), and numerous freshwater and saline wetlands (Figure 1). The majority of the area of interest is situated within Belize, with riverine and associated lowland areas specifically targeted for analysis. However, a small portion of the project area (550 km^2) spreads north into southern Mexico, based on the extent of the Rio Hondo floodplain and other viable wetland features.

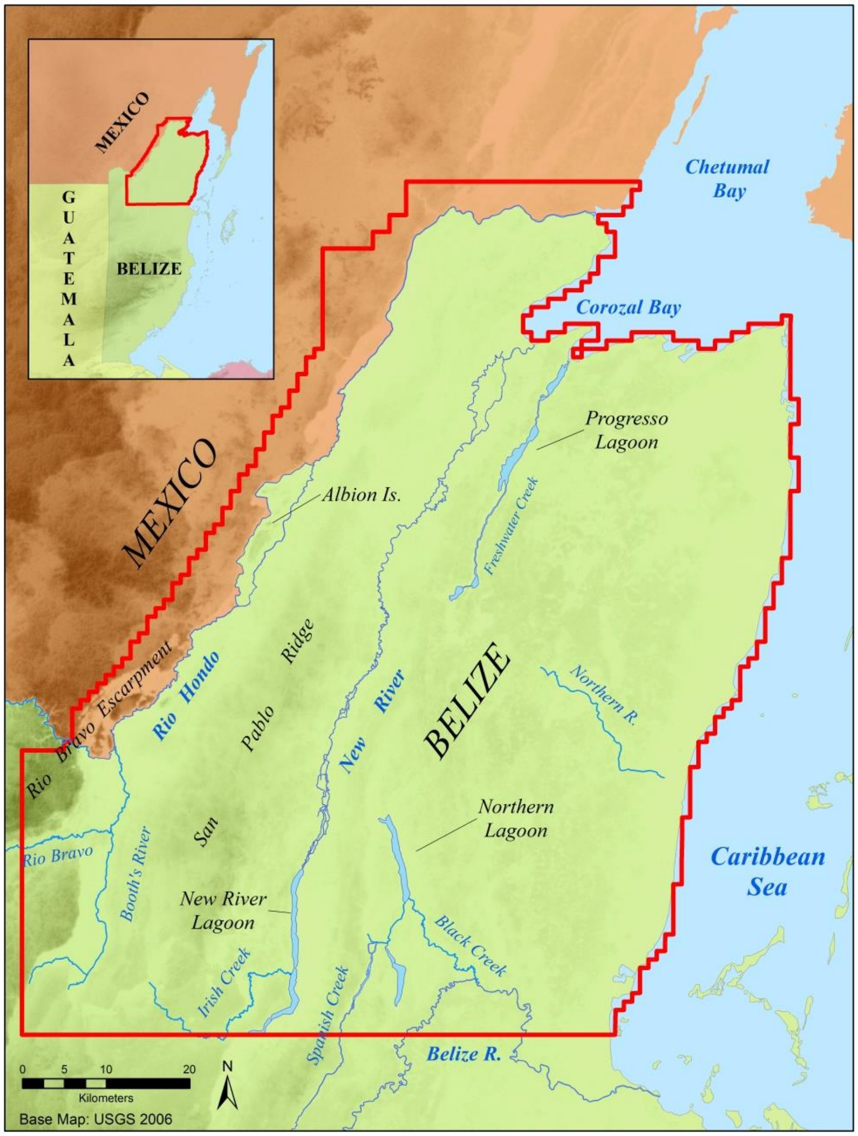

Figure 1. Project area overview map showing major drainage and natural features discussed.

Geology and Topography

The area of interest consists largely of broad, low-lying coastal plains of the Caribbean Sea. The Northern Coastal Plain of Belize, as defined by King et al. (1992: 32), stretches from the Caribbean west across mangroves, swamps, and rolling lowlands to the boundary along the Rio Bravo and Booth's River escarpments. These karstic ridges rise to heights of 40—100 meters along the escarpment margin and continue to the northeast into Quintana Roo, flanking the western edge of the Rio Hondo (Luzzadder-Beach et al. 2012: 3646). Neither escarpment reflects the overall topographic trend throughout the study area; however, several other features of moderate relief are found within the Northern Coastal Plain, including the San Pablo Ridge between the Hondo and New Rivers. Albion Island, centered along the middle reaches of the Rio Hondo, displays a central limestone spine rising to a height of 40 meters above the surrounding flood banks. Much of the study area contains average elevations ranging between sea level and 20 meters above mean sea level (AMSL), creating a prime region for expansive wetlands and slow-flowing, navigable riverine systems.

Climate and Rainfall

Like many tropical environments, northern Belize experiences substantial fluctuations in annual rainfall (King et al. 1992: 2), due to the complex climatic relationship between coastal environments and upland topography further inland. Annual rainfall ranges between 1294 millimeters (mm) (Ambergris Caye) and 2062 mm (Glenville) for the entire Northern Coastal Plain; data collected from 24 research stations in the region provide an average rainfall of approximately 1530 mm per year (King et al. 1992: Table 2). During the dry season—November to April—much of the savannah grasslands and smaller wetland areas desiccate, producing cracks in the soils to depths of 10 centimeters or more (Darch 1983: 58). Water levels within the larger *bajo* depressions remain fairly constant throughout the year, but may decline during the dry season due to evaporation. Average minimum mean temperature for the area ranges from 17.3°C in January to 23.3°C in June; maximum temperature for a similar span falls between 28.8—32.9°C (King et al. 1992: Table 3).

Riverine and Lagoonal Systems

Two main catchment systems reside within the area of interest: the Rio Hondo and the New River drainages. The Rio Hondo drains regions of northern Belize, northeastern Guatemala, and southern Quintana Roo, flowing approximately 150 kilometers over gradually undulating terrain before terminating at Chetumal Bay (King et al. 1992: 83). Main tributaries of the Rio Hondo include the Rio Bravo and Booth's River, which flow together just south of Blue Creek. The New River originates at the New River Lagoon, running 132 kilometers until discharging into the southeastern portion of Corozal Bay. Both rivers follow parallel synclinal folds, trending northeast towards the Caribbean Sea (Baker 2003: 94). Rivers in this section of Belize are characterized by relaxed flows and low rates of discharge compared to other systems in the Maya Lowlands, such as the Belize, Pasión, and Usumacinta Rivers (Siemens 1978: 122—123). River braiding and secondary channels are common, especially along the middle section of the New River; those features, severed by deposition, form long, shallow oxbow lakes. Heavy rains during the wet season can produce flooding along the banks of major drainages, although inundation is more pronounced along the Hondo compared to the New River due to the buffering effects of the inter-riverine swamplands (Johnson 1983: 18). Severe flooding currently occurs at an interval of approximately five years (King et al. 1992: 83).

Riparian wetlands spread along the middle and lower reaches of the rivers, where the gradual basin topography allows the features to extend as far as four kilometers from the banks. Lacustrine depressions and seasonally inundated *bajos* are scattered throughout the lower-lying areas of the karstic plateau separating both river systems. These wetland environments are ecologically diverse, supporting hardwood, sawgrass, sedge, and mangrove vegetation depending on soil quality and salinity of groundwater (Beach et al. 2009: 1712). Brackish swamplands are common within the eastern portion of the project area, extending as far as 40 kilometers inland from the coast in some instances.

East of the New River, a third catchment zone drains a series of large lagoons towards the Belize River via the Spanish and Black Creeks (King et al. 1992: 83). The flow of the creeks may reverse during the height of the rainy season, with flood waters traveling north into the Northern and Western Lagoons (Pyburn 2003: 123). Several smaller, connected lagoons, such as Doubloon Bank and Button, empty north through Freshwater Creek into Progresso Lagoon, which eventually joins the Caribbean immediately south of the Preclassic center of Cerros. Minor riverine systems are spread throughout the project area, often terminating into lagoons or traveling short distances towards the coast before merging with expansive thickets of mangrove.

Soils, Vegetation, and Agricultural Potential

King and colleagues (1992: Table 7) identify a number of specific land system types featured within the project area. Yalbac and Karst types are situated in the western portion of the area of interest, identified as rolling plains and limestone hills not exceeding 100 meters relief. Xaibe (shallow soils overlaying limestone), Glady (broadleaf-dominant marsh forest), Backshore (savannah-dominant marsh forest), Pine, and Strand Plain (coastal sand) types are all encountered further east across a broad plain dotted with saline swamps, riverine floodplains, and seasonally waterlogged soils.

Baillie and colleagues (1993: 9) attribute ten distinct suites to soils located within the area of interest, including the Yaxa, Pembroke, Guinea Grass, Altun Ha, Bahia, Revenge, Puletan, Tintal, Melinda, and Turneffe suites. Soil scientists classify these suites based on the color, consistency, and texture of the material. Soil studies are valuable to archaeologists studying ancient landscape usage because the materials possess a strong relationship between environmental, topographical, and vegetative patterns. Soils within the project area are further refined into subsuites, which divide soils into distinctive local or regional categories. Soils of the Northern Coastal Plain are variable across the landscape, ranging from dark clays and loams in the Orange Walk area to thick peats of freshwater and saline swamps to deep, sandy deposits in the cayes.

Based on the substantial association of Mesoamerican ditched field agriculture with perennially and seasonally inundated wetlands, several soils suites and subsuites are relevant for further discussion (Table 2). These include the Yaxa suite (Yalbac subsuite), Puletan suite (Crooked Tree, Haciapina, and Buttonwood subsuites), Tintal suite (Sibal, Ycacos, Pucte, and Chucum subsuites), Melinda suite (Hondo and Sennis subsuites), and Turneffe suite (Shipstern and Ambergris subsuites). These wetland soils reflect a mixture of freshwater and saline-specific classifications, with the exception of the alluvial sediments of the Melinda suite (Baillie et al.

1993: 7). Soils of the Yalbac subsuite are generally located around the margins of freshwater swamps or lower slopes where deposits retain additional moisture. Puletan soils are described as sandy clays attached to *bajo* features and slope margins of the eastern coastal plain; deposits from this suite are commonly found in more brackish or saline environments. Tintal suite soils are frequently located in connection with perennial freshwater wetlands or seasonally inundated *bajo* depressions of northern Belize. Ycacos soils are the only subsuite in the group associated with saline swamps and mangroves. The Turneffe suite contains sandy soils found in close proximity to mangrove and beach forest environments; such soils possess a limited distribution within northern Belize and nearby cayes.

Vegetation within the area of interest further demonstrates the diversity across northern Belize and southern Quintana Roo (Figure 2). Narrow beaches along the Caribbean coast quickly transition into thick tangles of red (*Rhizophora mangle*) and black mangrove (*Avicennia germinans*), situated within low-lying areas and along brackish portions of numerous drainages (Torrescano and Islebe 2006: 195). Slightly more elevated areas support expansive savannah grasslands with limited overstory. Portions of the northern and eastern Orange Walk District associated with Revenge suite soils contain Pine Ridge vegetation, including Caribbean pine (*Pinus caribea*), palmetto (*Paurotis wrightii*), oak (*Quercus* spp.), and calabash (*Cresentia cujete*) (Baillie et al. 1993: 13). Although the Pine Ridge landscape may seasonally inundate, these areas drain quickly and desiccate dramatically during the dry season. Further west, semi-deciduous broadleaf forests become prevalent across the landscape (Johnson and Rejmánková 2005: 90). Hardwoods such as cedar (*Cedrela mexicana*), sapodilla (*Manilkara zapota*), and mahogany (*Swietenia macrophylla*) are commonly encountered in addition to ramón (*Brosimum* *alicastrum*), cohune palm (*Attalea cohune*), and fig (*Ficus* spp.). Many of these species were economically important to the ancient Maya and likely attracted populations to the area.

Tropical wetlands represent perhaps the most varied facet of the overall vegetative pattern of the project area. Wetland features are sensitive to the local environment and are classified based on pedological, ecological, and hydrological factors (Beach et al. 2009: 1712). Herbaceous and forested wetlands are common throughout the area of interest. Mangrove wetlands indicate the extent of salinity or brackishness within the water table. These areas are often associated with salt marshes supporting limited low vegetation. Sedge (*Eleocharis* spp. and *Cladium jamaicense*) marshes become common once water quality has improved enough to allow freshwater vegetation, although some *Eleocharis* and *Cladium* species tolerate saline conditions (Johnson and Rejmánková 2005: 90). Both sedge and hardwood marshes dominate a majority of the project area beyond the mangrove zone. Marl flats associated with sedge vegetation are extensive along the lower floodplains of the Rio Hondo, creating a patchwork of wetland and barren niches based on drainage and sedimentation.

Along with the Belize River Valley, northern Belize boasts some of the most productive agricultural lands in the country. Much of the broadleaf forest between the upland areas of the Hondo and New Rivers has been felled in the past sixty years for the commercial production of sugarcane, maize, cotton, rice, and other agrarian commodities (King et al. 1992: 149). Some shallow wetland features, offering deeper and more productive soils, have been drained and reclaimed through modern efforts. However, many wetland and riparian areas within the project area retain high integrity and have not been impacted by contemporary farming activities. This allows for a high level of confidence when attempting detection of Maya wetland features through remote sensing.

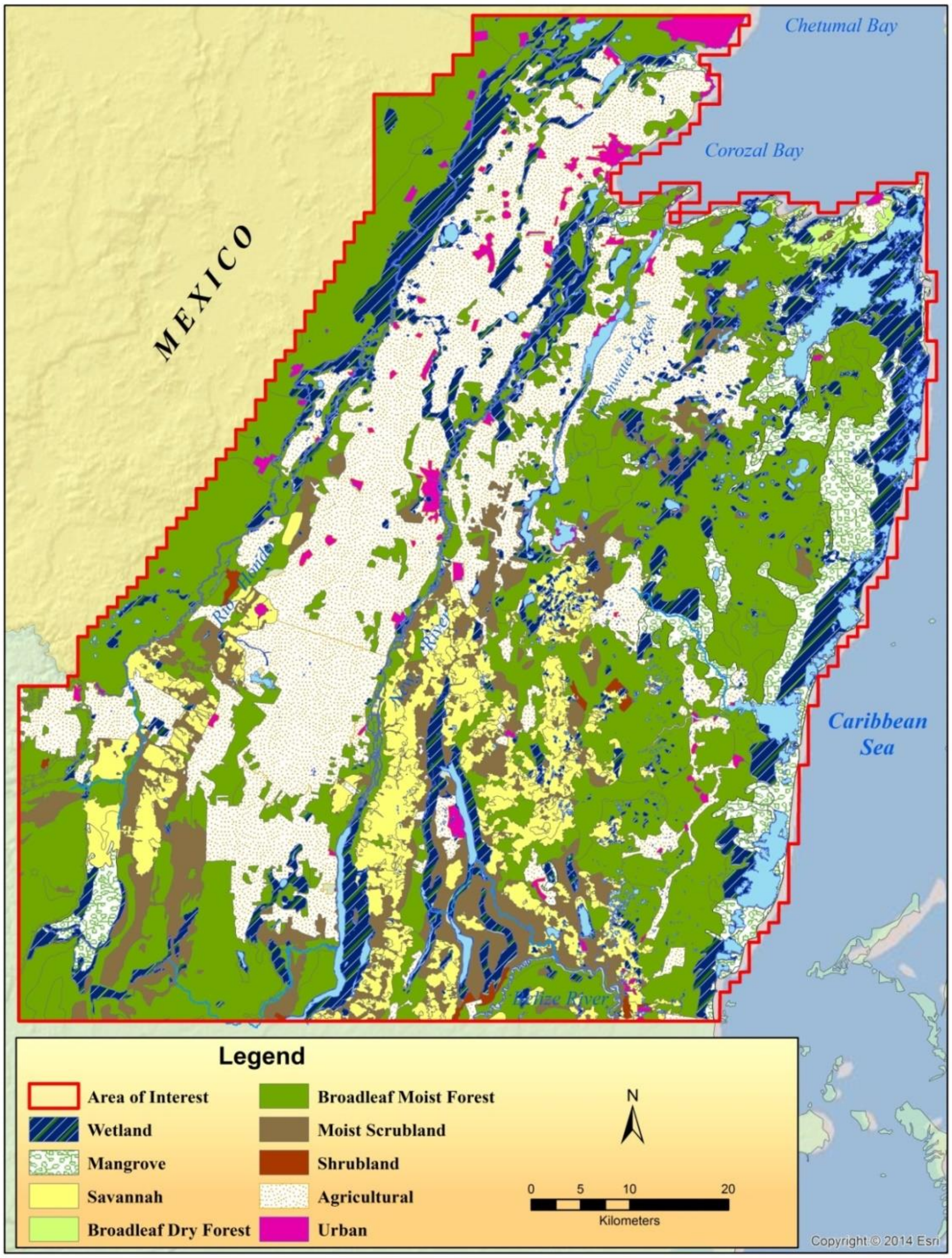

Figure 2. Vegetation and land use map for the area of interest based on BERDS (2015).

Table 2. Soil classifications within area of interest.

Soil Classifications within the Area of Interest (after Baillie et al. 1993)			
Suite	**Subsuite**	**Description**	**Distribution**
Yaxa	Yalbac	Shallow, dark clays over weathered limestone; soils deeper along swamp margins and lower slopes	Belize Valley north to Orange Walk Town
	Chacluum	Moderately shallow brownish and reddish clays over weathered limestone	Irish Creek to Hill Bank
Pembroke	Louisville	Moderately shallow dark grey and black clays over Tertiary limestone of the coastal plain	Coastal plain surrounding Louisville
	Xaibe	Shallow brown and red clays over limestone with coral inclusions	Undulating regions surrounding Xaibe
Guinea Grass	Lazaro	Dark grey to black loam; crumbly; overlying sandy clay and weathered limestone; shallow to moderately deep	Northern Orange Walk District
	Pixoy	Coarser variant of the Lazaro Subsuite	
Altun Ha	Jobo	Brown or dark grey clays and loams with possible chert inclusions; overlaying stony clay and harder limestone	Old Northern Highway; small portions of Orange Walk and Corozal District
	Rockstone	Brown or grey sandy stony loam over sandy loam or clay or chert-rich limestone	
Bahia	Consejo	Dark grey or black muck, peat, loam, or clay over gypsiferous limestone and coral	Northern shore of Corozal Bay
	Remate	Stony, shallow clays located in patches on recent coral limestone	Southern Shore of Chetumal Bay
Revenge	Felipe	Deep, black to dark grey sandy loam; associated with Pine Ridge vegetation	North Orange Walk District
	Tok	Moderately deep siliceous sand over grey sandy clay or clay; calcareous inclusions common	North Orange Walk District; central Belize River Valley
Puletan	Crooked Tree	Shallow sandy topsoil overlaying white sand and sandy clay loam or sandy clay to depths over 1 m	Lowland regions surrounding Crooked Tree and north of Belize River
	Boom	Sandy, dark topsoil transitioning to sand; over compact, mottled white and red sandy clay or sandy clay loam	Lower reaches of Belize River and region surrounding Burrell Boom
	Haciapina	Sandy, shallow grey topsoil over deeper, white sands; overlaying white and red sandy clay loam or sandy clay; located in association with wet areas of lower slopes	Eastern portion of Northern Coastal Plain
	Buttonwood	Reddish topsoil associated with saline, coastal environments or brackish inland springs	Limited coastal environments of Northern Belize
Tintal	Sibal	Perennially damp soils and peats of freshwater wetlands; mottled and gleyed with clays predominant	Northern Belize
	Ycacos	Perennially wet soils exceeding 50 cm deep; associated with saline swamps and mangroves; soils less peaty than those of the Sibal subsuite; abundant gypsum crystals	Coastal environments and brackish inland regions

Soil Classifications within the Area of Interest (after Baillie et al. 1993)			
	Pucte	Seasonally inundated fringes of freshwater swamps; brown topsoils over calcareous mottled clays; overlaying other calcareous clays with gypsum inclusions	Northern Belize
	Chucum	Dark clays located in seasonally inundated depressions; sandy clay occurs rarely; soil cracking in the dry season	Northern Belize
Melinda	Hondo	Black and grey clays associated with calcareous alluvium; gypsum contained in subsoil	Slow moving streams of the Northern Coastal Plain
	Sennis	Recent alluvium overlaying older Puletan type alluvium; brown and gray silts, clays, loams, and sands over white and red sandy clay	Booth River Lagoon
Turneffe	Shipstern	Shallow sand mixed with muddy sediment with coral and calcareous inclusions; associated with mangrove environments	Northern Belize coast and cayes
	Ambergris	Deeper calcareous sands and coarse soils; associated with mangrove and stunted beach forests	Northern Belize coast and cayes

CHAPTER 3: CULTURAL BACKGROUND AND PREVIOUS RESEARCH IN WETLAND AGRICULTURE

Introduction

Prehistoric populations inhabited a variety of environments within greater Mesoamerica since the end of the Pleistocene, successfully exploiting niches across coastal, montane, and plateau landscapes. Populations distinguished as culturally Maya have resided in portions of northern Belize for the past 3.5 millennia (Lohse 2010: 345). Some of the earliest social developments attributed to the Maya occurred initially in the region at sites such as Cuello, located on higher ground between the Hondo and New Rivers (Hammond 1991: 7). The rich riverine, lacustrine, and coastal environment provided Maya populations with numerous critical resources across generations (Rosenswig et al. 2014: 320). Substantial Preclassic, Classic, and Postclassic populations distributed themselves across the Northern Coastal Plain, demonstrating a level of flexibility and sustainability not normally realized in other sections of the Maya Lowlands. To understand the foundation and persistence of Maya wetland agriculture in the project area, one must first comprehend the cultural development of the area as a whole.

Cultural Background

Prehistoric populations have been documented at select locales in northern Belize by the beginning of the Late Archaic Period. Pohl and colleagues (1996: 361) identified evidence of crop cultivation along the lower Rio Hondo by approximately 3400 B.C. Preceramic sites have also been recognized in low-lying areas to the south, with Archaic occupations being recognized at sites such as Pulltrouser Swamp, Laguna de On, Colha, and Kichpanha (Rosenswig et al. 2014: 309). Populations during this time remained modest in scale, practicing limited horticulture while gathering local terrestrial, riverine, and lacustrine resources. Visible environmental impacts, such as widespread forest clearance, are not apparent until the second millennium B.C.

Northern Belize represents one of the first areas to exhibit culturally distinct Maya assemblages associated with the Swasey Ceramic Complex, initially attributed to the first half-millennium of the Early Preclassic Period (2000—1500 B.C.) (Kosakowsky 1987: 13). Although later revisions of radiocarbon dates associated with these levels would push the complex towards the early centuries of the Middle Preclassic (approximately 1200—700 B.C.) (Andrews and Hammond 1990: 572), the material still represents some of the earliest Maya ceramics found in the entirety of the Lowlands. Formal, non-residential monumental architecture also appears quite early within sites situated along or near the Rio Hondo and New River systems. Non-residential architectural manifestations and differential in material wealth occurred during the beginning of the Late Preclassic at sites such as Cuello (Hammond 1991: 239), Cerros (Freidel 1979: 42), Nohmul (Hammond et al. 1985: 197), and Lamanai (Pendergast 1981: 41). All sites are situated in areas adjacent to or neighboring wetlands or artificially raised/drained field systems; previous excavation projects conducted at these centers suggest that the fields were heavily utilized during the Late Preclassic and again in the Late to Terminal Classic Periods (Hammond et al. 1988: 1; Turner 1983: 50).

Maya sites contained within the area of interest lacked the expansiveness of the larger centers of the Petén during the Preclassic and Classic Periods (Figure 3). No prehistoric Maya site in northeastern Belize contains more than twelve formal courtyards (Adams 1982: 61), articulating with medium sized centers found in Petén and Campeche (Hammond 1975: 43). Nohmul possesses distinction as the largest center within the Northern Coastal Plains, followed by Lamanai, Aventura, Altun Ha, Cerros, and Cuello (Adams 1982: 63).

The ancient Maya established Nohmul, described as a regional ceremonial center within the northern Belize site hierarchy (Hammond 1975: 43), during the Late Preclassic before experiencing significant population declines during the Early Classic Period (Table 3). Neighboring sites, including San Estevan and those positioned on Albion Island, witnessed population growth during the same timeframe (Pyburn et al. 1998: 50; Levi 2003). Nohmul recovered dramatically during the Terminal Classic and survived into the Early Postclassic (Hammond 1988: 2). Cerros, Lamanai, and Cuello fluoresced during the Late Preclassic, with Lamanai sustaining recorded occupation beyond Spanish Contact. Altun Ha rose in prominence during the Early and Late Classic Periods (Pendergast 1979: 199), benefiting from an economic monopoly on the control of lithic tools produced at Colha to the north (Shafer 1982: 36). Aventura displays signs of occupation from the Late Preclassic, sustaining its highest populations during the Late and Terminal Classic Periods (Sidrys 1983: 18). The trajectory of Santa Rita Corozal shows settlement by the Late Preclassic, with occupation peaks during the Early Classic and most dramatically, the Late Postclassic Periods (Chase and Chase 1988: 10-11, 65).

Basics of Wetland Agriculture

Wetlands are commonly located within tropical, subtropical, and temperate environments, covering an estimated six percent of the world landmass (Rostain 2012: 25). These saturated areas reflect permanent or seasonal inundation by saline, fresh, or brackish waters in association with coastal, riverine, or lacustrine buffer zones. Prehistoric populations throughout the world have long utilized natural wetland environments for a variety of purposes. Traditional uses identified consist of procurement of wild fruits, vegetables, medicinal plants, fuelwood, construction materials, and aquatic faunal resources (McCartney et al. 2005: 15).

Wetland environments also functioned as ecotones between terrestrial and lacustrine/riverine ecosystems, purifying water for domestic consumption (Lan et al. 2012: 681). Modified wetlands, associated with raised or drained fields, were most frequently developed for intensive cultivation of a few chief crops.

Table 3. Site hierarchy of northern Belize Maya sites (adapted from Hammond 1975).

Level	Tier	Description	Type Site	Attribute(s)
9	I	Regional Ceremonial Center	Nohmul	Ballcourt; large ceremonial architecture; *sacbeob*; elevated acropolis feature(s)
8	II	Medium Major Ceremonial Center	San Estevan	Ballcourt; pyramidal structure exceeding 10 meters; elite and ceremonial residences
7		Small Major Ceremonial Center	Colha	Ballcourt; pyramidal structure exceeding 10 meters
6	III	Minor Ceremonial Center	Chowacol	2—3 defined plazas hosting structures serving administrative and religious functions
5		Minimal Ceremonial Center	Santa Rita Corozal	Larger (5+ meters) non-residential structure(s) occupying formal plaza or artificially leveled area
4	IV	Formal Cluster	Martinez Group	Sized mounds (6—12) arrange around a well-defined plaza space
3		Informal Cluster	Hipolito Group	Homogenous mounds (6—12) arranged around a centralized, open space
2	V	House-Compound/Plazuela	N/A	Cluster of 2—6 platforms
1		Single Isolated House Platform	N/A	No visible clustering or grouping

Wetland agricultural usage is not unique to Mesoamerica or other tropical environments. The oldest archaeologically documented raised field systems are located in Kuk Swamp of western Papua New Guinea, dating to approximately 5000—7000 B.C. (Denham et al. 2004: 839). Lacustrine manipulation for agricultural purposes has been documented in China by 221

B.C. (Lan et al. 2012: 681). Wetland field systems have also been reported in New Zealand (Horrocks and Barber 2005: 106), Africa (Menotti 2012: 60), the Mississippi drainage (Griffin 1967: 189), and southern Florida (Sears 1982: 145).

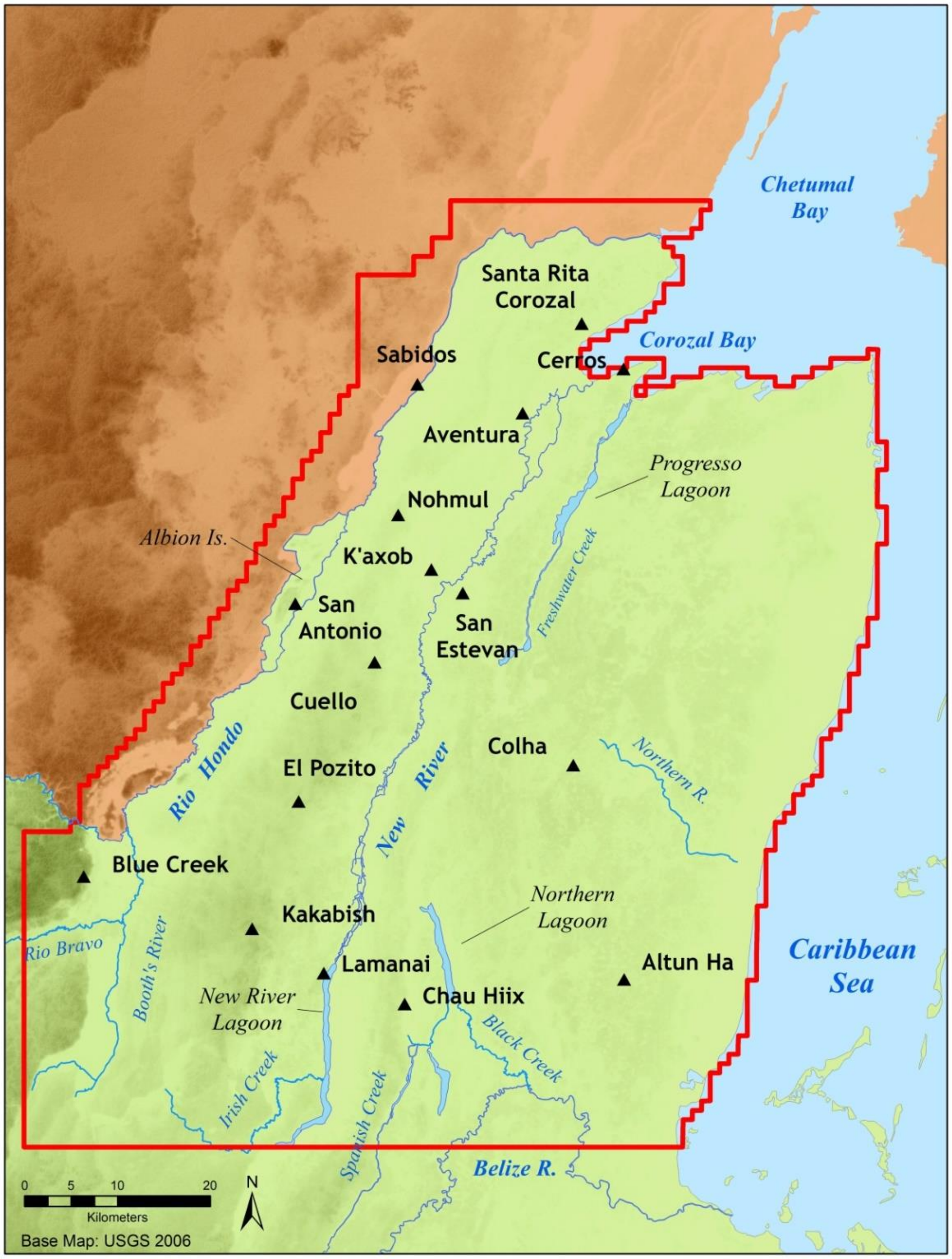

Figure 3. Overview of area of interest depicting key Maya sites discussed.

Since the late 1960s, researchers have sought to identify the various wetland agricultural systems throughout Latin America, spanning central Mexico and the Veracruz coast to the lofty *altiplano* of Peru and Bolivia (Denevan 1970, 2001). Within South America, raised and ditched field complexes are known for regions such as the Lake Titicaca Basin of the central Andes (Smith et al. 1968: 354), Llanos de Mojo region of Bolivia (Walker 2011: 3), coastal Guiana (Iriarte et al. 2010: 2985), Colombia, Surinam, Ecuador, and Venezuela (Denevan 1970: 648). Siemens and Puleston (1972) initiated aerial studies along the Rio Candelaria in southern Campeche, Mexico, and later extended research into southern Quintana Roo in association with Bajo de Morocoy and the Rio Hondo drainage (Figure 4). Following identification of fields, several archaeological projects were conducted at Maya sites associated with these features, such as Pulltrouser Swamp and Albion Island (Turner and Harrison 1983; Pohl et al. 1990; Pohl and Bloom 1996). Ongoing work in the larger region includes the Blue Creek Archaeological Project (Thomas Guderjan, Director), Aventura Archaeological Project (Cynthia Robin, Director), and the Instituto Nacional de Antropología e Historia (INAH) excavations at El Tigre in Campeche (Ernesto Vargas Pacheco, Director).

A number of unique factors influenced the investment and maintenance of such systems. Specific positive attributes of wetland agriculture include increased soil aeration, enhanced drainage, concentration of nutrients, availability of fertilizers, decreased fallow times, production of multiple annual crop yields, establishment of beneficial or specific crop microclimates, and conservation of water in times of drought (Wilken 1969: 226; McAnany et al. 2003: 74; Renard et al. 2012: 31; Rostain 2012: 155). Pyburn (1998: 278) suggests that recessional wetland systems—such as those associated with Chau Hiix along the Western Lagoon—mitigated agricultural pests through the management of flooding following harvest. Prehistoric groups also targeted wetland environments by necessity in regions where high population densities have occupied a majority of the available upland field areas (Rostain 2012: 184).

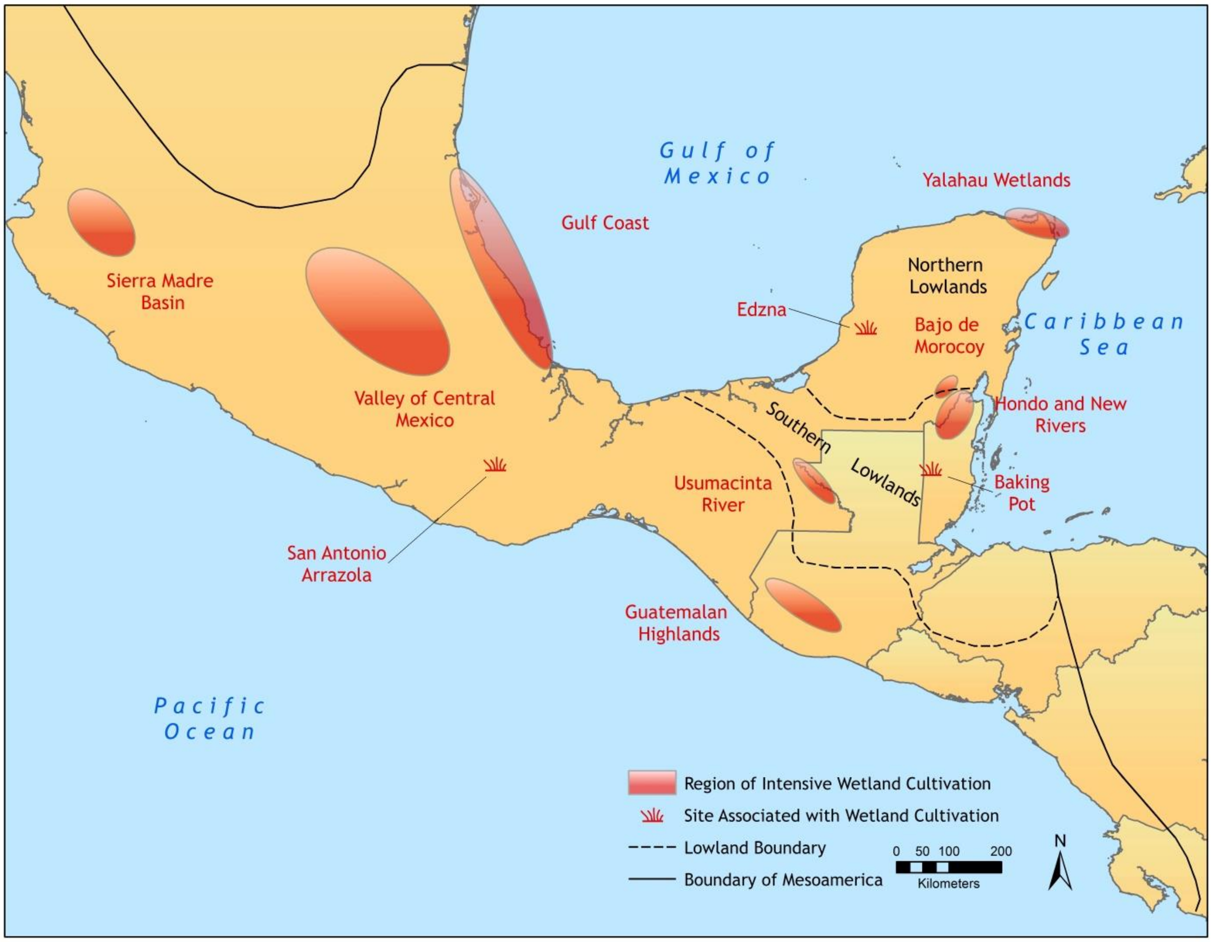

Figure 4. Distribution of intensive wetland agricultural regions and sites within Mesoamerica (adapted from Sluyter 1994: Figure 1).

Evolution of Maya Wetland Agriculture

Domesticate agriculture spread to the northern Belize region beginning around the Late Archaic (3000—2000 B.C.) as evidenced by the concentration of pollen in recovered lake and swamp cores (Pohl and Bloom 1996: 164). Both manioc (*Manihot esculenta*) and maize (*Zea* *mays*) appear in levels dating to approximately 3400 B.C. in cores recovered from Cob Swamp (Pohl et al. 1996: 362). The ratios of domesticated pollen to local species indicate that agriculture remained minimal in the region for over a millennium following introduction, suggesting that both Late Archaic and early sedentary populations persisted as dispersed and low density groups (Fedick and Ford 1990: 25). Lamanai appears to support agricultural crops by ca. 1630 B.C. (Rushton et al. 2012: 489); species found there included chile pepper (*Capsicum*), squash (*Cucurbita*), and *Zea Mays*. Rushton and colleagues (2012: 491) argue that the rise in domesticate pollen coincided with forest clearing and decreased amounts of *Pinus* levels.

Wetland agriculture first appears along main river systems in the area of interest by 1000 B.C., persisting until the Terminal Classic (A.D. 800—950) (Pohl et. al 1990: 189). Limited evidence provides the possibility that a minimal number of channelized fields persevered until the Late Postclassic Period (A.D. 1250—1500) (Beach et al. 2009: 1722). The extent of these initial wetland systems is currently unknown, but may have been restricted to sporadic flood recessional farming or the utilization of permanently saturated lands along the fringes of swamps, particularly during the dry season (Baker 2003: 21). Gradual recession of flood waters allowed areas to be utilized sequentially throughout the season based on the moisture requirements of particular crops.

Evidence of construction or channelization during this early period is minimal, as most of the archaeological material recovered from identified formal systems does not predate the Late Preclassic Period (Pohl et al. 1990: 215). Channelized wetland fields at Albion Island tend to cluster around this period and display signs of abandonment in potential association with rising water tables due to sea level change (Pohl et al. 1990: 220). Wetland systems within Pulltrouser Swamp also appear to develop around the Late Preclassic; however, use in this area continued until the Terminal Classic following a hiatus in the Early Classic (Turner and Harrison 1983: 254). The Maya constructed channelized fields near Blue Creek at the upper reaches of the Rio Hondo and utilized the systems in a piecemeal fashion throughout the Classic Period (Luzzader-Beach et al. 2012: 3650); the Bird of Paradise fields associated with Gran Cacao were built over a short span during the Late and Terminal Classic before being abandoned (Beach et al. 2009: 1720). Excavation work at the Nohmul/Douglas complex proved inconclusive but produced ceramics dating from the Terminal Classic to Postclassic Periods (Hammond et al. 1988: 1).

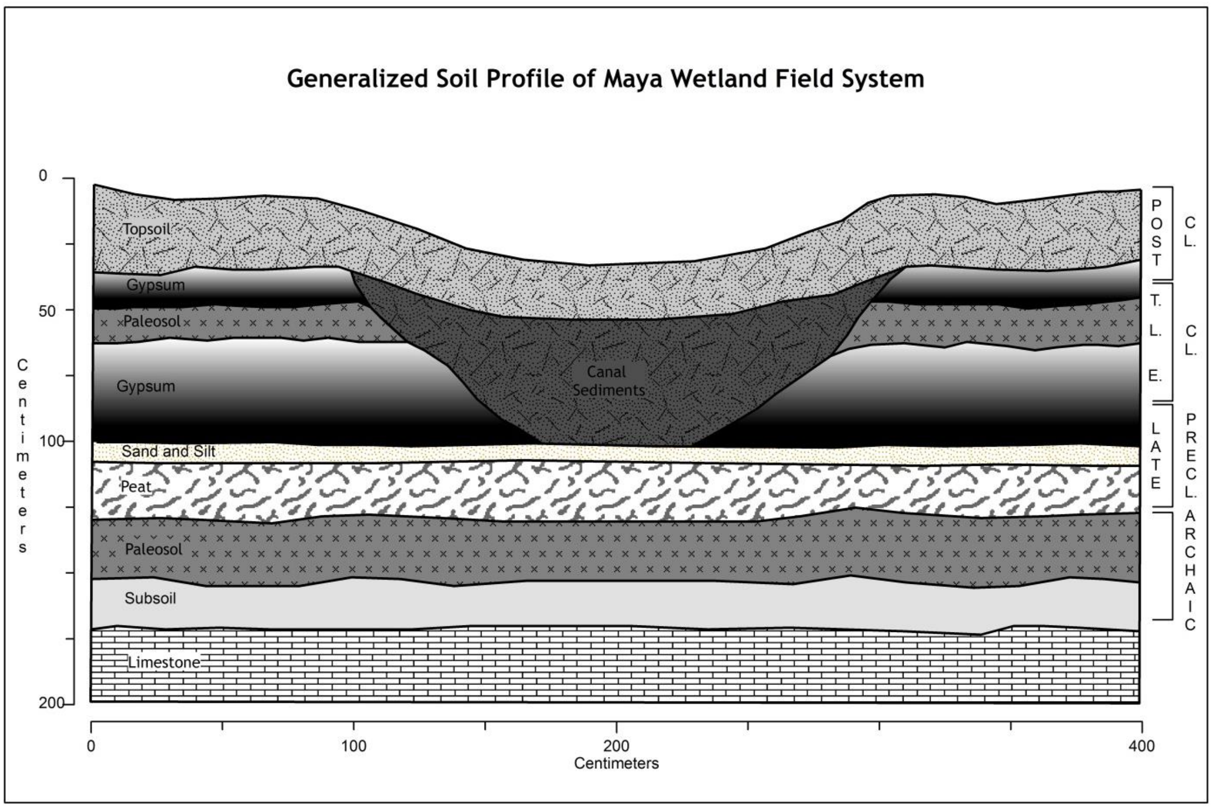

Figure 5. Generalized soil profile of Maya wetland field system (after Beach et al. 2009: Fig. 7).

Ancient Maya Riverine and Coastal Trade Routes

Ancient Maya trade and the movement of utilitarian goods—such as salt, ceramics, and lithics—illustrate substantial time depth in the northern Belize and southern Quintana Roo regions (Garber 1985: 14). Due to the high proportions of riverine and wetland environments in the project area, navigable waterways would have been targeted for the large-scale movement of economic materials. Major drainages such as the Hondo and New Rivers easily allowed transportation of large amounts of commercial items further into the interior, while coastal networks permitted long-distance transport of nonperishable elite goods (Guderjan 2007: 103). Both networks were established by Late Preclassic times, with sites such as Cerros participating in long-distance exchange into the Petén region (Reese-Taylor and Walker 2002: 90) and local distribution along the New River (Freidel 1979: 49; Garber 1989: 96). Additional artifactual evidence suggests that certain centers, including Cuello, rose to a high level of organization and complexity even earlier, during the Middle Preclassic, due to involvement with these trade routes (Hammond 1978: 33).

Indirect evidence relating to the development and integration of riverine trade includes the identification of potential commercial ports, harbors, docks, and jetties within the area of interest. Pring and Hammond (1985: 527) describe a stone jetty feature situated on the east side of the Rio Hondo approximately 3.7 kilometers from Nohmul. Although no datable material was recovered from the feature, nearby excavations recovered substantial amounts of ceramics attributed to the Late Preclassic and Early Classic periods. Excavations conducted at Cerros Structure 112 by Scarborough (1991: 102) connected the feature to marine commerce during the Late Preclassic. Pendergast (1981: 40) originally identified a low-lying feature in the northern portion of Lamanai as a proposed harbor for the unloading of goods. While further research into this area demonstrated a natural origin for the harbor (Powis et al. 2009: 259), Lamanai undoubtedly participated in trade along the New River in connection with Cerros. Barrett and Guderjan (2006: 232) noted a dock and dam complex at the termination of the navigable portion of the Rio Hondo northwest of Blue Creek. Other potential riverine and marine trade features may have been submerged by rising sea levels, obstructed by alluvial sedimentation, or obliterated by modern development.

The agriculturally rich soils of the Hondo and New Rivers likely resulted in the integration of these areas within the greater regional agronomic economy. The Maya transported a variety of subsistence and commercial crops along these trade networks during prehistoric times. Hellmuth (1977: 433—436) identifies numerous crops grown by the Maya in neighboring Petén based on ethnohistoric data. Pertinent species include the pepper (*Capsicum* spp.), manioc (*Manihot esculenta*), common bean (*Phaseolus* spp.), maize (*Zea mays*), chocolate (*Theobroma cacao*), vanilla (*Vanilla planifolia*), sweet potato (*Ipomoea batatas*), chayote (*Sechium edule*), achiote (*Bixa orellana*), elephant ear (*Xanthosoma Yucatánensis*), pineapple (*Ananas cosmosus*), and jicama (*Pachyrhizus erosus*). The region also supported non-edible cultivars, such as cotton (*Gossypium* spp.) and tobacco (*Nicotiana* spp.). Wiseman (1983: 117) suggests that maize, cacao, vanilla, pineapple, cotton, and tobacco represent the most viable trade commodities in the area based on the prevalence of such items in contact period markets. Spanish records produced during the sixteenth century indicate that the Maya provincial capital of Chetumal (now identified as the site of Santa Rita Corozal) maintained a reputation for large-scale export of local cacao and honey (Chase and Chase 1988: 67).

Riverine trade networks likely allowed for the easy distribution of agricultural goods via simple dugout canoes. Drennan (1984: 107) estimates a much reduced transportation cost associated with bulk goods are transferred by watercraft; a metric ton (1000 kg) of material can be transported a distance of one kilometer in six man-hours of effort compared to 22 man-hours overland. Experiments by Barrett and Guderjan (2006: 228) indicate that the prehistoric Blue Creek portage can be reached from Chetumal Bay in approximately three days of riverine travel. These combined data suggest that Maya groups transported an assortment of perishable and nonperishable goods effectively and swiftly throughout the area of interest and beyond to more distant coastal areas of Belize and Yucatán.

CHAPTER 4: SPATIAL EXTENT AND WETLAND LANDSCAPE MODELS

Introduction

As a tropical landscape rising gently from the Caribbean Sea and crisscrossed by countless rivers, streams, and lagoons, northern Belize is a prime candidate to support expansive wetland environments. However, when viewed through the lens of agricultural potential, not all wetlands are created equal. While wetland agriculture was arguably extensive within the area of interest, not every wetland area hosted agriculture nor was conducive to the sustained cultivation of agricultural commodities.

To understand the complete impact of wetland crop production on both regional and intraregional levels, the full spatial extent of these prehistoric features must be documented across the entire landscape. The placement, coverage, and organization of Maya wetland field systems all relate to the motivations governing the prehistoric populations that constructed the numerous features. Through the full realization of wetland field patterning in the project area, a variety of push and pull factors emerge in relation to ideal field location. These include natural impetuses (topography, vegetation, soils, drainage), economic participation (distance to navigable riverine or coastal trade routes), and political integration (distance to nearest major center and/or marketplace). Furthermore, the complete documentation of these particular agricultural systems is crucial for modeling construction energetics and potential agricultural productivity, subjects that will be revisited in later chapters.

Previous Research

Previous researchers approached spatial coverage of wetland systems on a localized, site-specific level. Early reconnaissance at Nohmul (1973), Albion Island (1977), and Pulltrouser

Swamp (1979), generated spatial data on a restricted level, tracing the extent of wetland agriculture only in association with an immediate regional center or settlement cluster. This early research was no doubt hindered by the lack of high resolution aerial and satellite imagery available at the time, combined with the difficulty of physically mapping such systems on the ground. Later projects began at K'axob and Blue Creek in 1990, augmenting the coverage at the local level, but failed to address the integration of all systems on a wider scope. Key issues such as average extent, dominant spatial organization, and relation to the overall regional economy were never raised through the comparison of multiple wetland field systems. Guderjan and Krause (2011) recently took steps to document wetland field systems on a broader level; however, the researchers limited analysis to the navigable expanse of the Rio Hondo, excluding established systems along the New River, Freshwater Creek, and other wetland features to the southeast. In order to produce valid arguments, archaeologists must attempt to outline all field systems within a more expansive area.

Research Methodology

GIS data for this research were produced and analyzed utilizing ESRI ArcMap (Vers. 10.2.2) and Google Earth (Vers. 7.1.2.2041). The study placed emphasis on accurately modeling natural and anthropogenic features within major and subsidiary watersheds based on high resolution satellite and aerial imagery. Combined with existing vegetation, geology, and soil information, spatial relationships were determined between the extensive collection of wetland agricultural fields and Maya habitation sites occupied during the Late Preclassic and Late/Terminal Classic Periods. Features were digitized and projected based on a Universal Transverse Mercator (UTM) projection (NAD 1983 Zone 16 North). Imported data not meeting this projection were properly transformed within ArcMap before additional analyses.

Table 4. Digitized natural and anthropogenic features within area of interest.

Layer Name	Layer Type	Scale Digitized	Source Layers	Resolution
Field Outlines	Polygon	1:4000	DigitalGlobe; Instituto Nacional de Estadística y Geografía	40 centimeters—1 meter
Field Parcels	Polygon			
Water Bodies	Polygon	1:10,000	I-Cubed; NASA LandSAT 7	15—30 meters
Coastline	Polyline			
Rivers	Polyline	1:20,000		

The initial archaeological site layer was obtained through the Electronic Atlas of Ancient Maya Sites, a GIS database created by Brown and Witschey (2010) containing more than 6000 documented prehistoric settlements throughout Mesoamerica. These data consisted of both excavated and terrestrially surveyed sites divided into a three-tier ranking system based on documented size. The layer was imported into ArcMap, where all sites situated within the northern Belize area of interest were selected and exported into a separate feature class; point data were further refined as needed to ensure locational accuracy based on supplemental survey maps. Relevant sites not depicted in this layer were added by providing UTM coordinates established through existing research articles or excavation reports. Point features depicting non-habitation agricultural production sites (i.e., Pulltrouser Swamp) were removed from the site layer. The final feature class contained 64 sites associated with Late Preclassic and Late Classic Maya occupations within the area of interest.

The analysis documented field systems through the creations of separate polygons bounding visible wetland agricultural groups. Due to the limits of imagery resolution, time constraints, and lack of ground truthing, individual field platforms were not digitized for the entire system. Instead, square acre sample plots were established over areas that demonstrated high levels of preservation and individual platforms digitized within the bounded extent to provide a sample of spatial dimensions for both planting and canal surfaces. The field outline layer provided an adequate representation of the extent of these features and allowed for further approximations of energetic investment values and potential crop yields. Layers were digitized at a scale of 1:4000, using satellite and aerial imagery provided by DigitalGlobe (Quickbird, GeoEye, WorldView, and Ikonos) and El Instituto Nacional de Estadística y Geografía at resolutions approaching one meter (Table 4). Digitization was only attempted on imagery that was free of cloud cover or smoke plumes produced by seasonal agricultural field clearance. Any area that displayed obscured coverage or failed to meet adequate spatial resolution (i.e. medium resolution data such as LandSAT) was supplemented with aerial or satellite imagery from Google Earth. In these cases, field systems were digitized within Google Earth as .KMZ files, converted to shapefiles within ArcMap, and joined to existing field data. Observed variance between the Google Earth and ArcMap files was minimal and did not affect the overall validity of these data. Additionally, Google Earth often provided a variety of images taken throughout the year, which proved useful for observing the change in field visibility between the wet and dry season. Polygons associated with field systems situated within Pulltrouser Swamp were supplemented with existing settlement maps where applicable (Harrison and Fry 2000).

Polylines were generated for major riverine systems and select minor drainages at a scale of 1:20,000 using I-Cubed and LandSAT 7 satellite data at a resolution of 15—30 meters. The Rio Hondo expanse was digitized from the community of Blue Creek, Belize to its terminus at Chetumal, Mexico. The complete length of the New River was digitized, including the entirety of the New River Lagoon. Major secondary channels paralleling the main river systems were also included in the final layer. This was especially important in the case of the upper New River, which displays extensive braiding between the modern towns of Tower Hill and Water Bank. Polyline layers were also created for sections of Booth's River, Rio Bravo, Freshwater Creek, Irish Creek, Black Creek, Belize River, and the Northern River.

While the polyline layers accurately depicted the courses of relevant drainages, important information such as acreage and distance to wetland field systems could not be computed without further processing. Additional polygon layers were generated for the Hondo, New, and Belize River systems as well as Freshwater Creek. These features contain substantial amounts of surface water or associated lagoons; polygon creation was necessary to model the spatial footprint of such drainages. Once properly digitized, a riparian buffer of 30.5 meters was established from the defined edges of major river systems within the area of interest. In the absence of more regionally specific data, the U.S. Code of Federal Regulations (National Archives and Records Administration 1985) provided the buffer width estimation utilized for North American riparian zones. The buffer represents potential highly-productive wetland ecotones throughout the project area; however, such areas would be prone to regular flooding events compared to wetlands situated on slightly more elevated ground.

Supplementary land use and vegetation layers were also constructed for the area of interest. Layers indicated modern agricultural lands, urban areas, wetland extent, water bodies, and vegetative coverage. The Biodiversity and Environmental Resource Data Systems of Belize (BERDS 2015) supplied the initial GIS information and was further refined based on the visible extent of features as depicted in aerial and satellite imagery. Data pertaining to the Mexican side of the project area were personally supplemented due to lack of coverage and available information. Water bodies under one acre and modern *aguadas* (stock reservoirs) were excluded from the sample. The resulting data provided important information regarding landscape classification and wetland accessibility during prehistoric times.

Results

Satellite and aerial imagery proved useful in identifying relic Maya agricultural field systems. Wetland fields reside in a variety of locations, including riparian floodplains, closed system *bajos*, inland lagoons, and recently drained modern farmlands. The latter case illustrated a rarity, as a majority of the visible fields were situated in areas free of impact from contemporary sugarcane and maize farmers. The outline of individual field parcels was best preserved along the fringes of the wetlands in association with *esocoba* (mixed palm) vegetation; marl flats, supporting only sparse sedges, often covered the floodplain areas near the banks of the rivers. Marl flats were particularly prevalent near the northern tip of Albion Island and along the lower reaches of the Rio Hondo. These areas may have been viable during the Late Preclassic Period and were likely utilized in the past for wetland agriculture; however, subsequent flooding events and sea level rise could have buried the fertile peats under less productive, gypsum rich clays. The extent of such marls hampered the visual identification of such field systems in the region.

Spatial analyses identified a total of 15226.7 acres (6162 hectares) of wetland field systems within the 6560 square kilometer area of interest. These data reflect only 6.7 percent usage when applied to the complete quantity of wetlands calculated for the project area. However, saline and brackish wetland environments are not considered conducive for the practice of drained field agriculture. Wetlands classified as brackish swamps or marine salt marshes were removed from the population to create a sample that accurately reflected agriculturally viable features. This exclusion raised the level of usage to 14.2 percent of arable wetlands (consult Table 5 for additional land use information).

Table 5. Landscape designation with area of interest.

Area of Interest Landscape Designation			
Type	**Area (km^2)**	**Acres**	**Hectares**
Riverine	30.72	7591.11	3072.01
Riparian	22.54	7650.18	3095.92
Wetland (Total)	913.03	225614.66	91303.01
Agriculturally Viable Wetland	433.37	107088.00	43336.98
Wetland (Relic Fields)	61.62	15226.69	6162.03
Water Body	237.51	58689.35	23750.74
Urban	95.03	23481.57	9502.65
Marine	106.46	26307.81	10646.39
Agricultural	1727.61	426900.75	172760.60
Shrubland	17.02	4205.26	1701.81
Lowland Broadleaf Moist Scrub	514.65	127173.14	51465.14
Lowland Broadleaf Moist	2213.19	546891.86	221319.28
Lowland Broadleaf Dry	22.59	5582.97	2259.35
Lowland Broadleaf Savannah	527.16	130264.59	52716.21
Mangrove	326.80	80755.23	32680.48

Field systems within the area of interest are most pronounced along the Rio Hondo drainage, especially along the middle and lower reaches of the river (Figure 6). The *bajo* areas fringing Albion Island and along both the Mexican and Belizean sides of the Rio Hondo down river to within 12 kilometers of Chetumal Bay supported dense quantities of extensive wetland agriculture. Some of the largest and best developed field systems are associated with the Rio Hondo at sites such as Blue Creek, San Antonio, and Sabidos (Figure 7). The proliferation of formal wetland agriculture in this area affirms that the Rio Hondo potentially served as a well-developed trade network for the movement of surplus agricultural commodities during the Late Preclassic and Classic Periods of Maya society.

A.
B.

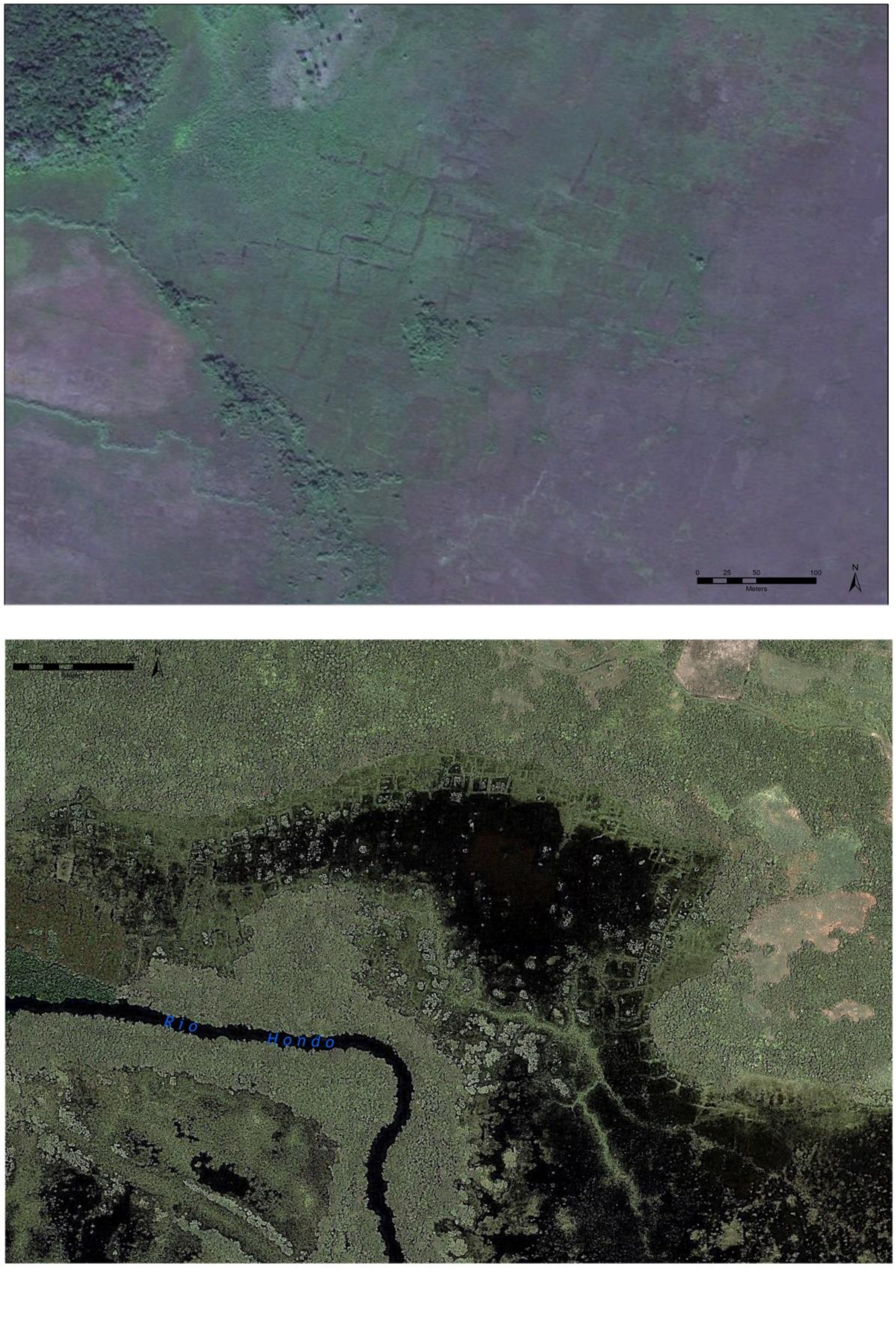

Figure 6. Formal wetland agriculture situated along the Rio Hondo. A) Well-preserved field system near the site of Sabidos; B) Partially inundated gridded fields on the western edge of Albion Island (Base Images: DigitalGlobe 2011a, 2013).

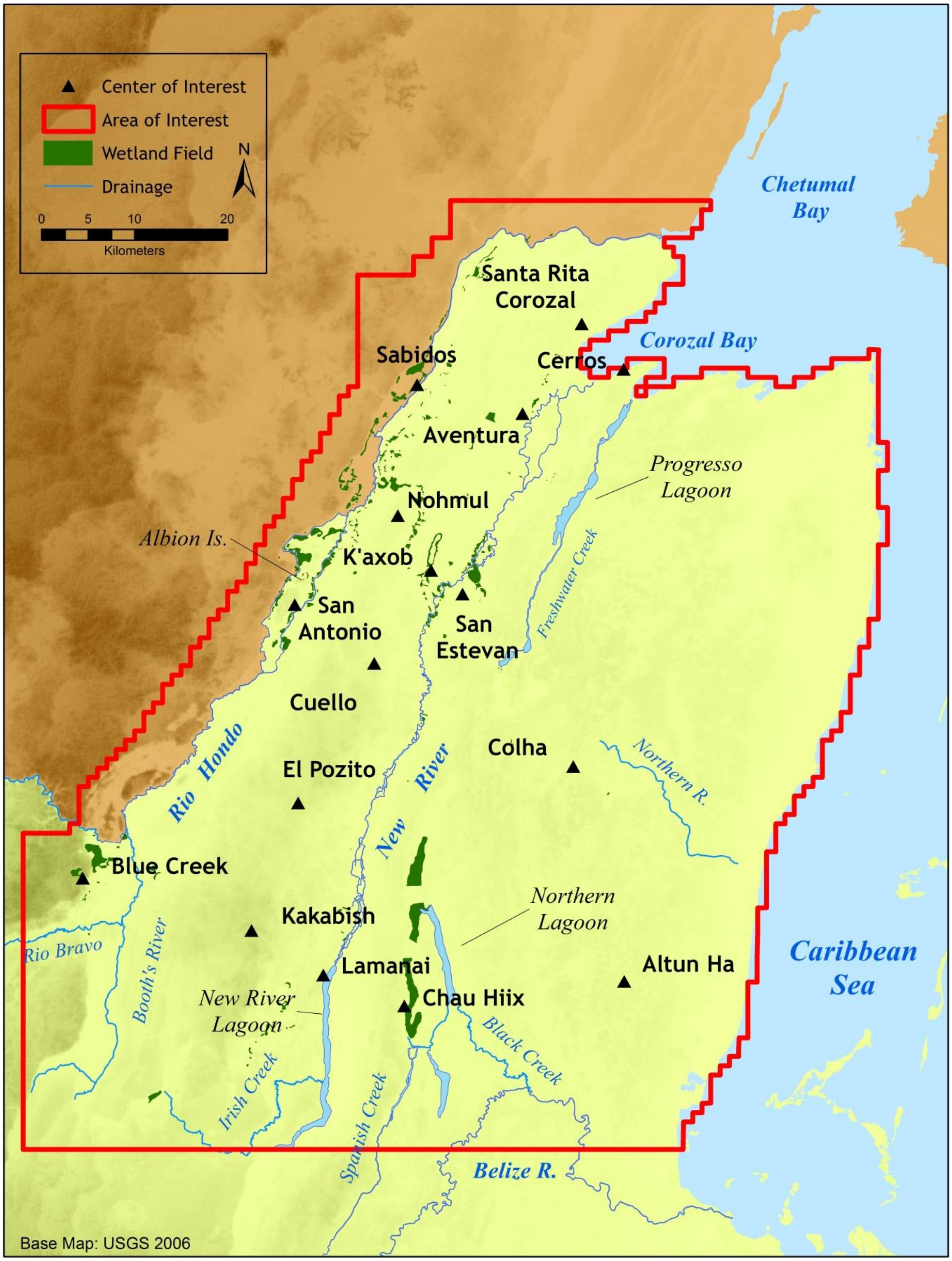

Figure 7. Extent of visible wetland field systems within the entire area of interest.

The spatial distribution of wetland agriculture drops steadily along the New River drainage when compared to the dominant established systems of the Rio Hondo. Field systems are most prevalent along a 13 kilometer stretch of the river in the Indian Hill area south of Pulltrouser Swamp, likely in association with the site of San Estevan. Minor complexes are also located north and south of Lamanai, southeast of Cuello, west of Shipyard, northeast of Caledonia, east of Aventura, and near the site of San Andreas. Field systems along the lower reaches of the New River reside as close as two kilometers from Corozal Bay. Remote sensing failed to observed any visible wetland fields along the banks of the New River Lagoon, as reported by Metcalfe and colleagues (2009: 629); however, a large series of ditched fields are located within a series of closed swamps beginning four kilometers southwest of Lamanai. The high density of wetland systems within the Indian Hill area suggests that crop production and distribution were connected to the Pulltrouser/Douglas complex and the Rio Hondo trade route to the north. Small, more isolated wetland fields associated with single sites indicate a more basic function within the overall distribution, likely operating as local supplemental systems or specific production niches for specialized crops.

The Pulltrouser/Douglas complex reflects a series of *Eleocharis* marshes scattered north-south between the Hondo and New Rivers. Canoe travel between both major rivers via the swamplands appears probable if canal systems were properly maintained; Harrison (1996: 177) reports a canal linking the southern portion of Pulltrouser Swamp to the New River. The site center of Nohmul resides 2—5 kilometers to the west of a majority of the field systems, while smaller settlements such as K'axob, Tibaat, and Kokeal distribute themselves along the margins of Pulltrouser Swamp in close proximity to the wetland agricultural features. The regular grid designs common within the northern and southern branches of Pulltrouser transform to more amorphous constructions in the northwest before returning to formal wetland fields within Douglas Swamp and along the Rio Hondo (Figure 8).

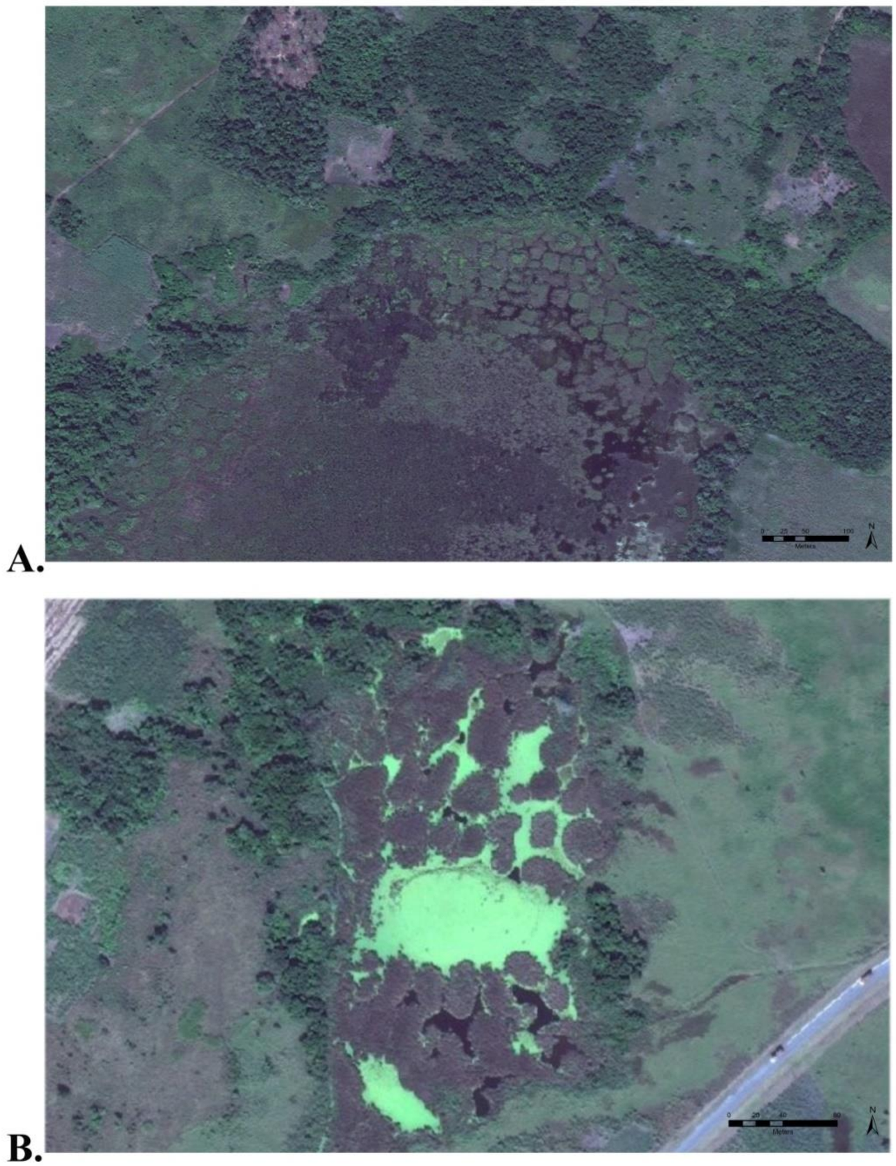

Figure 8. Examples of wetland field systems in the Pulltrouser Swamp area. A) Northern extent of Pulltrouser Swamp; B) Amorphous fields east of Nohmul (Base images: DigitalGlobe 2011c).

Flood recessional field systems within the area of interest are spatially restricted, occurring mainly in association with the Western Lagoon. Turner and Harrison (1983: 247) identified a small grouping of parallel ditch features situated east of San Estevan in Long Swamp; the location of the ditches at a constriction within the swamp suggests a function similar to those found in the Western Lagoon on a more expansive level. Another small complex is situated at the northern end of an elongated wetland near the modern settlement of San Roman, Belize, where eleven canals work to impede water outflow. Spatial analysis also detected a well-defined drained field system within the same wetland feature, demonstrating that such techniques were not mutually exclusive in a given environment.

Agricultural systems within the Western Lagoon are comprised of long canals (5 meters wide, 2—3 meters deep) running perpendicular to the length of the wetland (Figure 9). The Western Lagoon reaches widths exceeding 1.5 kilometers; ancient Maya canals created field systems stretching over eight kilometers long. While the construction mechanics and hydrology of these flood recessional agricultural systems differ from the channelized fields found throughout other portions of the project area, the Western Lagoon fields still represent a substantial devotion to wetland farming techniques.

Field systems demonstrate a minimal distribution of wetland agriculture along the Freshwater Creek drainage, a series of linked lagoons that penetrate only 36 kilometers into the project area. Less than one percent of the total field systems were attributed to Freshwater Creek, clustered tightly along a small portion of Doubloon Bank Lagoon (Figure 10). Two discrete ditched fields reside approximately one kilometer north of Kichpanha, a minor ceremonial center with documented occupation from the Middle Preclassic through Early Postclassic Periods (Gibson 1982: 152). Although several arable wetland depressions and lagoons surround

Kichpanha, previous archaeological reconnaissance failed to document raised or ditched field systems in the immediate area (Gibson 1982: 162). None of the field systems reach an extensive size, indicating that wetland agricultural techniques in the area were utilized for immediate need and did not exceed the consumption requirements of the immediate population.

Figure 9. Satellite image of flood recessional canal pattern spanning the Western Lagoon, north of Chau Hiix (Base image: DigitalGlobe 2011b).

Figure 10. Overview of minor field systems. A) Flood recession system with associated ditched field complexes east of Louisville; B) Isolated wetland field systems on Doubloon Bank Lagoon (Base images: DigitalGlobe 2011c).

The Irish Creek field system reflects a well-developed but minor series of ditched fields located in a closed swamp 22 kilometers southwest of Lamanai. The system may be significantly larger, if apparent canal features can be confirmed as anthropogenic. Fields are located at the headwaters of Irish Creek, which meanders to the northeast before flowing into the New River Lagoon. Portions of the Creek appear constricted and choked with vegetation based on aerial and satellite imagery, making canoe navigation between the fields and the New River Lagoon unlikely.

Upland field systems comprise those features not clearly related with a major river course or wetland complex. The fifty field systems identified are spread throughout the area of interest, but tend to cluster around the site of Blue Creek and north of the Pulltrouser/Douglas complex. Most of the field systems were constructed in minor, closed *bajos* or along the fringe of larger lacustrine features. Modern agricultural lands representing previously drained wetlands faintly preserved remnants of upland field systems. The distribution of these field systems suggests that the Maya selected principal wetlands based on proximity to navigable river routes. While upland fields reside in closed environments, a majority of the features fall within several kilometers of the eastern bank of the Rio Hondo. This relationship indicates the Hondo route supported riverine trade associated with potential surplus generated from wetland agricultural production.

The Cerros field system represents a discrete complex of two planting platforms integrated into a large canal that separates the site from low-lying lands to the south. The Cerros complex represents the only example of formal wetland agriculture occurring directly within the monumental limits of a major site center. Crane (1986) reports a more expansive distribution south of the main site center; based on the thick vegetation within the area and the quality of available imagery, these supplemental fields escaped detection by means of remote sensing. The location of Cerros on a small peninsula—combined with the marginal soil quality of the coastal region—suggests that field extent would remain minimal even with the additional acreage included. Given the limited dimensions and particular location of the field system within the monumental core of Cerros, the complex likely functioned as a specific niche for the growth of specialized crops such as cacao.

The Northern River field system consists of a single complex fringing the western edge of Cobweb Swamp, approximately 4.6 kilometers southeast of the major lithic production site of Colha. The ancient Maya constructed amorphous fields four kilometers west of Lopez Creek, which connects with the Northern River east of the modern community of Maskall and flows soon after into the Caribbean Sea. While the field complex resides within an acceptable distance of the Caribbean coastal trade route, the restricted extent of the Cobweb complex suggests that surplus agricultural export was not the primary function in the immediate area.

Additional spatial analyses employed kernel density methods (Gatrell 1994) to identify areas of high wetland agricultural acreage. Kernel density modeling involves establishing a local neighborhood (one square kilometer) to determine the weighed density of point features across a given landscape. Because wetland agricultural systems were digitized as polygons during initial documentation, additional processing was required before density methods could be calculated. Larger field systems were gridded in one acre increments and assigned a unique point depicting the centroid of a tile. Once the wetland systems were successfully converted to point features, kernel density analysis was performed for the entire area of interest.

Examination of the distribution of wetland fields corroborates the observed distributions of relic systems, highlighting seven major areas of agricultural activity within the project area (Figure 11). Areas associated with high densities of wetland agricultural systems include Blue

Creek, Western Lagoon, Albion Island, Pulltrouser Swamp, Douglas Swamp, San Estevan, and Sabidos. The most extensive concentrations are positioned along the Hondo and New River drainages, the interfluvial lowlands below Nohmul, and the large, seasonally inundated lagoons to the north of Chau Hiix. Minor complexes, such as those associated with Irish Creek and Aventura, are depicted on the kernel density map in light blue. The most minimal systems located within the area of interest failed to register at the larger, regional scale.

Several vegetative associations are apparent when considering the complete spatial distribution of wetland field systems within the project area. Not surprisingly, a negative correlation exists between the placement of raised and ditched field complexes and the documented extent of mangrove species. This type of vegetation thrives best in saline or brackish water conditions; although the local environment contains adequate organic material such as water-logged peats, the salinity is associated with higher quantities of gypsum. Soils saturated with gypsum are common on the coastal plain in regions lower than 30 meters above sea level, limiting the growth of all but the most adapted cultivars (Beach et al. 2015: 1617). Wetland field systems were similarly absent from the pine forest environments of the project area, mostly notably in the areas northeast of Orange Walk. Previous archaeological reconnaissance revealed that pine forest environments in northern Belize remained significantly underpopulated during prehistory. These areas support seasonally inundated lowland features; however, the pine vegetation generally exists in association with better drained, more acidic soils. Pine ridge vegetation experiences a dramatic range of annual soil moisture conditions, suggesting that any wetlands contained in the locations would be unsuitable for prehistoric cultivation.

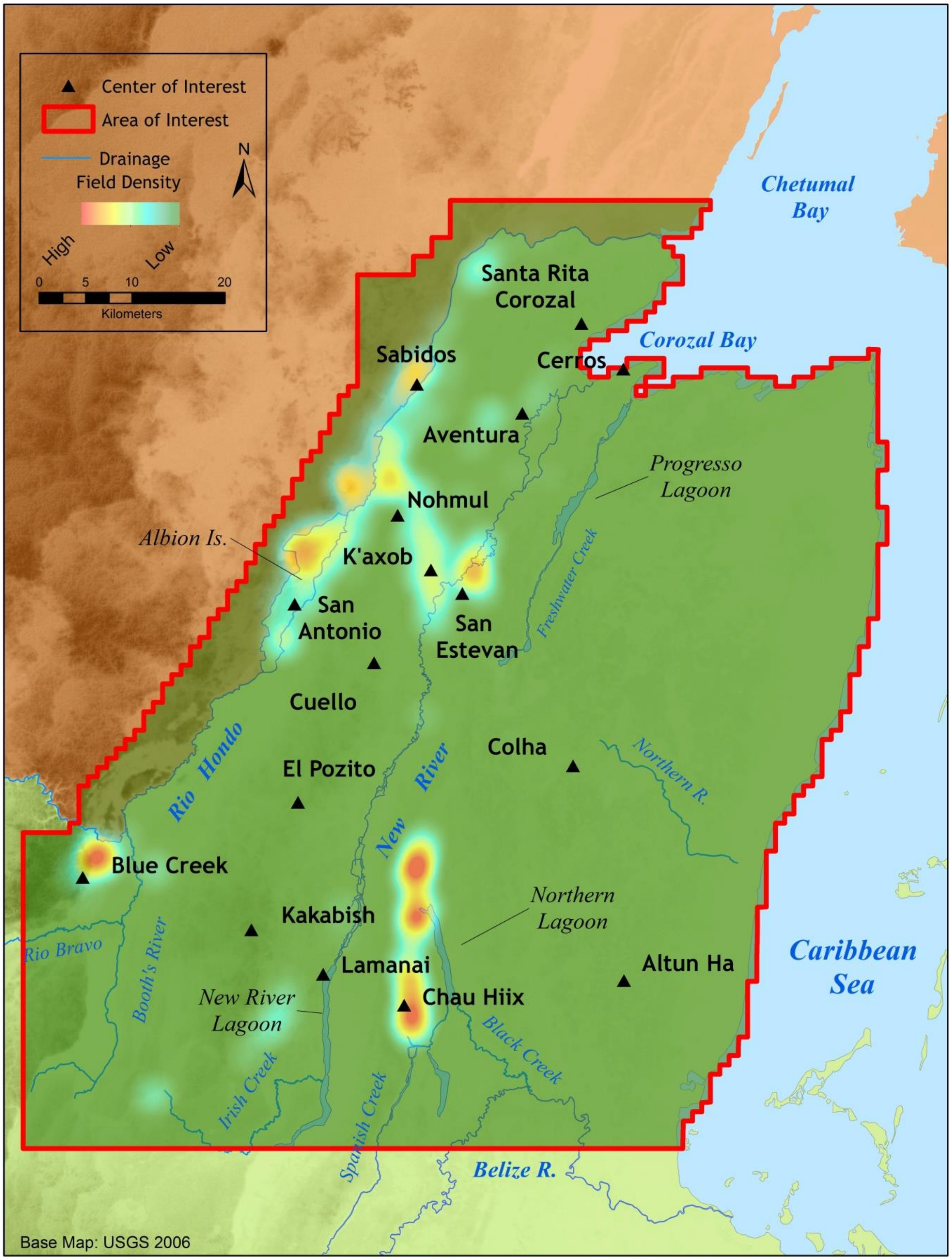

Figure 11. Kernel density map of wetland agricultural fields within the area of interest. The highest densities are depicted in red, with less expansive systems illustrated in light blue.

Wetland fields detected within the area of interest possessed a much stronger association with sedge, broadleaf, and hardwood vegetation. A majority of the *Eleocharis* and *Cladium* marshlands exist beyond the reach of saline-infused water tables but can be sustained by freshwater springs closer to the coast. Generally, the distributions of such marshland features begin west of the major center of Altun Ha; the inland extent of mangrove vegetation usually serves as a viable marker for this transition. These marshlands contain low vegetation that would have been cleared easily with the use of stone tools or fire, making such environments attractive to prehistoric populations. Researchers interpreted buried peats uncovered through the Albion Island excavations as the remnants of extensive *Cladium* marshes; vegetation in the area remains similar to patterns observed during the Late Preclassic and Early Classic usage of the field systems (Pohl et al. 1990: 208).

The ancient Maya also targeted broadleaf and hardwood swamps for the construction of wetland field systems, especially around the area of Douglas Swamp along the Rio Hondo. These wetlands contain valuable economic arboreal species that served the ancient Maya for construction and utilitarian purposes. Once cleared, the wetland would have remained open for the duration of field usage, reverting back to closed canopy only following abandonment.

The soils suites described in Chapter 2 similarly relate to the observed spatial distribution of the wetland field systems within the project area. Certain soil suites and subsuites can be removed from consideration due to their association with coastal, brackish, or pine ridge environments. These include the Bahai, Revenge, and Turneffe Suites, and the Ycacos and Buttonwood Subsuites. All other major suites and subsuites cannot be immediately discounted due to the resolution of the soils data maps produced. The most relevant classes associated with wetland agriculture include the Yalbac soils of the Yaxa Suite, the Sibal, Pucte, and Chucum soils of the Tintal suite, and the Hondo soils of the Melinda Suite. Excavations at Chan Cahal—a minor group at Blue Creek—previously identified Yalbac and Tintal soils in association with wetland field systems (Beach et al. 2013: 47). Tintal soils are further applicable for a majority of the wetland systems in the Pulltrouser Swamp area and the surrounding interfluvial zone. Hondo subsuite soils were most targeted along the middle and lower reaches of the Rio Hondo, in association with Albion Island and the Sabidos-Corrientes area.

Distances from each field system to the closest coastline were calculated utilizing the NEAR tool in ArcMap. The NEAR tool calculated the physical Euclidean distance between individual acre tiles within a given wetland system and the nearest coastal access regardless of environmental or topographic obstacles. The results demonstrated a negative correlation between field densities and proximity to the Caribbean Sea, further affirming the hydrological requirements governing field placement. No fields were located within a kilometer of the ocean, excluding the specialized raised fields reported at the site of Cerros. Four field complexes were situated just southeast of the minor site of San Andreas, within three kilometers of Corozal Bay. These complexes are positioned within the interfluvial zone between the Hondo and New Rivers; soils within the zone could be alluvial in nature and account for the close proximity of the systems to the coast. A majority of the systems appear to peak between 25 and 35 kilometers from the coast, rapidly declining by 50 kilometers inland.

Spatial analyses were also conducted on the complete population of field systems in the area of interest to determine the proximity to the nearest navigable water route (Figure 12; Table 6). Nearly half (48 percent) of all field systems (7312 acres) identified the Rio Hondo as the closest available riverine trade route. A majority of these wetland fields reside less than 1.5 kilometers from the river based on proximity values derived from ArcMap, only a short distance overland or through established transportation canals. The Northern Lagoon-Black Creek drainage supported 28 percent of the total field acreage (4205 acres); crops associated with this area were primed for easy transportation south towards the Belize River or quickly overland to the New River. Pyburn (2003: 123) reports that canals linking the New River and Western Lagoon possibly existed before infilling with sediment.

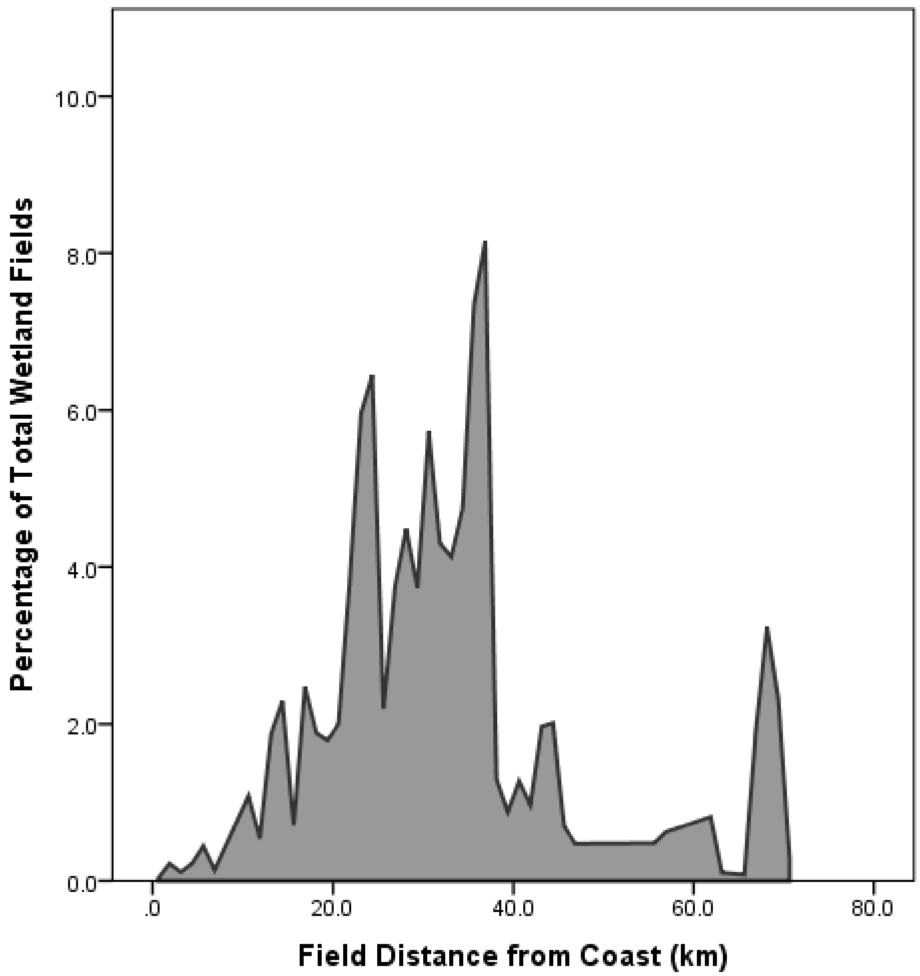

Figure 12. Histogram of percentage of total wetland fields in relation to distance from coast.

Aerial and satellite imagery between Chau Hiix and Lamanai reveal a number of distinct canal-like features. Although canal construction in this area might indicate earthworks associated with historic logging activities, the features may reflect an initial Maya origin. Approximately 20 percent of all fields (3121 acres) were identified in close proximity to the New River, with an average distance of only 2.2 kilometers from the drainage.

The remaining field systems factor minimally into the overall analysis. Slightly over two percent (315 acres) of the regional fields were associated with Irish Creek, itself a tributary of the New River. The Rio Bravo encapsulated just over 1.5 percent of the total fields (236 acres); these fields are located just west of the confluence of the Rio Bravo and Booth's River, from which the Rio Hondo can be promptly reached. The weakest connections are attributed to Freshwater Creek and the Northern River, each with less than one percent of the total documented acreage. Not only are few field systems associated with these drainages, but the average distance to the watercourse measures nearly four kilometers. These systems were clearly not as readily integrated into the northern Belize riverine trade network and may reflect restricted utilization by specific local populations.

Table 6. Field distance to navigable watercourse.

Wetland Agricultural Field Distance to Navigable Watercourse				
Watercourse	**Average Distance (km)**	**Maximum Distance (km)**	**Total Acres**	**Total Percentage**
Primary				
Rio Hondo	1.24	6.37	6252.51	45.66
New River	1.96	6.48	2859.67	20.88
Belize River	-	-	-	-
Secondary				
N. Lagoon-Black Creek	2.36	6.35	4203.71	30.70
Freshwater Creek	4.04	8.40	25.88	0.19
Northern River	3.69	3.87	12.80	0.09
Tertiary				
Irish Creek	1.19	2.11	176.51	1.29
Rio Bravo	1.36	2.23	163.54	1.19

Spatial data analyses also employed the NEAR tool to generate relationships between Maya sites and the total extent of field systems managed. The analysis attributed fields to the nearest known Maya site based on the assumption that proximity denoted exclusive or preferential access to any agricultural goods during the prehistoric tenure of a given wetland system. The tool calculated average and maximum distances to illustrate the potential sphere of influence (SOI) based on investment in these static wetland environments (Table 7). Spheres of influence illustrated circular buffers associated with the presumed area of management; tiered buffers are explained in Table 8. While most fields were located within four to five kilometers from a site, some were scattered as far as 13.8 kilometers away. This trend was mostly associated with upland sites such as Cuello, smaller sites along the upper reaches of the New River, and the eastern edge of the Rio Bravo Escarpment. Some sites, such as Altun Ha, Santa Rita, El Pozito, and Kakabish, were too distant from any recorded field system to be positively associated with wetland agriculture.

Because researchers have connected some smaller sites to larger centers through previous settlement surveys, the table above can be further refined to represent the combined wetland agriculture associated with first- and second-tier settlements. A steady distribution of housemound features connects Nohmul with the smaller site of Douglas to the north (Pyburn 1990: 183); Levi (1993: 78) documented a similar relationship with San Estevan, Chowacol, and the Hipolito and Martinez Groups east of the New River. Furthermore, ceramic and architectural characteristics suggest shared influence between San Estevan and a majority of the Pulltrouser Swamp sites, with the exclusion of Tibaat (Levi 2003: 91). Albion Island reflects the combination of the Maya centers of Santa Cruz, San Antonio, and Lagarto (Pohl et al. 1990: 188). These data show large combined acreage for the Lamanai, Cuello, Nohmul, El Pozito, San Estevan, Blue Creek, and Sabidos spheres of influences, with each sphere averaging over ten percent of the total documented wetland field acreage (Table 9).

Individual sites containing the highest total acreage (>1000 acres) relate to settlements managing large wetland systems positioned along the Rio Hondo and Western Lagoon (Figure 13). Known sites in this class consist of one second-tier center (Chau Hiix) and four fourth-tier settlements (Chan Cahal, Douglas, Lagarto, and Shipyard). The first regional ceremonial center, Nohmul, appears in the following level, those sites managing between 500—1000 acres of ditched fields. The remaining sites within this category include Sabidos (Tier III) and Corrientes (Tier IV). The proceeding class, sites managing between 250 and 500 acres of wetlands, contains Lamanai (Tier I), San Estevan (Tier II), Chowacol (Tier III), and Santa Cruz and Chi Ak'al (Tier IV). Archaeological sites that oversee between 100—250 acres incorporate a wide range of settlements, including Aventura (Tier II) and K'axob (Tier III). Besides the inclusion of the medium major ceremonial center of Aventura, a majority of the sites within this range retain the designation of minimal ceremonial center or below. A similar trend can be extended to the following category (50—100 acres managed). Class VI sites (20—50 acres) contain two small major ceremonial centers: Cuello and Blue Creek. A majority of the field acreage that might have been attributed to Blue Creek was instead incorporated into smaller clusters such as Chan Cahal. Cuello occupies an upland area south of the Rio Hondo and may never have significantly factored into wetland cultivation. Class VII sites (5—20 acres) contain Colha (Tier II), and Kichpanha and Gran Cacao (Tier III). The final sites—Cerros (Tier II) and Honey Camp and U Xulil Beh (Tier IV)—fall within the most meager designation, those settlements managing between 1—5 acres.

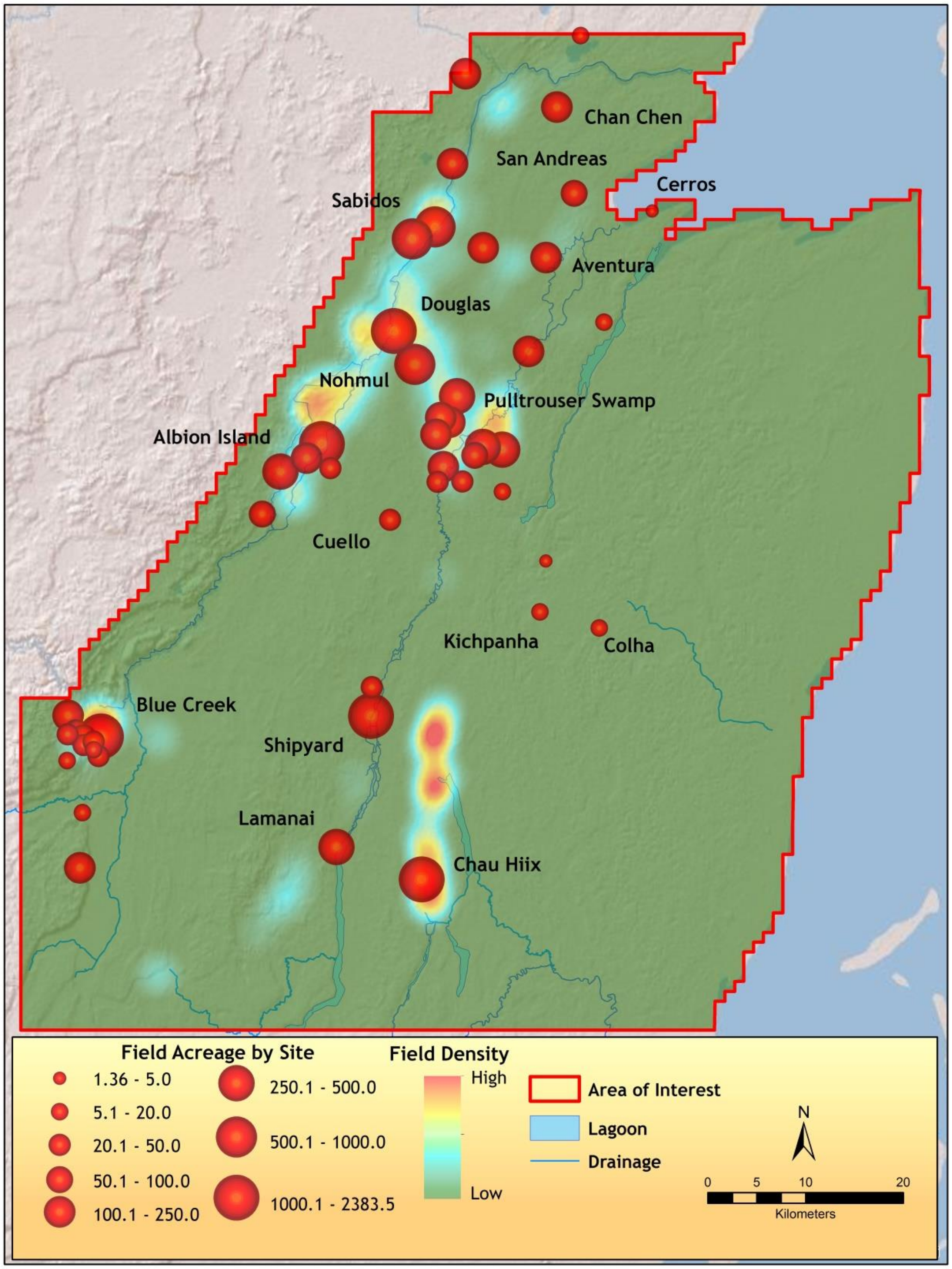

Figure 13. Total field acreage distributed by nearest site showing distinct clusters associated with wetland agricultural areas.

Table 7. Spatial relationships between relic fields and Maya sites.

Archaeological Sites and Associated Wetland Field System				
Site (Tier)	**Total Acreage**	**Total Percentage**	**Average Distance (km)**	**Maximum Distance (km)**
Altun Ha (I)	-	-	-	-
Aventura (II)	155.28	1.02	2.36	3.46
Blue Creek (II)	39.66	0.26	0.47	0.99
Caledonia (IV)	116.94	0.77	4.27	5.23
Cerros (II)	1.36	0.01	In Site	In Site
Chan Cahal (IV)	1017.38	6.68	2.33	6.62
Chan Chen (IV)	114.55	0.75	4.56	5.56
Chau Hiix (II)	2383.53	15.65	3.61	9.73
Chetumal (IV)	-	-	-	-
Chi Ak'al (IV)	406.58	2.67	2.18	5.29
Chowacol (III)	384.10	2.52	1.94	5.20
Colha (II)	12.80	0.08	4.71	4.83
Corrientes (IV)	562.98	3.70	2.56	5.15
Cuello (II)	48.09	0.32	7.88	8.28
Douglas (IV)	1610.31	10.58	2.89	7.04
El Pozito (II)	-	-	-	-
El Solitario (IV)	8.51	0.06	3.97	4.17
Gran Cacao (III)	10.38	0.07	1.15	1.29
Great Savannah (IV)	176.51	1.16	13.50	13.83
Guinea Grass (IV)	31.77	0.21	7.33	7.70
Hipolito Group (IV)	32.18	0.21	0.97	1.19
Honey Camp (IV)	1.52	0.01	4.04	4.08
Kakabish (II)	-	-	-	-
K'axob (III)	200.09	1.31	1.23	2.44
Kichpanha (III)	14.48	0.10	1.10	1.42
Kin Tan (IV)	55.61	0.37	0.40	0.87
Kokeal (IV)	181.28	1.19	1.09	2.16
Lagarto (IV)	1670.62	10.97	4.15	7.02
L. de los Milagros (IV)	16.35	0.11	3.53	3.69
Laguna de On (III)	-	-	-	-
Lamanai (I)	426.80	2.80	7.22	12.83
Last Resort (IV)	-	-	-	-
Los Saraguatos (IV)	53.20	0.35	2.97	3.73
Louisville (IV)	190.42	1.25	3.31	4.92
Martinez Group (IV)	90.84	0.60	1.72	2.22
Nohmul (I)	540.46	3.55	3.59	6.85
Nukuch Muul (IV)	80.52	0.53	0.86	2.33
Patchakan (III)	-	-	-	-
Pech Titon (IV)	133.96	0.88	0.92	2.20
Progresso (IV)	10.24	0.07	2.89	3.45
Pueblo Nuevo (IV)	-	-	-	-
Ramonal (IV)	125.31	0.82	1.97	5.14
Rempel Group (IV)	34.65	0.23	1.34	1.87
Rio Hondo (IV)	35.80	0.24	1.22	1.36
Rosita Group (IV)	124.13	0.82	2.33	3.33
Sabidos (III)	668.49	4.39	2.04	4.24
Sajomal (IV)	-	-	-	-
Sak Lu'um (IV)	8.58	0.06	0.55	0.69
Saltillo (IV)	-	-	-	-

Archaeological Sites and Associated Wetland Field System				
Site	**Total Acreage**	**Total Percentage**	**Average Distance (km)**	**Maximum Distance (km)**
San Andreas (IV)	56.08	0.37	2.13	3.58
San Antonio (III)	177.05	1.16	1.49	2.87
San Estevan (II)	381.31	2.50	2.59	3.98
Santa Cruz (IV)	359.63	2.36	2.44	3.78
Santa Rita (III)	-	-	-	-
Sayap Ha (IV)	22.83	0.15	0.39	0.59
Shipyard (IV)	2055.09	13.50	7.58	10.34
Sociedad Ganadera (IV)	-	-	-	-
Tibaat (IV)	139.30	0.92	1.56	2.91
U Xulil Beh (IV)	5.21	0.03	1.81	1.86
Ucum (III)	189.88	1.25	4.83	5.6
Ya'ab Muul (IV)	31.13	0.20	0. 70	1.02
Yakalche (IV)	-	-	-	-
Yo Tumben (IV)	32.93	0.22	0.83	1.10

Table 8. Sphere of influence buffer information.

Sphere of Influence Buffers				
Sphere Type	**Buffer (km)**	**Number of Sites**	**Sphere Acreage**	**Combined Acreage**
Major Sphere	8	4	49,683	198,732
Minor Sphere	6	9	27,948	251,532
Minimal Sphere	4	10	12,422	124,220
Local Sphere	2	41	3,106	127,346

Discussion

Spatial analyses of all observed field systems within the area of interest indicate that the ancient Maya were influenced by several environmental, hydrological, and economical factors when constructing and maintaining wetland agricultural systems. Not surprisingly, the ancient Maya avoided mangrove wetlands as the water and soil conditions negatively affected crop success with nearly all known major cultivars. Coastal populations residing in these areas likely relied on a much higher proportion of marine resources in lieu of marginal agricultural production from this environment. Similar negative pedological conditions explain the absence of field complexes situated in soil suites identified with coastal areas. Additionally, expanses of low-lying pine ridge vegetation remained unused due to extremely seasonal hydrological fluctuations and general unsuitability for agricultural production. These data agree well with the general lack of major prehistoric settlement in pine ridge areas across the region.

While the observed spatial extent of relic wetlands demonstrates favorable usage of sedge, hardwood, and sawgrass dominant wetlands, the vegetative characteristics alone were not the only motivation in the selection of a particular agricultural locale. Numerous viable wetland features west of Altun Ha and between the interfluvial zone of the New River and Freshwater Creek offer no visual indication of prehistoric agricultural usage. Instead, those wetlands—riparian, lacustrine, and lagoonal—within a close distance to major drainages were favored over more closed systems, even when such closed features were more expansive or protected against major flooding events. This suggests that production of agricultural commodities within the wetland complexes was only a portion of the reason these systems were constructed; the ancient Maya also sought ease of transportation via riverine craft. Based on the density of wetland field complexes along the Rio Hondo and New Rivers, fields were likely constructed with the expectation of moving potential agricultural surplus into more marginal interior and coastal regions of the Maya Lowlands.

When spheres of influence are established to document the potential division of wetland crop acreage, several interesting trends emerge. Generally speaking, the largest (Tier I) sites within the area of interest display a minimal amount of directly affiliated acreage. The highest densities are instead associated with more modest minor centers representing smaller populations, lower elite presence, and less substantial architectural constructions. Some minor settlements appear to have developed the capacity for wetland crop production beyond their immediate means; such surplus may have been redistributed by the larger regional administrative centers (Nohmul and Lamanai) or potentially exported to areas further abroad. Other settlements, such as Kichpanha, lacked substantial wetland field systems or were positioned beyond the presumed influence of other major centers. In these cases, wetland agricultural production could have served only the immediate population, either regularly or during times of severe drought.

The majority of the wetland field distributions calculated for the spheres of influence articulate well with the assumed settlement patterns for the area of interest, indicating that most minor sites reside close to the fields managed without having to navigate difficult terrain (Figure 14). In most instances, field systems beyond 3—4 kilometers would be relegated to another existing settlement. However, the El Pozito sphere (Sphere 4) includes a large amount of wetland crop acreage from Shipyard, a rather minimal residential site on the west side of the New River. The Shipyard acreage derives almost exclusively from the northern portion of the Western Lagoon, from which no riverine or canal access is visible to the site; furthermore, fields situated in this area reside approximately 7.5 kilometers from Shipyard.

If the settlement distribution of Chau Hiix follows a more linear pattern influenced by the western edge of the Northern Lagoon, then the Shipyard acreage may be under the cultivation of populations associated with that site due to ease of access from prehistoric canal routes. In such a scenario, the substantial Shipyard acreage would be placed under the control of Chau Hiix and the Lamanai sphere, with El Pozito potentially managing only meager amounts of wetland agricultural product. The discrepancies between the attributable acreage demonstrates the fallibility of assigning spheres of influence without determining the potential settlement patterning factors associated with each site included.

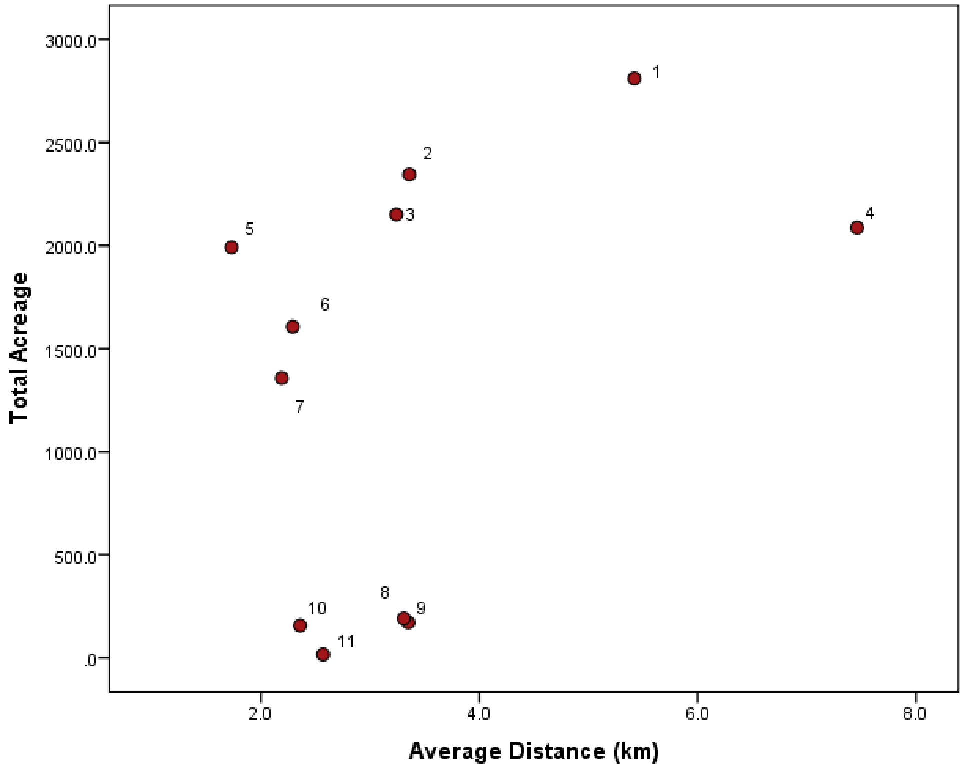

Figure 14. Scatterplot of relationship between total wetland acreage and average distance by sphere of influence (consult Table 9).

Table 9. Field association by sphere of influence.

Field Association by Sphere of Influence (SOI)				
SOI #	**Site**	**Total Acreage**	**Total %**	**Average Distance (km)**
1	**Lamanai**	426.80	2.80	7.22
	Chau Hiix	2383.53	15.65	3.61
	Kakabish	-	-	-
	SOI Totals	**2810.33**	**18.45**	**5.42**
2	**Cuello**	48.09	0.32	7.88
	Lagarto	1670.62	10.97	4.15
	Los Saraguatos	53.20	0.35	2.97
	Rio Hondo	35.80	0.24	1.22
	San Antonio	177.05	1.16	1.49
	Santa Cruz	359.63	2.36	2.44
	Soc. Ganadera	-	-	-
	SOI Totals	**2344.39**	**15.40**	**3.36**
3	**Nohmul**	540.46	3.55	3.59
	Douglas	1610.31	10.58	2.89
	SOI Totals	**2150.77**	**14.13**	**3.24**
4	**El Pozito**	-	-	-
	Guinea Grass	31.77	0.21	7.33
	Shipyard	2055.09	13.50	7.58
	SOI Totals	**2086.86**	**13.71**	**7.46**
5	**San Estevan**	381.31	2.50	2.59
	Chi Ak'al	406.58	2.67	2.18
	Chowacol	384.10	2.52	1.94
	El Solitario	8.51	0.06	3.97
	Hipolito Group	32.18	0.21	0.97
	K'axob	200.09	1.31	1.23
	Kokeal	181.28	1.19	1.09
	Martinez Group	90.84	0.60	1.72
	Pech Titon	133.96	0.88	0.92
	Tibaat	139.30	0.92	1.56
	Yo Tumben	32.93	0.22	0.83
	SOI Totals	**1991.08**	**13.08**	**1.73**
6	**Blue Creek**	39.66	0.26	0.47
	Chan Cahal	1017.38	6.68	2.33
	Gran Cacao	10.38	0.07	1.15
	Great Savannah	176.51	1.16	13.50
	Kin Tan	55.61	0.37	0.40
	Nukuch Muul	80.52	0.53	0.86
	Rempel Group	34.65	0.23	1.34
	Rosita Group	124.13	0.82	2.33
	Sak Lu'um	8.58	0.06	0.55
	Sayap Ha	22.83	0.15	0.39
	U Xulil Beh	5.21	0.03	1.81
	Ya'ab Muul	31.13	0.20	0. 70
	SOI Totals	**1606.59**	**10.56**	**2.29**
7	**Sabidos**	668.49	4.39	2.04
	Corrientes	562.98	3.70	2.56
	Ramonal	125.31	0.82	1.97
	SOI Totals	**1356.78**	**8.91**	**2.19**
8	**Louisville**	190.42	1.25	3.31
	Patchakan	-	-	-
	SOI Totals	**190.42**	**1.25**	**3.31**
9	**Santa Rita**	-	-	-
	Chan Chen	114.55	0.75	4.56
	San Andreas	56.08	0.37	2.13
	Sajomal	-	-	-
	SOI Totals	**170.63**	**1.12**	**3.35**
10	**Cerros**	1.36	0.01	In Site
	Aventura	155.28	1.02	2.36
	Last Resort	-	-	-
	Pueblo Nuevo	-	-	-
	Saltillo	-	-	-
	SOI Totals	**156.64**	**1.03**	**2.36**
11	**Kichpanha**	14.48	0.10	1.10
	Honey Camp	1.52	0.01	4.04
	Laguna de On	-	-	-
	SOI Totals	**16**	**0.11**	**2.57**

CHAPTER 5: WETLAND SYSTEMS AND ENERGETIC COSTS

Introduction

Wetland agriculture represents a substantial commitment to intensive cultivation within a given environment compared to the more extensive strategies of traditional *milpa* farming. Wetland field systems must be channelized prior to use; even the most modest complex would arguably require the excavation of a significant amount of soil in order to decrease the immediate water table level. Canal features necessitate maintenance several times per year to ensure the proper flow of water and balance of nutrients within the system (Wilken 1969: 227). Larger field systems entail a high level of cooperation in the realms of construction and maintenance to ensure the appropriate function. Such collaboration is not normally attributed to slash-and-burn agriculture, which arguably operates in a more informal, flexible manner. The ancient Maya could ostensibly offset initial energetic costs by reduced or non-existent fallow periods associated with wetland fields and the diminished need for canopy clearing, especially in *Eleocharis* and *Cladium* marshlands dominated by low vegetation. Analysis of the relationship between energetic construction costs and estimated agricultural productivity is thus necessary to understand the impetus behind the proliferation of wetland field systems within the area of interest.

Background on Wetland Energetic Models

Erasmus (1965: 284—285) was the first to apply energetic construction models for use in Mesoamerican archaeology. Erasmus conducted field experiments to determine the labor costs for the establishment of monumental architecture at the site of Uxmal in northern Yucatán. Abrams (1994: 5) further refined models of architectural energetics at Copán in terms of labor-time expenditure. Many of the existing monumental structures at major sites across Mesoamerica reflect centuries of earth moving activities, as earlier versions of a given temple or plaza are subsequently blanketed by tons of soil and limestone rubble transported from nearby quarries. Thus, at the most basic level, even the greatest Maya structures can be quantified by the total volume of construction fill utilized for a particular remodeling event.

Although raised and ditched agricultural constructions lack the ornate facing stones and modeled relief of formal Maya architecture, the wetland systems still operate under the same underlying construction principles. The relic field systems illustrate substantial investment in the movement of local subsurface material to lower the ground water level and create an environment conducive to the production of crops. While the grand pyramids of the ancient Maya often overshadow the impressiveness of wetland field systems, the documented extent of such complexes argues for an intense commitment to such infrastructure.

The importance of expanding energetic models to more modest constructions has not been lost on previous researchers. During the 1974 field season, Puleston conducted archaeological experiments along the Rio Hondo, reconstructing a small field platform through the transportation of 86 tons of upland limestone marl from local quarry. The excavated soil covered an area of approximately 620 square meters to a depth of 10—15 centimeters; topsoil from the ditched canals was then heaped upon the marl base (Puleston 1978: 239). The construction effort required 34.5 person-days (p-d) of work and resulted in the establishment of a viable environment for both agriculture and pisciculture. While the upland origin for wetland agricultural soils would later be discounted (Turner 1993; Harrison 1996), the Puleston experiment still illustrated both the investment and return of raised fields on a local level.

Additional modeling was attempted in association with the Pulltrouser Swamp fields based on the calculations of Turner (1983). A 311 hectare (768.5 acre) zone containing the best defined field platforms was documented and surveyed for construction energetic calculations. Analysis by Turner and Harrison (1983: 259) indicated that field systems in the area would take between 833—3833 person-days to construct per hectare (337—1551 p-d/acre); creation of the entire system within the 311 hectare area was estimated to involve between 710—3266 work-years. With a workforce of approximately 32 individual per square kilometer, the Pulltrouser Swamp sample would require nearly 33 years to construct (Turner and Harrison 1983: Table 13-1). The wide range of construction estimates demonstrates the variability in calculations of this kind; the researchers indicate that construction rates can be influenced by the physical environment or economic circumstances (Turner and Harrison 1983: 259). Such factors are difficult to account for in the archaeological record unless additional, finer-grained analyses are performed across a larger area to capture a comparative sample.

Further abroad, Arco and Abrams (2006: 911—914) extended the Copán model to explore the establishment of central Mexican *chinampa* systems of the Chalco-Xochimilco lakebed. The model analyzed both the subsurface trenching and earth moving activities of wetland field construction in terms of person-days required for total construction of the 120 square kilometer system. Spatial attributes associated with the fields (canal/platform depth, width, and platform height above water) were combined with Erasmus' (1965: 285) estimates of daily soil excavation (2.6 cubic meters per person-day); the results indicated that approximately 65,000,000 cubic meters of soil were excavated at the lake, requiring 25,000,000 person-days. When assessed in association with the accessible portion of the population available for *chinampa*-related activities (20—50 percent), the researchers argued for a construction period lasting between 9—79 years (Arco and Abrams 2006: 913). These energetic-modeling investigations indicate that wetland field construction would require significant investment if all systems were established contemporaneously. Once constructed, proper system function would be dependent on further investment in maintenance activities.

Research Methods

Energetic construction models necessitate several attributes to determine soil movement volumes, including canal width/depth, platform length/width, and height above water level. While aerial and satellite imagery provides accurate spatial information for field system dimensions, canal depth and planting platform height cannot be acquired through remotely sensed means. In these instances, previously published estimates in association with the Pulltrouser, Albion Island, Blue Creek, and Bird of Paradise field complexes served as a basis for depth and height information. Although Beach (2015) has produced rare evidence for the construction of raised field parcels with non-local cobblestone material, most of the planting platforms within the area of interest were raised only through the excavation of canal sediments. Thus, construction costs were calculated only on the volume of soil transported from the canal to the neighboring planting platform.

Because of the extensive distribution of wetland field systems within the project area, precise digitization of all planting platforms and canal areas was beyond the scope of this analysis. In order to generate platform-to-canal ratios, a sample of 92 one square acre plots was established in relic field systems across the area of interest with the best aerial visibility and resolution. Field parcels contained within a given sample plot were digitized within ArcMap at the largest viable scale; the planting platforms were then extracted from the sample plot polygon to determine the surface areas of canals and field parcels per acre. The combined average of all sample plots was utilized to infer the overall field-canal ratio across the entire area of interest.

Flood recessional systems, such as those situated north of Chau Hiix, required the implementation of slightly different techniques due to dissimilarities in reticulation patterns when compared to the average drained field complex. As earth moving activities were restricted to the canals running perpendicular to the linear wetland system, polygon buffers representing the average canal width were established for each visible relic ditch. No plot sampling or field-canal ratios were attempted for these areas.

Construction estimates were generated based on the soil excavation data established by Erasmus (1965: 285). The 2.6 m^3/p-d of soil excavation remains viable in lieu of more accurate experimental data produced for the specific area of interest. Wetland soils throughout the project area are unlikely to contain any large rubble inclusions or other materials that would significantly affect Erasmus' original estimates. A workforce of between 20—50 percent of a given maximum average local population was established founded on the previous research of Arco and Abrams (2006: 913); a maximum annual construction period of 100 days was also based on this past study. Workforce estimates were generated based on two factors: percentage of population based on total field acreage and percentage of population attributed to canal acreage.

Results

The study analyzed twelve groups of sample plots to obtain spatial information and field-to-canal ratios. Channelized planting platforms comprised between 60—75 percent of a given wetland field system; available planting surface averaged approximately 67 percent across the entire area of interest (Table 10). These estimates are slightly higher than the 3:2 ratio reported for the Chalco-Xochimilco fields (Arco and Abrams 2006: 911) but articulate well with the average field surface estimates reported for Pulltrouser Swamp (Turner 1983: 46). Field systems with the most available planting surface area were observed along the western banks of the Rio Hondo and near the site of Sabidos on the lower reach of the river. These wetland complexes display regular, well-defined rectangular plots with narrow, minor canals. Field systems located on the east side of the Rio Hondo, east of Nohmul, and the upland interfluvial zone also displayed similar average field percentages. Canal ratios were greatest in association with coastal wetland systems near Corozal Bay and within the three branches of Pulltrouser Swamp. These complexes reflected more widely spaced platforms, especially near the center of the western arm of Pulltrouser Swamp.

Table 10. Wetland agricultural construction estimates for observed field systems.

Wetland Agricultural Construction Estimates					
Sample Plot Group	**Average Field Percentage/Acre**	**Average Canal Percentage/Acre**	**Planting Platforms/Acre**	**Volume of Soil Moved/Acre**	**Person-Days/Acre**
Sabidos	75	25	13	1014.2 m^3	390
Hondo Riparian West	75	25	15	1016.0 m^3	391
Nohmul Swamp	72	28	11	1145.8 m^3	440
Upland	70	30	12	1198.1 m^3	461
Hondo Riparian East	70	30	18	1227.2 m^3	472
New River Riparian	68	32	16	1277.3 m^3	491
Albion Island	65	35	13	1398.5 m^3	537
Douglas Swamp	65	35	19	1434.3 m^3	552
Aventura	64	36	15	1450.8 m^3	558
Freshwater Creek	63	37	21	1477.1 m^3	568
Coastal	60	40	12	1622.2 m^3	624
Pulltrouser	59	41	10	1659.0 m^3	638
Average	67	32	15	1280.0 m^3	510

Volumetric calculations were generated based on canal depths established through archaeological excavations at the Pulltrouser Swamp, Albion Island, and Blue Creek complexes. Turner (1983: Table 4-1) reports average depths of approximately one meter; wetland fields at San Antonio (Pohl et al. 1990: 209) and Chan Cahal (Luzzadder-Beach et al. 2012: 3649) produced similar measurements. Soil excavation estimates were thus derived based on the amount of canal sediments channeled to a depth of one meter. Calculations indicate the ancient Maya excavated between 1000—1660 cubic meters of wetland soils from each acre during the construction of the relic field systems, requiring an average of 510 person-days. Such estimates fall within the 337—1551 person-days per acre identified by researchers at Pulltrouser Swamp (Turner and Harrison 1983: 259). Creation of a single planting platform would demand approximately 34 person-days, articulating well with previous findings noted by Puleston (1978).

Because construction volumes differ between ditched and flood recessional fields, acreage associated with the Western Lagoon complexes was removed before attempting energetic calculations. Based on the average volume of material excavated during field creation, construction estimates can be obtained for the total extent of wetland field systems within the area of interest. Utilizing canal volume estimates of 32 percent of the complete acreage, the entire northern Belize wetland field system required the excavation of 13,850,263 cubic meters of wetland soils. At an excavation rate of 2.6 cubic meters per day, the fields mandated 5,327,024 person-days of effort.

Determining the percentage of the population responsible for the construction of the ancient Maya field systems can be difficult. Within a given group, a certain percentage of the population would be excluded from the presumed workforce due to age, health, gender, or social status. Non-agricultural specialists or those involved in the management of upland field systems would also be removed from the workforce pool. Turner and Harrison (1983: Table 13-1) established a workforce of between 100—1000 individuals for field construction within the 311-hectare wetland zone of Pulltrouser Swamp; this suggests an agricultural workforce density of 32 to 322 persons per square kilometer. Based on maximum population estimates advanced for the southern Yucatán (100 persons/km^2), the lower end of the Pulltrouser Swamp workforce represents about a third of the total population (Turner et al. 2003: 363). The higher end of the Pulltrouser workforce would exceed all but the highest population estimates established for the area (Houk and Lohse 2013: 29), often associated with the larger urban centers. With the uppermost densities in northwestern Belize cited at 510 persons per square kilometer, a workforce of 322 individuals would exceed sixty percent of the total local population. Because many of these estimates indicate maximum Late Classic populations, the available workforce is likely to cluster around the lower examples given by Turner and Harrison.

If the lower, more realistic estimates are advanced for purposes of field construction, a picture of the investment required begins to emerge. With the workforce population of 32 individuals per square kilometer spread across the entire expanse of wetland field systems within the project area, a maximum labor force of 448 people was available for construction purposes based on canal acreage excavated. At this level, a workforce could excavate approximately 1165 cubic meters of soil per day, resulting in 11,891 person-days of effort. Each excavator involved in the project would oversee 24.2 acres of wetland field systems if parcels were allocated proportionally. Based on a 100 day work year, field systems could have been constructed in 118.9 years. More modest ranges (30—60 workdays per year) devoted to wetland field construction would result in between 198—396 years for the establishment of all systems.

Workforce calculations associated with ditched field systems within the area of interest can also be constructed based on the total field acreage (4872.5 acres). When workforce estimates are multiplied by the 13.85 square kilometers of detected ditched fields, the number of individuals available for construction tasks increases from 448 to 1401 persons. When divided equally amongst the complete working population, a total construction quota of 7.7 acres of wetland field complexes would be required from each laborer. Construction tasks could be completed in roughly 3,802 shared work-days; at a maximum annual construction schedule of 100 days, roughly 38.1 years would be required for each individual to complete their share of the field systems. With 60 days per year attributed to wetland field construction, estimates exceed 63 total years for complete creation. A modest investment of only 30 days per year devoted to canal excavation pushes construction estimates past 126 years. Clearly, the Maya directed much time and effort in the creation of large networks of ditched field systems (Tables 11 and 12). The work required several generations of determined individuals to transform the wetland landscapes into viable, productive agricultural features.

Table 11. Construction estimates for wetland field systems within area of interest.

Temporal Costs of Wetland Field Construction				
Workforce Designation	**Acres/Person**	**30 Days/Year**	**60 Days/Year**	**100 Days/Year**
Canal Coverage (20 km^2)	24.2	396.4 years	198.2 years	118.9 years
Total Fields (62 km^2)	7.7	126.7 years	63.4 years	38.1 years

Table 12. Volumetric, energetic, and work-population estimates by site.

Site Name	Total Acreage	Canal Acreage	Soil Moved (m^3)	Person-Days Required	Available Population (Total Acreage)	Available Population (Canal Acreage)
Lagarto	1670.6	534.6	684286.0	263186.9	216	69
Douglas	1610.3	515.3	659583.0	253685.8	209	67
Chan Cahal	1017.4	325.6	416718.8	160276.5	132	42
Sabidos	668.5	213.9	273813.5	105312.9	87	28
Corrientes	563.0	180.2	230596.6	88691.0	73	23
Nohmul	540.5	173.0	221372.4	85143.2	70	22
Lamanai	426.8	136.6	174817.3	67237.4	55	18
Chi Ak'al	406.6	130.1	166535.2	64052.0	50	17
Chowacol	384.1	122.9	157327.4	60510.5	49	16
San Estevan	381.3	122.0	156184.6	60071.0	47	16
Santa Cruz	359.6	115.1	147304.4	56655.6	26	15
K'axob	200.1	64.1	81956.9	31521.9	25	8
Louisville	190.4	60.9	77996.0	29998.5	25	8
Ucum	189.9	60.8	77774.8	29913.4	23	8
Kokeal	181.3	58.0	74252.3	28558.6	23	8
San Antonio	177.1	56.7	72519.7	27892.2	20	7
Great Savannah	176.5	56.5	72298.5	27807.1	18	7
Aventura	155.3	49.7	63602.7	24462.6	17	6
Tibaat	139.3	44.6	57057.3	21945.1	16	6
Pech Titon	134.0	42.9	54870.0	21103.9	16	6
Ramonal I	125.3	40.1	51327.0	19741.1	15	5
Rosita Group	124.1	39.7	50843.6	19555.2	15	5
Caledonia	116.9	37.4	47898.6	18422.5	12	5
Chan Chen	114.6	36.7	46919.7	18046.0	10	5
Martinez Group	90.8	29.1	37208.1	14310.8	7	4
Nukuch Muul	80.5	25.8	32981.0	12685.0	7	3
San Andreas	56.1	18.0	22970.4	8834.8	7	2
Kin Tan	55.6	17.8	22777.9	8760.7	6	2

Site Name	Total Acreage	Canal Acreage	Soil Moved (m^3)	Person-Days Required	Available Population (Total Acreage)	Available Population (Canal Acreage)
Los Saraguatos	53.2	17.0	21790.7	8381.0	5	2
Cuello	48.1	15.4	19697.7	7576.0	5	2
Blue Creek	39.7	12.7	16244.7	6248.0	4	2
Rio Hondo	35.8	11.5	14663.7	5639.9	4	1
Rempel Group	34.7	11.1	14192.6	5458.7	4	1
Yo Tumben	32.9	10.5	13488.1	5187.7	4	1
Hipolito Group	32.2	10.3	13180.9	5069.6	4	1
Guinea Grass	31.8	10.2	13013.0	5005.0	3	1
Ya'ab Muul	31.1	10.0	12750.8	4904.2	2	1
Sayap Ha	22.8	7.3	9351.2	3596.6	2	1
Lg. de los Milagros	16.4	5.2	6697.0	2575.8	2	1
Kichpanha	14.5	4.6	5931.0	2281.2	1	1
Colha	12.8	4.1	5242.9	2016.5	1	1
Gran Cacao	10.4	3.3	4251.6	1635.2	1	<1
Progresso	10.2	3.3	4194.3	1613.2	1	<1
Sak Lu'um	8.6	2.7	3514.4	1351.7	1	<1
El Solitario	8.5	2.7	3485.7	1340.7	1	<1
U Xulil Beh	5.2	1.7	2134.0	820.8	1	<1
Honey Camp	1.5	0.5	622.6	239.5	<1	<1
Cerros	1.4	0.4	557.1	214.3	<1	<1

When considering the energetics involved in the creation of flood recessional field systems, such as those associated with Chau Hiix along the Western Lagoon, additional calculations are necessary. Instead of constructing a reticulate pattern of channelized fields, a series of berms were implemented to control the flow of surface water across the wetland. This system of wetland agriculture resulted in wider, deeper canals crossing the low-lying area perpendicular to its length. Pyburn (2003: 124) estimates these canal features to measure approximately five meters wide and 2—3 meters in depth. For the sake of simplicity, an average depth of 2.5 meters was attributed to the Chau Hiix wetland features.

A total of 81.2 acres of flood recessional ditches were identified within the Western Lagoon, supporting 4406.2 acres of potential agricultural wetlands. Coverage suggests that flood recessional canals comprise less than two percent of the total available wetland system. Although the ditched features within the system spread along the lagoon, the volume of soil excavated in association with the ditches averaged 10,114 cubic meters per acre, much higher than those values associated for regular channelized field construction. Construction of the complete system required the excavation of approximately 821,229 cubic meters of soil, mandating 315,857 person-days (865 person-years) of effort. The combined spatial extent of the recessional canal features represents coverage of approximately one-third of a square kilometer. Scaled proportionally, a workforce of only eleven individuals would be available for construction activities. Based on the person-days allocated for field construction, the Western Lagoon system would require between 287 and 957 years to fully establish.

The proportional workforce attributed to the Western Lagoon flood recessional system appears noticeably low for the amount of acreage transformed into arable land. Unlike the more discrete, gridded wetland systems, the Western Lagoon complex represents a more linear distribution stretched over approximately eight kilometers. The distance between individual flood recessional canals suggests an available workforce larger than eleven persons. A base workforce of 32 individuals would dramatically lower construction time, ranging between 98 and 329 years. If workforce is estimated based on total acreage (4406.2 acres), a workforce of 571 individuals would have been available for construction activities. Based on the previously cited soil excavation rates, the Western Lagoon systems would have required approximately 5.5 years to complete at a rate of 100 work days per year. Even at the relaxed rate of 30 work days per year, the canals represent less than 20 years of total energetic investment among the local population.

Discussion

Energetic calculations indicate that although such wetland fields are extensive throughout the area of interest, the Maya possessed the ability to construct the systems in several decades with a workforce comprised solely of members of the local population. This observation should not detract from the overall impressiveness of the sheer volume of soil moved in association with the channelized complexes; these constructions are on par with the effort involved in the erection of formal monumental architecture throughout the Maya Lowlands and were a necessary form of infrastructure that allowed populations to thrive in the tropical environment. However, the presumed involvement of elite management regarding the planning and oversite of wetland field construction is not warranted. While the fields may have been established to produce agricultural surplus for local and regional export, the construction and management capabilities were well within the range of the common population. Regional centers surrounding wetland systems possibly represent the direct consumers of any agricultural surplus, yet the control of this system was not likely direct or coercive (Masson 2004: 101). If the development of a given field system is viewed as an accretionary response to population growth, these complexes may have been constructed over several generations with relative ease.

Both types of wetland field systems present within the area of interest—channelized and flood recessional—involved the excavation of massive amounts of soils to lower the immediate water table or affect the rate of water flow. Energetic analyses suggest that flood recessional systems transformed more wetland area per acre for the production of agricultural crops; however, flood recessional systems are only viable in certain regions of the project area, such as sawgrass lagoons and the lower reaches of the Hondo and New Rivers. Flood recessional systems would not be practical during the rainy season for crop production, when certain other channelized systems in closed system swamps may remain active. Finally, recessional systems lack the hydrological control attributed to the more compact, gridded field complexes and pose a higher risk of crop failure due to flooding or drought.

A labor population of 32 individuals per kilometer appears ineffective in regard to the entire complex of formal systems within the area of interest. However, on a more local scale, the above workforce could transform an acre of swamp into arable farmland in approximately fifteen days. Within a span of 100 days, communities could establish close to seven acres of wetland field systems. Given the established work rate, a square kilometer of fields would take nearly forty years to construct. Both the labor pool and rate suggest that the impact and establishment of the wetland systems would have been felt initially at the local level, with incremental growth over several decades to accommodate either population expansion or commercial production.

The available workforce in the area of interest may have arguably exceeding the estimates utilized for this chapter. Pyburn and colleagues (1998: 49) note high structural densities on Albion Island during the Early Classic Period; if dense populations on the island where involved predominantly with wetland agricultural production, a higher labor pool might have been involved with fields in this area. Management of a larger field area was likely facilitated by riverine transportation. No matter what impetus drove the Maya to construct these massive field systems, the work required extensive transformation of wetland landscapes over a significant time span. The following chapter will explore possible motivations for such wide scale investment in terms of agricultural productivity and the generation of potential surplus.

CHAPTER 6: MODELING WETLAND AGRICULTURAL PRODUCTIVITY

Introduction

The ancient Maya managed the environment in order to incorporate diverse agricultural strategies. The impacts of extensive *milpa* farming required a varied strategy to prevent landscape degradation. Environmental evidence derived from soil and pollen analyses suggests that widespread deforestation during both the Late Preclassic and Late Classic Periods exacerbated soil erosion in many densely settled regions of the Maya Lowlands, limiting crop productivity and decimating the extent of viable upland agricultural areas (Beach et al. 2006: 175; Rushton et al. 2012: 485). Intensive methods, such as terracing and wetland field systems, prevented soil loss while expanding agriculture into new topographic and environmental locales (Beach et al. 2002: 372). Generating wetland agricultural productivity models must take into account the origin and purpose of such systems in relation to the dynamic populations who constructed them. If wetland complexes were constructed due to population pressure or environmental stresses, one would expect to model crop productivity based on the mosaic of crops generally planted together in a normal *milpa* field. Alternatively, if the microenvironments of wetlands were targeted to raise a particular commodity for economic export, monocropping would become a more viable basis for the establishment of productivity models. The following chapter will explore the motivations behind wetland agriculture, the foundation of productivity models, and the most feasible crops suited for wetland agriculture.

Subsistence and Commercial Crops of the Maya

Researchers have experienced difficulty in determining prehistoric crop production in association with raised and channelized fields. Miksicek (1983: 103) indicates that neither pollen data nor plant macrofossil data are adequately sufficient to define wetland target crops, as material can often be incorporated into planting platforms from adjacent locations. However, these data still provide the best evidence for the crops within or adjacent to wetland environments. A number of diverse agricultural floral remains have been recovered from archaeological contexts in association with wetland field systems in Mesoamerica. These include maize, manioc, beans, squash, and cotton; economic arboreal species such as sapodilla and avocado were also present in excavated material. Cropping of important tree species, including cacao, has been advanced by Pring and Hammond (1985: 766) for the wetland complexes surrounding Nohmul; however, macrobotanical or pollen evidence has not been conclusively obtained for any wetland field system within the project area.

Although the exact ratios of crops produced within wetland field systems are unknown, maize appears as the chief cultivar amongst prehistoric Mesoamerican populations. Stable isotope analysis at the site of Tikal reflected a local diet of approximately 50 percent maize (Balzotti et al. 2013: 5869). Among modern Maya populations in Yucatán, maize comprises approximately 75 percent of total crop acreage (Alexander 2006: 454). Yet ancient evidence for maize monocropping has been difficult to produce; taxation of soil nutrients and increased pest problems have typically arrested large-scale monocropping in prehistoric societies (Netting 1993: 33). The ancient Maya likely combated these issues through the practice of intercropping of multiple agricultural and economic species within a given plot (Turner et al. 2003: 374). Pohl and colleagues (1990: 207) argue for the prevalence of maize monoculture at Albion Island based on the predominance of macrobotanical remains recovered from field excavations. Turner and Harrison (1983: 258) tentatively advanced the crop as the main cultivar at Pulltrouser

Swamp. Monocropping of maize within these field systems may have been viable due to their distinctive soil and water management strategies.

Soil quality articulates intimately with the types of crops selected for cultivation (Pyburn 1998: 274); nutrient load, drainage, and physical properties are all relative to the particular species grown. Wetland agricultural fields were favored for their ability to create highly fertile microenvironments for a variety of subsistence and economic crop species. Olson (1977: 26) identified elevated amounts of phosphorus, potassium, and organic matter within the channel bottom sediments at San Antonio, making the material ideal for a natural fertilizer. Algae and macrophytes, such as water lily (*Nymphae* sp.), thrive within the wetland systems. Inclusion of these materials within the soil matrix would additionally fix nitrogen and phosphorus values (Renard et al. 2012: 36). Researchers previously documented evidence for the use of periphyton obtained from wetland environments in association with Prehispanic agricultural fields in the Yalahau region of northeast Quintana Roo (Fedick and Morrison 2004: 213). Waste produced by fish within the canals may have also dramatically increased the fertility levels of the planting platforms (Puleston 1977: 455). Baillie and colleagues (1993: 7) classified riverine alluvial soils, such as those associated with the Hondo and New Rivers, as some of the most fertile soils in Belize. Taken together, the unique attributes of wetland agricultural systems heightened the carrying capacity in these areas while allowing for near continuous cultivation of ditched field plots.

Background on Agricultural Productivity Models

Previous ethnographic research in the Central Petén region of Guatemala by Cowgill (1962: 276—277) demonstrated that traditional swidden techniques produced an average annual maize crop of between 408—646 kilograms (kg) of seed before experiencing declines in successive years due to loss of soil nutrients. Initially, Cowgill (1960: 1010) estimated that a single individual required 288 kg of maize annually; this was later revised to 524 kg per year due to the discrepancy between cob and shelled maize. Swidden production was projected to support 39—77 persons per square kilometer across the region (Cowgill 1962: 277).

Estimates of agricultural productivity within wetland field systems require additional calculations due to the limited or non-existent fallow periods associated with the channelized complexes. Experimental research conducted at the Llanos de Mojos systems in Bolivia (Erickson 1995: 92; 2006: 253) produced crop estimates of 907 kg of maize and 22,680 kg of manioc per hectare. Research in the Basin of Mexico by Sanders (1976: 147) concluded that *chinampa* cultivation could have generated approximately 3,000 kg of maize per hectare based on a single annual harvest, capable of supporting 19 individuals per hectare. Niederberger Betton (1987) argued that approximately 100,000 people may have been supported through the cultivation of 9000 hectares of prehistoric *chinampa* fields, or roughly 11 persons per hectare. Although data for these estimates were produced in environments variable from those documented in the area of interest, the information demonstrates that maize productivity within wetland field systems was substantially higher than those documented for traditional upland agriculture.

Additionally, many of the wetland systems situated within Mesoamerica and Central Mexico were capable of multiple annual crops, significantly increasing agricultural return per unit area compared to *milpa* cultivation. Contemporary drained field systems in Tlaxcala support three crops per year, divided between maize and other root crop species (Wilken 1969: 233). Regarding *chinampa* fields, Coe (1964: 52) noted the practice of sowing up to seven annual crops in certain field systems without allowing the use of fallow. Turner and Harrison (1983:

260) speculated that the Pulltrouser Swamp complex could produce two crops per year, with the second annual harvest declining to approximately one-half of the first. The possibility of multiple annual crops was also advanced for the flood recessional systems associated with Chau Hiix (Pyburn 2003: 127).

The practice of multiple annual harvests in association with wetland agricultural field systems should be approached with caution, as flood waters rendered some complexes inactive during portions of the rainy season. Research by Pohl and colleagues (1990: 208) indicates that field complexes situated along the flood banks of Albion Island were inundated at certain times of the year, making wetland agriculture impossible. Instead, the ancient Maya of Albion Island likely practiced year-round cultivation shifting between wetland fields in the dry season and upland fields in the wet season. Wetland field systems limited to a single annual crop are estimated to be situated in the expansive floodplain areas of the Rio Hondo; those complexes located in closed systems swamps or along the river systems further to the east would experience less substantial water level fluctuations, providing the capability to support multiple crops per year.

Research Methods

With these calculations in mind, it becomes possible to estimate maximum crop yields from the wetland field systems in relation to the overall agricultural landscape. Projected maximum yields and carrying capacity were generated for the wetland fields based on both single and dual season agricultural strategies; those systems located along the Rio Hondo were capped at one crop per year, while the remainder of the complexes were calculated for a multiple annual usage pattern. These estimates assume maximum utilization and cultivation of a single maize species with yields comparable to modern varieties. Nutrient decline and fallow periods were not considered due to the increased productive capabilities associated with wetland agricultural methods. Monocropped maize estimates were calculated based on three scenarios derived from previous research; yields per hectare were generated from ethnographic analogies provided by Sanders (1976), Cowgill (1960, 1962), and Erickson (1995, 2006).

Results

Annual maize production estimates varied greatly based on the formulas previously attached to prehistoric wetland agriculture. Calculations associated with the central Mexican *chinampa* systems produced the highest yields, with annual production ranging between 14,052,540—24,148,290 kg of seed. The amount grown within a single year would support a population of 51,525—152,940 individuals across the entire system; each square kilometer of a wetland field possessed a sustaining value of 1,100—3,800 persons (Table 13). Such estimates would be far beyond the local consumption needs, arguing for the creation of substantial agricultural surplus for export or redistribution. Alternatively, these data may indicate that population estimates are underrepresented in the area of interest.

Table 13. Annual maize production estimates (3000 kg/ha).

Annual Maize Production Estimates (3000 kg/ha)				
Field Classification	**Planting Area (ha)**	**Pop. (Sanders 1976)**	**Pop. (N. Betton 1987)**	**Pop. (Cowgill 1960)**
Rio Hondo Inundation Risk	1,318.93	25,060	14,508	7,551
Interfluvial/Flood Stabilized	1,614.94	30,684—61,368	17,764—35,529	9,246—18,492
Flood Recessional	1,750.31	33,256—66,512	19,253—38,507	10,021—20,042
Totals	4,684.18	89,000—152,940	51,525—88,544	26,818—46,085

Secondary estimates were run utilizing the annual crop production estimates observed by Cowgill (1962: 276) among modern Petén farmers for their initial, most productive harvest before nutrient loss (1,596 kg/ha). At this presumed level of crop production, annual yields fall between 7,475,951—10,741,878 kg of seed (Table 14). The total population supported across the entire functioning wetland system at maximum usage ranged between 14,267—81,310 individuals. Based on the functioning estimates, each complex would be able to carry approximately 305—1,736 people per square kilometer of modified wetland.

Table 14. Annual maize production estimates (1596 kg/ha).

Annual Maize Production Estimates (1596 kg/ha)						
Field Classification	**Planting Area (Ha)**	**Single Annual Crop (Kg)**	**Double Annual Crop (Kg)**	**Pop. (Sanders 1976)**	**Pop. (N. Betton 1987)**	**Pop. (Cowgill 1960)**
Rio Hondo Inundation Risk	1,318.93	2,105,012	-	13,323	7,711	4,017
Interfluvial/Flood Stabilized	1,614.94	2,577,444	5,154,888	16,313—32,626	9,441—18,882	4,919—9,838
Flood Recessional	1,750.31	2,793,495	5,586,990	17,680—35,361	10,233—20,465	5,331—10,662
Totals	4,684.18	7,475,951	10,741,878	47,316—81,310	27,385—47,058	14,267—24,518

Final estimates were generated utilizing Erickson's (2006: 253) calculations for experimental field systems located in the Llanos de Mojos region of Bolivia. Erickson's experimental yields are approximately thirty percent of the production established for *chinampa* systems and even fall below the crop yields observed by Cowgill for modern Petén upland agriculture (1962: 277). Crop estimates are further limited in this scenario, with the maximum production falling well below the minimum assessment calculated above. At full usage, the wetland fields in the area of interest would support between 3,030—20,095 individuals, or 173—986 persons per square kilometer of actively cultivated wetlands (Table 15).

Table 15. Annual maize production estimates (907 kg/ha).

Annual Maize Production Estimates (907 kg/ha)						
Field Classification	**Planting Area (Ha)**	**Single Annual Crop (Kg)**	**Double Annual Crop (Kg)**	**Pop. (Sanders 1976)**	**Pop. (N. Betton 1987)**	**Pop. (Cowgill 1960)**
Rio Hondo Inundation Risk	1,318.93	1,196,270	-	7,571	4,382	2,283
Interfluvial/Flood Stabilized	1,614.94	1,464,751	2,929,501	9,271—18,541	5,365—10,731	2,795—5,591
Flood Recessional	1,750.31	1,587,531	3,175,062	10,048—20,095	5,815—11,630	3,030—6,059
Totals	4,684.18	4,248,552	6,104,563	26,890—46,207	15,562—26,743	8,108—13,933

Discussion

Annual crop production estimates illustrate the productivity and potential surplus capabilities of wetland agricultural systems within the project area. Generation of primary crop production estimates assumed complete usage through space and time. Although previous research indicates that certain systems may have been utilized in an accretional manner or abandoned before the construction of others, these productivity data indicate the ability for production beyond the immediate need in both a local and regional context. The wetland field systems show how initial investment can be returned in the form of agricultural surplus, due to the capacity to yield multiple crops per year and limit fallow periods. When combined with the more extensive upland agriculture also practiced in the area during prehistoric times, the expansive wetland systems likely provided surplus for distribution to regional population centers and perhaps other, more marginal areas of the Maya Lowlands.

The discrepancies between Erickson's estimates and those obtained for other wetland field systems may relate to the experimental nature of the research. Puleston's own experiments at Pulltrouser Swamp (1977: 457) were largely inconclusive; modern raised or channelized fields may be constructed in areas where substantial changes have occurred since prehistoric abandonment. Within the project area, the most likely culprit relates to gypsum accumulation, which is commonly found in historic irrigation systems following prolonged use. Alternatively, raised field agriculture within the Llanos de Mojos region of Bolivia may have been better suited for the cultivation of manioc at the expense of maize production; manioc was reported to have thrived exceedingly well within the reconstructed systems. Results from the productivity analyses performed within the area of interest indicate that modern archaeological experiments may be restricted by local environmental, ecological, pedological, and geomorphological factors. While such experiments are arguably useful, the reconstructed estimates can only provide a palimpsest of the true agricultural output of ancient Maya wetland field systems.

CHAPTER 7: CONCLUSIONS AND AVENUES OF FUTURE RESEARCH

Discussion

Wetland agricultural systems clearly played an important role in the development and support of the Maya in northern Belize during the Late Preclassic Period and again in the Late/Terminal Classic. The spatial extent, uniformity, and wide-spread adoption of the intensive farming techniques speak of the success of the system during an influential era in the rise of the Maya civilization. Later field usage during the Classic Period demonstrates the longevity and resilience of wetland agricultural techniques in this region of the Maya Lowlands. However, the degree of impact within the local political sphere requires further discussion, specifically concerning the level of wetland utilization and the translation of agricultural surplus into physical and ceremonial wealth.

Previous researchers, such as Hammond (1985) and Pohl and Bloom (1996), have argued that intensive agriculture associated with the wetland systems allowed the growth of elite individuals at sites such as Cuello and Nohmul. This social distinction was achieved through organizing labor, generating surplus, and creating sedentary investment in a particular locale. While the wetland systems allowed for greater carrying capacity and population growth, the researchers suggested that it also required additional labor in terms of management and construction. If such a scenario did occur in the region during the Late Preclassic, one would expect the spatial distribution to reflect this organizational model.

GIS analysis of the area of interest confirmed that these particular fields were restricted to a specific, targeted environment. The general lack of field systems within the first few kilometers of the Caribbean coast suggests that the elevated and potentially saline water table would inhibit crop growth. Populations settled within this coastal buffer zone were perhaps more likely to exploit the plentiful marine and lagoonal resources instead of participating in wide-scale agricultural production.

The spatial distribution of the wetland field systems along navigable waterways argues for the utilization of watercraft to transport agricultural surplus in bulk along these trade routes. In addition to visible remnant fields situated directly along the banks of major drainages, prehistoric Maya canals were observed in aerial and satellite imagery linking closed wetland systems with the Rio Hondo. Other canal systems have been previously reported connecting Pulltrouser Swamp and the Western Lagoon with the New River (Turner and Harrison 1983: 247; Pyburn 2003: 123). These systems demonstrate the importance of access to riverine routes and arguably increased the sphere of agricultural influence compared to other upland-based Maya settlements outside the range of these major drainages. These important riverine trade routes provided transportation of crop surplus west into the Petén interior, east to the Caribbean coast, and south to the lower Belize River.

The spatial distributions of the fields substantiate the influence of sites such as Nohmul, San Estevan, Blue Creek, Chau Hiix, and greater Albion Island. Each of these settlements existed in close proximity to considerable expanses of riverine and swampland field systems. Such juxtaposition may explain the incredibly high population densities proposed for Albion Island, on par with major sites such as Tikal and Calakmul (Pyburn et al. 1998: 49). However, the manner in which high agricultural surplus translated into material wealth on the island remains unknown, as the formal architecture presently excavated is quite modest compared to other sites in the Maya Lowlands. If the strategy of Albion Island was to maximize productive wetland environments to generate agricultural surplus primarily for export, this may explain the relatively underwhelming characteristics of its largest centers.

First-tier centers within a given sphere of influence often possessed the least amount of wetland field acreage. Smaller settlements, at some distance from the nearest major site, instead managed a majority of the agricultural acreage. These more minor centers and settlements, such as San Estevan and K'axob, were initially established adjacent to swampland and riverine environments to take advantage of the diverse aquatic and floral resources that these areas provided (McAnany and Peterson 2004: 280). Primary centers—excluding Lamanai and Cerros—were alternatively attracted to higher upland settings where ceremonial architecture was prominently visible.

Lamanai represents one of the few primary centers in the area of interest positioned adjacent to wetland environments along the New River Lagoon. The lagoonal environment provided the population of Lamanai with adequate aquatic resources but also represented the termination of the riverine route between the site and Cerros. Although approximately 426 acres of wetland agricultural fields were attributed to Lamanai, no clear connection exists between these fields and the direct management or oversight of the systems by the site's elites. The most substantial field complexes within the Lamanai sphere of influence were associated with flood recessional systems within the Western Lagoon to the northeast.

Concerns over coverage and visibility regarding wetland field systems along the upper reaches of the New River continue to remain unclear. Analyses of aerial and satellite data demonstrated that fields in this area were incredibly difficult to detect as the lack of sedge-dominated flood plains bordering the drainage encourages thick *escoba* growth along the river banks. Identification of field systems associated with Lamanai proved possible only because the land had recently been cleared for modern agricultural purposes. Other systems likely exist in this area but are obscured by dense vegetation.

Construction energetics modeling illustrated that the wetland systems within the area of interest required a significant investment to establish. The sheer amount of soil excavated during the creation of a single field complex speaks to the quantity of labor needed. The scope of the work, however, appears within the range of a given settlement without necessitating elite management or specialized workforce groups. Considering the presumed longevity of the wetland systems in the area, a more modest, accretional model for field construction by the hands of the immediate population would easily account for the total spatial extent of the complexes visible today. However, if some regional authority managed the planning and execution of large wetland field systems, the cited workforce (32 individuals per km^2) would likely prove inadequate for construction purposes. Although a higher population may have been directed towards wetland field construction, no definite evidence of a specialized labor force currently exists.

Wetland systems arguably required more initial investment to adequately function when compared to the extensive methods of *milpa* agriculture. While *milpa* agriculture mandates the felling of trees and other lower vegetation, no other labor is needed prior to planting. Such slash-and-burn fields, however, are only viable for several years before the area must be abandoned and the process repeated again. Wetland systems, in contrast, are firmly established following construction and can allow for multiple annual crops without obligatory fallow periods. Proper maintenance of wetland field complexes throughout the years would offset initial construction investment by circumventing felling activities associated with shifting fallow requirements. Additionally, the wetland systems provided access to aquatic resources, such as turtle and fish, which would not be available in an upland setting.

Analyses of wetland crop productivity indicate that the relic complexes were capable of generating a large amount of agricultural surplus. Certain fields, such as those positioned along the lower reaches of the Rio Hondo, were likely fully submerged during portions of the wet season and thus limited to a single annual crop. When the entire acreage is combined, however, the resulting yields show agricultural production exceeding the dietary requirements of the immediate population (173—3,800 persons/km^2) if current estimates are accepted without major reservation. The crop abundance indicates distribution of additional maize or other cultivars beyond the settlements managing the complexes, either to other neighboring communities, regional primary centers, or further abroad to the Petén or north into the Yucatán Peninsula.

Problems Encountered during Research

Although high resolution aerial and satellite imagery provides a detailed overview of relic wetland fields within the project area, complete detection of the ancient agricultural systems lies beyond the grasp of this technology. Such imagery cannot properly account for areas obscured by tall, broadleaf forest or covered by post-abandonment sediments. The marl flats of the lower reach of the Rio Hondo retain potentially buried field segments outside detection by aerial means. Morehart (2012: 2541) reports that a layer of aeolian soil concealed fields in the Xaltocan region of Central Mexico, preserving no topographic relief of the agricultural systems. Detection of these features was only possible through Normalized Difference Vegetation Index (NDVI) techniques applied to multispectral imagery. Even in more static regions not influenced by alluvial sediment load or aeolian factors, canals trap soils over time when not properly maintained. Beach and colleagues (2009: 1716) calculated a canal filling rate at the Chan Cahal fields of 0.65 meters per 1,000 years.

Historic and modern disturbances are two other major factors that influence the detection of relic field systems throughout the area of interest. Darsh (1983: 29) reports hardwood logging activities in association with low-lying depressions throughout the project area for the past 300 years. Half a century of contemporary agricultural and cattle ranching practices has resulted in the transformation of both upland and wetland environments. Guderjan (2007: 64) describes areas of potential wetland fields that have been disturbed by such activities around Blue Creek, creating difficulty in terms of accurate detection. GIS analyses during the course of thesis research produced similar regions of impacted field systems near the modern settlements of San Victor and Ranchito in the Corozal District of Belize. While modern agricultural operations have not reclaimed the majority of existing arable wetlands, the integrity of some Maya field complexes has been negatively impacted throughout the project area.

Avenues of Future Research

The remotely sensed imagery utilized for this research provides a viable starting point for the synthesis of local and regional trends in ancient Maya wetland use over time. The complete spatial extent and site-field system associations demonstrate multiple developments and motivations for wetland agriculture across the project area. The total distribution, however, remains tentative due to the quality and capability of the imagery. Regional analysis of the same area through high-resolution multispectral imagery would prove useful in a variety of situations. Manipulation of band combinations highlights differences between healthy and stressed vegetation or indicate changes in soil consistency and moisture retention. Such techniques offer the ability to provide information on the existing hydrology of ancient field systems or designate potential areas of disturbed wetland systems. Lidar-derived data would furthermore clarify the extent, morphology, and hydrology of field systems in the project area. A bare-earth surface model might be particularly useful for lands east of the New River, where broadleaf and *escoba* vegetation have a higher potential to obscure additional wetland field systems. While the funds required for lidar acquisition within such a large area remain cost prohibitive, even a small sample obtained in a documented sector of well-developed field systems would produce useful data.

The previous four decades of research into wetland associated sites provide great insight into the function and integration of intensive agriculture throughout the eastern Maya lowlands. Based on the full extent of wetland agricultural systems throughout the area of interest, a number of additional features are primed for further ground truthing and excavation. The most pertinent of these features relate to the extensive network of ditched fields surrounding the sites of Sabidos and Ramonal on the Mexican side of the Rio Hondo. The high density of fields in this area suggests substantial investment in agricultural production beyond the means of the local population. The field systems associated with the two sites are positioned on the lower reaches of the river and would have experienced similar environmental changes as those attributed to Albion Island. A temporally restricted usage pattern centered around the Late Preclassic Period would help to solidify Pohl and colleague's claim that sea level rise influenced the demise of wetland agriculture along a significant portion of the Rio Hondo by the beginning of the Early Classic. Analysis of less extensive field complexes—such as those attributed to Aventura and Kichpanha—would also represent a worthwhile investment. The association of these fields with surplus crop production is less apparent compared to the widespread wetland complexes of Blue Creek, Albion Island, or Pulltrouser Swamp. Research into these systems could help determine whether limited wetland agriculture was utilized for general subsistence needs, specialized or commercial crop production, or as mitigation against prolonged drought conditions on a local level. Through the documentation of field usage across a wide range of spatial, environmental, and temporal settings, a more refined understanding of Maya wetland agriculture can be produced.

Conclusion

Maya wetland agriculture was well established along the Hondo and New Rivers by the Late Preclassic Period and enjoyed continued utilization into the Terminal Classic. The exploited areas, considered marginal by contemporary agrarian standards, demonstrated the Mayas' resilience within a dynamic tropical environment. The highly fertile field systems not only fulfilled the agricultural needs of the immediate population, but also produced surplus for distribution throughout the region and further abroad. A variety of data generated from spatial analysis, construction energetics, and agricultural productivity suggest that these field systems were not under direct elite control. However, the high level of agricultural surplus generated argues for an established network for the movement and access of such goods. Centralized involvement in association with these wetland fields would likely relate to the management of formal markets, tribute systems, or trade routes within the area of interest.

Some of these explanations require further archaeological research before a conclusion can be attempted. While annual fieldwork continues at Blue Creek, Lamanai, and Aventura, other sites remain underexplored or completely unexcavated. This includes Douglas and Sabidos, two sites with some of the best preserved and extensive channelized field along the entirety of the Rio Hondo. Action must be taken soon, as modern agricultural development continues to encroach into relic field areas on both sides of the border. In the meantime, further digitization of individual plots and channels will provide a better understanding of production estimates, construction technique, and relation to known archaeological sites.

APPENDIX: ADDITIONAL FIGURES

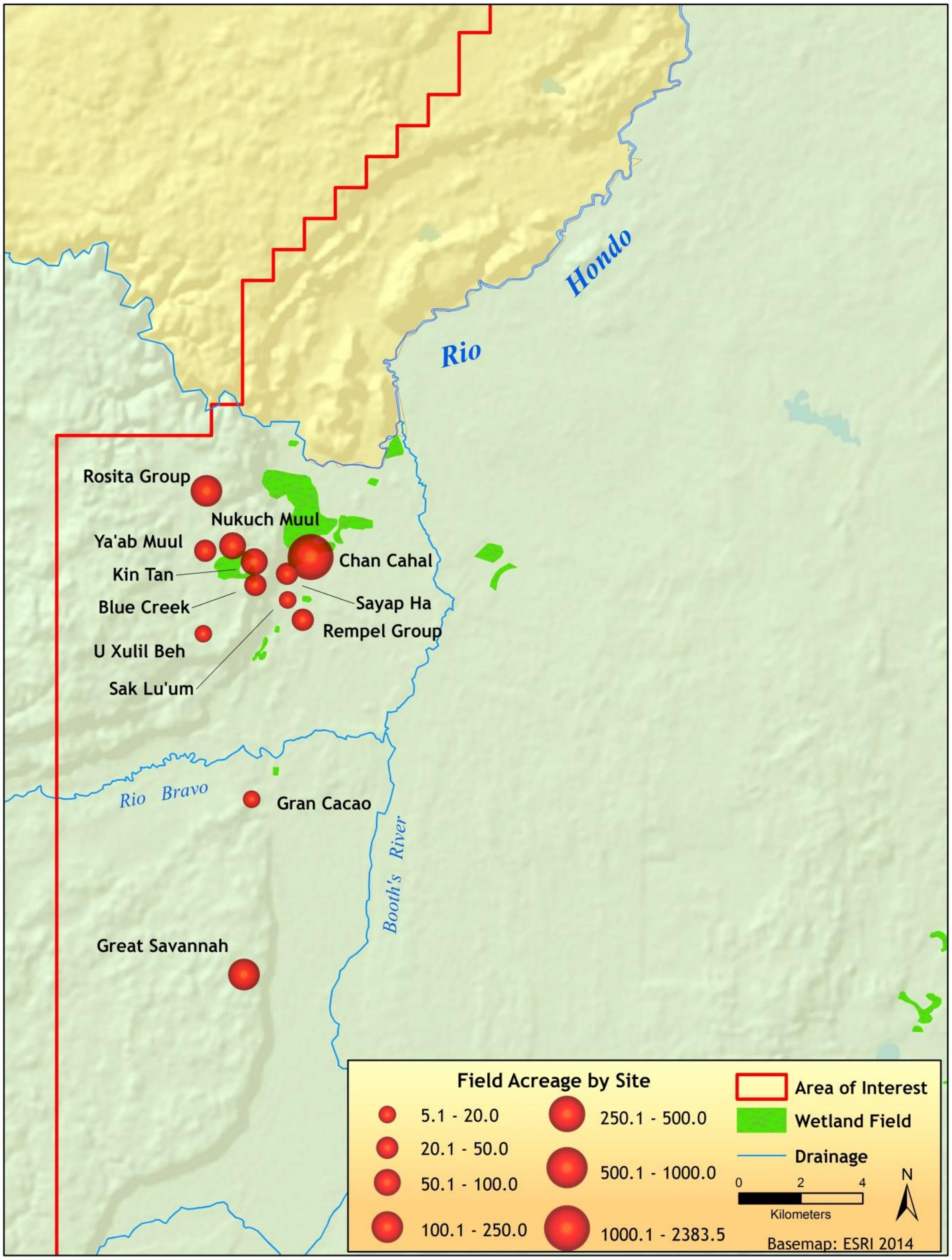

Figure 15. Extent of visible wetland field systems within Blue Creek area (1:150,000).

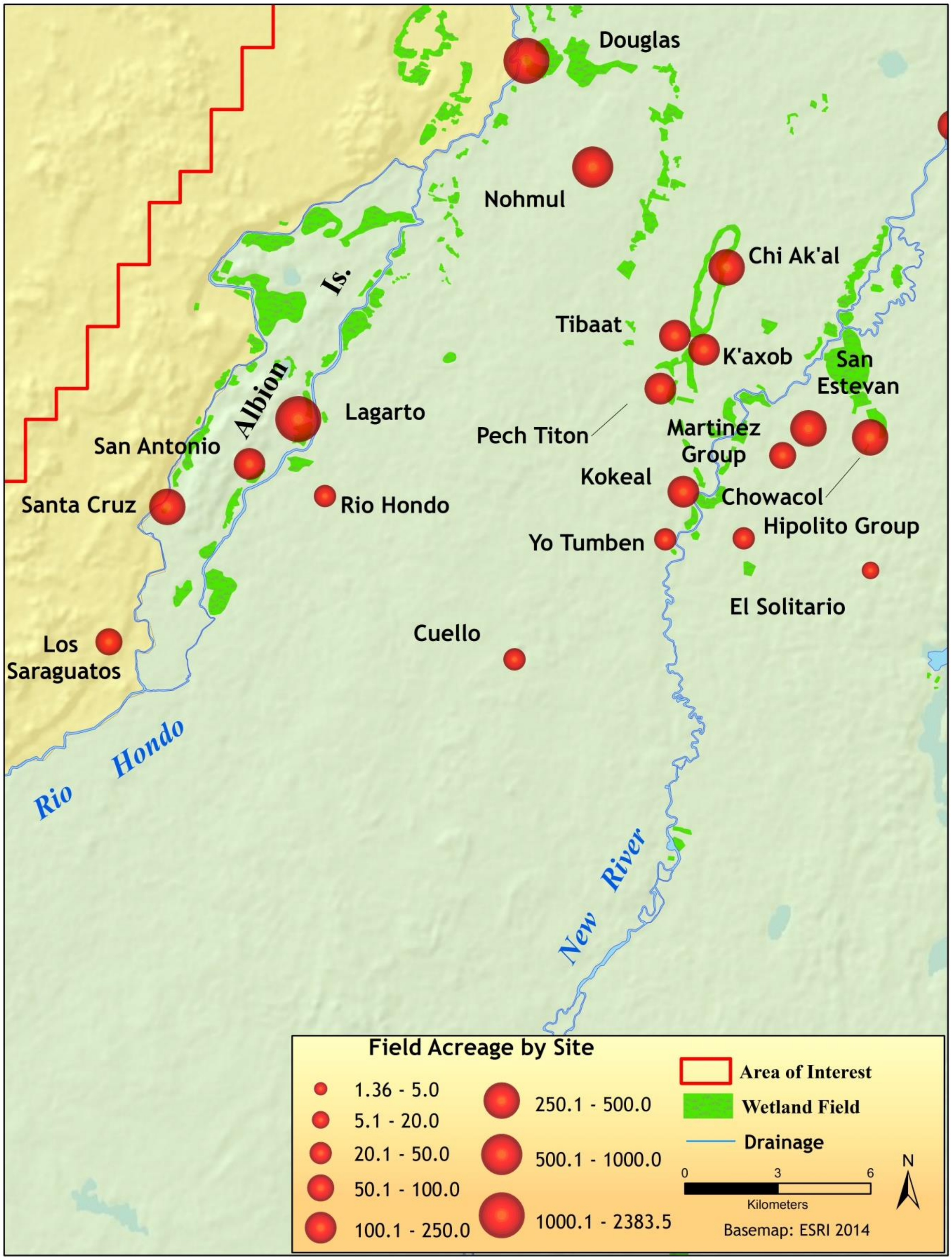

Figure 16. Extent of visible wetland field systems within Albion Island and Pulltrouser Swamp area (1:150,000).

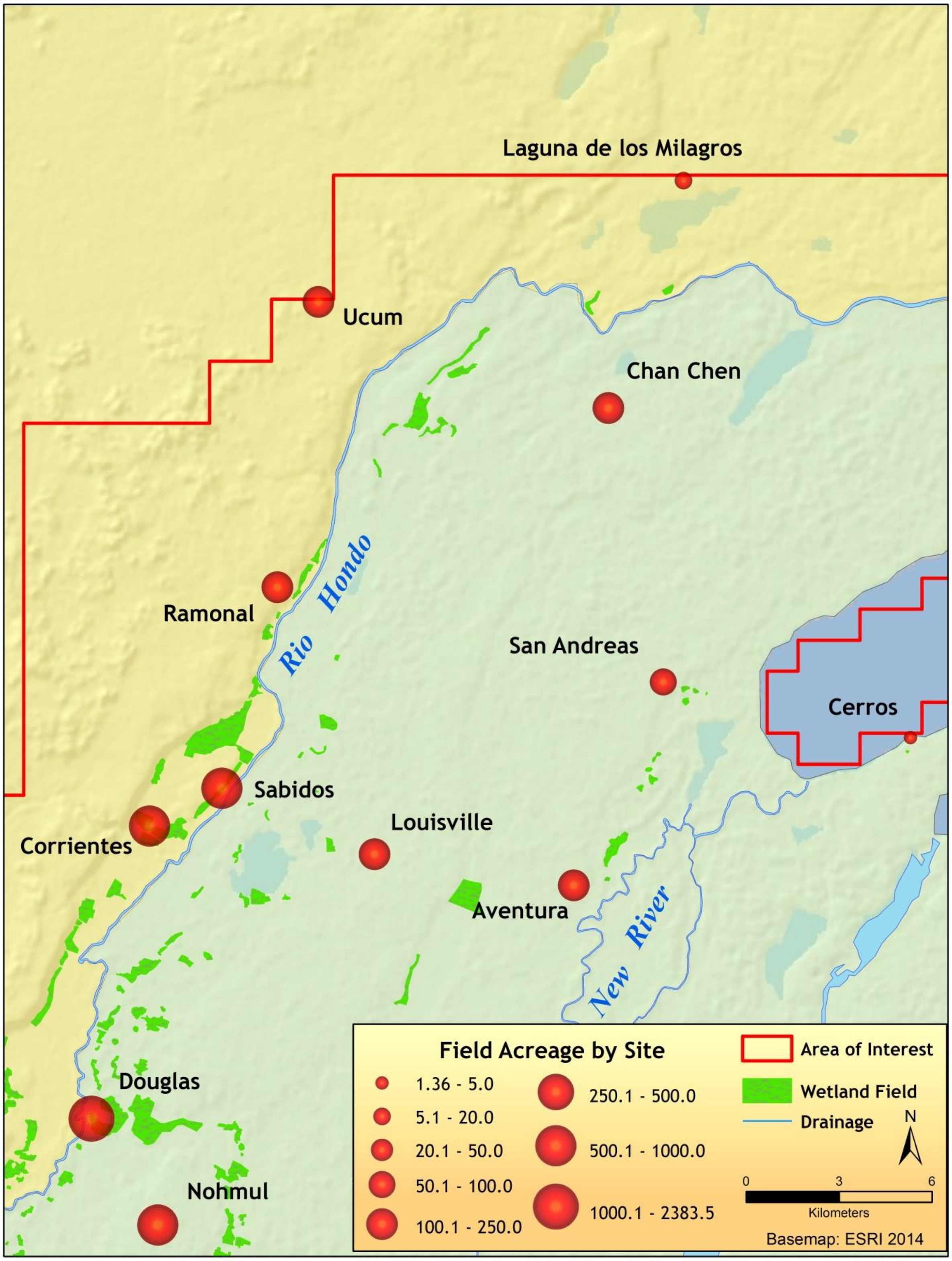

Figure 17. Extent of visible wetland field systems along lower Hondo and New rivers (1:150,000).

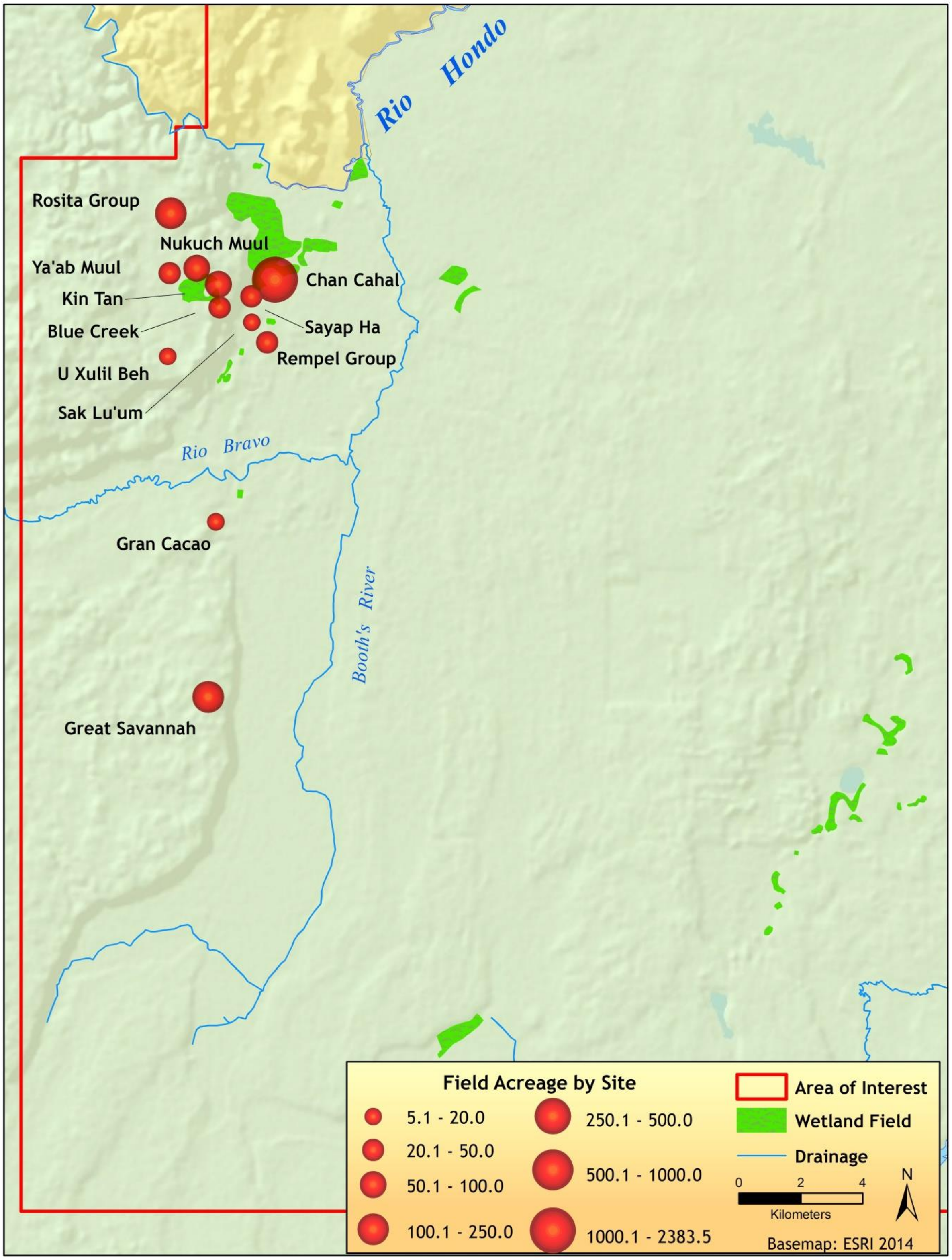

Figure 18. Extent of visible wetland field systems in the southwest portion of the area of interest (1:150,000).

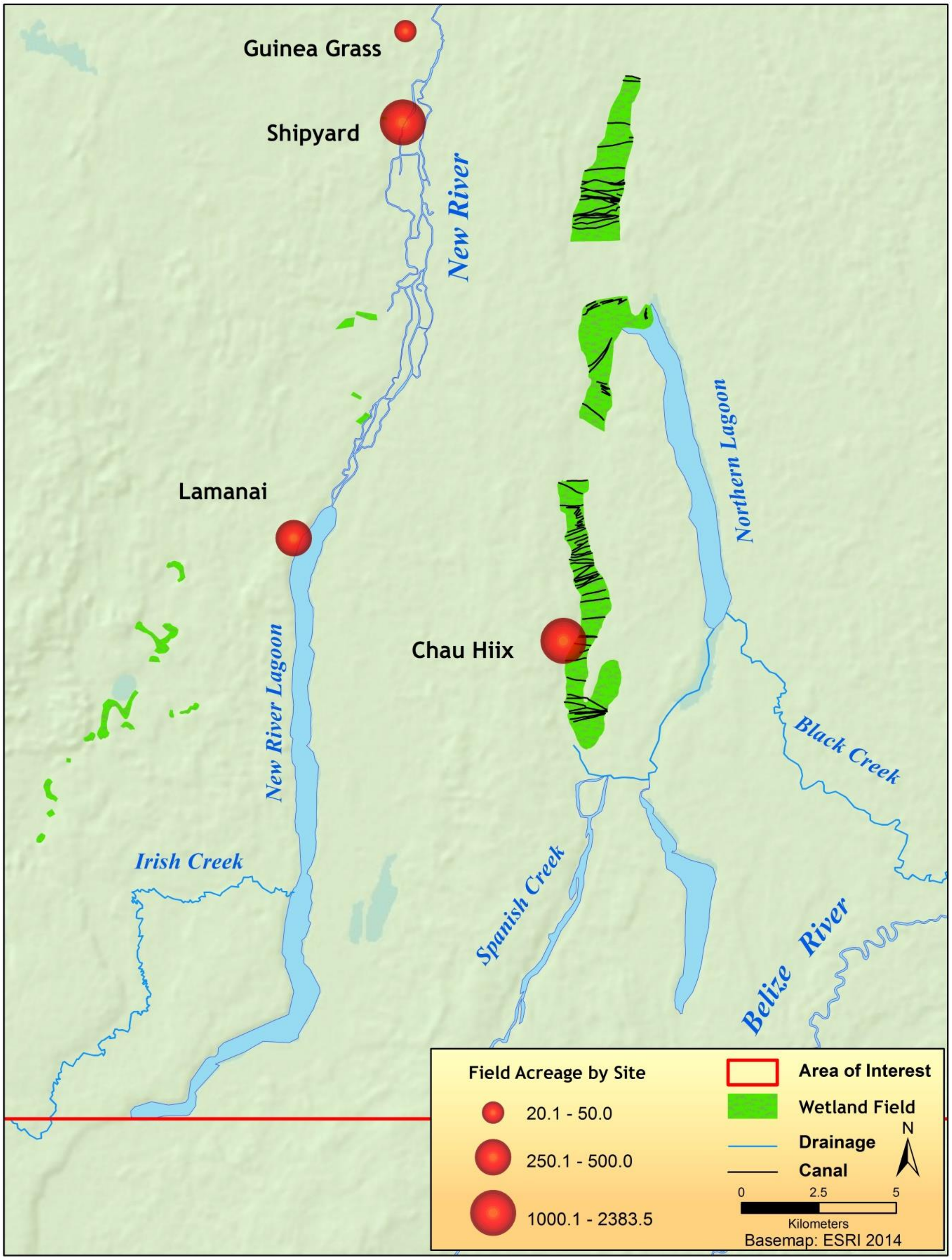

Figure 19. Extent of visible wetland field system surrounding Lamanai and Chau Hiix (1:150,000).

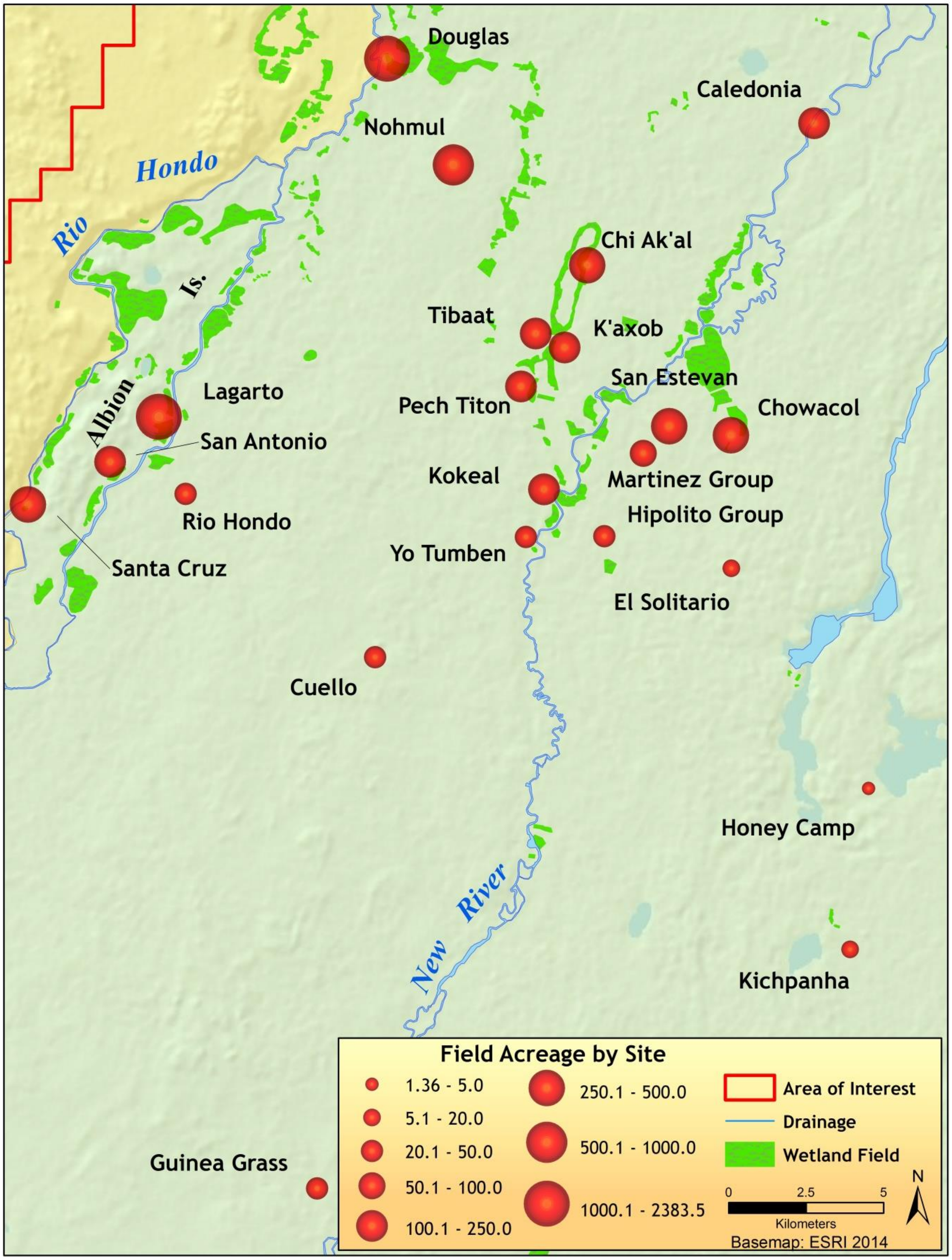

Figure 20. Extent of visible wetland field systems surrounding Pulltrouser Swamp and Nohmul (1:150,000).

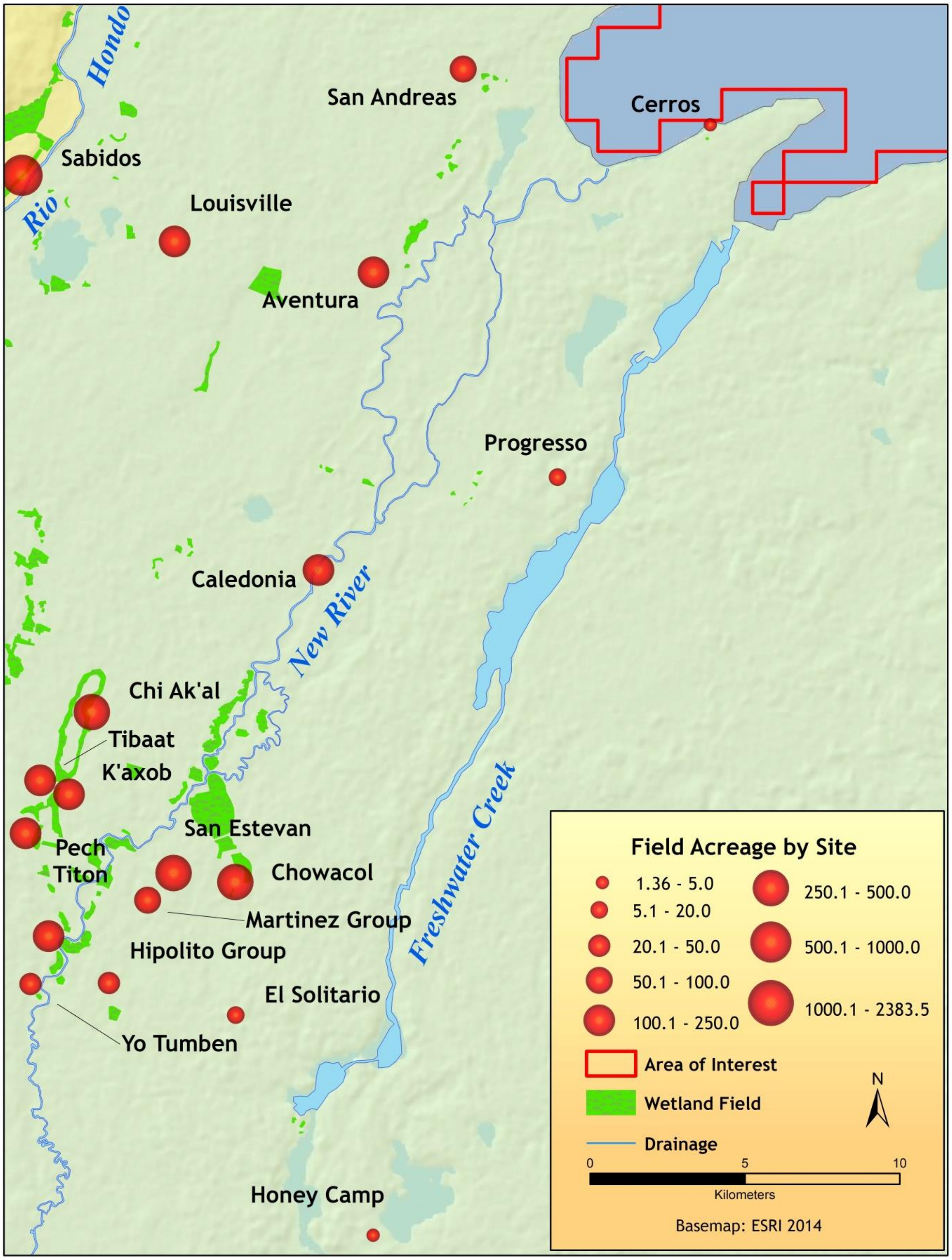

Figure 21. Extent of visible wetland field systems surrounding Aventura and Cerros (1:150,000).

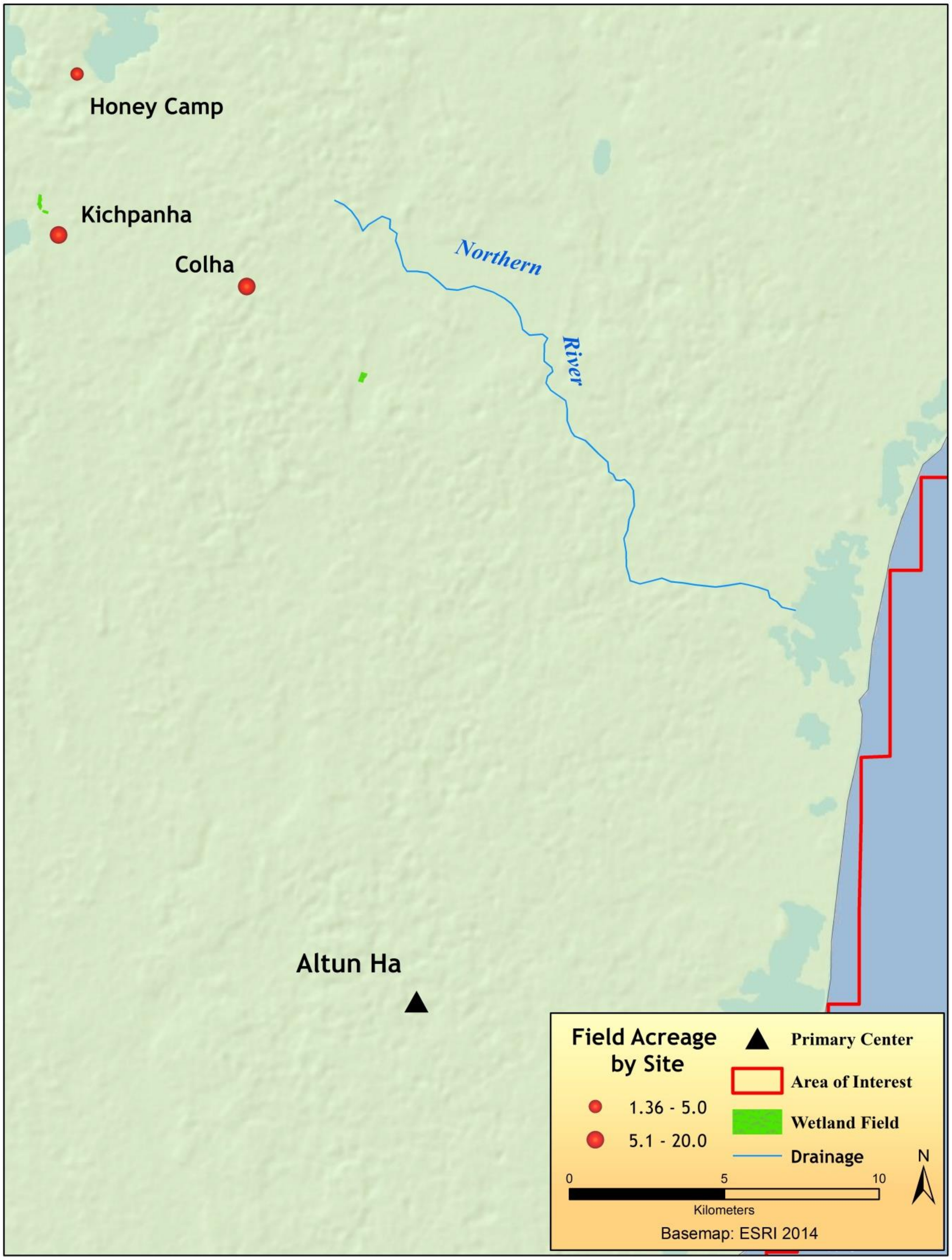

Figure 22. Extent of visible wetland field systems surrounding Colha and Northern River (1:150,000).

LIST OF REFERENCES

Abrams, Elliot M.
1994 *How the Maya Built Their World*. University of Texas Press, Austin.

Adams, R.E.W.
1982 Rank Size Analysis of Northern Belize Maya Sites. In *Archaeology at Colha*, *Belize: the 1981 Interim Report*, edited by Thomas R. Hester, Harry J. Shafer, and Jack D. Eaton, pp. 60-64. Center for Archaeological Research, the University of Texas at San Antonio, San Antonio.

Alexander, Rani T.
2006 Maya Settlement Shifts and Agrarian Ecology in Yucatán, 1800-2000. *Journal of Anthropological Research* 62(4): 449-470.

Andrews V, E. Wyllys and Norman Hammond
1990 *Redefinition of the Swasey Phase at Cuello, Belize*. American Antiquity 55(3): 570-584.

Arco, Lee J. and Elliot M. Abrams
2006 An Essay on Energetics: the Construction of the Aztec Chinampa System. *Antiquity* 80: 906-918.

Baillie, I.C., A.C.S. Wright, M.A. Holder, and E.A. FitzPatrick
1993 *Revised Classification of the Soils of Belize*. NRI Bulletin 59. Natural Resource Institute, Chatham, UK.

Baker, Jeffrey
2003 Maya Wetlands Ecology and Pre-Hispanic Utilization of Wetlands in Northwestern Belize. Doctoral Dissertation, University of Arizona. University Repository, Tucson.

Balzotti, Chris S., David L. Webster, Tim M. Murtha, Steven L. Peterson, Richard L. Burnett, and Richard E. Terry
2013 Modelling the Ancient Maize Agriculture Potential of Landforms in Tikal National Park, Guatemala. *International Journal of Remote Sensing* 34(16): 5868-5891.

Barrett, Jason W. and Thomas H. Guderjan
2006 An Ancient Maya Dock and Dam at Blue Creek, Rio Hondo, Belize. *Latin American Antiquity* 17(2): 227-239.

Beach, Timothy P.
2015 Maya Wetland Fields from 2014 and Earlier Coring Evidence. Paper Presented at the 80th Annual Meeting of the Society of American Archaeology, San Francisco.

Beach, Timothy P., Sheryl Luzzadder-Beach, Nicholas Dunning, Jon Hageman, and Jon Lohse
2002 Upland Agriculture in the Maya Lowlands: Ancient Maya Soil Conservation in Northwestern Belize. *Geographical Review* 92(3): 372-397.

Beach, Timothy P., Nicholas Dunning, Sheryl Luzzadder-Beach, Duncan E. Cook, and Jon Lohse
2006 Impacts of the Ancient Maya on Soils and Soil Erosion in the Central Maya Lowlands. *Catena* 65: 166-178.

Beach, Timothy P., Sheryl Luzzadder-Beach, Nicholas Dunning, John Jones, Jon Lohse, Tom Guderjan, Steve Bozarth, Sarah Millspaugh, and Tripti Bhattacharya
2009 A Review of Human and Natural Changes in Maya Lowland Wetlands over the Holocene. *Quaternary Science Reviews* 28: 1710-1724.

Beach, Timothy P., Sheryl Luzzadder-Beach, and Jon C. Lohse
2013 Landscape Formation and Agriculture in the Wetlands of Northern Belize. In *Classic Maya Political Ecology: Resource Management, Class Histories, and Political Change in Northwestern Belize, edited by Jon C. Lohse, pp. 43-68.* Cotsen Institute of Archaeology Press, Los Angeles.

Beach, Timothy P., Sheryl Luzzadder-Beach, Samantha Krause, Stanley Walling, Nicholas Dunning, Jonathan Flood, Thomas Guderjan, and Fred Valdez
2015 'Mayacene' Floodplain and Wetland Formation in the Rio Bravo Watershed of Northwestern Belize. *The Holocene* 25(10): 1612-1626.

Biodiversity and Environmental Resource Data System for Belize (BERDS)
2015 GIS and Spatial Data for Belize. Electronic document, http://www.biological-diversity.info/GIS.htm, accessed October 27, 2015.

Bronson, Bennet
1975 The Earliest Farming: Demography as Cause and Consequence. In *Origins of Agriculture*, edited by S. Polgar, pp. 23-48. The Hague, Mouton.

Brown, Clifford T. and Walter R.T. Witschey
2010 The Electronic Atlas of Ancient Maya Sites: a Geographic Information System (GIS). Electronic document, http://www.mayagis.smv.org, accessed September 30, 2015.

Chase, Diane Z. and Arlen F. Chase
1988 *A Postclassic Perspective: Excavations at the Site of Santa Rita Corozal, Belize.* Monograph 4. Pre-Columbian Art Research Institute, San Francisco.

Coe, Michael D.
1964 The Chinampas of Mexico. *Scientific American* 211: 90-98.

Cowgill, Ursula M.
1960 Soil Fertility, Population, and the Ancient Maya. *Proceedings of the National Academy of Sciences* 46(8): 1009-1011.

1962 An Agricultural Study of the Southern Maya Lowlands. *American Anthropologist* 64(2): 273-286.

Crane, Cathy J.
1986 Late Preclassic Maya Agriculture, Wild Plant Utilization, and Land-Use Practices. In *Archaeology at Cerros, Belize, Central America, Volume I: an Interim Report*, edited by R. Robertson and D. Freidel, pp. 147-164. Southern Methodist University Press, Dallas.

Culbert, T. Patrick and Don S. Rice
1990 *Precolumbian Population History in the Maya Lowlands*. University of New Mexico Press, Albuquerque.

Dalle, Sarah P. and Sylvie de Blois
2006 Shorter Fallow Cycles Affect the Availability of Noncrop Plant Resources in a Shifting Cultivation System. *Ecology and Society* 11(2): 2.

Dahlin, Bruce H. and Arlen F. Chase
2013 A Tale of Three Cities: Effects of the AD 536 Event in the Lowland Maya Heartland. In *The Great Maya Droughts in Cultural Context: Case Studies in Resilience and Vulnerability*, edited by G. Iannone, pp. 139-174. University Press of Colorado, Boulder.

Darch, Janice P.
1983 Vegetation Associations at Pulltrouser Swamp. In *Pulltrouser Swamp: Ancient Maya Habitat, Agriculture, and Settlement in Northern Belize,* edited by B.L. Turner II and Peter D. Harrison, pp. 21-29. University of Texas Press, Austin.

de Landa, Fr. Diego
1566 [1978] *Yucatán Before and After the Conquest*. Translated by William Gates. Dover Publications, New York.

Denevan, William M.
1970 Aboriginal Drained-Field Cultivation in the Americas. *Science* 169(3946): 647-654.

2001 *Cultivated Landscapes of Native Amazonia and the Andes*. Oxford University Press, Oxford.

Denevan, William M. and Alberta Zucchi
1978 Ridged-Field Excavations in the Central Orinoco Llanos, Venezuela. In *Advances in Andean Archaeology*, edited by David L. Browman, pp. 235-245. Mouton Publishers, Paris.

Denham, Tim, Simon Haberle, and Carol Lentfer
2004 New Evidence and Revised Interpretations of Early Agriculture in Highland New Guinea. *Antiquity* 78(302): 839-857.

DigitalGlobe
2011a GeoEye-1 Scene 105041000122EF00. Level Standard 2A. Imagery Date: 01/23/2011. DigitalGlobe, Longmont, Colorado.

2011b GeoEye-1 Scene 1050410001582200. Level Standard 2A. Imagery Date: 03/22/2011. DigitalGlobe, Longmont, Colorado.

2011c WorldView-2 Scene 103001000F0A4100. Level Standard 2A. Imagery Date: 12/10/2011. DigitalGlobe, Longmont, Colorado.

2013 WorldView-2 Scene 10300100298E6000. Level Standard 2A. Imagery Date: 11/28/2013. DigitalGlobe, Longmont, Colorado.

Drennan, Robert D.
1984 Long-Distance Transport Costs in Pre-Hispanic Mesoamerica. *American Anthropologist* 86: 105-112.

Driver, W. David and James F. Garber
2004 The Emergence of Minor Centers in Zones between Seats of Power. In *The Ancient Maya of the Belize Valley: Half a Century of Archaeological Research*, edited by James F. Garber, pp. 287-304. University Press of Florida, Gainesville.

Dunning, Nicolas P., Sheryl Luzzadder-Beach, Timothy Beach, John G. Jones, Vernon Scarborough, and T. Patrick Culbert
2002 Arising from the Bajos: The Evolution of a Neotropical Landscape and the Rise of the Maya Civilization. *Annals of the Association of American Geographers* 92(2): 267-283.

Erasmus, Charles J.
1965 Monument Building: Some Experiments. *Southwestern Journal of Anthropology* 21(4): 277-301.

Erickson, Clark L.
1995 Archaeological Methods for the Study of Ancient Landscapes of the Llanos de Mojos in the Bolivian Amazon. In *Archaeology in the Lowland American Tropics: Current Analytical Methods and Recent Applications*, edited by Peter W. Stahl, pp. 66-95. Cambridge University Press, Cambridge.

2006 The Domesticated Landscapes of the Bolivian Amazon. In *Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands*, edited by William Balée and Clark L. Erickson, pp. 235-278. Columbia University Press, New York.

Fedick, Scott L. and Anabel Ford
1990 The Prehistoric Agricultural Landscape of the Central Maya Lowlands: An Examination of Local Variability in a Regional Context. *World Archaeology* 22(1): 18-33.

Fedick, Scott L., Bethany A. Morrison, Bente Juhle Anderson, Sylviane Boucher, Jorge Ceja, Acosta, and Jennifer P. Matthews
2000 Wetland Manipulation in the Yalahau Region of the Northern Maya Lowlands. *Journal of Field Archaeology* 27(2): 131-152.

Fedick, Scott L. and Bethany A. Morrison
2004 Ancient Use and Manipulation of Landscape in the Yalahau Region of the Northern Maya Lowlands. *Agriculture and Human Values* 21(2-3): 207-219.

Ford, Anabel
1996 Critical Resource Control and the Rise of the Classic Period Maya. In *The Managed Mosaic. Ancient Maya Agriculture and Resource Use*, edited by S. Fedick, pp. 297-303. University of Utah Press, Salt Lake City.

Freidel, David
1979 Culture Areas and Interaction Spheres: Contrasting Approaches to the Emergence of Civilization in the Maya Lowlands. *American Antiquity* 44(1): 36-54.

Garber, James F.
1989 *Archaeology at Cerros, Belize, Central America: the Artifacts*. Southern Methodist University Press, Dallas.

Gatrell, Anthony C.
1994 Density Estimation and the Visualization of Point Patterns. In *Visualizations in Geographic Information Systems*, edited by H.J. Hearnshaw and D.J. Unwin, pp. 65-75. Wiley Publishing, Chichester.

Gibson, Eric C.
1982 An Analysis of the Late Classic Maya Settlement Pattern at Kichpanha, Northern Belize. In *Archaeology at Colha: the 1981 Interim Report*, edited by Thomas R. Hester, Harry J. Shafer, and Jack D. Eaton, pp. 152-166. Center for Archaeological Research, the University of Texas at San Antonio, San Antonio.

Griffin, James B.
1967 Eastern North American Archaeology: a Summary. *Science* 156(3772): 175-191.

Guderjan, Thomas H.
2007 *The Nature of an Ancient Maya City: Resources, Interaction, and Power at Blue Creek, Belize.* University of Alabama Press, Tuscaloosa.

Guderjan, Thomas H. and Samantha Krause
2011 Identifying the Extent of Ancient Maya Ditched Field Systems in the Rio Hondo Valley of Belize and Mexico: A Pilot Study and Some of its Implications. *Research Reports in Belizean Archaeology* 8: 127-136.

Gunn, Joel D., William J. Folan, and Hubert R. Robichaux
1995 A Landscape Analysis of the Candelaria Watershed in Mexico: Insights into Paleoclimates Affecting Upland Horticulture in the Southern Yucatán Peninsula Semi-Karst. *Geoarchaeology* 10(1): 3-42.

Hammond, Norman
1975 Maya Settlement Hierarchy in Northern Belize. In *Contributions of the University of California Archaeological Research Facility, Studies in Ancient Mesoamerica II*, edited by J.A. Graham, pp. 40-55. University of California, Berkeley.

1976 Radiocarbon Chronology for Early Maya Occupation at Cuello, Belize. *Nature*, *260*, 579-581.

1978 *Cuello Project, 1978: Interim Report.* Archaeological Research Program, Douglas College, Rutgers University.

1983 Nohmul, Belize: 1982 Excavations. *Journal of Field Archaeology* 10(3): 245-254.

1985 *Nohmul, a prehistoric Maya community in Belize: excavations, 1973-1983* (Vol. 250). British Archaeological Reports, Oxford.

1991 The Maya and their Civilization. In *Cuello: an Early Maya Community in Belize*, edited by Norman Hammond, pp. 1-7. Cambridge University Press, Cambridge.

Hammond, Norman, Duncan Pring, Richard Wilk, Sara Donaghey, Frank P. Saul, Elizabeth S. Wing, Arlene V. Miller, and Lawrence H. Feldman
1979 The Earliest Lowland Maya? Definition of the Swasey Phase. *American Antiquity* 44(1): 92-110.

Hammond, Norman and Charles H. Miksecik
1981 Ecology and Economy of a Formative Maya Site at Cuello, Belize. *Journal of Field Archaeology* 8(3): 259-269.

Hammond, Norman, Catherine Clark, Mark Horton, Mark Hodges, Logan McNatt, Laura J. Kosakowsky, and Anne Pyburn
1985 Excavation and Survey at Nohmul, Belize, 1983. *Journal of Field Archaeology* 12(2): 177-200.

Hammond, Norman, K. Anne Pyburn, John Rose, J.C. Staneko, and Deborah Muyskens
1988 Excavation and Survey at Nohmul, Belize, 1986. *Journal of Field Archaeology* 15(1): 1-15.

Harrison, Peter D.
1978 So the Seeds Shall Grow: Some Introductory Comments. In *Pre-Hispanic Maya Agriculture,* edited by Peter D. Harrison and B.L. Turner II, pp. 1-11. University of New Mexico Press, Albuquerque.

1996 Settlement and Land Use in the Pulltrouser Swamp Archaeological Zone, Northern Belize. In *Managed Mosaic: Ancient Maya Agriculture and Resource Use*, edited by Scott L. Fedick, pp. 177-190. University of Utah Press, Salt Lake City.

Harrison, Peter D. and Robert E. Fry
2000 *Pulltrouser Swamp, A Lowland Maya Community Cluster in Northern Belize: The Settlement Maps*. University of Utah Press, Salt Lake City.

Hellmuth, Nicholas M.
1977 Cholti-Lacandon (Chiapas) and Peten-Ytza Agriculture, Settlement Pattern and Population. In *Social Processes in Maya Prehistory: Studies in Honor of Sir Eric Thompson*, edited by Norman Hammond and J. Eric S. Thompson, pp. 421-428. Academic Press, New York.

Horrocks, Mark and Ian Barber
2005 Microfossils of Introduced Starch Cultigens from an Early Wetland Ditch in New Zealand. *Archaeology in Oceania* 40(3): 106-114.

Houk, Brett A. and Jon C. Lohse
2013 Northwestern Belize and the Central Lowland Classic World. In *Classic Maya Political Ecology: Resource Management, Class Histories, and Political Change in Northwestern Belize*, edited by Jon C. Lohse, pp. 25-42. Cotsen Institute of Archaeology Press, Los Angeles.

Iriarte, José, Bruno Glaser, Jennifer Watling, Adam Wainwright, Jago Jonathan Birk, Delphine Renard, Stéphen Rostain, and Doyle McKey
2010 Late Holocene Neotropical Agricultural Landscapes: Phytolith and Stable Carbon Isotope Analysis of Raised Fields from French Guianan Coastal Savannahs. *Journal of Archaeological Science* 37(12): 2984-2994.

Johnson, Sarah and Eliška Rejmánková.
2005 Impacts of Land Use on Nutrient Distribution and Vegetation Composition of Freshwater Wetlands in Northern Belize. *Wetlands* 25(1): 89-100.

Johnson, William C.
1983 The Physical Setting: Northern Belize and Pulltrouser Swamp. In *Pulltrouser Swamp: Ancient Maya Habitat, Agriculture, and Settlement in Northern Belize*, edited by B.L. Turner II and Peter D. Harrison, pp. 8-20. University of Texas Press, Austin.

Jacob, John S.
1995 Ancient Maya Wetland Agricultural Fields in Cobweb Swamp, Belize: Construction, Chronology, and Function. *Journal of Field Archaeology* 22(2): 175-190.

King, R.B., Baillie, I.C., Abell, T.M.B., Dunsmore, J.R., Gray, D.A., Pratt, J.H., Versey, H.R., Wright, A.C.S. and Zisman, S.A.
1992 *Land Resource Assessment of Northern Belize*. NRI Bulletin 43(1). University of Greenwich Press, London.

Kosakowsky, Laura J.
1987 *Preclassic Maya Pottery at Cuello, Belize*. University of Arizona Press, Tucson.

Kunen, Julie L.
2004 *Ancient Maya Life in the Far West Bajo: Social and Environmental Change in the Wetlands of Belize.* University of Arizona Press, Tucson.

Lan, Yan, Baoshan Cui, Yongtao Zhang, Zhen Han, Nannan Gao, and Tingting Wang
2012 Influence of Raised Fields on Ecological Environment and Economic Benefits in Baiyangdian Lake, China. *Procedia Environmental Sciences* 13: 680-686.

Levi, Laura J.
1993 *Prehispanic Residence and Community at San Estevan, Belize*. Ph.D. Dissertation, Department of Anthropology, University of Arizona, Tucson.

2003 Space and the Limits to Community. In *Perspectives on Ancient Maya Rural Complexity*, edited by Gyles Iannone and Samuel V. Connell, pp. 82-93. Cotsen Institute of Archaeology, Monograph 49. Cotsen Institute, Los Angeles.

Lohse, Jon C.
2010 Archaic Origins of the Lowland Maya. *Latin American Antiquity* 21(3): 312-352.

Lucero, Lisa J.
1999 Water Control and Maya Politics in the Southern Maya Lowlands. *Archaeological Papers of the American Anthropological Association* 9(1): 35-49.

Luzzadder-Beach, Sheryl, Timothy P. Beach, and Nicholas P. Dunning
2012 Wetland Fields as Mirrors of Drought and the Maya Abandonment. *Proceedings of the National Academy of Sciences* 109(10): 3646-3651.

Masson, Marilyn A.
2004 Fauna Exploitation from the Preclassic to the Postclassic Periods at Four Maya Settlements in Northern Belize. In *Maya Zooarchaeology: New Directions in Method and Theory,* edited by Kitty F. Emery, pp. 97-124. Cotsen Institute of Archaeology Press, Los Angeles.

McAnany, Patricia A.
2004 *K'axob: Ritual, Work, and Family in an Ancient Maya Village*. Cotsen Institute of Archaeology Press, Los Angeles.

McAnany, Patricia A., Kimberly A. Berry, and Ben S. Thomas
2003 Wetlands, Rivers, and Caves: Agricultural and Ritual Practice in Two Lowland Maya Landscapes. In *Perspectives on Ancient Maya Rural Complexity*, edited by Gyles Iannone and Samuel V. Connell, pp. 71-81. Cotsen Institute of Archaeology Press, Los Angeles.

McAnany, Patricia A. and Polly A. Peterson
2004 Tools of the Trade: Acquisition, Use, and Recycling of Chipped Stone. In *K'axob: Ritual, Work, and Family in an Ancient Maya Village*, edited by Patricia A. McAnany, pp. 279-305. Cotsen Institute of Archaeology Press, Los Angeles.

McCartney, Matthew P., Musta Masiyandima, and Helen A. Houghton-Carr
2005 *Working Wetlands: Classifying Wetland Potential for Agriculture*. Research Report 90. International Water Management Institute, Colombo, Sri Lanka.

Menotti, Francesco
2012 *Wetland Archaeology and Beyond: Theory and Practice*. Oxford University Press, Oxford.

Metcalfe, Sarah, Ann Breen, Malcolm Murray, Peter Furley, Anthony Fallick, and Angus McKenzie
2009 Environmental Change in Northern Belize Since the Latest Pleistocene. *Journal of Quaternary Science* 24(6): 627-641.

Miksicek, Charles H.
1983 Macrofloral Remains of the Pulltrouser Area: Settlements and Fields. In *Pulltrouser Swamp: Ancient Maya Habitat, Agriculture, and Settlement in Northern Belize,* edited by B.L. Turner II and Peter D. Harrison, pp. 94-104. University of Texas Press, Austin.

Morehart, Christopher T.
2012 Mapping Ancient Chinampa Landscapes in the Basin of Mexico: A Remote Sensing and GIS Approach. *Journal of Archaeological Sciences* 39: 2541-2551.

Morgan, Lewis H.
1907 *Ancient Society: Researches into the Lines of Human Progress from Savagery through Barbarism to Civilization*. Henry Holt and Company, New York.

National Archives and Records Administration
1985 *Code of Federal Regulations, Title 50, Wildlife and Fisheries*. U.S. Government Printing Office, Washington, D.C.

Netting, Robert McC.
1993 *Smallholders, Householders: Farm Families and the Ecology of Intensive, Sustainable Agriculture*. Stanford University Press, Stanford.

Niederberger Betton, Christine
1987 *Paleopaysages et Archeologie Pre-Urbaine du Bassin de Mexico (Mexique)*. Etudes Mesoamericaines, Vol. 11. Centre d'Etudes Mexicaines et Centraméricaines, Paris.

Olson, Gerald W.
1977 Significance of Physical and Chemical Characteristics of Soils at the San Antonio Archaeological Site on the Rio Hondo in Northern Belize. *Journal of Belizean Affairs* 5: 22-35.

Palerm, Ángel and Eric R. Wolf
1957 Ecological Potential and Cultural Development in Mesoamerica. *Pan American Union Social Science Monograph 3*: 1-37.

Pendergast, David
1979 *Excavations at Altun Ha, Belize, 1964-1970, Volume 1*. Royal Ontario Museum, Toronto.

1981 Lamanai, Belize: Summary of Excavation Results, 1974–1980. *Journal of Field Archaeology* 8(1): 29-53.

Pohl, Mary D.
1990 *Ancient Maya Wetland Agriculture: Excavations on Albion Island, Northern Belize*. University of Minnesota Publications in Anthropology and Westview Press, Boulder, Colorado.

Pohl, Mary D., Paul R. Bloom and Kevin O. Pope
1990 Interpretation of Wetland Farming in Northern Belize: Excavations at San Antonio, Rio Hondo. In *Ancient Maya Wetland Agriculture: Excavations on Albion Island, Northern Belize*, edited by Mary D. Pohl, pp. 187-278. University of Minnesota Publications in Anthropology and Westview Press, Boulder, Colorado.

Pohl, Mary D. and Paul R. Bloom
1996 Prehistoric Farming in the Wetlands of Northern Belize: Albion Island and Beyond. In *The Managed Mosaic. Ancient Maya Agriculture and Resource Use*, edited by S. Fedick, pp. 145-164. University of Utah Press, Salt Lake City.

Pohl, Mary D., Kevin O. Pope, John G. Jones, John S. Jacob, Dolores R. Piperno, Susan D. deFrance, David L. Lentz, John A. Gifford, Marie E. Danforth and J. Kathryn Josserand
1996 Early Agriculture in the Maya Lowlands. *Latin American Antiquity* 7(4): 355-372.

Powis, Terry, S. J. Mazzullo, and Elizabeth Graham
2009 An Archaeological and Geological Assessment of a Presumed Ancient Maya Harbour at Lamanai, Belize. *Research Reports in Belizean Archaeology* 6: 253-262.

Pring, Duncan and Norman Hammond
1985 Investigations of a Possible River Port at Nohmul. In *Nohmul: a Prehistoric Maya Community in Belize*, edited by Norman Hammond, pp. 527-551. BAR International Series 250. British Archaeological Reports, Oxford.

Puleston, Dennis E.
1977 The Art and Archaeology of Hydraulic Agriculture in the Maya Lowlands. In *Social Processes in Maya Prehistory: Studies in Honor of Sir Eric Thompson*, edited by Norman Hammond and J. Eric S. Thompson, pp. 449-467. Academic Press, New York.

1978 Terracing, Raised Fields, and Tree Cropping in the Maya Lowlands: A New Perspective on the Geography of Power. In *Pre-Hispanic Maya Agriculture*, edited by Peter D. Harrison and B.L. Turner, pp. 225-245. University of New Mexico Press, Albuquerque.

Pyburn, K. Anne
1990 Settlement Patterns at Nohmul: Preliminary Results of Four Excavation Seasons. In *Precolumbian Population History in the Maya Lowlands*, edited by T. Patrick Culbert and Don S. Rice, pp. 183-198. University of New Mexico Press, Albuquerque.

1998 Smallholders in the Maya Lowlands: Homage to a Garden Variety Ethnographer. *Human Ecology* 26(2): 267-286.

2003 The Hydrology of Chau Hiix. *Ancient Mesoamerica* 14: 123-129.

Pyburn, K. Anne, Boyd Dixon, Patricia Cook, and Anna McNair
1998 The Albion Island Settlement Pattern Project: Domination and Resistance in Early Classic Northern Belize. *Journal of Field Archaeology* 25(1): 37-62.

Reese-Taylor, Kathryn and Debra S. Walker
2002 The Passage of the Late Preclassic into the Early Classic. In *Ancient Maya Political Economies*, edited by Marilyn A. Masson and David A. Freidel, pp. 87-122. Altamira Press, Walnut Creek.

Rejmankova, Eliska, Kevin O. Pope, Mary D. Pohl and Jose M. Rey-Benayas
1995 Freshwater Wetland Plant Communities of Northern Belize: Implications for Paleoecological Studies of Maya Wetland Agriculture. *Biotropica* 27(1): 28-36.

Renard, D., J. Iriarte, J. J. Birk, S. Rostain, B. Glaser, and D. McKey
2012 Ecological Engineers Ahead of their Time: the Functioning of Pre-Columbian Raised-Field Agriculture and its Potential Contributions to Sustainability Today. *Ecological Engineering* 45: 30-44.

Rice, Don S.
1978 Population Growth and Subsistence Alternatives in a Tropical Lacustrine Environment. In *Pre-Hispanic Maya Agriculture*, edited by Peter D. Harrison and B.L. Turner, pp. 35-61. University of New Mexico Press, Albuquerque.

Rosenswig, Robert M.
2009 The Emergence of Complexity and the Middle to Late Formative Occupation of San Estevan, Belize. *Research Reports in Belizean Archaeology* 6: 101-108.

Rosenswig, Robert M. and Douglas J. Kennet
2008 Reassessing San Estevan's Role in the Late Formative Political Geography of Northern Belize. *Latin American Antiquity* 19(2): 123-145.

Rosenswig, Robert M., Deborah M. Pearsall, Marilyn A. Masson, Brendan J. Culleton, and Douglas J. Kennett
2014 Archaic Period Settlement and Subsistence in the Maya Lowlands: New Starch Grain and Lithic Data from Freshwater Creek, Belize. *Journal of Archaeological Science* 41: 308-321.

Rostain, Stéphen
2012 *Islands in the Rainforest: Landscape Mangement in Pre-Hispanic Amazonia*. Left Coast Press, Walnut Creek.

Rushton, Elizabeth AC, Sarah E. Metcalfe, and Bronwen S. Whitney
2012 A Late-Holocene Vegetation History from the Maya Lowlands, Lamanai, Northern Belize. *The Holocene* 23(4): 485-493.

Sanders, William T.
1976 The Agricultural History of the Basin of Mexico. In *The Valley of Mexico: Studies in Pre-Hispanic Ecology and Society*, edited by Eric R. Wolf, pp. 101-159. University of New Mexico Press, Albuquerque.

Scarborough, Vernon L.
1991 *Archaeology at Cerros, Belize, Central America: The Settlement System in a Late Preclassic Maya Community*. Southern Methodist University Press, Dallas.

1996 Reservoirs and Watersheds in the Central Maya Lowlands. In *The Managed Mosaic. Ancient Maya Agriculture and Resource Use*, edited by S. Fedick, pp. 304-314. University of Utah Press, Salt Lake City.

Sears, William H.
1982 *Fort Center: An Archaeological Site in the Lake Okeechobee Basin*. University of Florida Press, Gainesville.

Shafer, Harry J.
1982 Maya Lithic Craft Specialization in Northern Belize. In *Archaeology at Colha: the 1981 Interim Report*, edited by Thomas R. Hester, Harry J. Shafer, and Jack D. Eaton, pp. 31-38. Center for Archaeological Research, the University of Texas at San Antonio, San Antonio.

Sharer, Robert J. and Loa P. Traxler
2006 *The Ancient Maya*. Stanford University Press, Stanford.

Siemens, Alfred H.
1978 Karst and the Pre-Hispanic Maya in the Southern Lowlands. In *Pre-Hispanic Maya Agriculture*, edited by Peter D. Harrison and B.L. Turner II, pp. 117-143. University of New Mexico Press, Albuquerque.

1983 Wetland Agriculture in Pre-Hispanic Mesoamerica. *Geographical Review* 73(2): 166-181.

Seimens, Alfred H. and Dennis E. Puleston
1972 Ridged Fields and Associated Features in Southern Campeche: New Perspectives On The Lowland Maya. *American Antiquity* 37(2): 228-239.

Sidrys, Raymond V.
1983 *Archaeological Investigations in Northern Belize, Central America.* Cotsen Institute of Archaeology, University of California, Los Angeles.

Sluyter, Andrew
1994 Intensive Wetland Agriculture in Mesoamerica: Space, Time, and Form. *Annals of the Association of American Geographers* 84(4): 557-584.

Smith, Clifford Thorpe, William M. Denevan, and Patrick Hamilton
1968 Ancient Raised Fields in the Region of Lake Titicaca. *The Geographical Journal* 134(3): 353-367.

Torrescano, Nuria and Gerald A. Islebe
2006 Tropical Forest and Mangrove History from Southeastern Mexico: a 5000 Yr Pollen Record and Implications for Sea Level Rise. *Vegetation History and Archaeobotany* 15: 191-195.

Turner II, Billie L.
1983 Constructional Systems for Major Agrosystems of the Ancient Maya. In *Drained Field Agriculture in Central and South America,* edited by Janice P. Darch, pp. 11-26. British Archaeological Reports, Oxford.

1993 Rethinking the "New Orthodoxy": Interpreting Ancient Maya Agriculture and Environment. In *Culture, Form, and Place: Essays in Cultural and Historical Geography*, edited by Kent Mathewson, pp. 57 – 88. Geoscience and Man, vol. 32. Geoscience Publications, Department of Geography and Anthropology, Louisiana State University, Baton Rouge.

Turner II, Billie L. and Peter D. Harrison
1983 *Pulltrouser Swamp: Ancient Maya Habitat, Agriculture, and Settlement in Northern Belize*. University of Texas Press, Austin.

Turner II, Billie L., Peter Klepeis, and L.L. Schneider.
2003 Three Millennia in the Southern Yucatán Peninsula: Implications for Occupancy, Use, and Carrying Capacity. In *The Lowland Maya Area: Three Millennia at the Human-Wildland Interface,* edited by A. Gómez-Pompa, M.F. Allen, S.L. Fedick, and J.J. Jímenez-Osornio, pp. 361-387. Food Products Press, New York.

Walker, John H.
2011 Amazonian Dark Earth and Ring Ditches in the Central Llanos de Mojos, Bolivia. *Cultural, Agriculture, Food, and Environment* 33(1): 2-14.

Whitney, Bronwen S., Elizabeth A.C. Rushton, John F. Carson, José Iriarte, and Francis E. Mayle
2012 An Improved Methodology for the Recovery of *Zea Mays* and Other Large Crop Pollen, with Implications for Environmental Archaeology in the Neotropics. *The Holocene* 22(10): 1087-1096.

Wilken, Gene C.
1969 Drained-Field Agriculture: An Intensive Farming System in Tlaxcala, Mexico. *Geographical Review* 59(2): 215-241.

Wiseman, Frederick M.
1983 Analysis of Pollen from the Fields at Pulltrouser Swamp. In *Pulltrouser Swamp: Ancient Maya Habitat, Agriculture, and Settlement in Northern Belize,* edited by B.L. Turner II and Peter D. Harrison, pp. 105-119. University of Texas Press, Austin.

Wittfogel, Karl A.
1955 Developmental Aspects of Hydraulic Societies. In *Irrigation Civilizations: A Comparative Study*, edited by Julian H. Steward, pp. 43-52. Pan American Union, Washington, D.C.