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# Ancient Maya Cultivation in a Dynamic Wetland Environment: Insights into the Functions of Anthropogenic Rock Alignments at El Edén Ecological Reserve, Quintana Roo, Mexico

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

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in

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by

Jennifer Andrea Chmilar

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Dissertation Committee:
    Dr. Scott L. Fedick, Chairperson
    Dr. Wendy Ashmore
    Dr. Karl Taube

The Dissertation of Jennifer Andrea Chmilar is approved:

Committee Chairperson

University of California, Riverside

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# ABSTRACT OF THE DISSERTATION

## Ancient Maya Cultivation in a Dynamic Wetland Environment: Insights into the Functions of Anthropogenic Rock Alignments at El Edén Ecological Reserve, Quintana Roo, Mexico

by

Jennifer Andrea Chmilar

Doctor of Philosophy, Graduate Program in Anthropology
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Dr. Scott L. Fedick, Chairperson

Cultivation has taken many forms throughout the Maya lowlands. In the Yalahau region of the northern Maya lowlands, a series of wetlands produce a dynamic environment of wet, dry, and intermediate areas depending on fluctuations of the annual hydrologic cycle. Within these wetlands, anthropogenic rock alignments suggest human use and manipulation of the environment dating to the late Preclassic period. The dissertation is based on research at a single wetland at El Edén Ecological Reserve, Quintana Roo and concerns the function of the rock alignments as well as their duration of use to the ancient Maya. In terms of function, hypotheses are that they modified soil and water movement within a system of cultivation, and/ or acted as boundary markers, and/ or provided bases for fish weirs. As for when the rock alignments were used, hypotheses follow that they were used for a single hydroperiod, that the same features were built as the hydroperiod changed, or that new functions emerged as the water table shifted. Data was collected through topographic mapping of four areas of the wetland containing a total of twelve rock alignments, high-resolution GPS of these mapped areas, recording of water table fluctuations for a period of two years, and analysis of a sediment

core documenting pollen extending back nearly 2500 years.  The computer program arcGIS was used to create a series of topographic maps, both with and without the rock alignments, that demonstrate the influence of the rock alignments on the movement of water on the landscape. The rock alignments impacted water movement on a small scale. Within El Edén wetland, the ancient Maya constructed lines of rock to cause water to pool in localized depressions, either by dividing existing basins or surrounding them to direct water back inward, where it was maintained into the dry season so that valuable plants were encouraged to thrive for a longer period of time. Sinuous lines of rock were constructed to provide the base for a fish weir. Rock alignments were built at various points along the topography to take advantage of varying annual hydroperiods.

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# 1. INTRODUCTION

One of the most basic relationships is that of human groups with their environment. Early on in human existence, people developed a sophisticated understanding of their surroundings. As days shifted in length, temperatures became warmer or cooler, seasons oscillated between wet and dry, plants transformed into their next stage of growth, and wildlife migrated, it was necessary for humans inhabiting the landscape to perceive these environmental pulses and range of variation. With an understanding of environmental changes, human groups could plan their movements or modify the environment to ensure access to necessary resources. When confronted by an event outside the experienced normal range of variation, however, human groups were forced to find a way to adapt.

Subsistence practices, how ancient peoples obtained food and resources, has been a pressing issue of archaeological inquiry. Integral to this line of research is the reconstruction of past environments and the need to understand how ecosystems change through time. How did ancient populations come to understand and make their environment productive? What impact did ancient people have on their environment, and how did they respond to such changes?

Within the Maya area, many previously unrecognized forms of landscape engineering for agriculture and subsistence production have been identified and studied, particularly in the southern Maya Lowlands. In the northern Maya Lowlands, however, modification of the environment for subsistence production has remained largely undocumented. One striking difference between the southern and northern Maya Lowlands is the distribution of surface water – a requirement for cultivation. In the south, water is available on the surface in the form of rivers and extensive wetland systems. In the north, open sources of water are generally restricted to *cenotes* – natural karst sinkholes. However, within the northeastern portion of the Yucatán Peninsula of Mexico, the Yalahau region, there is a major freshwater wetland system; a unique environmental setting in the northern Maya Lowlands. A single wetland contained within El Edén Ecological Reserve has been systematically surveyed, resulting in the documentation of 78 human constructed rock alignment features. Over the last several years, reconnaissance has recognized similar rock alignments in several other Yalahau wetlands. While various functions and chronological assessments have been hypothesized for these rock alignments, these ideas are only now being tested.

The research presented here will describe the forms and elucidate the functions of rock alignments within El Edén wetland. First, a description of the environment and resources of the Yalahau wetlands, including how they have changed through time, is integral to understand with what and for what the wetlands were modified. A sample of the rock alignments will be presented in detail. A discussion elucidating the context of the rock alignments within the environment and how they would have functioned.

## DISSERTATION OUTLINE

The current chapter will outline the relevant environmental background. Chapter two will outline the theoretical perspective of historical ecology and resilience, as well as the relevant background information. It will conclude by discussing the hypotheses and research questions. Chapter three will summarize the methods and methodology of the research. Chapter four will present the data that will be discussed and interpreted in chapter five.

Chapter six will conclude and summarize the research presented here. Throughout the dissertation, the aim is to demonstrate how the ancient Maya developed specifically adapted wetland agricultural techniques by elucidating the functions of the rock alignments. While ascertaining the function of the rock alignments, the dissertation will also comment on how a changing environment might have contributed to the population history of the Yalahau region. The dissertation will culminate in a summary of how the rock alignments functioned in a dynamic wetland environment.

## The YALAHAU REGION

The Yalahau region (Figure 1.1), defined since 1993 (Fedick and Taube 1995; Fedick et al. 2000; see also Dunning, Beach et al. 1998; Dunning and Beach 2010:370), has been the subject of a wide range of archaeological and ecological studies (for example: Fedick and Mathews 2005; Fedick and Morrison 2004; Glover and Esteban Amador 2005; Glover 2006; Perry, Velazquez-Oliman, and Socki 2003; Shaw and Mathews 2005; Torrescano and Islebe 2006; Wollwage 2008; Wollwage et al. 2012; at El Edén wetland: Anaya et al. 2003; Goode and Allen 2008; Morrison 2000; Morrison and Cózatl-Manzano 2003; Novelo and Tavera 2003; Schultz 2001; Solleiro-Robolledo et al. 2011). Recent and ongoing studies provide baseline data on ancient settlement patterns, distribution of natural resources, and impacts of climatic changes on wetland ecosystems. Plausible hypotheses can be formulated concerning the possible functions of the rock alignments and how the function of these features may have ceased or been modified in response to long-term changes in wetland water levels. A detailed study of a single wetland system is necessary to understand the placement of engineering features in

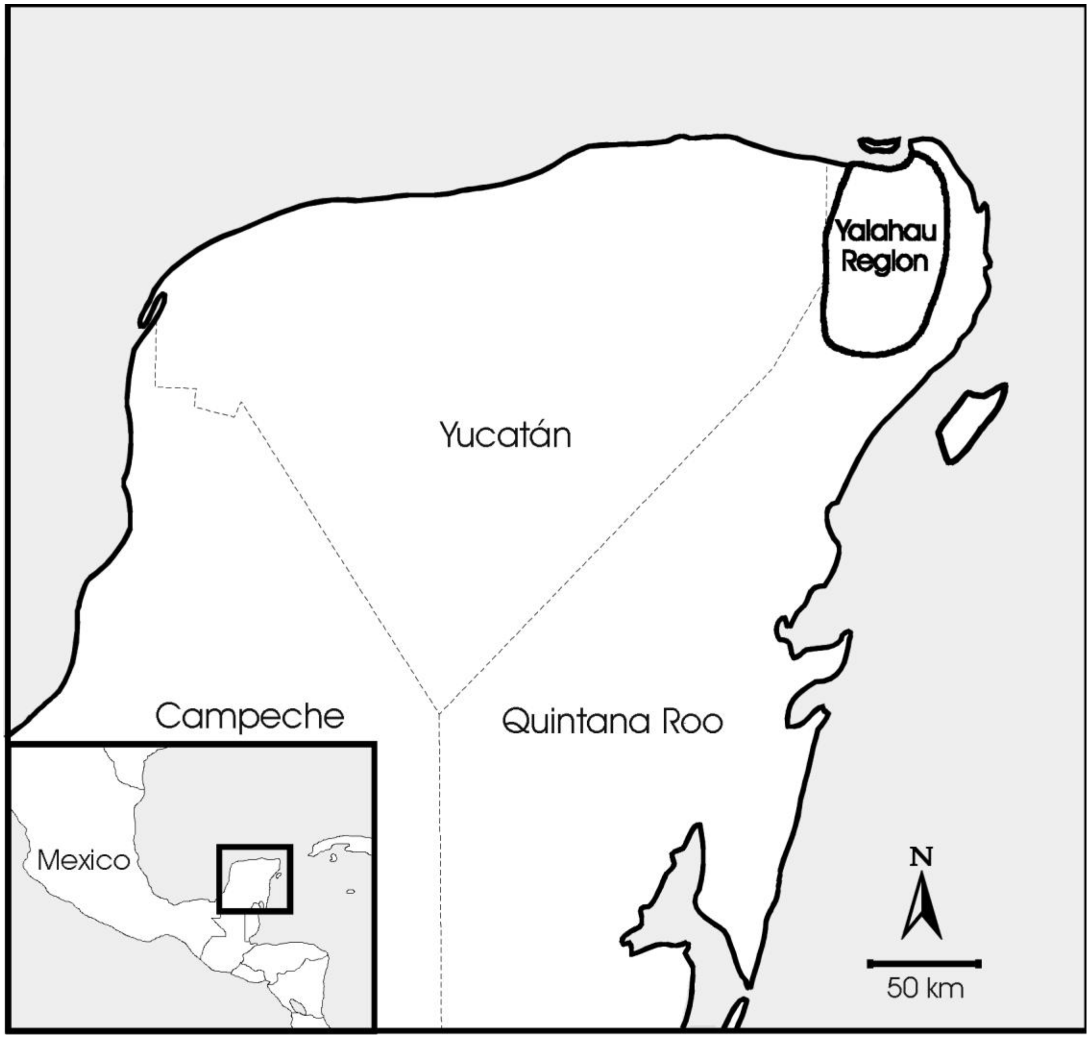

Figure 1.1 Map of the Yucatán Peninsula showing the location of the Yalahau Region. Image courtesy of Scott Fedick.

relation to fine-scale topographic, hydrologic, and environmental contexts. A reconnaissance level regional survey of the Yalahau wetlands, currently being undertaken as a collaborative study and additional dissertation (Leonard, personal communication), will allow extrapolation of the detailed findings at El Edén to be tested and refined at the regional scale.

A multidisciplinary historical ecological approach combining archaeology with natural sciences is indispensable to investigate human use of wetlands through time (Whitmore et al. 1996). To understand the intended functions of the rock alignments in the wetlands, the past environment must also be reconstructed. The Yalahau wetlands exhibit a dynamic pulse-based ecosystem of fluctuating water levels at scales that range from annual, decadal, through centennial and beyond in response to seasonal precipitation, hurricanes, and global climate change, respectively. Boundaries of vegetation zones mirror shifts in the water table. While challenging, the diverse and changing wetland environment may have offered the ancient Maya a wide range of adaptive strategies.

## ENVIRONMENTAL SETTING

### *Mesoamerica*

Mesoamerica is a culture area that, loosely bounded, spans the geographic areas between northern Mexico south to Nicaragua. It incorporates the modern day countries of Mexico, Belize, Guatemala, El Salvador, Honduras, and Nicaragua (West 1964; Whitmore and Turner 2001). Due to the longitudinal extension of Mesoamerica, it spans a wide range of environmental zones from tropical through subtropical and including the Mexica Highlands, the

Pacific Littoral, the Gulf Coast Lowlands, the Maya Lowlands, and the Maya Highlands. Deserts occur in the northern portions. Volcanic highlands dominate the central highlands through the south and west. A narrow coast runs between the highlands and the Pacific. The Gulf coast is lush and humid. To the south and east, the area of the Yucatán Peninsula, flat limestone plains monopolize the terrain but this land faults, creating an undulating topography as one moves south. Distributions of natural resources including the geology, vegetation, water, and soils as well as climatic influences are variable throughout this area.

Throughout Mesoamerica, the climate varies from a tropical-wet climate on the west to a tropical wet-dry climate on the east. Seasons are more pronounced in the northern portions, whereas toward the more tropical sections each year there is a rainy season in the summer and fall with a dry period and potential drought during the winter and spring dry season. Climate is further divided into zones based on altitude, as temperatures drop with an increase in elevation. Vegetation is dependent on climate, soils, and topography resulting in each of the elevation divisions exhibiting a distinct vegetation regime (Olmsted 1993; West 1964; Whitmore and Turner 2001; Vivó 1964).

Geology. Underlying geology variable throughout Mesoamerica due to the convergence of multiple tectonic plates. Bedrock “is a mixture of crystalline, volcanic, and old, folded limestone and sandstone uplands (mountain ranges, tablelands, and escarpments) and lowlands of youthful sediments and limestone shelves” (Whitmore and Turner 2001: 8).

Northern Mexico, on the northern margins and extending beyond the boundaries of Mesoamerica, is composed of three areas including the Mesa del Norte, Sonora and northern Sinaloa, and most of Baja California. Within the extensive dry deserts of Baja California bare rock and sand dunes predominate. Deserts also dominate the area of Sonora and northern Sinaloa, but streams from the Sierra Madre Occidental carve out desert valleys. The Mesa del Norte features a high plateau and basin-and-range topography of volcanic and karstic bedrock (West 1964).

The central portion of Mexico is bounded by two mountain ranges; the Sierra Madre Occidental on the north and northeast side (that grades into the Sierra Madre del Sur in its southern extent, until the Isthmus of Tehuantepec) and by the Sierra Madre Oriental on the south and southeast, running along the western gulf coast until the Isthmus of Tehuantepec. The central portion is called the Mesa Central (Meseta Central by Whitmore and Turner 2001). Within the Mesa Central there are valleys and uplands, including the Valley Of Mexico and the Transverse Neo-volcanic range (marking the southern termination of the Meseta Central) (Whitmore and Turner 2001). The interior geology is volcanic. South of the Mesa Central, the body of Central America thins at the Isthmus of Tehuantepec, dividing east and west Mesoamerica (West 1963; Whitmore and Turner 2001).

To the north and north west of the Isthmus of Tehuantepec and running alongside the east of the Sierra Madre Oriental are the Gulf Coast Lowlands. The Gulf Coast Lowlands are a relatively wide and flat alluvial plain where many rivers flow before emptying into the Gulf Coast (West 1964).

Along the west coast is the Pacific Coastal Plain. Unlike the Gulf Coast Lowlands, the Pacific Coastal Plain is a thin band of land running between the southern mountain ranges and the Pacific Ocean. Also unlike the Gulf Coast Lowlands, where the river drainage are wide and muddy, in the Pacific Coastal Plain they are short and deep, leading nearly straight from the highlands into the Pacific (West 1964; Whitmore and Turner 2001).

To the east and northeast of the Isthmus of Tehuantepec are the Maya Lowlands, consisting of the Yucatán Peninsula and Belize, terminating at the southern continuation of the Sierra Madre del Sur. The Maya Lowlands are a comprised of a karst plateau that, in the north, is almost entirely flat but subject to horst and grabben faults towards the south (Dunning, Beach, et al. 1998). Almost no rivers run on the surface in the Northern Lowlands between the Bahía de Chetumal and the Laguna de Terminos. The Maya Highlands begin in Chiapas, after the Isthmus of Tehuantepec and continue south and southeast with many volcanic peaks among them.

Soils*.* Soils vary widely throughout Mesoamerica. “[T]he variety of the underlying bedrock and soil-forming processes spawns diversity in specific soil types and conditions. … [M]any of the soils throughout Middle America are excellent for cultivation, constituting some of the best found in the tropical world. These soils are volcanic, limestone, or alluvial in origin; they are found in the better-drained portions of the highlands, on volcanic slopes, on levees of major rivers, and on the limestone shelves where sufficient soil depth has accrued. Well-drained flood plains are uncommon, but many wetlands offer good soils for cultivation if inundation is controlled” (Whitmore and Turner 2001: 10).

Very generally, within the northern portion, sediments are often rocky and sandy, typical desert conditions. Soils along the Gulf Coast are eroded from the east side of the highlands and provide a fertile wide pain. Throughout the highlands, soils are volcanic in origin. Finally, in the lowland areas, soils are derived from limestone bedrock. Of course, extensive variation exists specific locales (Stephens 1964).

Soil formation is based on parent material, climate, plants and animal action, topography and associated water flow, time, and human impact (Stevens 1964). The material from which soils are formed provides the foundational minerals or fertility to the soil. Climate affects soil formation by determining the temperature, moisture, and wind regimes. Plants further break down the parent material and lends the developing soil organic matter. All plants, from large trees through microscopic algae, are critical factors in soil formation. Different compositions of plant communities contribute differently to pedogenesis.  In deserts and arid areas, little organic matter is contributed to the soil. In grasslands, much of the organic matter is provided beneath the ground as the plant dies, is replaced, but the roots decompose and provide organic matter. In forested areas, organic matter is not incorporated into the soils but leaves decomposing on the surface leach into the soil. In areas, such as the northern Yucatán, where both grasslands and forest exists, both vegetation communities contribute to soil formation.  Animals may help to break up soil and provide air space. Topography matters as it controls factors such as erosion and sedimentation, sun exposure, and facilitates the growth of vegetation. Soil needs time to form. Human action can be deliberate or not, such as the intentional excavation and movement of soil material or passive such as the contribution of phosphates (Stevens 1964).

Climate. Climate is variable across Mesoamerica .  In general, dominant influences are latitude, altitude, location within the Mesoamerican landmass, and ocean currents (Vivó 1964). Latitude impacts how much direct sunlight an area receives, the more northern areas exhibit distinct summer and winter seasons due to the annual fluctuation, whereas Mesoamerican areas closer to the equator have less yearly difference (Vivó 1964).  In terms of altitude as a climatic determinant, three altitudinal zones are recognized, each that imbue specific attributes to the land within that zone.  The zones are called: *tierra caliente* (hot land), *tierra templada* (temperate land), and *tierra fria* (cold land) (Whitmore and Turner 2001: 13; Vivó 1964).

Location within the landmass and distance from an ocean are highly related. Warm, humid air does not extend far inland and consequently, deep inland areas are drier than thinner portions of Mesoamerica. Additionally, warm currents move northwards from tropical waters and bring associated warm air into the land whereas cool currents travel southwards (Vivó 1964).

The *tierra caliente* occupy the lands below an elevation of 1000 m. Daytime temperatures range from 29 - 32˚ C while temperatures during the night may dip to 20 - 24˚ C. The *tierra templada* exist between 1000 to 2000 m elevation and here daytime temperatures range from 24 - 27˚ C, though may reach 35˚ C during the dry season, and night temperatures are cool between 14 - 20˚ C. Frosts may occur in the more northern latitudes. The highest altitudinal zone, the *tierra fria*, exists above 2000 m. Within the *tierra fria*, temperatures during the day range from 20 - 27˚ C and the nights may be colder than 10 - 15˚ C with frosts potentially occurring between November and February (Vivó 1964).

In terms of rainfall, there is a distinct seasonality and almost no zone receives a stable year round rainfall. Most rain falls during the hot months of May through October and the least rain occurs between December and April. March is usually the driest month and September the wettest (Vivó 1964). Rainfall patterns are influenced by the movement of air masses from the ocean currents onto land, more rain falls within the coastal regions and on the eastern side of Mesoamerica (Vivó 1964).

Climatically, Mesoamerica is dominated by tropical wet and tropical wet-dry climates as well as some desert areas (Whitmore and Turner 2001). Vivó (1964) describes the climates of Mesoamerica as per the Koeppen classifications. Within Mexico, 50 percent of the area is a dry climate, 25 percent belongs to the tropical rainy climates, and the remaining 25 percent exhibits temperate climates (Vivó1964: 206). Generally, tropical wet climates occur along the Gulf Coast and the eastern sides of mountainous areas as well as on the Caribbean side of Lower Central America. Tropical wet-dry climates occur over the Yucatán Peninsula and along the Pacific side of Mexico and Central America. Deserts are more common in northern and central Mexico.

Of the dry climates, there are two types; desert and steppe. Both are arid but steppe receives nearly twice the rainfall as deserts. Steppe occurs on the margins of deserts, both covering the majority of northern Mexico and Baja California. Proper desert covers the majority of Baja California, western Sonora, and eastern Chihuahua and Coahuila. Variations further divide each the desert and steppe based on rainfall and temperature. Humid temperate climates occur, for the most part, within highland areas. Designation of humid temperate climates is based on the average temperature of the coldest month being above 0˚ C and the warmest above 18˚ C. Further variation divides the humid temperate climates on the basis of amount and seasonality of rainfall. Tropical lowland climates are defined on the basis that the average monthly temperature never falls below 18˚ C. Within the tropical lowland climates there are two subtypes: tropical wet-and-dry climates and tropical rainy climates. Tropical wet-and-dry climates exhibit a distinct dry season. Included are such areas as the Gulf Coast Lowlands and northern Yucatán. In tropical rainy climates, the dry season is very short to non-existent and occurs along the both the eastern and Pacific coasts of Mexico and Central America (Vivó 1964).

Vegetation. Across Mesoamerica, plant communities range from desert through tundra, into tropical rain forests and also extensive grass lands (Wagner 1964). Vegetation is influenced by multiple factors primarily climate but also including proximity to water, topography and altitudinal gradient, and soils and underlying geology. As per Whitmore and Turner (2001), evergreen tropical forest predominates throughout the Gulf Coast, through Chiapas and northern Guatemala, and southeastern Central America. In areas of a longer dry season, such as the Yucatán Peninsula and the Caribbean coast stretching along Honduras and Nicaragua, a semi-deciduous tropical forest dominates. Xerophytic vegetation occurs in desert climate zones with minimal water. Wetland vegetation occurs along the Gulf Coast, along major rivers and their drainages, as well as in periodically flooded lowland areas.

A number of factors play into the resultant vegetative community, as elaborated by Wagner (1964). Geographic controls, such as amount of sunshine - both daily and annually -, temperatures, latitude, altitude, slope and aspect, precipitation, proximity to water and/ or inundation (also whether this water is fresh or saline). Climate influences such as temperature, seasonal availability of moisture, and soils (as their development relates to climatic factors) will influence vegetation distribution. Finally, existing patterns of vegetation will also contribute to the patterning of vegetation zones.

Wagner (1964:222) divides Mesoamerica into six series, these include: the tropical rain forest, the montane formation, the seasonal formation, a dry evergreen formation series, a swamp series, and a seasonal swamp series.

Wetlands. Wetlands occur variously across Mesoamerica – from within highlands on the west side of Mexico, through the central valley, across lowlands, and along coasts, particularly the Gulf Coast – and take a variety of forms. Mangroves, salt marshes, salt flats, low inundated forests, *popales*, savannas, freshwater marshes, prairies, and palm thickets are some of the variety of forms that wetlands take within Mexico (Olmsted 1993; Smardon 2006). General characteristics of wetlands include standing water, unique soils, and vegetation adapted to the wetland regime (Mitsch and Gosselink 1994), but will vary individually in terms of the amount and duration of water (the hydroperiod), the influence of and on adjacent uplands, composition of specific – and often unique – wetland flora and fauna, size, extent, as well as location within a continent or land mass (Mitsch and Gosselink 1994).

An attractive feature of wetlands is that they often exist in ecotonal areas (Gunn and Folan 2000; Siemens 1996). At any point in a year, a wetland will be comprised of an area that is submerged as well as the surrounding dry area. The margins of a wetland, however, migrate across the landscape creating various zones throughout the year; there is an intermediate area that will vacillate between wet and dry for differing lengths each year. Vegetation distribution is influenced by the fluctuation between wet and dry zones according to the tolerance of vegetation communities to periods of excessive moisture or dryness. In terms of human occupations, these ecotonal areas are representative of dependable zones for resources.

Olmsted (1993) documented the variety of wetlands exhibited across Mexico. Throughout Mexico types of wetlands vary based on vegetative community, inundation, and salinity and include marine wetlands, estuarine wetlands, palustrine, and lacustrine wetlands (Olmsted 1993; Smardon 2006). The majority of Mexican wetlands are located along coasts, while other wetlands occur inland surrounding lakes or rivers, or seasonally within topographically low areas.

Of marine wetlands, there are two types present in Mexico (Olmsted 1993). The first type of marine wetlands are bays, the second are sea grass beds or "*ceibadales*" (Olmsted 1993: 643) Bays are identifiable in that they are connected to the ocean and receive minimal freshwater runoff. *Ceibadales* consist of essentially a meadow of sea grasses that occur along shores, often on the outside of mangrove ecosystems. *Ceibadales* may occur all over the coast but are conspicuously absent on the east and west coasts of the Northern Baja California.

Estuarine wetlands include both river deltas and coastal lagoons. Olmsted (1993) distinguishes four types of estuarine wetlands: mangrove swamps, hammocks, saline and brackish marshes, and salt flats. Multiple types of mangrove swamps occur throughout Mexico, depending on the particular location, specific geology, tides and wave action, salinity, as well as disturbance history. Generally, mangroves occur along river deltas or in narrow strips along the coast where there may be a deep development of soils. Mangrove vegetation is specifically adapted to waterlogged conditions in water that may be brackish to saline.

Hammocks (Olmsted 1993) occur frequently throughout the Yucatán Peninsula within wetlands of Campeche, Yucatán, and Quintana Roo. Hammocks, or *petenes*, are forested islands on deep organic soils within coastal wetlands but are not affected by tides. Even though they may be surrounded by saline water, the predominant source of water comes from a fresh water spring. One area of particular notice is the northwestern coast of the Yucatán peninsula east towards, and essentially terminating at, Rio Lagartos.

Saline and brackish marshes, or simply salt marshes, occur predominantly along the northern Pacific coasts, often in association with mangrove wetlands, coastal lagoons, or river deltas (Olmsted 1993). Salt marshes have some salinity and are somewhat affected by tidal action. Salt flats differ from salt marshes in that the soil salinity is higher. Salt flats occur along coasts and the specific vegetation community will depend on geographical location.

Lacustrine wetlands are broken down into two categories: freshwater lakes, reservoirs, and their littorals, and salt lakes (Olmsted 1993). First, freshwater lakes, reservoirs (both natural and anthropogenic), and the littorals occur throughout Mexico. Some characteristics include submerged and floating vegetation within shallow lakes. Salt lakes, the second type of lacustrine wetlands, are highly saline lakes that occur in more arid regions.

Palustrine wetlands occur as emergent wetlands including floodplain marshes, freshwater marshes, prairies, and savannas; shrub-scrub wetlands; and forested wetlands including riparian forests, palm thickets, and low inundated forests (Olmsted 1993). Palustrine wetlands are inland, lack flowing water, and are not influenced by tidal action.

Of palustrine emergent wetlands, floodplain marshes occur in areas that are almost constantly flooded over deep organic soils. Floodplain marshes occur especially in deltaic regions of rivers flowing into the Gulf of Mexico from the states of Tabasco, Campeche, and Veracruz.

Freshwater marshes of palustrine emergent wetlands in Mexico are most common overlying Cenozoic limestones in the state of Quintana Roo. Prairie and savanna palustrine emergent wetlands are similar except that savannas have more regular stands of trees. Both occur throughout the Yucatán Peninsula, savannas also occurring in Tabasco, Veracruz, and Chiapas. Shrub-scrub palustrine wetlands generally may occur within mangroves and savannas in Tabasco, Campeche, and Quintana Roo (Olmsted 1993). The vegetation is thick and dense, composed of viney shrubs not more than 4 m high.

Riparian forests are the first type of forested palustrine wetlands (Olmsted 1993). Riparian forests occur along rivers that are seasonally flooded in essentially all parts of Mexico. Specific vegetation communities are variable depending on where in Mexico the Riparian forest is.

Palm thickets occur along the Pacific, Gulf, and Caribbean coasts. Some palm thickets tolerate continues flooding whereas others do not. As per the name, the predominant vegetation is a type of palm. When the main palm is the tasiste palm (*Paurotis wrightii*), the area is called a *tasistal*. The specific vegetation community will differ depending on the local water regime.

Low inundated forests, or *selva baja inundable*, are the third variety of forested palustrine wetlands and occur especially through southeastern Mexico. Vegetation community is the primary difference between types of low inundated forests. Here the hydroperiod may range from six to twelve months and the trees comprising these wetlands must be adapted to long term inundation. Within low inundated forests, specific trees may dominate. When the predominant tree is palo tinto (*Haematoxylon campechianum*) the area is termed a *'tintal'*. Likewise, when the most frequent tree is the chechem tree (*Metopium brownei*) the area is termed a *'chechenale'*.

## *The Maya Area*

Within Mesoamerica, the Maya area encompasses the Mexican states of Quintana Roo, Yucatán, and Campeche as well as portions of Tabasco and Chiapas, the countries of Belize and Guatemala, as well as portions of Honduras and El Salvador. Physiographically, the Maya area can be divided into the Highlands, the southern Lowlands, and the northern Lowlands (Demarest 2004; West 1964).

The highlands are comprised of southern Guatemala and El Salvador are named as such due to the predominance of mountain ranges and volcanoes in this area. Altitudes often peak above 1500 meters above sea level while valley floors dip to low elevations. Due to the extreme elevations, there are a variety of environmental zones in the Maya Highlands. The highest zone, above 1500 meters above sea level, is a cloud forest. Between 800 to 1500 meters above sea level are pine oak forests.  Below the highlands at 800 meters above sea level are a mix of tropical wet forests, tropical dry forests, and savanna.

Within high reaching cloud forests, clouds are present most of the year at about thirty meters above the surface.  Due to the condensation of water from the clouds into the trees, the canopy supports epiphytes, ferns, mosses, orchids, and liverworts whereas the understory is relatively open.  Below the cloud forests in the pine-oak forests, the dominant vegetation is either pine or oak standing up to 35 meters high.  The air and soil are much drier than that of the cloud forests.  The tropical wet forests and the tropical dry forests can be found at lower elevations still. In the tropical wet forest, the canopy stands up at least 30 meters and houses multiple levels of vegetation leaving the forest floor relatively open.  In a tropical dry forest, the canopy is much lower, standing up to only 20 meters or less.  Vegetation of the tropical dry forest is adapted to an extended period without water and will lose their leaves in the dry season.  At the lowest elevations, there are savannas.  In savannas, grasses, shrubs, and small trees are the dominant vegetation, and gallery forests will occur where water collects.

Availability of water is variable throughout the highlands.  Water can be found in a few rivers and lakes scattered throughout the tropical wet forest.  Within the cloud forest, on the other hand, water is condensed from clouds.

The southern Lowlands cover the Petén of Guatemala, and Belize.  The underlying bedrock is limestone, resulting in rather flat region.  However, there are areas of rolling hills and also areas of steep escarpments caused by the faulting of limestone (Beach, Dunning, et al. 1998).  Vegetation zones grade between tropical wet forests, tropical dry forests, and savanna.

One of the unique environments within the southern Lowlands savannas are *bajos*. *Bajos* are low lying wooded areas that become swamps during the rainy season when water causes the clays to swell.  Vegetation is dense and the canopy is lower. Although there is lack  of available water throughout much of the year, the vegetation is diverse and home to epiphytic species of orchids and bromeliads.

The Northern Lowlands extend north across the Yucatán Peninsula.  Like the Southern Lowlands, the dominant geology is karst, but the limestone is of an older age.  The Northern Lowlands are much flatter than the Southern Lowlands, the only relief occurring in the Puuc Hills region on the west side of the peninsula.  Also due to the underlying karst bedrock, across much of the peninsula, water is not generally available on the surface in rivers and lakes.  Due to the porous nature of limestone, there is an extensive subterranean water system, accessed through *cenotes* or wells excavated into the relatively shallow bedrock.

### *The Yucatán Peninsula and Yalahau Area*

Approximately 335,000 ha of wetlands occur within the state of Quintana Roo, with another 184,000 ha located in the state of Yucatán (Olmsted 1993: 656).  The wetlands in Quintana Roo are comprised of mangrove swamps, large coastal bays, brackish and freshwater marshes, savannas, prairies, low inundated forests, and palm thickets (Olmsted 1993: 657).

Though the Yucatán Peninsula is essentially devoid of major sources of water, wetlands occur around the coastline as well as throughout faulted areas.  Perry et al. (2003: 120) note five hydrogeologic areas within the Yucatán Peninsula.  The first is a saline swamp around the north coast.  Second is a faulted east coast.  Third, is a pock-marked karstic plain in north-central Yucatán.  Fourth, on the west side in the northern portion of Campeche there is a region of large, flat, enclosed basins. The fifth area, in Quintana Roo, consists of the area surrounding Lake Chichancanab where the ground water has a high sulfate concentration.

In the northeastern corner of the peninsula is an area called the Yalahau region (see Figure 1.1). The Yalahau region covers about 2000 km$^2$ (Fedick et al. 2000; Fedick and Mathews 2005). It occurs to the south of the Holbox Island and extends south/southwest for approximately 30 kilometers. The Yalahau region is approximately 20 kilometers wide and does not contact the east coast. Within this area is the Holbox fracture zone, a deep geological anomaly (Perry et al. 2003; Tulaczyk 1993; Tulaczyk et al. 1993). The Holbox fracture zone is composed of a series of north-south trending elongated depressions in the limestone bedrock. Water table is exposed within depressions thus creating access to a resource that is often absent on the limestone shelf. The resultant 174 wetlands – and numerous *cenotes* – within the Holbox fracture zone are karstic freshwater inland marshes (Figure 1.2; Allen and Rincón 2003; Fedick 2003; Graham 2003; Mitsch and Gosselink 1994; Morrison 2000; Morrison and Cózatl-Manzano 2003; Perry et al. 2003), a type of palustrine wetland (Olmsted 1993).

The Yalahau wetlands are tapped into the water table and therefore water table levels are not solely reflective of precipitation and evapotranspration. A freshwater lens fed and recharged by precipitation and surface runoff rests on a saline water intrusion. Where the fractures of the Holbox zone extend below the water table, water is exposed. The water table beneath the Yucatán Peninsula ranges from a few meters at the coast to upwards of 100 meters inland in the Puuc region. Because the freshwater lens rests upon a seawater intrusion, consequently, water levels of the wetlands are also influenced by global sea level changes. All these multiple environmental pulses contribute to the water level at any given time.

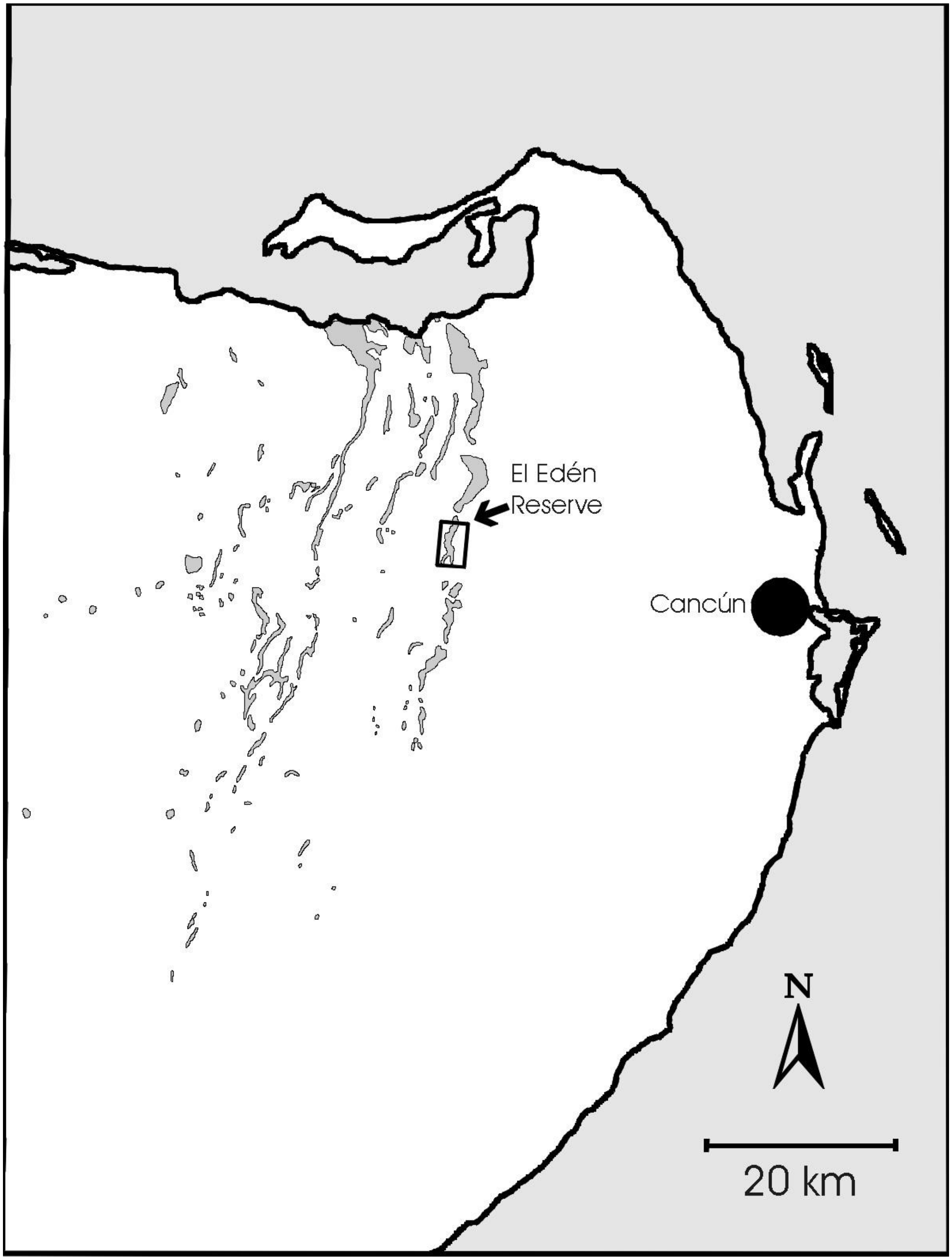

Figure 1.2 Map of the northeastern portion of the Yucatán Peninsula displaying the extent of wetlands within the Yalahau area. Image courtesy of Scott Fedick.

Throughout the Yalahau, wetlands are not uniform (Fedick et al. 2000; Fedick et al. 2010; Fedick and Mathews 2005; Leonard 2011; Morrison and Cózatl-Mazano 2003; Wollwage et al. 2012). Some wetlands occur over flatter areas while some are constrained within hilly terrain. Due to the diverse range of topography, the resultant flooding regimes and environmental gradients are quite different. In flatter terrain, an increase in the height of the water table results in a shallow but more widely spread flooding, whereas rising water levels within wetlands constrained between slopes will display less horizontal spread.

Across the Yucatán Peninsula and Yalahau wetlands there is minimal soil cover, rarely more than one meter except in karst depressions and *rejolladas* (Perry et al. 2003). Thus, water quickly percolates through the porous limestone bedrock to the water table. It should be noted, however, that some of the soils within the Yucatán Peninsula formed over limestone bedrock comprise some of the richest soils in Mexico (Fedick et al. 2000).

Climatic changes and weather also influence water table level fluctuations in the Yalahau region. Changes in climate impact global sea levels (Brenner et al. 2003; Gill et al. 2007; Gunn 1994; Gunn and Folan 2000; Hodell et al. 2000, 2007; Leyden et al. 1994, 1998; Whitmore et al. 1996). When the global climate is cooler, water is caught up in glaciers resulting in a lower sea level. Sea level will affect the baseline for the Yalahau wetlands as the fresh water lens rests on a sea water intrusion (Perry et al. 2003). The freshwater aquifer of the Yalahau region rests over a sea water intrusion and has been subject to cycles of raising and lowering in response to sea level change (Wollwage 2008). Sea level fluctuations, in turn are stimulated by global climatic changes (Gill et al. 2007; Hodell et al. 2000, 2007).

Weather patterns are influenced by global air streams but result in local events (Gunn and Folan 2000). Precipitation creates a seasonal rise in the water table level and causes the wetlands to expand. The northeastern corner of the Yucatán Peninsula is characterized by a rainfall anomaly that distributes similar volumes of precipitation as in the southern Maya Lowlands (Fedick et al. 2000; Wilson 1980; Winzler and Fedick 1995). Since the Yucatán Peninsula has a karst geology, high rainfall in one area will slowly percolate through the limestone into the regional aquifer (Giddings and Soto 2003). Hurricanes are one weather phenomenon that can raise the water table for several years afterwards (Whigham et al. 2003). The Yalahau wetland ecosystem can be characterized as a pulse system, the resulting vegetation distribution and water table level is subject to the convergence of these various pulses and will vary year to year.

### *La Reserva Ecologica El Edén*

The Wetland. El Edén Ecological Reserve is an ecological reserve that encompasses a single wetland within the Yalahau region (see Figure 1.2). It is located approximately 40 km northwest of the city of Cancun and covers 5.5 km north – south and 0.8 km east – west. Like the Yalahau region, El Edén is situated upon a limestone plateau and is thus governed by the same geologic and weather processes. The topography of El Edén is relatively flat, unlike some other wetlands that exhibit more hilly terrain that constrain the flooding of water. When the water table rises during the rainy season the flooding zone at El Edén is horizontally extensive. Whereas previous designations (El Eden Ecological Reserve 2006; Schultz 2001) have defined the wetland as those areas that contain permanent bodies of water throughout the year, the wetland, as defined here, will include all that area that is impacted by the seasonal fluctuation of water levels.

In terms of vegetation, even though El Edén was the focus of Schultz's (2001) formative vegetation study of the region, it greatly differs from other Yalahau wetlands (personal observation; Daniel Leonard, personal communication 2010). Due to the flatter topography, the gradients between vegetation zones are more extended. Particularly notable is the extent of tasiste palm (*Paurotis wrightii*) forming stands of *tasistal*, El Edén exhibits *tasistal* between areas of sawgrass and other sedges.

El Edén is under the same climatic influences as the greater Yalahau region and Yucatán Peninsula. A rainy season extends from June through December (Fedick et al. 2000) and rain within a few days may cause the wetland to swell with water (personal observation). As exhibited throughout the Yalahau and Yucatán Peninsula, the ecosystem is pulse-based, being driven by events of differing magnitudes and frequencies.

El Edén wetland is in an area of low relief and therefore has a relatively wide flooding zone. There is minimal soil development or sediment cover within most wetlands, averaging 10 centimeters in depth and rarely exceeding 50 centimeters. Pockets of deep soil occur in small limestone holes as well as larger *cenotes* (Wollwage et al. 2012).

Vegetation. As has also been recognized elsewhere (Fedick et al. 2000; Shultz 2001; Solleiro-Rebolledo et al. 2011), vegetation is patterned according to elevation and duration of contact with the water table. Areas that are inundated all year round or nearly all year round exhibit plant species adapted to that specific hydrologic regime. Within the El Edén Ecological Reserve there are comprised by seven major ecosystems (El Eden Ecological Reserve website 2006; Shultz 2001): semideciduous tropical rainforest, secondary semideciduous forest, seasonally inundated forest, palm grove, savanna, other wetlands, *cenote*. Olmsted's (1993) classification corresponds to El Edén (2006) and Shutlz (2001) in the following manner;

seasonally inundated forest is the same as low inundated forest. Both comment on the tendency of stands of palo tinto (*Haematoxylon campechianum*) that are called *tintal*. Palm grove and palm thickets are the same, at El Edén the dominant palm being the tasiste and the resultant areas being *tasistal*. Shultz's savanna corresponds to Olmsted's emergent freshwater marsh, emergent prairie, and emergent savanna. Olmsted bases these differences based on a gentle gradation from more grassy vegetation types to more frequent trees.

The vegetation of El Edén has been classified generally as including successional stages of medium-statured-semideciduous forest (*selva mediana*) and seasonally inundated forest (*tintal*) (El Eden Ecological Reserve 2006; Shultz 2001). Shultz (2001:80) defines five major vegetation types at El Edén Ecological Reserve: mature medium-statured semideciduous forest (*selva mediana*), secondary/ successional forest (*acahual*), seasonally inundated forest (*tintal*), savanna, and wetlands. Of primary focus for the current dissertation are the final three zones, *tintal*, savanna, and wetland. Also substantial within El Edén is the area called *tasistal*, synonymous with the palm grove as defined on the El Edén Ecological Reserve website. It is transitional between the *tintal* and into the savanna.

Mature medium-statured semideciduous forest is located furthest from the wetland area of El Edén. It is comprised of trees older than 50 years, a canopy that reaches generally 10 – 12 meters with some trees extending to 15 meters height. Due to the maturity of the forest, the understory of smaller plants, including plants and herbs, is open and well established. Dominant tree species include: *Manilkara sapota*, *Metopium brownei*, *Lysiloma latisiliquum*, *Thrinax radiata*, *Bursera simaruba*, *Sebastiana adenophora*, *Vitex gaumeri*, *Brosimum alicastrum*, *Ficus pertusa*, and *Acacia dolichostacya*. Dominant shrubs include: *Psychotria nervosa*, *Psychotria pubescens*, *Randia aculeate*, *Piper psilorachis*, *Piper Yucatánensis*, and

*Bromelia plumieri*. Dominant herbs include *Stendandrium subcordatum*, the grass *Olyra latifolia* and *Lasiacis ruscifolia*, the sedge *scleria litheosperma*, and the fern *Anemia adiantifolia* (Shultz 2001: 80).

Called secondary or successional forest, or *acahual*, is forest younger than the mature medium-statured semideciduous forest. Consequently, the trees may be of varied ages with a canopy up to 8 meters. Due to the younger age (as compared to mature forest), the undergrowth is dense and often impassable. The dominant tree species include: *Metopium brownei*, *Swartzia cubensis*, *Lysiloma latisiliquum*, *Busera simaruba*, *Vitex gaumeri*, *Lonchocarpus rugosus*, *Lonchocarpus xuul*, *Nectandra coriacea*, *Jatropha gaumeri*, and *Piscidia piscipula*. The dominant plant species, shrubs and small trees, within the understory include: *Acacia cedilloi*, *Acacia collinsii*, *Croton* spp., *Callicarpa acuminata* and *Randia aculeata*. Also within the acahual are many vines and lianas including *Similax* spp., *Pisonia aculeata*, *Bauhinia jenningsii*, *Cynanchum schlechtendalii*, as well of species from the Convolvulaceae and Cucurbitaceae families (Shultz 2001: 81). Parts of the study area, such as along the transects, are representative of *acahual*.

Seasonally inundated forest, or *tintal*, is heavily represented within the study area. Water from the expanding wetland encroaches into the *tintal* for 4 - 6 months of inundation. Because the ground is not even, there are outcrops of upraised bedrock as well as depressions, the resulting distribution of vegetation is patchy and dependent on specific tolerances to extent of inundation (Fedick et al. 1998). Upon raised outcrops are plant species that are slightly less tolerant of prolonged inundation such as the trees *Haematoxylon campechianum*, *Eugenia winzerlingii*, *Erythroxylon confusum*, and *Byrsonima bucidaefolia*; and the shrubs *Jacquinia macrocarpa* spp. *macrocarpa* and *Randia aculeata*. Epiphytes are abundant and include twelve species from Orchidaceae, nine species from Bromeliaceae, three species from Cactaceae, as well as *Anthurium schlectendallii*. Slightly lower and flatter areas are more open in terms of vegetation and are dominated by the sedge *Rhynchospora nervosa* and herbs such as *Cuphea gaumeri*, *Spermacoce verticillata*, *Heliotropium ternatum*, and *Evolvulvus alsinoides* (Shultz 2001: 81).

Bordering on the *tintal* is the savanna area, where the extent of inundation is more prolonged and the vegetation in the savannas are adapted to the specific hydrologic regime. Some areas of the savanna are dominated by the tasiste palm (*Paurotis wrightii)* (Fedick et al. 2000). The calabash tree, (*Crescentia cujete)* is also prominent in this vegetation area. Lower portions of the savanna endure more prolonged flooding and are dominated more by grasses. Sedges, particularly *Cladium jamaicensis* (sawgrass) and *Eleocharis* spp., grow in and around the tasistal. Stands of *Typha dominguensis* (cattail) and *Pragmites australis* (reeds) occur in more frequently inundated areas with deep sediments. Other prominent plants include: *Nymphoides indica*, *Sagitarria lancifolia*, *Bacopa procumbens*, *Lippia nodiflora*, *Lippia stochidaefolia*, *Hymenocallis littoralis*, *Pluchea symphytifolia*, *Solanum donianum*, and *Ouratea lucens*. Throughout this area there may be individuals or clusters of *Crescentia cujete* (calabash tree) (Shultz 2001: 81-81). Each of these zones in the savanna will be differentiated based on the dominant plant assemblage; *tasistal* or palm savanna, sawgrass savanna, and cattail savanna.

A few locations at El Edén contain water throughout the year. Within areas that do contain permanent bodies of water, dominant plants include the aquatics *Nymphaea ampla*, *Polygonum hydropiperoides*, *Ludwigia octavalvis*, and *Utricularia gibba* (Shultz 2001: 82).

Soil. Soil development in the Yalahau region is influenced by the underlying limestone bedrock as well as the local flooding regime (Sedov et al. 2007, 2008; Solleiro - Rebolledo et al.

2011). Soils in the upland areas surrounding the wetland are generally Leptic Phaeozems and Rendic Leptosols, whereas the soils within the wetland area are Leptic Calsisols (Sedov et al. 2008). Upland soils show more influence from the contribution of organic matter whereas soils formed in the wetland are due to the secretions of periphyton. Along the margins of the wetland, however, the soils are polygenic having different causes of pedogenesis. Some bands of the soils resemble the more organic upland soils whereas other bands resemble soils formed within the wetland. Such banding of different soils indicates the dynamic environment of the wetland shifting through time, remaining stable during either extended dry or wet periods.

## PAST and ONGOING RESEARCH

Agricultural and paleoenvironmental research have been a focus of Maya archaeology for at least the past fifty years. Domesticated crops known to have come from Mesoamerica and South America include maize, or corn (*Zea mays* L.), sweet potato (*Ipomoea batatas* L.), cassava, or manioc (*Manihot* spp.), New World cotton (*Gossypium hirsutum* L.), tobacco (*Nicotinna rustica* L.), cacao (*Theobroma cacao* L.), tomato (*Lycopersicon esculentum* Mill.), squashes (*Cucurbita* spp.), beans (*Phaseolus* spp.), cocoyam (*Xanthasoma sagittifolium*), chilies (*Capsicum* spp.), avocado (*Persea americana* Mill.), and papaya (*Carica papaya* L.) (Whitmore and Turner 2001: 3). Shifts have occurred in the conceptions of ancient Maya subsistence. Early interpretations were of small scale production, later replaced by intensive, shifting cultivation, and now is characterized by a more nuanced and detailed study into specific environmental mosaics (Fedick ed. 1996). In some cases, management of the environment for cultivation blended into the landscape and mimicked nature (Demerest 2009; Gómez-Pompa and Kaus

1990, 1999; Whitmore and Turner 2001). Wetlands of the northern Maya Lowlands provide a unique environment to investigate new possibilities of landscape and agricultural management.

### *Mesoamerica*

Evidence for wetland management through Mesoamerica extends back over two thousand years (Frederick 2007; Luzzader-Beach et al. 2012; Sluyter 1994; VanDerwarker 2006; Whitmore and Turner 2001). Upon arrival to the New World, Cortés and his conquistadores were brought to the Valley of México where they witnessed wetland fields and canals; a great marvel of agricultural and environmental engineering (Whitmore and Turner 2001). Other water management techniques were spread throughout the different environmental zones of Mesoamerica, some were witnessed but some had already fallen from use. Comprehension of local environments is demonstrated in each case by the implementation of specific and effective adaptations.

In wetlands throughout Mesoamerica, the primary type of modification was the creation of ditches and canals as well as raised planting surfaces (Whitmore and Turner 2001). Wetland agriculture occurred in various contexts such as along streams, flooded river plains, in lake basins, and at springs (Sluyter 1994).

Intensive wetland management and cultivation systems, those that required more labor and modification in order to alter the water table level for cultivation, are also present throughout Mesoamerica, in many of the same locations that recessional cultivation is practiced (Whitmore and Turner 2001). Such intensive wetland practices took the form of ridged fields, raised fields, ditched fields, platform fields, island beds, ditched fields, ditched or drained fields, channelized fields, mounded fields, and *chinampas* (Sluyter 1994; Whitmore and Turner 2001).

All are variations in terms of depth, height, and shape of canals, ditches, and planting surfaces and may be suited to specific water regimes.

Sluyter (1994) identifies five distinct areas within Mesoamerica where wetlands and settlement coincide. Each area has a distinctive geologic and climatic situation that warrants wetland management. The five areas are as follows: the Mesa Central, the Southern Highlands, the Gulf Coast, the Maya Lowlands, and the Maya Highlands. Most evidence of settlement and management of wetlands occurs in the Mesa Central region, the Gulf Coast region, and the Maya Lowlands. Additionally, Whitmore and Turner (2001: 196) have identified three types of wetland cultivation: recessional and subsurface moisture cultivation, intensive wetland cultivation, and *chinampa* cultivation. Each system different in terms of how much human labor was invested into it, how extensively the landscape was modified, and the intensity of output. Wetland cultivation systems were prominent in the tropical lowlands approximately 500-800 years before contact whereas in the highlands, wetland cultivation systems were in use at contact.

The first of these areas defined by Sluyter (1994) is the Mesa Central; the area throughout central Mexico's volcanic ranges and basins. Wetlands occur in an arc from northwest to southeast through these basins. One of the main basins is the Xochimiloco-Chalco basin around the location of Tenochtitlan. Other basins that contain archaeological evidence of wetland management include the Puebla-Tlaxcala Basin, the Huamantla Basin, and the Toluca Basin, as well as the Etzatlán and Teuchitlán basins (Sluyter 1994). In the Valley of Mexico, wetlands and settlement extended throughout the east of Lago Texcoco, Río Cuauhtitlán, east of Lago Chalco, and surrounding Teotihuacán (Whitmore and Turner 2001). Much intensive wetland cultivation occurred throughout the Valley of Mexico, especially on the margins of lakes, including Lagos Chalco, Texcoco, Xaltocán, Citlaltepec, and Xochimilco (Whitmore and Turner 2001). The primary modification of this area are chinampas, raised and constructed planting surfaces on the margins of lakes (Frederick 2007).

The second area are the Southern Highlands, located south of the Mesa Central east to the Isthmus of Tehuantepec (Sluyter 1994). Within this area, there is not much evidence for cultivation or management of wetlands. However, there are some possible wetland fields near to Monte Alban in the Valley of Oaxaca, the association may hint at ancient use and management. Due to a high water table, wetland cultivation was possible in the Valley of Oaxaca, though these are not proper wetland areas (Whitmore and Turner 2001). Additionally, at the headwaters of the Río Lerma in the Toluca basin, there are many swamps and shallow lakes. The Etatlán-Magdalena and Teuchitlán-Ahualulco-Tala basins in Jalisco as well as the Ciénaga de Tala between the Ríos Salado and Cuisillos. These latter areas show signs of ancient settlement and wetland use.

Within the Mexica Highlands Whitmore and Turner (2001: 213) report that although there are vestiges of intensive wetland systems, the evidence has been obscured. In the Puebla-Tlaxcala area raised fields were created on the floodplains of numerous rivers including Ríos Zahuanpan, Atoyac, and at Lago Acuitalapilco.

The third area that contains ample evidence of wetland management is the Gulf Coast region (Sluyter 1994). Many of the rivers that drain from the highlands into the Gulf of Mexico create back swamps near the mouths of the streams. Here, the "lower portion of the back of levees, and the edges of swamps, marshes, and shallow lakes where moisture-rich soils are exposed during the dry season" (Whitmore and Turner 2001: 199-200). Although Sluyter (1994) reports the vestigial fields here are understudied, some work has been done at Estero de Tres

Bocas, Río Recolutla, and Río San Juan. Settlement within the Gulf Coast Lowlands was extended throughout the Río Coatzacoalcos and the Río Tonalá basins, the Río Tuxpan to the Río Nautla, the Tlaxcala Basin, the Toluca Basin, and Lago Patzucaro (Fisher 2007; Whitmore and Turner 2001). Areas of wetland cultivation and settlement within the Gulf of Mexico drainage include the Río Coatzacoalcos, and Ríos Mezcalapa, Grijalva, and Usumacinta (Siemens 1996, 1998; Whitmore and Turner 2001). Additionally, wetlands along the southern Gulf Coast throughout the Tuxtla Mountains were heavily managed (VanDerwarker 2006).

### *Maya Area*

Human populations are present within the Maya area and practicing cultivation by 3000 BC as there is evidence for maize in the Rio Hondo valley in Belize (Pohl et al. 1996). Evidence for maize is also present in the area of Coba by 850 BC (Leyden et al. 1998). Modifications of the environment for agricultural purposes occurred throughout periods of extensive environmental and climatic fluctuations.

Specifically in the Maya area, within the karstic southern Maya Lowlands wetland manipulation took advantage of seasonally inundated soils along the margins of clay-filled basins called *bajos* (Beach et al. 2003; Dunning and Beach 2000; Dunning et al. 1998; Folan et al. 2002; Harrison 1978; Kunen 2004; Luzzader-Beach et al. 2012; Scarborough 1996). Other research into wetland use in the southern Maya Lowlands has focused in riverine associated wetlands (Harrison 1996; Siemens 1996; Pohl and Bloom 1996; Pohl et al. 1996; Pope et al. 1996).

Sluyter (1994) also discussed the Maya Lowlands, a region that extends from the western margin of the Gulf Coast and Isthmus of Tehuantepec, through the Yucatán Peninsula, and border the Maya highlands to the south and east. The Maya Lowlands is dominated by karst, or limestone, geology (Allen and Rincón 2003; Dunning and Beach 2000; Gill 2000; Graham 2003; Gunn and Folan 2000; Olmsted 1993; Perry et al. 2003; Sluyter 1994; Ward et al. 1985; Whitmore and Turner 2001). Water is not generally retained on the surface. In the Northern Maya Lowlands, particularly the Yucatán Peninsula, there is a series of wetlands extending from the Holbox on the northeast corner approximately 50 km south, south-west (Fedick et al. 1994; Perry et al. 2003). Within the Central and Southern Lowlands, water may be held on the surface seasonally in inundated clayey depressions called *bajos* (Beach et al. 2003; Dunning and Beach 2000; Dunning et al. 2002; Dunning et al. 1998; Harrison 1977, 1978; Kunen 2004; Scarborough 1996). In some riverine areas, such as the Río Candelaria (Hodell and Brenner 2001; Sluyter 1994) on the western side of the Yucatán Peninsula, water created back swamps that were utilized for cultivation.

Across the Maya Lowlands there is documentation of wetlands and settlement (Whitmore and Turner 2001). Within the Río Candelaria Basin in Campeche, Mexico and Northern Belize there is evidence of wetland cultivation. Another area of wetlands that have evidence of management include the areas from the Bahía de Campeche west through the lower Mezcalapa-Grijalva-Usumacinta basin in Tabasco. Also, throughout the lower Río Motagua as well as the Río Ulúa draining into the Gulf of Honduras in eastern Guatemala, the Río Sastún in Belize and Guatemala, as well as the Sula and Chamelecon valleys in Honduras, on the Río Dulce in Guatemala, Ríos Naco and Motagua in Honduras there was settlement combined with wetland management (Whitmore and Turner 2001). Areas of wetland management and settlement in the Gulf of Honduras drainage include the areas surrounding Río Ulúa, Río Chamelecón, Río Motagua, Río Dulce, Río Sarstún, and Río Belize (Whitmore and Turner 2001).

Within the Maya Lowlands, intensive wetland management systems occur in three of the major drainage areas: Gulf of Mexico, Gulf of Honduras, and the Guatemalan highlands (Whitmore and Turner 2001). Within the Gulf of Mexico, settlement and wetland cultivation occurred along the Río Candelaria, and the Mezcalapa-Grijalva-Usumacinta basins. Within the Gulf of Honduras, the areas along Ríos Ulúa, Chamelecón, and Motagua were settled and utilized wetlands.

Sluyter's fifth defined area is the Maya Highlands, to the south and west of the Maya Lowlands bordering the Pacific Ocean coastal plain (Sluyter 1994). There is some evidence for wetland cultivation in some volcanic basins near Quetzaltenango, Almolonga, Antigua, and Panajachel. There is minimal evidence for intensive wetland management within the Maya highlands, however, throughout the Guatemalan Highlands the areas surrounding Lago Atitlán, Alomolonga and Quetzaltenango, as well as Antigua and Santa Catarina Barahona took advantage of wetlands for cultivation (Whitmore and Turner 2001).

Climate. Climate and paleoenvironmental research (such as the studies conducted by Brenner et al. 2003; Hodell et al. 2000, 2007; Islebe and Sánchez 2002; Leyden et al. 1994, 1998; Mueller et al. 2009; Solleiro-Robolledo et al. 2011; Torrescanao and Islebe 2006; Whitmore et al. 1996) have clarified fluctuating environmental conditions, particularly water table levels and distribution of major plant communities, throughout the Maya occupation of the Maya Lowlands. Analysis of sediment cores indicate that basins within the Yucatán Peninsula began filling with water beginning around 6500 BC. Conditions were predominantly wetter until about

4000 years ago when a general drying trend began. Throughout the early Preclassic, from approximately 1900 – 1500 BC, the water table was lower. After centuries of wet to dry oscillations, from the Late Preclassic into the Classic period, 500 BC – AD 500, overall rainfall increased although the water table remained nearly 1 m below current conditions. A shift to a warmer and drier climate began at the start of the early Classic, AD 250, through the Terminal Classic, AD 1080, with especially dry periods from about AD 535 – 550 and in the Terminal Classic, AD 700 - 900. Conditions returned to a warmer and wetter in the Postclassic, after the Terminal Classic drought. Water table rose slowly but consistently from the Preclassic period.

Other Anthropogenic Landscape Modifications. Kunen (2001) reports on the construction of terraces within northwest Belize as a practice of modifying the landscape to make it productive ecologically while sustaining a social population.. Relevant to the current research question are the description of dry slope terraces that may be constructed either along topographic contours or straight and often perpendicular to slope in efforts to increase depth of sediment and conserve moisture (more references). There are two other types of terraces, not so relevant there, including cross dam terraces and footslope terraces.

In terms of human reaction to environmental fluctuations, Beach, Dunning, and colleagues (Beach et al. 2009; Dunning et al. 1998, 2002; Luzzader-Beach et al. 2012) have documented changing landscape management practices such as the abandonment or modification of water and land management practices in the southern Maya Lowlands. Dunning et al. (1998) found that intensive agricultural technologies – terraces and check dams – were used to mediate increased soil loss due to deforestation occurring during periods of climatic change. Dunning et al. (2002), through the study of agricultural modifications and climatic shifts, trace the transformation of perennial wetlands and shallow lakes or *civales*, into *bajos* now present in the southern Maya Lowlands. Specifically relating to wetland agricultural practices, Beach et al. (2009) seek to define the various trajectories of wetland formation, through both natural and anthropogenic modifications. Both anthropogenic and climatic changes converge and are demonstrated in changing agricultural and water management practices or migration.

### *The Yalahau Area*

Recent research in the Yalahau region has documented an abundance of ancient Maya settlements dating back to at least the Middle Preclassic, approximately 700 BC, with a sharp population increase during the Late Preclassic that was sustained into the Early Classic (Fedick and Mathews 2005; Glover 2006; Glover and Amador 2005). Subsequently, there appears to be a near abandonment of the region during the Early Classic, with minimal evidence of occupation through the Late and Terminal Classic periods. However, beginning in the Late Postclassic period, approximately AD 1250, there was a resurgence of settlement in the region that lasted until European contact in the early sixteenth century.

Human use and manipulation of the Yalahau wetlands is indicated by constructed rock alignments within them (Figure 1.3). Rock alignments were first observed at a wetland contained within El Edén Ecological Reserve in 1993 by Arturo Gómez-Pompa and subsequently verified and documented by Scott Fedick (Fedick 1996, 1998, 2003; Fedick et al. 2000). Additional rock alignments are present in a number of other wetlands in the Yalahau region (Fedick and Morrison 2004; Fedick et al. 2010; Leonard 2011).

Within the El Edén wetland, a total of 78 individual rock alignments have been documented (Figure 1.3; Fedick et al. 2000). These alignments were constructed of limestone boulders and slabs, and vary in length from a few meters to over 700 meters. The alignments also vary in shape, construction, and are found in a number of different physiographic settings within the wetland. Fedick et al. (2000) produced a typology of the rock alignments based on basic form and orientation and location within the wetland.

The five rock alignment types can be summarized as follows: Type one alignments close off or divide up large portions of the wetland. Examples of Type Two alignments block lower parts of the wetland and often occur along the margins of natural depressions. Type Three alignments run perpendicular to slight slope gradients in areas of higher elevation, such as tintal vegetation zones. Type Four alignments run perpendicular to slight slope gradients in areas of lower elevation, such as in tasistal, sawgrass savanna, and cattail savanna. Type Five alignments cross narrow and relatively deep channels in the wetland.

During the 1996 - 1997 field season, Fedick et al. (2000) excavated an example of each type of rock alignment with the exception of Type Five. During the course of excavation, Fedick et al. (2000) were able to discern the construction techniques of the rock alignments. Essentially, though they do not list it as such, there are three general construction techniques that were employed in building the rock alignments. The first type is exhibited in rock alignment 41. Slabs of limestone were propped upright and held in place by boulders on the outside. The limestone slabs average 60 cm across and 10 cm thick, the boulders between 10 - 30 cm in diameter (Fedick et al. 2000: 138). Alignment 42 was also constructed using the boulder and slab method, though the average size was smaller, between 20 - 40 cm. Excavations revealed that both alignments 41 and 42 were constructed directly on bedrock.

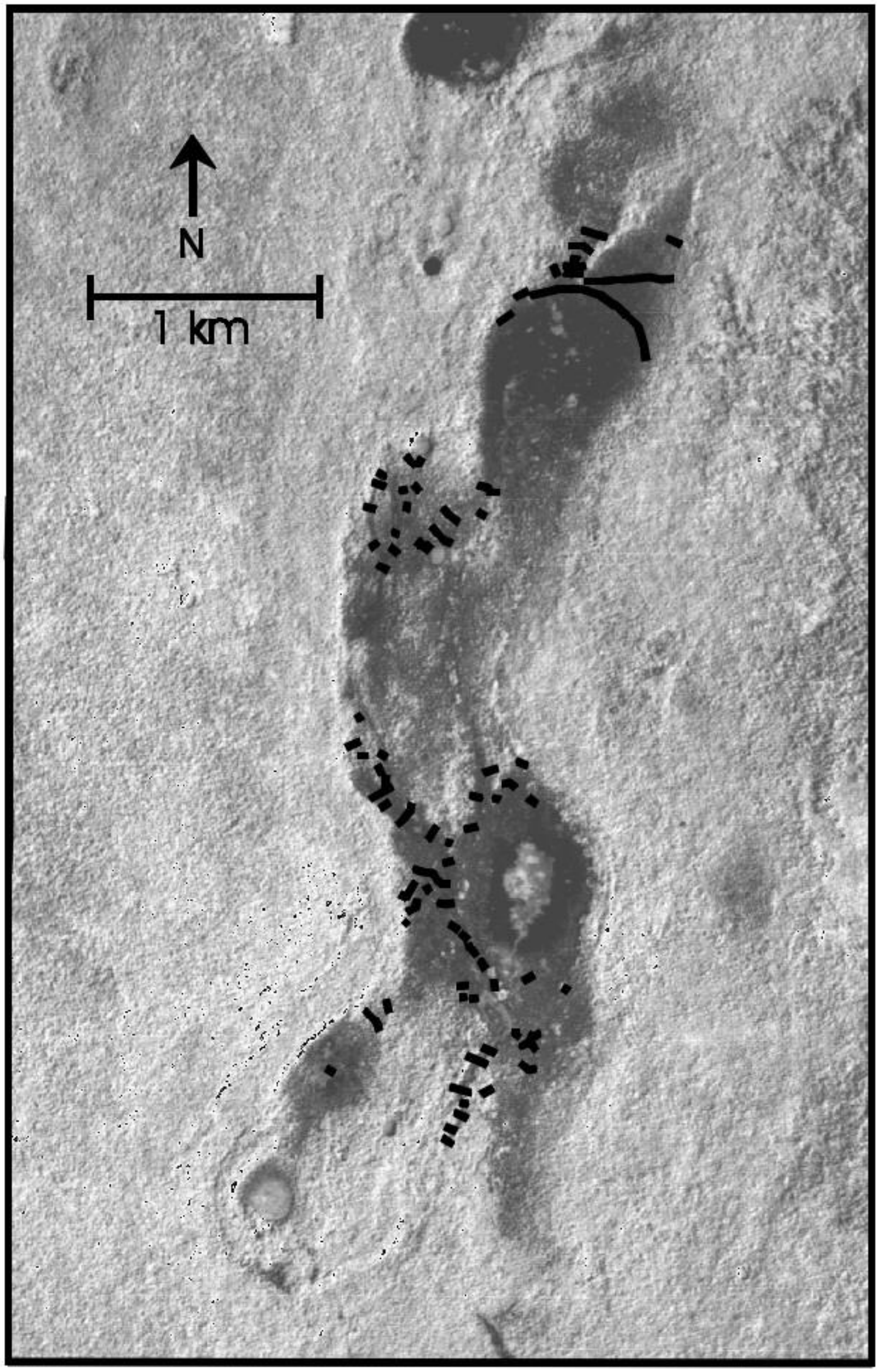

Figure 1.3 El Edén wetland showing the location of the 78 anthropogenic rock alignments. Image courtesy of Scott Fedick.

A second construction method is demonstrated with Alignment 57. For sections of this alignment, large slaps are piled up on top of each other (Fedick et al. 2000: 139-140). Many of the slabs measure up to a meter on one side, though many are significantly smaller than that, measuring only 40 cm. Fedick et al. (2000: 139) comment that, due to this construction technique, there are more rocks involved in the construction than initially appears. Alignment 57 was also found to have been constructed directly on bedrock.

The third excavation technique is exemplified by Alignment 11. Rows of boulders were placed directly on bedrock with cobbles lining either side. Although some slabs were encountered, it was not the same construction technique as seen in Alignments 41 and 42. Here, the size of boulder and cobbles ranged in size from 20 to 50 cm in diameter (Fedick et al. 2000).

Excavations of the rock alignment features confirmed that they were indeed anthropogenic and not a naturally occurring phenomena. In parts of the El Edén wetland short lines of apparently straight rocks will occur on the margin of an exfoliating limestone outcrop or due to the uplift of bedrock created when a tree falls (Fedick et al. 2000). The line of rocks created, however, is rather easily distinguished by at least one of the following: proximity to a bedrock outcrop, or shorter than 5 meters, or lack of intentional design in the construction.

Within the El Edén wetland periphyton – a mat of epipeolon, plocon, epiphyton, phytoplankton, and other algaes – flourishes (Novelo and Tavera 2003). Periphyton grows during periods of high water levels, on exposed bedrock as well as existing vegetation and dried periphyton (Figure 1.4). Studies have demonstrated that periphyton acts to create a more fertile soil within the wetlands and archaeological research suggests that periphyton, or

Figure 1.4 Photographs showing periphyton. Top image shows periphyton growing in water, bottom image shows dry periphyton on vegetation.

enriched wetland soil, was transported by the ancient Maya for use in local homegardens (Morrison 2000; Morrison and Cózatl-Mazano 2003).

Within the Yalahau region, Wollwage (2008; Wollwage et al. 2012) has documented fluctuations in the water table level. Through his series of sediment cores, taken at various locations, Wollwage suggests that before AD 250, the water table rested approximately one meter lower than at present. The water table then rose quickly at the beginning of the Early Classic period and fluctuated through the Late and Terminal Classic. Water levels then rose and stabilized during the Postclassic period, then dropped slightly and have fluctuated into modern times. Generally, Wollwage's (2008) findings converge with findings by Brenner et al. (2002) and Hodell et al. (2000, 2007). Unfortunately, his cores do not extend to sediments earlier than AD 250.

Daniel Leonard (2011, 2013; Fedick et al. 2010) has also studied the Yalahau wetlands and rock alignments within them. His dissertation describes the ubiquity of rock alignments throughout the Yalahau wetlands. Leonard (2013) concludes that with the water table in a lower position during the Preclassic, the rock alignments were constructed in a different environment than what is seen now. Although there would have been zones of wetland vegetation as dominates now, the rock alignments would have been situated in less inundated areas.

# 2. RESEARCH and HYPOTHESES

Given that one of humanity's primeval relationships was with their environment, it follows that there has been much theorizing on the nature of this relationship. Many models have been generated within social sciences that describe the interaction of human groups with their environments. Whereas some of these theoretical models have cast the environment in a relatively static and deterministic role, other models recognize the diversity and unpredictability inherent within the environment. Similarly, some models consider human groups as separate from and only reacting to the environment, while contrasting models outline the dynamic interplay of human populations and changing environments as they concomitantly impact and react through time. Though the older explanatory models that contributed to more recent understandings of human – environment interactions will be briefly described, the stance taken here is mostly akin to that of historical ecology and resilience theory.

Dating back to the late 1700's through early 1800s, in his treatise, 'Essay on the Principles of Population', Malthus (1993 [1798]) argued that population size was finite and in part determined by existing agricultural and cultivation technologies. Thus, a society not engaged in extensive or intensive agriculture would not be able to produce enough food to support the same size of population that as an agricultural society. Boserup (1965), however, countered Malthus' position through her suggestion that human populations would not surpass a built in carrying capacity without the implementation of new agricultural developments that would allow for the production of more food. Both conceptions of agricultural production and innovation are integral to the consideration of the development ancient populations and cultivation techniques. Contrary to mobile populations that could follow the seasonal trail of resources, sedentary populations required an available and stable food supply in order to live and thrive.  As populations increased, food production needed to increase concomitantly to support the blooming population. Both Malthus' and Boserup's ideas were integrally related to the environment, would the environment be a determining factor, as Malthus believed, or would human innovation allow populations to exceed current numbers, as Boserup suggested?

Human - environment interactions and their multifaceted relationships are more nuanced than as suggested by either Malthus or Boserup.  Many factors contribute to human - environment relationships.  At times, the natural environment may dictate the limits of human activity, whether by naturally available resources or changes in climate and weather patterns. Available resources and seasonal patterns may have influenced the development of technologies to manage economically valuable resources as well as directed migrations.  On the other hand, changes in climate may have had the opposite effect, rendering human innovations relatively useless in the face of a weather disaster or a new climatic regime. Natural disasters are particularly potent, leaving human innovations inadequate during and potentially after a disaster.  At these times, the relationship is one sided: environment impacts human groups but is not effected by them.  Environmental form and change is unrelated to human activities, only impacts humans within the system, and human activity has no causal effect.

The environment has, however, been modified and managed through human action and innovation. Technologies have often been developed to mediate the relationship between humans and the environment and to provide favorable conditions for humanity.  In terms of cultivation and agriculture, technologies have ranged from intensive to extensive methods of modifying the environment - from water management techniques, to terraces and mounds, to extensive agricultural fields, to managed forests, and many strategies in between.  Human innovations take control of subtle changes within the environment to reconstruct it into a stable, productive landscape. Often, these anthropogenic landscape modifications create a positive feedback of sustained and bountiful harvest. Other times, however, such modifications take their toll on the environment as they continually tweak the sustainability, and the environment ceases to be productive due to such events as erosion or salinization of the soil. In both cases, human action is considered as being the causal factor for environmental changes, but these environmental changes have minimal to no reciprocal impact on human groups.

As should be apparent, the intricacies of the human - environment relationship are not one sided. Both the environment and human action have the potential to affect the other. Human modifications have had impacts on the local environment, the extended environment, as well as weather patterns. Environmental changes and disasters of different scales all command a reaction by human groups. The exact relationship between human and environmental systems is not linear, a change in one does not immediately nor necessarily bring about a change in the other. Also, despite the innovative technologies of cultural groups, natural hazards and disasters have the capability to disrupt well-established human - environmental systems. As noted by Diaz and Stahle;

> paradoxically, human vulnerability to natural hazards has in some cases, increased over time despite vigorous engineering efforts … there is ample evidence that large, naturally occurring climate fluctuations have had profound impacts on many ancient and modern societies. These impacts take a variety of forms, and may operate through famine, disease, and social upheaval. Historical and archaeological research has highlighted cases in which great societal changes are associated chronologically with major climatic anomalies [Diaz and Stahle 2007: 3].

Culture, in part, determined the type of interaction with the environment. Through time, human groups learned and encoded into their culture the significance of a variety of environmental events as well as how to appropriately act in this time. Whereas an event such as a drought may bring forward behaviors thought to bring rain, an event such as a flood or hurricane would bring about different behaviors to cope and get through the event:

> Societies spanning the economic scale can be impacted by weather and climate extremes. However, many societies have developed elaborate economic cushions against the negative effects of climate disasters. All decadal droughts do not bring societies to their knees, and every cultural collapse cannot be attributed to climatic catastrophes [Diaz and Stahle 2007: 4].

Historical ecology and resiliency theory accurately convey the subtleties of the human - environment relationship. The subsequent review will begin by offering necessary definitions of terms and then outlining the founding ideas of cultural ecology, political ecology, and landscape studies, with their contribution to historical ecology. The examples given above will be further elucidated using historical ecology, resilience theory. Finally, the theoretical review will then move into discussing historical ecology and resilience theory as a means to evaluate and understand the data that will be presented.

## CULTURE and the ENVIRONMENT

When dealing with human - environment interactions, a few definitions are necessary, principally those related to both environmental and human systems. Ecosystem has been the key model for environmental studies whereas culture has been the major concept when addressing human groups. In general, a system includes all the components, at multiple scales, that comprise the whole. In the case of the research, systems are not closed and nor can every component necessarily be accounted for. An ecosystem is an open system, a set of elements that are defined by an observer and subject to examination on different scales (Bončina et al.

2001; Patterson and Hoalst-Pullen 2011).Often, components will overlap between different systems and even appear to wander in and out of a system, thus entailing an open system. The idea of a system is more conceptual than real.

Ecosystem is a vital concept when considering the functioning of the physical world and the complex interactions of humans, other biological organisms, and the environment (Abel 2007; Dickson and Murphy 1998; Patterson and Hoalst-Pullen 2011; Winterhalder 1994). The ecosystem is "an open system in which interdependent interaction, exchange, and transformation of energy, materials, or information occurs within a given environment" (Patterson and Hoalst-Pullen 2011: 642). Examples of ecosystems are numerous, a pond, mountain valley, garden, a wetland, are a few. In each case of ecosystem, the boundaries are not fixed and each contain a number of internal and external components that both regulate and perturb the system. Everything from the underlying geology and soils through microorganisms, plants, insects, animals, and humans comprise the working components of an ecosystem contribute to the functioning and sustainability of the system. All these multiple components within an ecosystem will fluctuate and change through time, the entire ecosystem itself also subject to transformations through time. “An ecosystem is an indirect manifestation of its own special kind of history, a functional history arising from the partial coevolution and adjustments of the species composing it. Without knowledge about the system’s actual history, our understanding is quite limited” (Winterhalder 1994: 20).

Culture is a concept that has been generally left out of ecosystem. Humans, as part of the ecosystem, participate within the ecosystem and actively contribute their culture and cultural values in the formation and modification of an ecosystem. Culture, essentially, is the lens through which one understands and views the world around them. How culture matters is that it is through culture that humans negotiate the physical world and it is culture that describes exactly how humans navigate the physical world. More technically, culture is composed of five criteria: culture is learned, culture is shared, culture is symbolic, culture is all-encompassing, culture is integrated, and culture may be either adaptive or maladaptive (Kottak 2008). For the most part, as people grow up, the culture that is shared among the group is taught, both overtly and covertly. People make sense of their world and much of the meaning is bound up in symbols whose meaning is culture-specific. How past peoples viewed their world and utilized it will be bound in their culture and there may be archaeological traces still present.

In some literature, the term 'bioculture' is used. “Bioculture means the regional-scale interaction of biological organisms and cultural organizations with climate and geology, as well as with the residue of that interaction, soil” (Gunn and Folan 2000: 224). Thus, in terms of ecosystems, culture and bioculture are integrally related in that bioculture describes the evolving human relationship with the environment. “Rather than being determinants of human systems, biological organisms have been interactive with humans for millions of years. Culture is the more adaptable system, so it will retard or hurry the biological systems at its pace. This pace is regulated by the partially unpredictable element of human agency” (Gunn 1994: 83).

In other literature, the human - environment relationship is conceived of as a socioecological system. At its most basic level, it is the combination of both the environmental system and the human system. When both are combined, neither can necessarily be considered separate from the system. Human groups have a reciprocal relationship with the environment; changes within one may incur a reaction in the other (Liu et al. 2007; Turner and Sabloff 2012). Scale may not be a factor, as interactions at one scale may have impacts beyond that scale (Patterson and Hoalst-Pullen 2011; Turner and Sabloff 2010). The socioecological system is a complex adaptive system (Lansing 2003; Turner and Sabloff 2012). Being a complex adaptive system refers to the fact that the human - environment relationship is an open system and not all the contributing factors can necessarily be identified but nonetheless they have an impact. Any disturbance brings an element of chaos into the system, but the human - environment relationship will attempt to recover and adapt through reorganization (Phillips 1999).

Although in the current dissertation neither the term 'bioculture' nor 'socioecological system' will be used, the concepts behind these terms are relevant and applied to the use of human - environment interaction and human - environment relationship. Humans are integrally and dialectically linked with their environment.

> Culture is the body of knowledge that a people amass and pass from generation to generation, and physical environment is geology and climate. Biological systems, soils, and hydrology are so completely interactive with humans and culture, and appear to have been so for at least a million years, that they should be treated as a richly networked analytical unit. Geology and climate, on the other hand, are relatively independent of the biocultural network and can be treated as somewhat independent of life systems [Gunn 1994: 67].

Changes in one part will influence alterations in another as the system strives to maintain stability through maintenance of the environment and continuation of the cultural group.

Concerning the nature of the relationship between culture and environment, in many cases, humans have been actively manipulating the external environment to better suit their cultural needs. In terms of cultivation and agriculture, environmental modifications have taken the form of irrigation systems, terraces, and gardens, to cite a few examples. When making the environment more productive, the people are investing *landesque* capital. "*Landesque* capital refers to long-lived capital improvements for cropping, such as irrigation and drainage canals. Other solutions relied far less on controlling the environment, than on 'rolling' with it, as in agroforestry and swidden cultivation"  (Whitmore and Turner 2001: 19).   Pertaining to the type of landesque capital, there are generally two alternate ways to manipulate the environment, in an accretional or an expansionist manner (Scarborough 2003).  When the landscape is modified accretionally, the developments are slow and at first the output may not be substantially higher but in the long run the developments are more sustainable and so the output will be greater. Expansionist development is essentially exploiting the environment for short term gains but ultimately, the landscape productivity suffers.

Equifinality is an important concept to introduce here (Patterson and Hoalst-Pullen 2011; Phillips 1997).  Essentially, equifinality highlights the possibility that two phenomena - currently appearing in the same state - may have had different initial starting conditions, and travelled through different circumstances.  Thus, in terms of archaeology, what is currently visible today may look like another feature, but it may have been constructed differently and for different purposes.  Human behavior introduces an element of unpredictability that is not otherwise inherent in the landscape. Patterson and Hoalst-Pullen (2011:648) introduce the concept of dynamic equifinality as "an open system whereby different initial conditions or causal pathways lead not to a given static end state but in fact a cyclical one". With dynamic equifinality, the end state of the system is not necessarily static, and as it changes, those changes itself are part of what defines the system.

### *Cultural Ecology and Landscape Studies*

Developed by Julian Steward in the 1950's, cultural ecology (Steward 1955) conveys the mechanisms through which human groups adapt within their environments. The external environment is envisioned as a necessarily limiting but creative force, providing the backdrop and raw materials available to human groups. Culture, therefore, is partly determined by environmental factors and inherently predictable across similar environmental zones.

Cultural ecology is, very broadly:

> the determination of recurrent causal relationships in independent cultural traditions. … certain features are functionally related to others, and time depth or development is necessarily implied; for, regardless of which features are considered causes and which are considered effects, it is assumed that some must always be accompanied by others under stipulated conditions. Whether it requires ten, twenty, or several hundred years for the relationship to become established, development through time must always take place [Steward 1972: 27].

Cultural ecology evaluates the interrelationship of people and their environment by functional innovations through time and compares cultural developments in order to gain a more holistic understanding of the processes involved in culture development and change.

Returning to both people and the environment, Steward (1972:40) emphasizes three important considerations of cultural ecology: the environment, cultural behaviors, and how the interaction of both affects other developing aspects of culture. As for the environment, it provides the raw materials for the creation of aspects, such as technology for subsistence, but not all elements within the environment will be used. "Relevant environmental features depend upon the culture. The simpler cultures are more directly conditioned by the environment than advanced one. In general, climate, topography, soils, hydrography, vegetational cover, and fauna are crucial, but some features may be more important than others" (Steward 1972:40).

As for the behaviors and technologies that are employed, a pattern is created through the dialectical interaction of environment and people. The pattern is essentially culture, and consists of the creation of material aspects of culture, as well as the ideas, and forms of organization. Lastly, both environment and behavior affect developing aspects of culture through the continual modification of the environment, as the environment is modified; it is changed so that the relationship between people and environment is never static.

Political ecology (Robbins 2004), an offshoot of cultural ecology, focuses specifically on the impact of the environment and its products on the construction and maintenance of political systems. Within political ecology, the variability of the environment is key to influencing human groups locally and also their interaction with each other, as guided by political and economic interaction. Political ecology focuses on how the environment, and the environment through time, is manipulated for political interests.

Though much of political ecology focus on issues related to modern, capitalistic issues, some considerations formulated within it are relevant for the current research. Robbins' (2004) ideas of destruction, construction, and production are especially relevant. Destruction refers to the degradation or replacement of one environment to a form that is either not as natural, productive, or the same as the previous one. Construction refers to not only the physical construction of an environment, but also to the social reinvention of an environment. Some of the key points of destruction are loss of natural productivity, loss of biodiversity, and loss of usefulness. Discourse and power relations become incredibly important here in terms of who is defining the destruction of the environment, how they are defining it, why, and to whom.

Similarly, the construction of the environment is imbued with political and economic tones that may be interpreted differently by different discourses. Robbins (2004:110) explains that first, truth of an environmental process is sometimes simply in its repetition. Second, because one truth is believed, alternative explanations are not sought. Third, both the physical and ideological constructs of what environment should be feeds on each other. Thus, an environment may be constructed that is not natural, but through discourse, is naturalized.

Robbins advocates the idea of production instead of destruction and construction. In this, Robbins (2004) suggests that:

> The environments around us, including and especially those composed of non-humans, are clearly produced. Forests are produced as much as factories, polar ice sheets as much as reservoirs, Yellowstone's wilderness as much a toxic dump. That human beings are by no means the only players in the production of these spaces makes them no less artificial (in the sense of "created"). Indeed, as political ecologists continually emphasize, the environment is not a malleable thing outside of human beings, or a tablet on which to write history, but instead a produced set of relationships that include people, who, more radically, are themselves produced [Robbins 2004:209].

Such a conception of production fits in well with Robbins push from a switch of emphasis on chains of explanation to networks of explanation (Robbins 2004:210). The chain of explanation focused too much on a linear system, a change in one part would reverberate and cause change in predictable ways in other elements. The idea of a network is more akin to the idea of landscape. "Networks organize and are organized by a range of human and non-human actors, through systems of accumulation, extraction, investment, growth, reproduction, exchange, cooperation, and coercion" (2004:212). A focus on landscape and networks allow for more varied relationships between people, politics and economies, the environment, and also time depth. Networks and landscapes also allow people and environments to be physically real as well as produced, through time.

By far, political ecology preferences human groups and culture as the dominant contributor within the human - environment relationship. In this case, human culture attributes meaning and determines what is important within the environment, but it also constructs the environment as a political tool. Although based in capitalist analysis, political ecology fares well to consider the reason for the construction of agricultural features in non-capitalist societies. The organization of labor and incorporation of people within the construction of landscape and maintenance of cultural system. Environment is more of a backdrop for cultural activities and only contributes to culture in the sense that it was constructed for the purpose of reinforcing the cultural system.

Landscape studies, from a geography perspective, that were overseen by Carl O. Sauer (Denevan 2001; Doolittle 2000; Whitmore and Turner 2001) offer yet another view of human - environment relationships. Each volume explores the agricultural landscape at the time of new world conquest. Denevan (2001) covers South America, Doolittle (2000) discusses North America, while Whitmore and Turner's (2001) volume encompasses the area of Middle America. While acknowledging the diverse cultural groups across these spaces, these volumes do not explore the landscape and its changes through time. Such a narrow range of time neglects the unique genesis of each landscape.

Archaeologically, landscape studies consider landscape in a more holistic manner. A landscape is not isolated at one point in time but is continually created with the addition of new influences, the alteration of importance of preexisting influences, and the termination of influences. The landscape is not a static or neutral entity; it creates, changes, evolves with, and mirrors those who live on it or with it. Studies of the landscape highlight human – environment interaction and emphasize the “interrelationships among people and such traces, places and features, in space and through time" (Knapp and Ashmore 1999:2). Both the physical environment and cultural participation are integral components in the formation and maintenance of landscape.

Environmental and ecology is important because it will determine what is physically available to construct the environment with and define the limit of settlement. Through episodes of changing climate, the environmental type also shifts, altering the physical landscape and thus also what was available for human groups. Archaeologically, such changes in past environmental type are important to discern: "Paleoecological studies have been focused on the reconstruction of vegetation distribution on different scales to understand the dynamics between vegetation and their main modifying agents: climate and human activities" (Carillo-Bastos et al. 2012: 1). Landscape, time, and environment are thoroughly interwoven.

People are likewise important because they provide both physical and ideological means to construct and produce their landscape. A central contributing factor of the landscape is how people lived on it and used it, not solely the elites but the commoners as well (Dunning 2004; Gonlin 1994; Hayden 1994; Iannone and Cornell 2003; Lohse and Valdez 2004; Marcus 2004; Schwartz and Falconer 1994; Yaeger 2000). Marcus points out that somewhere between 80 and 98 percent of ancient Maya were commoners,

> since "commoner" simply means anyone who is not of noble birth, it includes everyone from impoverished subsistence farmers to wealthy craftsmen, or even trusted commoners appointed to bureaucratic offices by nobles. Wealthy commoners may have commanded as many resources and build houses just as impressive as some of the minor nobility [Marcus 2004:277].

Ashmore (2004) comments that human settlement and landscape are inseparable. Dunning (2004) characterizes this dual relationship between people and their environment well:

> … Classic Maya monumental architecture was characterized by its intentional conspicuousness, in which scale equated with power. At the other end of the social/architectural spectrum, the modest dwellings of commoners are conspicuous only in their large number. Nevertheless, these features are all part of the same landscape, a landscape in which the tremendous disparities in wealth and power were given both material and symbolic expression. The "voices" of Maya rulers still speak loudly to us from the crumbling monuments erected to reify their high-status world. However, the voices of those who toiled in the fields have become even more muted by the passage of time. To hear them, we must take care to listen more closely [Dunning 2004:109].

Conceptually, the landscape presents a palimpsest; a layered and tangled phenomenon formed through time by the movement of many people through a shifting environment. Political ecology elaborates on the cultural influence in constructing the environment and landscape while cultural ecology focuses on the influence of environment on shaping the culture. In all, the human - environment relationship is a reciprocal and continually evolving one.

### *Historical Ecology and Resilience*

Historical ecology and resilience theory build upon the ideas presented and further link the dynamic interplay of human populations and their environment as each undergo changes through time (Anderies 2006; Balée and Erickson 2002; Biersack 1999; Costanza et al. 2005, 2007; Crumley 1994a, 1994b, 2007; Foster et al. 2010; Jackson 2007; Kinzig 2001; Little 1999; O'Brien 2001; Patterson 1994; Redman et al. 2005; Scoones 1999; Tainter 2006; Winterhalder 1994). Historical ecology is necessarily multidisciplinary and innovative, drawing on natural and human sciences to understand environmental history and changes, human intention and action, as well as the connections between environment and humanity through time. Resiliency theory traces the dynamic process of change and adaptation in social and ecological systems (Beratan 2007; Blanton 2010; Liu et al. 2007; Redman 2005; Walker et al. 2006).

Historical ecology is a multidisciplinary tool that draws from a wide theoretical breadth. Ecology has traditionally focused on the ecosystem and relationships between elements within the 'natural' environment. Often in ecological analysis, human impact is not considered as part of the ecosystem. Humans are treated as apart from nature, solely responding to natural ecosystemic changes but having no consequential impact within the ecosystem. Historical ecology, however, recognizes humans as a vital component of the ecosystem. Human groups, through cultural applications, innovations, and adaptive responses, have solved, caused, as well as passively responded to environmental challenges (Beratan 2007; Blanton 2010; Costanza et al. 2005, 2007; Kinzig 2001; Liu et al. 2007; Tainter 2006; Walker et al. 2006).

Historical ecological approaches to archaeological questions are concerned with the action of human groups within the environment, the impacts one may have on the other, and how each change through time. Generally, historical ecology considers about seven questions. First, what factors contribute to the resilience and sustainability of the human - environment relationship? Conversely, what factors contribute to chaos and vulnerability within the system? What emergent properties may arise during this time? When and how do the elements of the system reorganize to once again achieve a stable state? Finally, what does the reorganized state look like, how is it the same and different from the initial conditions?

Archaeological research, however, can only gather so much information. Other analyses, within sciences such as geomorphology, botany, and pedology, are essential to complement study. Paleobotanical studies highlight how plant communities changed over time, thus alluding to human action in precipitating change of plant communities or suggesting a requirement of adaptation by human groups to environmental shifts (Carillo-Bastos et al. 2012; Islebe and Sanchez 2002; Mueller et al. 2009; Torrescano and Islebe 2006). Similarly, studies of ancient soils elucidate how environments changed, either by human action or possibly requiring a cultural response (Sedov et al. 2007, 2008; Solleiro-Rebolledo et al. 2011).

Spatial and temporal scales determine the relevant elements of social and ecological relationships (Cumming et al. 2008; Liu et al. 2007). The earths ecosystems can be conceptualized at global, regional, and local scales. Temporal scale can vary greatly; the earth can be considered in the billions of years, great climatic shifts in the millions of years, and the impact of humans within the ecosystems in the tens to thousands of years (Costanza et al. 2005, 2007; Little 1999). A set of ecosystem relationships considered at one level may appear inconsequential at a different temporal and spatial scale. Conversely, relationships between elements at one scale may have subsequent impacts on elements within a different scale (Patterson and Hoalst-Pullen 2011).

Present conditions are contingent on the past resulting from environmental fluctuations, human modifications, and the interaction between the two (Costanza et al. 2007; Jackson 2007; Turner and Sabloff 2012). The relationship between environmental and human change is neither causal nor direct (Norburg et al. 2008); both have the potential to alter the other (Kinzig 2001). At times humans have sacrificed longer term environmental stability for short terms gains (Anderies 2006; Dunning et al. 1998; Luzzader-Beach et al. 2012; Turner and Sabloff 2012; Wollwage et al. 2012). The ability for a human group to effectively confront environmental challenges varies through time (Costanza et al. 2005, 2007; Redman et al. 2005; Tainter 2006). Historical ecology traces such fluctuations and also identifies the thresholds beyond which recovery is difficult for both the ecosystem and the human group (Redman et al. 2005).

Stability and sustainability is maintained, at a general level, through reorganization of existing elements (Jackson 2007; Lansing 2003; Liu et al. 2007; Norburg et al. 2008; Phillips 1999; Turner and Sabloff 2012). During phases of dynamic reorganization emergent features may appear to replace failing elements or support emergent features. Such emergent features contribute to the stability of the system. Resilient systems will return to similar initial conditions through reorganization but other times the perturbation is great enough to require total reorganization of the system (Blanton 2010; Costanza et al. 2005, 2007; Tainter 2006). A lack of resilience may be illustrated by a long term water table drop or a population movement. Also at times, resiliency may be compromised by an extreme dependence on one element of the system (Blanton 2010).

Resiliency theory supplements the ideas of historical ecology by offering a deeper explanation of the cyclical and adaptive mechanisms of dynamic change. Resiliency describes the ability of a socio-ecological system to retain similar features and functions throughout and after a disturbance to the system. Within resilience there are four stages towards change: rapid growth and exploitation, conservation, collapse or release, and renewal or reorganization (Costanza et al. 2005, 2007; Liu et al. 2007; Redman 2005; Redman et al. 2005). Disturbances may arise from either the social or ecological systems at various spatial and temporal scales and may challenge the threshold within the entire socio-ecological system. Not all disturbances are necessarily bad. A highly resilient system will require minimal reorganization and may appear the same as before a disturbance. A non-resilient system will be greatly affected by a disturbance, emergent features may appear to aid the flailing system, and the end result will have the system in a different form than it began with (Norburg et al. 2008).

Archaeology is ideally structured to engage in historical ecological research (for example see Beach et al. 2009; Dunning et al. 1998; Foster et al. 2010; Gunn and Folan 2000). Cultural practices mediate human interaction with their environment. Archaeology is necessarily interdisciplinary, drawing on a range of sciences to elucidate past environmental conditions and processes of dynamic change. Temporal and spatial scales can be adjusted to suit archaeological research questions. Although the goals of the Yalahau Regional Human Ecology Project are of a more regional and longer time scale, the current project will integrate the environmental history of a single wetland to identify why the ancient Maya constructed features within the wetland, how they reacted to climatic change, and subsequently left.

## RESEARCH AND HYPOTHESES

The research presented within the following dissertation seeks to explain both the seasonal and long-term use of the Yalahau wetlands by the ancient Maya, using the wetland contained within El Edén Ecological Reserve as a case study. El Edén was selected for study because it is the only Yalahau wetland to have been fully surveyed, with the distribution and form of rock alignments already documented. It is not assumed that all rock alignments were built for the same function nor can is it assumed that all rock alignments were constructed at the same time. The following seven hypotheses have been formulated to consider a possible range of functions as well as times of use.

### *Hypotheses related to function of rock alignments*

A number of untested hypotheses suggest that rock alignments within El Edén wetland functioned within a subsistence system to facilitate the cultivation of domestic crops, useful wetland plants, or the harvesting of other biological resources by modifying soil and water movement within an area of the wetland (Chmilar 2011; Fedick et al. 2000; Fedick and Morrison 2004; Leonard 2011; Wollwage et al. 2012). The first four hypotheses address the function of the rock alignments and the range of environmental settings and variety of forms of landscape engineering used by the ancient Maya in their subsistence practices at El Edén.

Hypothesis 1 and Implications. If the rock alignments were constructed to function in the management of water movement in a plant cultivation system, then alignments would be situated within surrounding topography so as to: ***a***) slow and disperse water flowing into lower areas that would be appropriate for plant cultivation, or, ***b***) slow water in order to promote the deposition of suspended sediments behind rock alignments to create areas of deeper soil appropriate for plant cultivation, or, ***c***) slow water in order to promote the deposition of suspended sediments behind rock alignments that would be transported to another area.

Hypothesis 2 and Implications. If rock alignments were constructed as property boundary markers to delimit the extent of gardens or agricultural fields, then the alignments would be expected to: ***a***) delimit areas of preferable agricultural soils, without necessary regard to local slope characteristics, or, ***b***) divide areas of preferable agricultural soils, without necessary regard to local slope characteristics.

Hypothesis 3 and Implications. If rock alignments served as engineering features or boundary markers in a plant cultivation system, then physical evidence for the cultivated crops will be present in associated soils or within sediment located near the cultivation area. Physical remains could take the form of pollen, phytoliths, and starch grains from plant species known to be of economic importance to the Maya. These cultivated plants could include domesticated species such as maize (*Zea mays*) and cotton (*Gossypium hirsutum*), or a variety of wetland species, such as duck potato (*Sagittaria lancifolia*), known to have been used by the Maya.

Hypothesis 4 and Implications. If rock alignments were constructed to function as the bases for fish weirs, then they would be situated within the surrounding topography so as to: ***a***) cross channels of water flow below natural reservoirs of sufficient volume to support fish populations, or, ***b***) impound areas of water above a natural reservoir of sufficient volume to support fish populations that would be trapped behind the weir as seasonal water levels receded. As bases for weir superstructures of wood pole and nets, rock alignments would not necessarily need to have a level upper elevation.

### *Hypotheses of rock alignment function in relation to changes in water table*

It is possible that ancient Maya use of the wetland for crop production or management of biological resources changed in response to climatic pulses – beyond the annual cycle of relatively predictable seasonal pulses – that resulted in long-term changes in the water level and flooding regime of the wetland. To this end, the Maya may have demonstrated resilience in the face of environmental change by duplicating the system of rock alignment features up or down slope to accommodate the altered hydrological regime. In an emergent response, the Maya may have reorganized management strategies in response to changing hydrological conditions, such as a shift from using the wetland for crop cultivation to using it for fish harvesting. Alternately, the Maya may have responded to environmental change by abandoning use of the wetland altogether, perhaps impacting the stability of associated settlements. The testing of these hypotheses will contribute to the broader theoretical understanding of Maya sustainability in response to environmental change.

Hypothesis 5 and Implications. If some or all of the proposed rock alignment functions (Hypotheses 1-4) were in operation within an average annual hydrologic regime (wet season – dry season), then all of the rock alignments should fall within an elevation range that would compliment a typical annual hydrological pulse that can be modeled (Figure 2.1a). In this case, long-term changes of the wetland hydrologic system were not adapted to. No resilience or emergence would be evident in the wetland management system. If paleoenvironmental reconstructions of water-level changes can be physically correlated with elevations of rock alignments and chronologically correlated with occupation and abandonment of nearby settlements, then environmental changes may have impacted settlements and resulted in abandonments.

Hypothesis 6 and Implications. If rock alignments of a specific function (Hypotheses 1-4) are found to be situated in a range of elevations that fall outside of a typical annual hydrological regime (wet season – dry season) that can be modeled, then the subsistence system exhibits evidence for resilience through the construction of management features of the same function, or functions, in new locations (up slope or down slope) in response to environmental change. If paleoenvironmental reconstructions of water-level changes can be physically correlated with elevations of rock alignments, and chronologically correlated with occupation and abandonment of nearby settlements, then settlements may have remained sustainable through times of environmental change with little or no changes in the subsistence resources utilized.

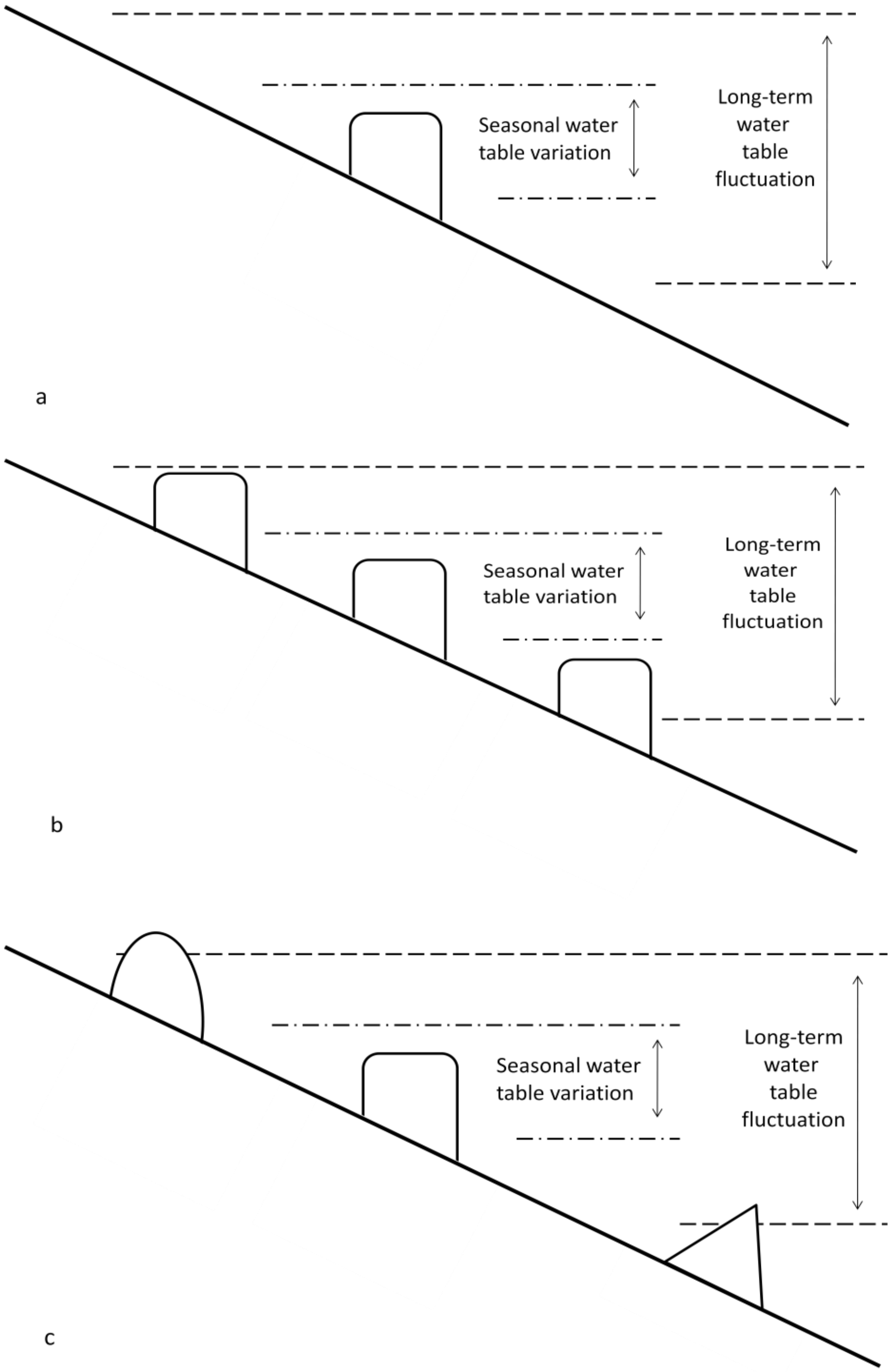

Figure 2.1a-c Figure 2.1a illustrates the placement of a rock alignment to only take advantage of a narrow range of seasonal variation in the wetland water table. Figure 2.1b shows the construction of rock alignment features at different levels to take advantage of longer term variation in water table level. Figure 2.1c demonstrates the construction of rock alignments for different purposes at different physiographic levels.

Hypothesis 7 and Implications. If rock alignments of different proposed functions (Hypotheses 1-4) are situated in a range of elevation outside of an average annual hydrologic regime (wet season – dry season), but are restricted to narrow elevation ranges that represent the highs and lows of a range that can be modeled for long-term changes in water-table level, then the subsistence system exhibits evidence for sustainability through emergence of new subsistence practices, such as shifting from cultivation of seasonally inundated wetlands to the harvesting of fish from shallow lakes. If paleoenvironmental reconstructions of water-level changes can be physically correlated with elevations of rock alignments, and chronologically correlated with occupation and abandonment of nearby settlements, then settlements may have remained sustainable through times of environmental change with shifting emphasis in the subsistence resources utilized.

# 3. METHODS

The methods employed in the following study included five components. The first component was a pilot study, followed by three seasons of field reconnaissance involving extensive topographic mapping, a session of sediment coring, installment and recording of water table fluctuations and temperature using pressure transducers, and finally compilation of field data into maps with the associated analysis.

Before research began, a pilot study aimed to clarify the relationships between topography, distribution of plant communities, and contact with the water table. Based on the results from the pilot study, research consisted of delineating four areas in the wetlands where the topography would be intensively mapped as well as the topographical contours of rock alignments within. Sediment cores were taken throughout the wetland. Pressure transducers were installed at various locations in and around the wetland to measure changes in the water table. All data was compiled into a GIS (Geographic Information System) for detailed modeling.

In order to test the function of and time periods of use for the rock alignments (detailed in the previous chapter), an important component of the research requires an understanding of correlations between rock alignment forms and the elevations at which they are situated within the wetland. The modern distribution of wetland plant communities can be used as a proxy measure of elevation as wetland plants have different tolerances for amount and duration of flooding. Defining the relationship between plant communities and elevation acted to guide the selection of a sample of alignments for detailed study and assisted in the modeling of ecological change (including plant-community migration) under conditions of long-term fluctuation of the water table.

## PILOT STUDY

In preparation for dissertation research, a pilot study was conducted at El Edén wetland in the spring of 2009 by Dr. Scott Fedick, Dan Leonard, and Jennifer Chmilar (the author), along with the collaborating team of soils scientists from the National Autonomous University of Mexico (Spanish acronym UNAM), and a staff botanist with El Edén Ecological Reserve (Solleiro-Rebolledo et al. 2011). The pilot study used Schultz's (2001) vegetation map, supplemented with an unsupervised classification of a Landsat TM from February 2009 to select two locations within the wetland to establish a transect through different zones of plant communities, elevation, hydroperiod, and soil units. Two transects, each 600 m in length, began in upland forest and extended well into the interior of the northern and southern portions of the wetland.

A permanent datum was established just off the main path and from that point, using a Total Station (Topcon GTS 213), elevation measurements were taken at 5 m intervals for bedrock contact, soil surface, and water level (when present). Soils along each transect were mapped and sampled by the UNAM team (Solleiro-Rebolledo et al. 2011), and plant communities were defined by the El Edén staff botanist. The UNAM team excavated small units to take note of any stratigraphy and note the soil formation.

### *Sample Selection*

Based in part on the ongoing refinement of the El Edén vegetation map, a sample of four rock alignment clusters were selected for detailed study (Figure 3.1). Twelve alignments

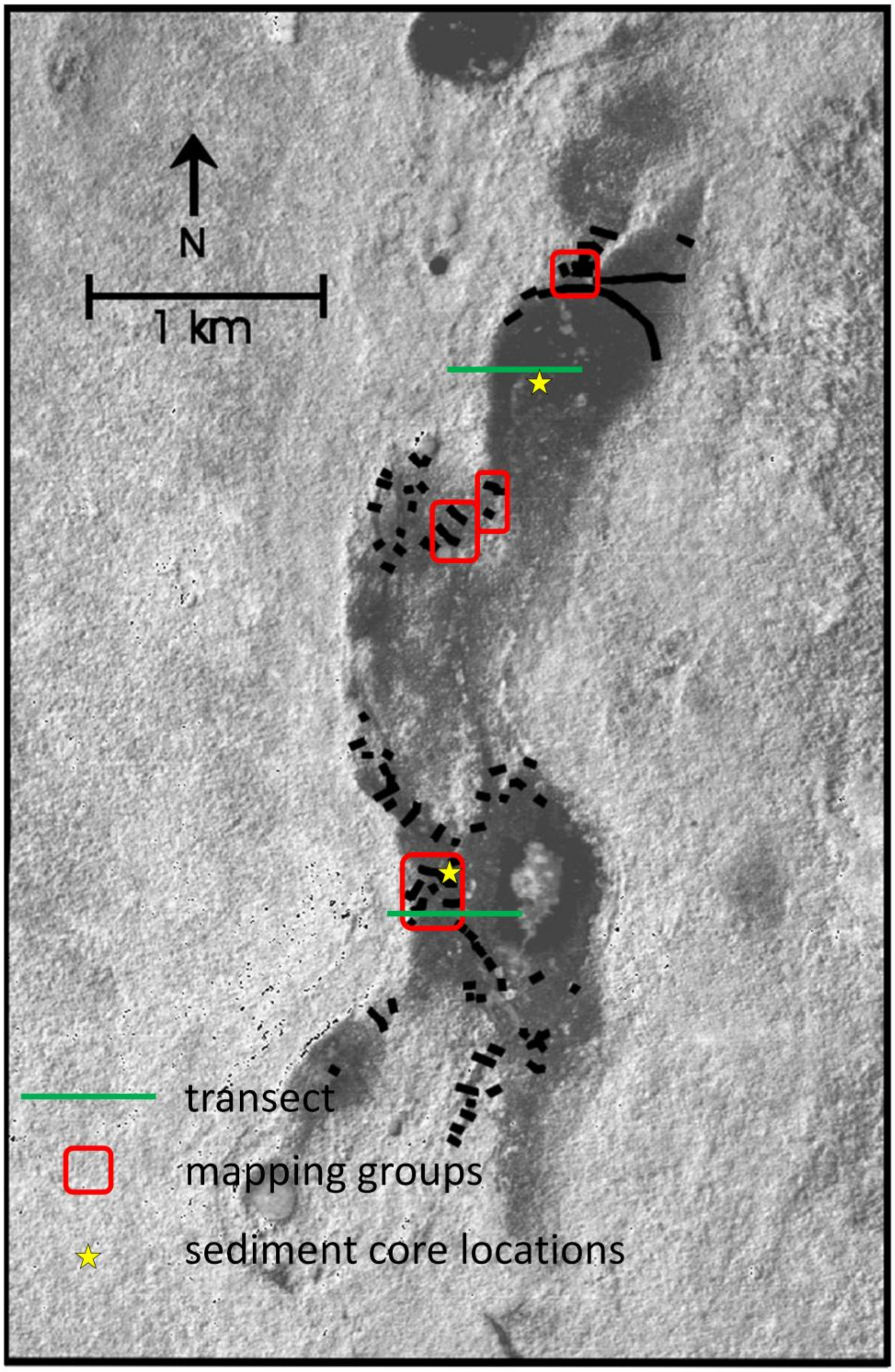

Figure 3.1 Image showing the location of two vegetation transects, locations of the selected mapping groups, and locations of the two deepest sediment cores. Base image provided by Scott Fedick.

are contained within the study groups. The judgmental sample consisted of alignments representing the various alignment types, as per Fedick et al. (2000) as well as vegetation, elevation, and hydroperiod as defined through the completed pilot study.

Before entering the field to conduct the research, six possible sets of rock alignments were selected for investigation. In the field, each area was visited and each rock alignment tracked using a handheld GPS (geographic positioning system, model Garmin etrex Vista Hcx). Each rock alignment was then drawn on graph paper and an appropriate sized area, generally ranging from 90 to 170 meters on a side, was delineated surrounding the rock alignments. Due to time constraints, only four areas were selected for final investigations.

### *Detailed Mapping*

In each of the four sample groups selected, the datum was set at the southwest corner of each mapping area. From the datum, transects running north and east were cut using a machete. Straight lines were achieved using a compass to back and fore sight, distance was gauged using a handheld GPS unit and verified using a measuring tape. On the main transect, a stake was placed to mark each five meter interval. Additional *brechas* (a small paths) were cut across the mapping group at each five meter mark. The *brechas* needed only be about one meter wide and clear of all vegetation so that the prism was visible to the Total Station along the path.

Topography within the study groups was mapped using a Total Station Topcon GTS 213. Measurements were taken at the scale of 5 m horizontal intervals. Mapping detailed both surface (soil surface or exposed bedrock) and subsurface topography (buried bedrock), as well as water level if present. The Total Station measured the point from the current surface while the assistant measured the depth of soil or sediment at that location using a fiberglass soil probe. If water was present at the time, it was noted. Figures 3.2 through 3.5 show the grid layout within each mapped group overlaid on an aerial image.

One area is an exception to the aforementioned methods. Mapping of Group Two was not completed in either the 2010 nor 2011 seasons, however, parts of it were mapped. Upon returning to the area in March 2012, the water level was too high to allow the Total Station to be set up. Having a known elevation along the north transect line, the *brechas* that had previously not been mapped using the Total Station were mapped using a compass, measuring tape, stadia rod, and hand level. The existing *brechas* were re-cleared and a tape stretched out along the water (Figure 3.6). Additionally, the rock alignments were not shot in using the Total Station, only a hand held GPS. The data from Group Two is not as accurate as the data from the other groups.

Points shot in with the Total Station were recorded using the program Survey GX (Tripod Data System) on an external data receiver, an HP-48GX. Subsequently, the points were downloaded directly to a computer using a free version of ForeSight DXM 3.4.0 (Tripod Data Systems 2007). Using the program ForeSight DXM, points were viewed and any data that needed to be modified (as noted during field investigations) was changed. Finally, all data was prepared for import into ArcMap 10.1 (ESRI 2012).

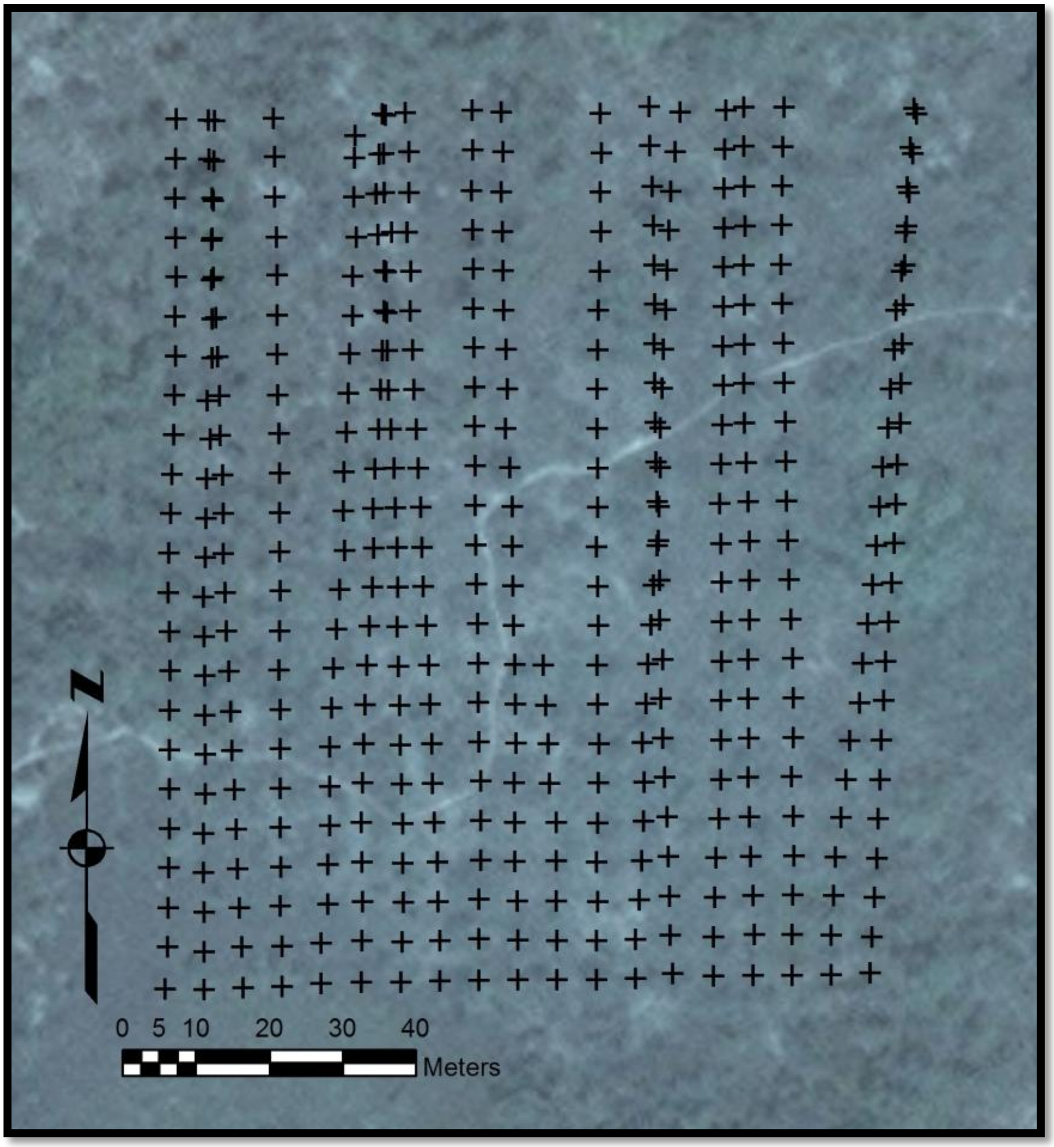

Figure 3.2 Image showing the location of survey points in Group One.

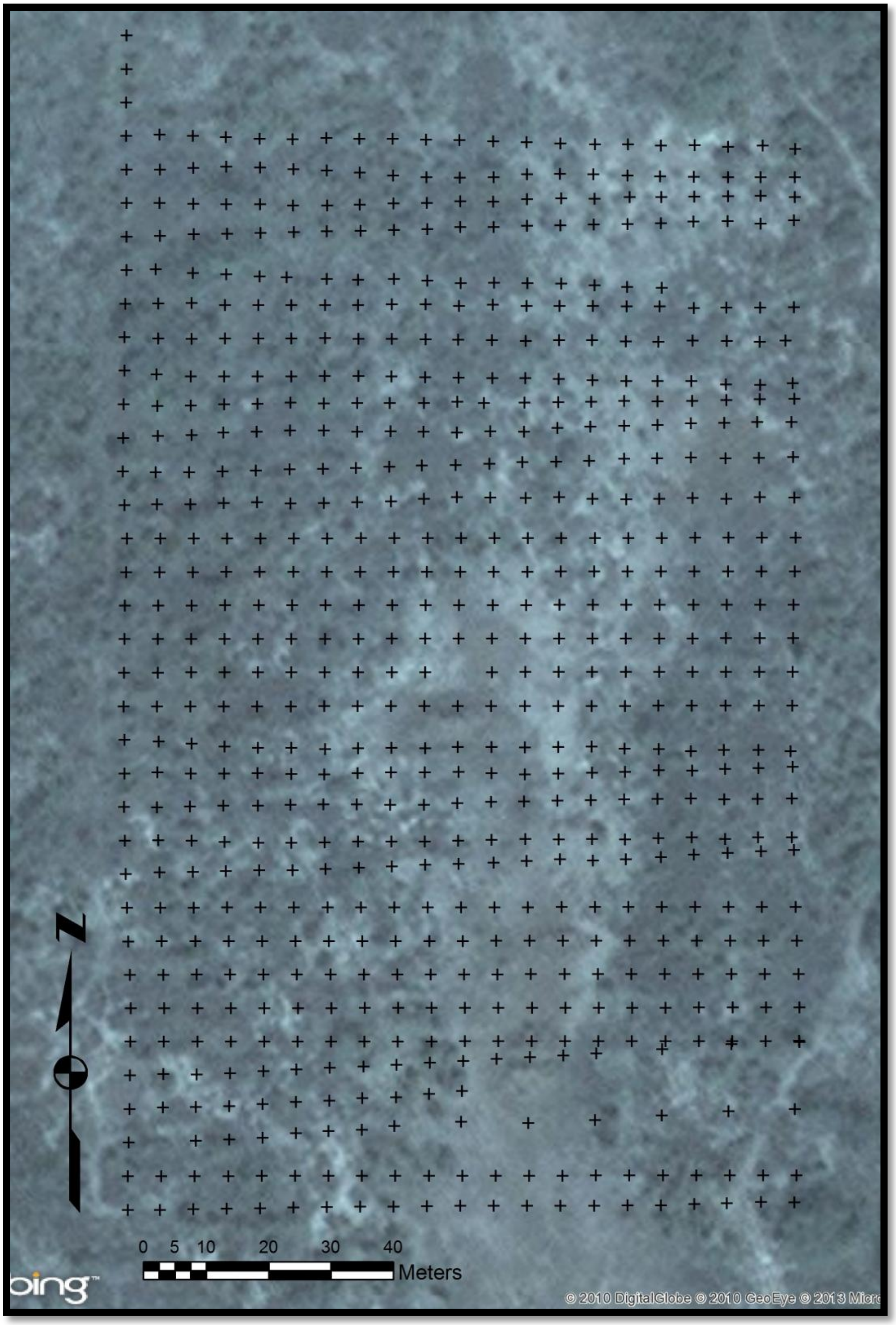

Figure 3.3 Image showing the location of survey points in Group Two.

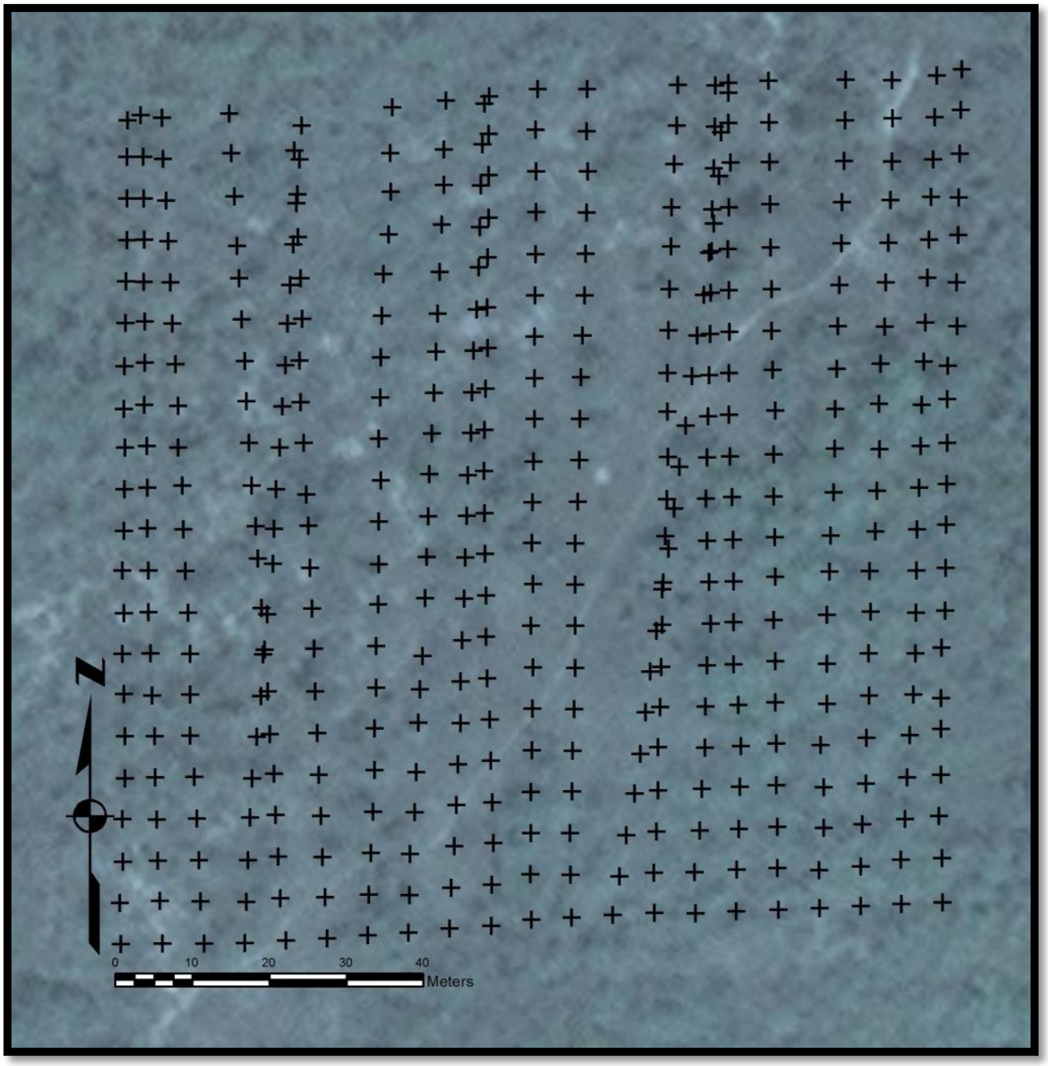

Figure 3.4 Image showing the location of survey points in Group Three.

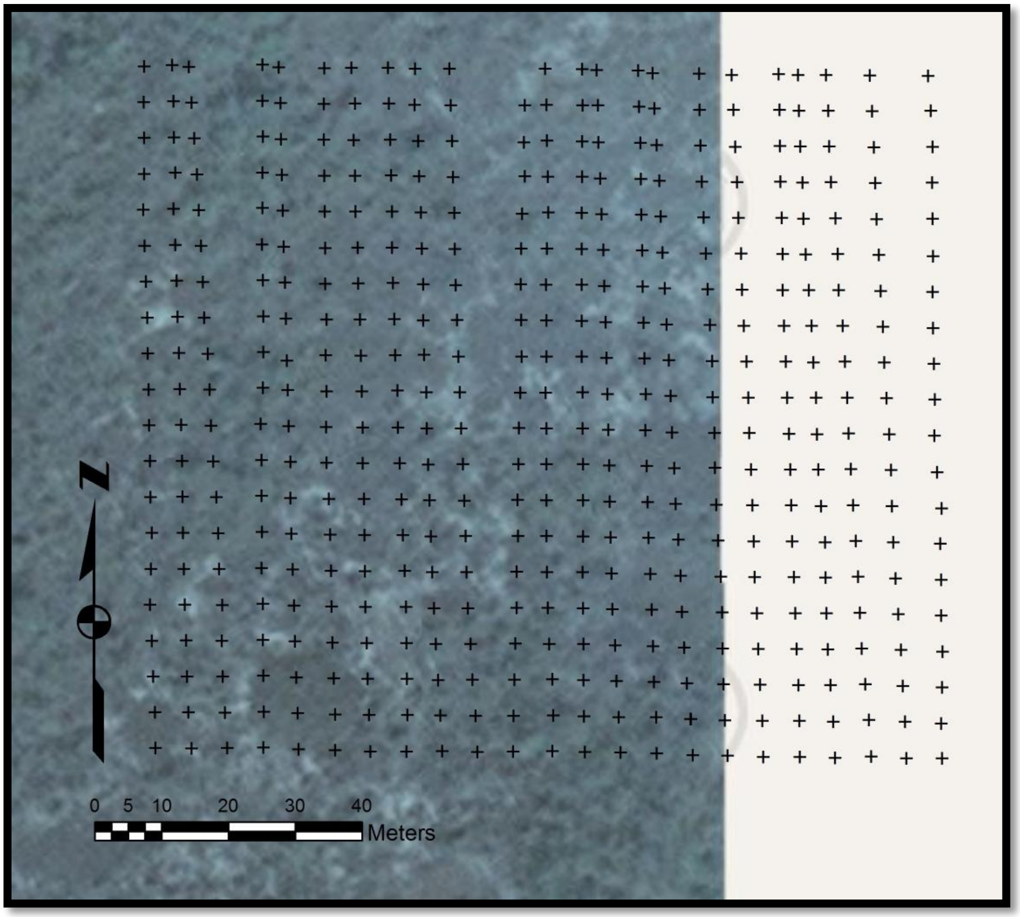

Figure 3.5 Image showing the location of survey points in Group Four.

Figure 3.6 Image showing location of transects in Group Two through water.

### *High Resolution GPS*

Within each mapped area, a permanent datum was established, the absolute elevation of which was determined to near centimeter resolution through use of a high-resolution Global Positioning System (GPS) receiver (Figure 3.7) . The locations of the three pressure transducers, the datum for the south transect, and a datum set up at the main field house were also given high resolution GPS points. A high resolution point for the datum on the north transect had previously been taken in June 2009 (Chavret 2009; Solliero-Rebolledo et al. 2011).

In August 2012, a team from the University of Quintana Roo Geographic Information Center (*Centro de Información Geográfica)* was contracted to take and post-process a total of nine points within El Edén Reserve. They used a Promark II system that included a GPS hooked up to a collector disk. Each point was taken over an aluminum datum marker that had been inserted into a hole drilled into the bedrock. A 2 m pole was erected directly over the datum and stabilized by two other poles. At the top of the pole was the disk that collected locational readings from satellites. Approximately half an hour was required at each point to collect an adequate amount of readings. Out of the field the GPS readings were calibrated. A base point had been set up in Chetumal and it has collected readings for between five to ten years. Knowing the date and time that readings were being collected at El Edén, the point in Chetumal is used to calibrate the wetland readings for any errors introduced by the motion of the earth and of the satellites. The resulting accuracy of the calibrated readings is within centimeters.

Figure 3.7 The set-up of the high-resolution GPS receiver on the datum of Group Two.

### *Recording of Water Level Fluctuation*

At the commencement of the project, no data on annual fluctuations of the water table existed for the Yalahau region. Three pressure transducers, Solinst Levelogger Golds, were established within El Edén wetland to measure water depth at perennially flooded locations. Data collectors linked to the pressure transducers recorded changes in water depth within the wetland beginning July 1, 2010 extending through August 21, 2012. Plans are in place to reinstall pressure transducers in 2013 to continue recording data for a longer period of time. The data on water depth has been correlated with local precipitation and barometric pressure recorded by an additional pressure transducer, a Solinst Barologger Gold, installed at the main house of El Edén Ecological Reserve. Thus, a baseline for understanding the pulses of water fluctuation has been established for El Edén wetland.

The first pressure transducer (ID# 1017039) was installed in the south *aguada* (Figure 3.8). A hole was drilled upon an exposed section of bedrock on the margin of the *aguada*, into which a metal pipe was inserted and cemented in place. From that pipe, using a pvc elbow, a second pipe of 160 cm was attached and extended out over the water. Using another pvc elbow, a pvc pipe reached 81 cm below, into the water. The pressure transducer was in a holding container and rested 3 cm above the bottom surface of the *aguada*.

The second pressure transducer (ID #1017066) was installed within a small opening in the bedrock within the mid-northern portion of the wetland (Figure 3.9). The set up was the same as the first pressure transducer, except that the top pipe was only 37 cm long. The pipe extended 1.29 m into the water and the pipe containing the pressure transducer rested approximately 5 cm from the bottom.

Figure 3.8 Pressure transducer set-up in the south *aguada*.

Figure 3.9 North pressure transducer installed in a small opening in the bedrock.

The third pressure transducer (ID# 1030630) was installed within a well outside the flooding area of the wetland (Figure 3.10). A pipe was cemented into the upper ring of the well. The pipe extending into the well dropped 7.14 m and rested approximately 8 cm above the base of the well.

A final pressure transducer, the Barologger (ID# 1051648), was strapped to a support beam outside the main field house at El Edén. The purpose of the Barologger is to collect ambient temperature and pressure data with which to calibrate and correct the water level readings from the three submerged pressure transducers.

A measurement was taken by each pressure transducer every hour beginning midnight of July 1, 2010. Data from the pressure transducers were collected twice during the duration of the study. Using a Solinst Leveloader Gold with Solinst Levelogger 4.0.3 software (Solinst 2012), data were downloaded from the pressure transducers first in May 2011 and then again in August 2012. Subsequently, data were transferred from the Leveloader to a computer and viewed using Solinst Levelogger Software 4.0.3 (Solinst 2012). Pressure transducers were removed in August 2012.

### *Sediment Coring and Pollen Analysis*

Sediment cores are being used to further refine the history of water table fluctuation and sedimentation of the El Edén wetland in comparison with other reconstructions (Wollwage 2008) and to refine the vegetation history of El Edén. Pollen, pytholiths, and starch grains present within the cores may indicate cultivation of specific crops. Analysis of sediment cores will be done in collaboration with Gerald Islebe, the paleobotanist at the College of the Southern Frontier (Spanish acronym ECOSUR).

Figure 3.10 Pressure transducer installed within a well just outside of the wetland.

Figure 3.11 The barologger attached to a support beam at the main El Edén house.

A total of seven sediment cores were extracted in November 2010 from perennially flooded locations within the wetland. The team was comprised of Jennifer Chmilar (author), with Gerald Islebe, his assistant Margarito Tuz Novelo, and his students Pablo Ramírez Berajas, and Pierre Charruau. Combining the author's knowledge of the wetland topography and location of rock alignments with Islebe's discernment of locations with a good probability of pollen preservation, seven locations were cored. Sediment cores ranged in length from 25 centimeters to two meters.

Samples were processed by Gerald Islebe for AMS dates. Radio carbon dating was performed at the University of California, Irvine lab. Gerald Islebe extracted the samples from the sediment cores while at his lab at ECOSUR and sent them to Jim Sickman. At UCR, Jim Sickman processed and treated the samples for shipment to the UCI lab.

Only one sediment core was analyzed in time for this project. Gerald Islebe directed the extraction of fossil pollen for the core and the enumeration of different species of pollen grains. The data were compiled in a chart to illustrate vegetation change through time. Pollen was extracted from samples of soil every five centimeters in the core. Five radiocarbon dates on the same core provide the range of dates.

Pollen analysis can identify plants to the species level. Frequencies of pollen from different species and their variation through time is compiled to create a general illustration of how the flora of the environment changed through time.

### *Computer Modeling*

A Geographic Information System (GIS), specifically ArcMap 10.1 (ESRI 2012) was used as a platform for all spatial and temporal data, with the capability of modeling static conditions and changes through a time sequence. Surfaces surrounding mapped rock alignments will be created at 5 m resolution using the data from mapping with the total station.

For each map produced (aside from the map already produced and supplied by Scott Fedick), either an aerial image bought from INEGI or a free online map provided by BING (2013) were used as the base map for each image. The World Geodetic System 1984 (WGS84) was selected as the map datum. Maps and data were projected using the Mexican Datum 1993 UTM Zone 16 projected coordinate system. Using the topographic data gathered with the Total Station, multiple surface rasters were created that illustrate the surface topography without the rock alignment, subsurface topography both without the rock alignments incorporated, and soil accumulation. For both the surface and subsurface topographic maps, contour lines were created at 5 cm intervals.

Within the spatial analyst extension, ArcGIS provides a number of spatial interpolation tools to create a surface from a set of point data. Of all spatial interpolation methods, kriging is the chosen geostastical method used to create a 3D surface using the data from the Total Station points in this study. Other methods, such as inverse distance weighting (IDW) are less appropriate because they take into account the data from all the points. Kriging, on the other hand takes into account a set number of points surrounding each point. Considering the scale of surface variation at El Edén, taking into account the elevation of a point 100 meters away, even 10 meters away, does not hold influence. However, all methods of creating a surface attempt to smooth the points such that neither the highest nor lowest points recorded are incorporated into the final surface.

In order for the rock alignments to be incorporated into the topographic surface, they had to be sketched as polygons on a new layer. Each point was assigned a buffer with a diameter of the width of the rock alignment at that point. Once the polygons were traced, divisions were drawn between each rock, and that segment was assigned a value of the height of the rock alignment at that point. The polygons representing the rock alignments were then converted into a raster and mosaiced with a raster of the subsurface topography.

A difference to this process existed for Group Two. Since the data only measured the height of the rock alignment and not the elevation of the rock alignment, the raster first had to be added to the surface before the rock alignment and surface could be mosaiced into a single surface.

The subsurface topographic surfaces, with and without the rock alignment, were used to evaluate flow direction. Because of the complexity of the surface and lack of sediment accumulation, the subsurface topography will best represent the movement of water.

Before conducting a flow direction analysis, the surfaces needed to be filled. Filling eliminates small sinks in the surface that will confuse the flow direction analysis. Like kriging to create a smoother surface, filling again creates a smoother surface. Unfortunately, as the character of the surface within El Edén wetland is highly irregular, such smoothing and filling is necessary to proceed with the flow direction analysis.

Flow direction analysis shows in which direction water would flow from a given point. The point is given one of eight values in the cardinal and inter-cardinal directions. Once direction analysis is completed, it needs to be resampled at a coarser scale. In this case, squares of 2 m by

2 m were used and the resulting square was assigned the value of the majority of points within. The resampled raster is then converted to points, the points symbology changed to an arrow in the direction of water flow.

Basin analysis is preformed using the original flow direction raster. Basin analysis delineates the internal areas that would receive runoff. The points generated within flow direction analysis further demonstrate the directions of flow within the basins.

# 4. RESULTS

The following chapter will present the data collected in the field and the results of analyses performed using arcGIS.  It will begin by discussing the high resolution GPS points and then describing each area that was mapped, the vegetation and terrain within, as well as describe the rock alignments.  Topographic maps will also be included to visually display the terrain and vegetation.  Direction of flow analysis for each mapping group using both a surface with and without the rock alignments will  then be discussed. Following that, the chapter describes the locations of the sediment cores, as well as the results of the one core that was analyzed.  The final section will discuss the observed variation in water level throughout the duration of fieldwork at El Edén and summarize the measurements recorded by the pressure transducers.

## HIGH RESOLUTION GPS

During the course of study, eight points within the study area were selected to be verified using a high- resolution GPS.  The locations selected for high resolution GPS included the southwest corner of each mapped area, the location of each pressure transducer, as well as the datum marker for each the north and south transect.  The north transect high resolution GPS point was taken by Guillaume Chavret (2009) in 2009 during studies for his Master's degree.  In August 2012, the following eight high-resolution GPS points were obtained (Table 4.1):

| Point | y | Error to 95% | x | Error to 95% | Ellipsoid Height | Error to 95% | Geoid Height | Orthometric Height |
|---|---|---|---|---|---|---|---|---|
| PJ1- | 2347485.003 | 0.466 | 479995.2124 | 0.651 | 10.83 | 0.792 | -11.32 | 22.15 |
| PJ2- | 2346439.004 | 0.702 | 479605.6752 | 0.829 | 11.092 | 0.956 | -11.3 | 22.39 |
| PJ3- | 2346288.219 | 0.772 | 479396.3674 | 0.817 | 10.71 | 0.837 | -11.3 | 22.01 |
| PJ4- | 2346218.474 | 0.829 | 479402.9439 | 0.79 | 10.289 | 0.755 | -11.3 | 21.59 |
| PJ5- | 2344261.827 | 0.896 | 479739.0733 | 1.005 | 9.308 | 0.998 | -11.25 | 20.55 |
| PJ6- | 2344705.383 | 0.802 | 479543.6651 | 0.784 | 13.172 | 0.829 | -11.26 | 24.43 |
| PJ7- | 2344713.414 | 0.862 | 479444.6779 | 0.811 | 11.523 | 0.759 | -11.26 | 22.78 |
| PJ8- | 2343815.676 | 0.764 | 482732.7468 | 0.721 | 17.42 | 0.729 | -11.19 | 28.61 |

Table 4.1 Table showing the results of the high resolution GPS.

There is a discrepancy with the orthometric heights obtained in August 2012 with those obtained previously (see Chavret 2009; Leonard 2013). Most elevations in this area are in the range of only a few meters above sea level, not close to exceeding 20 masl (meters above sea level). The current study will use the orthometric heights obtained in August 2012, based on the explanation provided below.

Orthometric height is the surface of the earth, measured in meters above mean sea level. Calculating orthometric height uses both a geoid and an ellipsoid. The geoid approximates the surface of the earth and mean sea level, it is not flat and has peaks and valleys like that of the earth surface. The GPS bases its measurements on the height relative to an ellipsoid, a shape with a regular surface. The formula for determining orthometric height is H = h - N where H is the orthometric height, or the height above the geoid. The ellipsoid height is h. 'N' represents the geoid height as it approximates mean sea level. Because the geoid is not flat, it may be above or below the ellipsoid and thus either positive or negative (ESRI 2003).

In the data obtained in August 2012 (Table 4.1), the ellipsoid used is WGS84 and the resulting ellipsoid heights, h, are positive. This means that the point measured is above the geoid. The geoid height, N, is negative because it is below the ellipsoid. It is possible that h would be negative if the orthometric surface were also below the geoid and ellipsoid.

In Chavret's data (2009:A4-5), the ellipsoid is also negative and the resulting measurements are in the order of a few meters above sea level, at El Edén Ecological Reserve he measured the *cenote* in the northern part of the wetland, not very far from Group Four, at 5.119 masl (2009: A5). If the ellipsoid value in Table 4.1 is switched to negative, the following values result (Table 4.2).

| Point | y | x | Ellipsoid Height | Geoid Height | Orthometric Height |
|---|---|---|---|---|---|
| PJ1- | 2347485.003 | 479995.2124 | -10.83 | -11.32 | 0.49 |
| PJ2- | 2346439.004 | 479605.6752 | -11.092 | -11.3 | 0.21 |
| PJ3- | 2346288.219 | 479396.3674 | -10.71 | -11.3 | 0.59 |
| PJ4- | 2346218.474 | 479402.9439 | -10.289 | -11.3 | 1.01 |
| PJ5- | 2344261.827 | 479739.0733 | -9.308 | -11.25 | 1.94 |
| PJ6- | 2344705.383 | 479543.6651 | -13.172 | -11.26 | -1.91 |
| PJ7- | 2344713.414 | 479444.6779 | -11.523 | -11.26 | -0.26 |
| PJ8- | 2343815.676 | 482732.7468 | -17.42 | -11.19 | -6.23 |

Table 4.2 Hypothetical elevation values if using a negative ellipsoid height.

Chavret also used the WGS84 ellipsoid (2009: 25). In further communication regarding his negative ellipsoid value, the reasoning was that it seemed illogical that the locations he measured would be that much above mean sea level (personal communication 2012).

Orthometric heights as obtained in August 2012 will be used in the present study even though they do not fully accord with previously measured orthometric heights in the area. Table 4.3 summarizes the location of each point and compares it to a non- high resolution GPS point.

| Point | Northing | Easting | Meters above sea level | Northing (non high - res GPS) | Easting (non high - res GPS) |
|---|---|---|---|---|---|
| (1) Group 4, SW datum | 2347485.003 | 479995.2124 | 22.15 | 2347430 | 480003 |
| (2) Group 3, SW datum | 2346439.004 | 479605.6752 | 22.39 | 2346380 | 0479610 |
| (3) Group 1, SW datum | 2346288.219 | 479396.3674 | 22.01 | 2346220 | 479460 |
| (4) North Pressure Transducer | 2346218.474 | 479402.9439 | 21.59 | | |
| (5) South Pressure Transducer | 2344261.827 | 479739.0733 | 20.55 | | |

| | | | | | |
|---|---|---|---|---|---|
| (6) South transect datum | 2344705.383 | 479543.6651 | 24.43 | 2344640 | 0479550 |
| (7) Group 2, SW datum | 2344713.414 | 479444.6779 | 22.78 | 2344650 | 0479445 |
| (8) Well Pressure Transducer | 2343815.676 | 482732.7468 | 28.61 | | |

Table 4.3 A summary of the high resolution GPS points, the elevation (masl) that will be used, and any non-high resolution GPS points.

## MAPPING GROUP ONE

### *Group One*

Group One is located in the central portion of the wetland, on the north side of the troque line, a raised historic rail bed that divides the wetland. It measures 110 m north to south by 90 m east to west and contains two rock alignments, numbers 53 and 54.

### *Vegetation, Topography, Soils and Sediments*

The terrain contained within Group One is highly transitional, ranging from a low-lying areas of sawgrass savanna through higher areas of tasistal and into both rocky stands and flat open areas of tintal (see figures 4.1-4.5). The southwest corner of Group One is located in lower

Figure 4.1 Looking north from the southwest corner of Group One.

Figure 4.2 Looking east from the southwest corner of Group One.

Figure 4.3 The margin of the depression in Group One, branches of solanum grow on the exposed sediment.

Figure 4.4 An area of open tintal within Group One.

Figure 4.5 An area of tintal in Group One.

terrain dominated by sawgrass with a few scattered tasiste palms and is subject to more frequent and longer term inundation. The depression in the southwest corner extends approximately 35 m to the north and 50 m to the east. Sawgrass, interrupted by the occasional tasiste palm or calabash tree, is the predominant vegetation within the depression. Along the margin of the depression single branches of *solanum* sprout from the bare sediment covered ground to nearly 2 m tall. Towards both the north and east the terrain rises. The northern boundary of the mapping area is a raised and rocky area of tintal. The southeast corner, and along the eastern boundary, is another area of tintal. The area between the rocky tintal and outside of the sawgrass depression grade between palm savanna and open tintal, depending on the topography.

Figure (4.6) is a topographic map of the exposed surface of Group One, with the locations of the rock alignments marked. Contour lines are in 5 centimeter intervals. The lowest area is in the southwest corner, the highest areas are along the northern and eastern boundaries, and the remaining area is of undulating terrain with a few other minor depressions. The highest surface point within Group One measures 22.3408 masl, the lowest surface point at 21.371 masl, a total topographic variation of 1.0734 m within the mapped area. The average elevation is 21.6551 masl, making it, on average, the lowest elevation of all mapped groups.

Figures 4.7 and 4.8 are topographic maps of the subsurface bedrock of Group One. The high and low points mirror those of the exposed surface with the lowest region in the southwest corner. The lowest subsurface point is 21.0555 masl and rises 84.14 cm to 22.3108 masl. The lowest subsurface point is 4.97 cm below the lowest surface point. Figure 4.8 incorporates the elevation of the rock alignments into the topography.

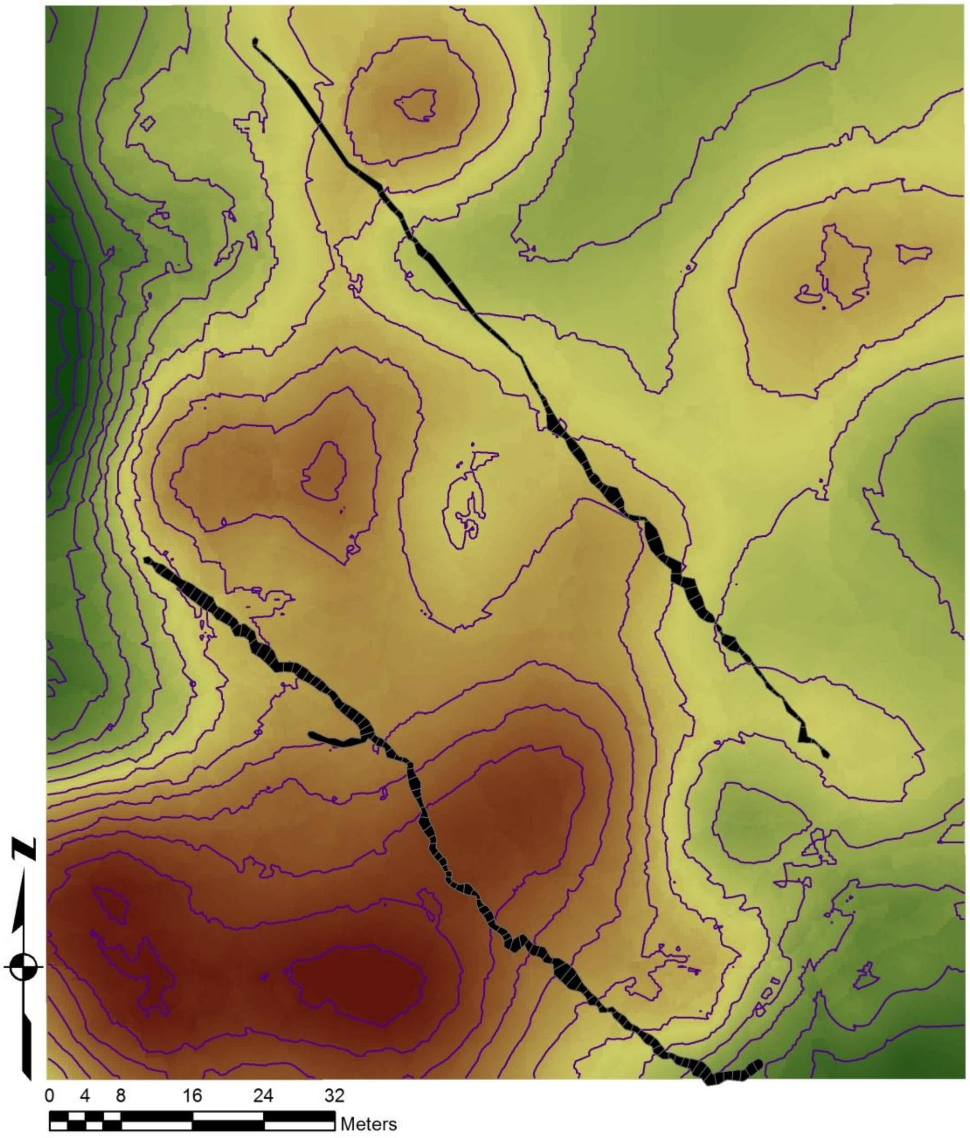

Figure 4.6 Surface topography of Group One. Green represents high areas while brown shows lower areas, while yellow grades between high and low areas. Contour interval is 5 cm.

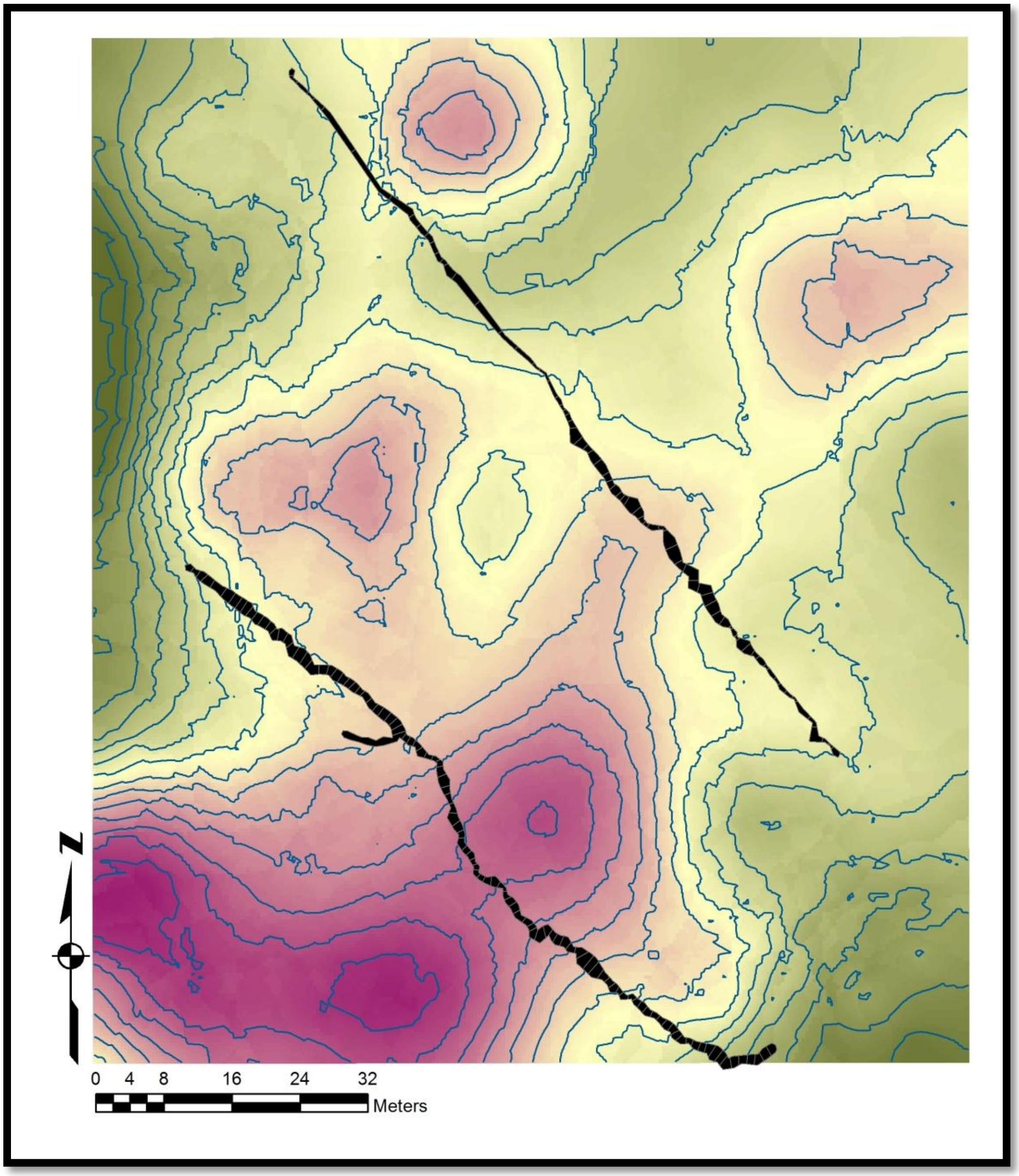

Figure 4.7 Subsurface topography of Group One. Green represents high areas while purple shows lower areas, while yellow grades between high and low areas. Contour interval is 5 cm.

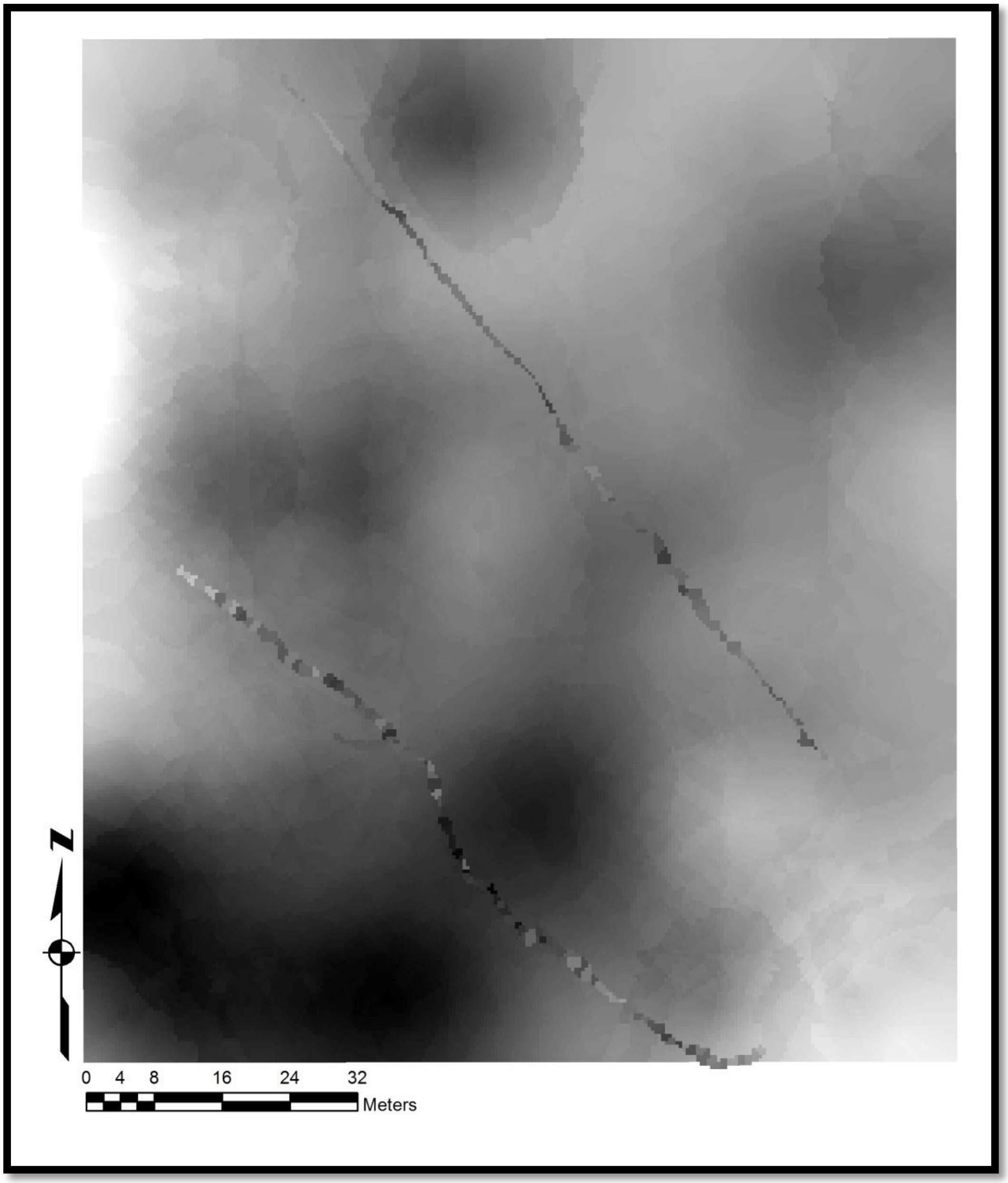

Figure 4.8 Subsurface topography of Group One and the rock alignments 53 and 54. Dark areas are lower while lighter areas are higher.

Soil and sediment accumulation are visible in figure (4.9). Sediment accumulation averages approximately 6.20 cm across the mapped area, the deepest measurement of 35 cm made within a depression in the southwest portion of Group One. Of the 423 measurements taken, 48, or 11.35 percent, of the soil depths are zero. Sediment formation, as to be expected, is least atop the rocky outcrops along the west side and southeast margin of the mapped group. Sediment tends to accumulate in the central lower portions of the Group.

### *Rock Alignments*

Rock alignments 53 and 54 border the margin of the low-lying area and are parallel to each other, approximately 40 m apart. They both run through the central, lower area, roughly connecting higher ground along the north and eastern portion of the mapped group. Fedick et al. (2000: 138) classified both of these alignments as Type Three: each run perpendicular to slight slope variations within a higher area.

Rock Alignment 53. Rock alignment 53 is the more northern alignment in Group One. Rock alignment 53 extends from the east margin of the area, about 35 m north, then proceeds northwest through a predominantly grassy terrain until the northern margin. It is straight and composed of smaller boulders, generally not more than between half a meter and a meter wide.

A combination of the piled slab technique as well as lines of boulders and cobbles are the construction methods of rock alignment 53. The northern half to three quarters is composed of slabs, usually single slabs (Figure 4.10). On the path by the *chicozapote* tree (Figure 4.11), the alignment is composed of multiple slabs piled on top of each other. The

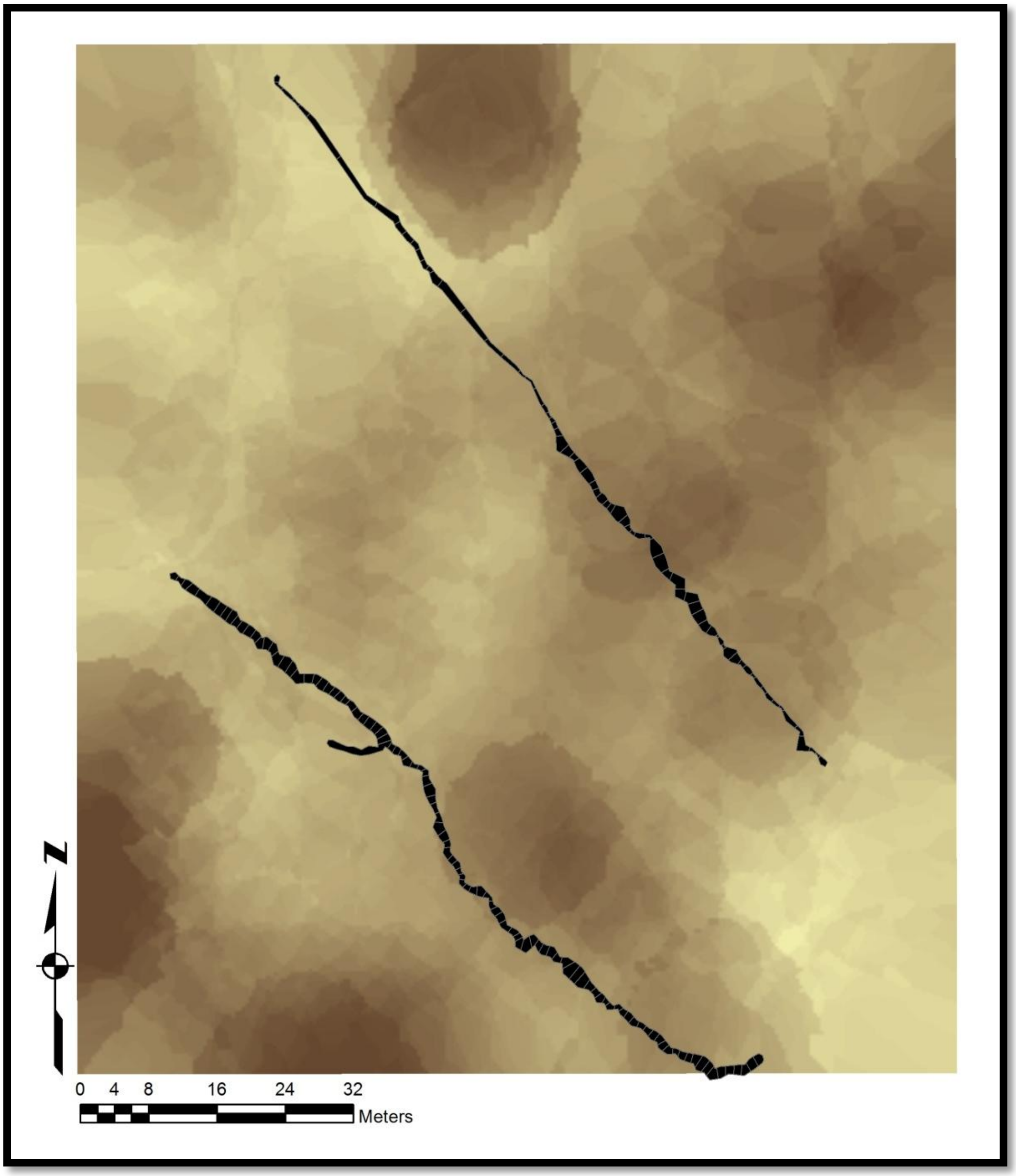

Figure 4.9 Soil and sediment accumulation in Group One. Darker brown areas show deeper sediment accumulation.

Figure 4.10 Slabs used to construct Rock Alignment 53

Figure 4.11 Rock Alignment running across the bath and beneath the *chicozapote* tree. The ground is saturated and covered in moist periphyton.

southern quarter of the alignment is more representative of the boulder and cobble building technique.

The size of rocks used in the construction of rock alignment 53 vary, averaging 50 cm on a side. Often, as mentioned previously, the rock alignment is composed of larger boulders and smaller cobbles together, and other time, slabs.

Rock Alignment 54. Rock alignment 54 extends from atop a rocky outcrop in the southeast portion of the area, curves northwest, for much of its length on top of the rocky ridge, terminating near the western margin at about 60 m north (Figure 4.12). The central portion of the alignment dips down and runs along the margin of the depression, here the rocks are fully submerged in the wet season (Figure 4.13). Alignment 54 is mostly straight and exhibits a slight branching for about 5 m in the mid-northern section. It also corresponds to a Type Three alignment. Rock alignment 54 is constructed primarily using the boulder and cobble technique (Figure 4.14). At times, there is only a single line of rocks composing the alignment and at other locations the alignment is a few rocks wide, up to a meter. Rocks within this alignment are generally in the range of 30 cm diameter but may be as large as 1 meter in diameter. Rocks on both ends of this alignment tend to be larger whereas rocks in the central portion are smaller.

### *Water Flow*

Figure 4.15 through Figure 4.16 illustrate the direction of flow of surface water in Group One. Figure 4.15 disregards the influence of the rock alignments whereas Figure 4.16 incorporates the influence of the rock alignments to interpret resultant water flow patterns. There are 16 basins within Group One. The main basin comprises approximately half of

Figure 4.12 Rock alignment 54 on a raised, rocky ridge.

Figure 4.13 Rock alignment 54 running through a depression.

Figure 4.14 A section of Rock Alignment 54 showing its construction as a line of cobbles.

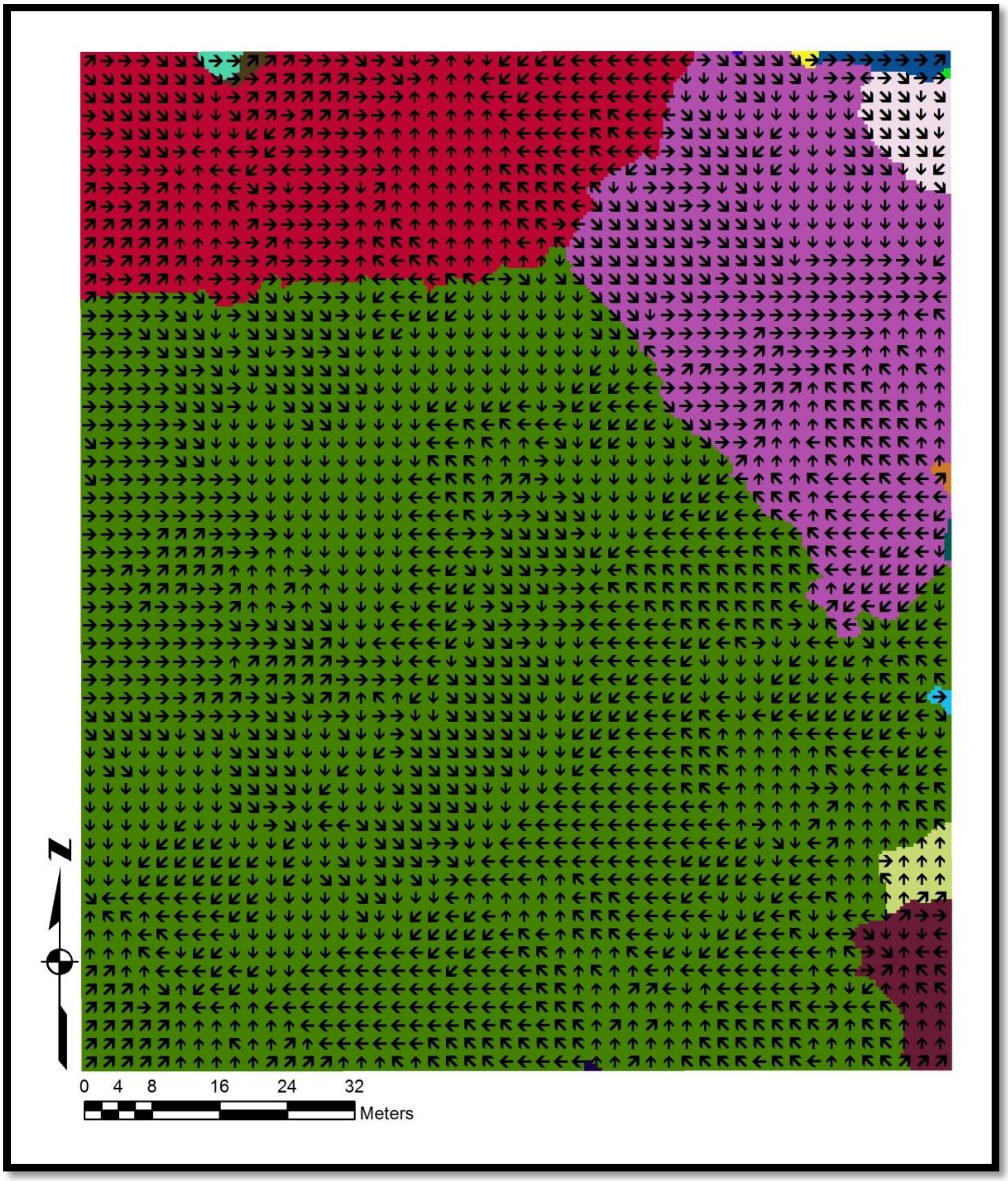

Figure 4.15 Group One flow direction arrows on the internal basins, not accounting for rock alignments.

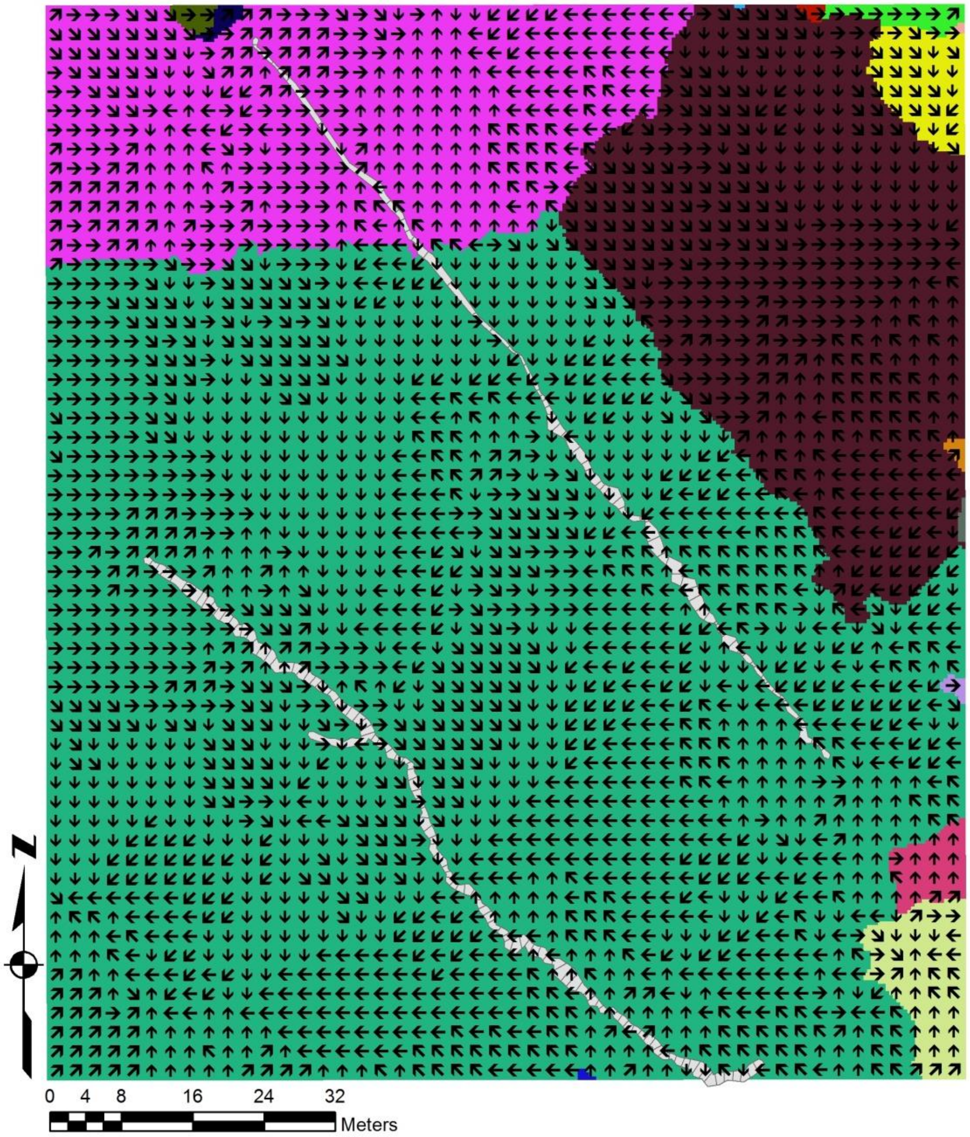

Figure 4.16 Flow direction of Group One, shown on the internal basins and rock alignments, both accounting for the impact of rock alignments.

the group in the southern portion of the group, and two secondary basins cross the northern portion of the group. Another 13 smaller basins are situated along the edges and in the southeast corner. There are no differences between the basins created using the raster with only the surface or the raster with the rock alignments.

Similarly, the direction of flow is altered little to not at all by the presence of the rock alignments. Along the rock alignments, water will generally continue flowing in the direction of the greater basin despite the presence of a rock alignment. Thus, rock alignment causes water to flow along it, but does not necessarily modify its direction.

## MAPPING GROUP TWO

### *Group Two*

Group Two is the only group in the southern portion of El Edén. It measures 170 m north – south by 100 m east – west and contains five rock alignments, numbers 14, 15, 16, 17, and 18.

### *Vegetation, Topography, Soils and Sediments*

The eastern portion of Group Two is generally of higher terrain that is undulating and rocky supporting a palm savanna. Between approximately 60 – 90 m east – west, there is a depressed channel containing areas of *eleocharis* slough and some typha marsh (Figure 4.17).

Figure 4.17 In the channel of Group Two, looking north.

To the north the vegetation transitions to tintal and to the northeast portion the channel ceases and the area becomes more uneven and rocky (Figure 4.18).

Topography of group two can be seen in Figure 4.19. The elevation at the southwest corner (datum) is 22.78 masl. There is a variation of 2.86 meters within the area of group two. The highest recorded elevation is 24.09 masl while the lowest point in this group reaches 21.71 masl. The average elevation of group two is 22.63 masl, making this, of all mapped groups, the highest average elevation.

The subsurface topography is similar to the surface topography (Figures 4.20 and 4.21). The highest point is the same point as the surface, at 24.09 masl, while the lowest point is nearly a meter below the lowest surface point at 20.60 masl. The difference between the high and low subsurface points is 2.39 meters.

Because two strips of Group Two were surveyed using a less accurate method than the Total Station, there is an obvious difference in the data. These sections appear higher than the surrounding topography. Unfortunately, the data is skewed due to the application of inconsistent methods. The area will still be considered in the analysis, however, with the understanding that it is not fully representative of the surface that truly exists.

Soil and sediment accumulation in Group Two is concentrated within the central channel (Figure 4.22). On the rockier margins of either side, soil accumulates within crevices between rocks. In terms of soil and sediment accumulation, group two exhibits the second highest average soil accumulation of all groups at 11.42 cm. The highest accumulation is 1.23 m, and 15.03 percent (101 out of 672) of the surveyed points had no sediment accumulation. Soil accumulation is still accurate, unlike the surface and subsurface topography.

Figure 4.18 About 20 m north on the north transect line, looking north to tasistal and tintal in the background.

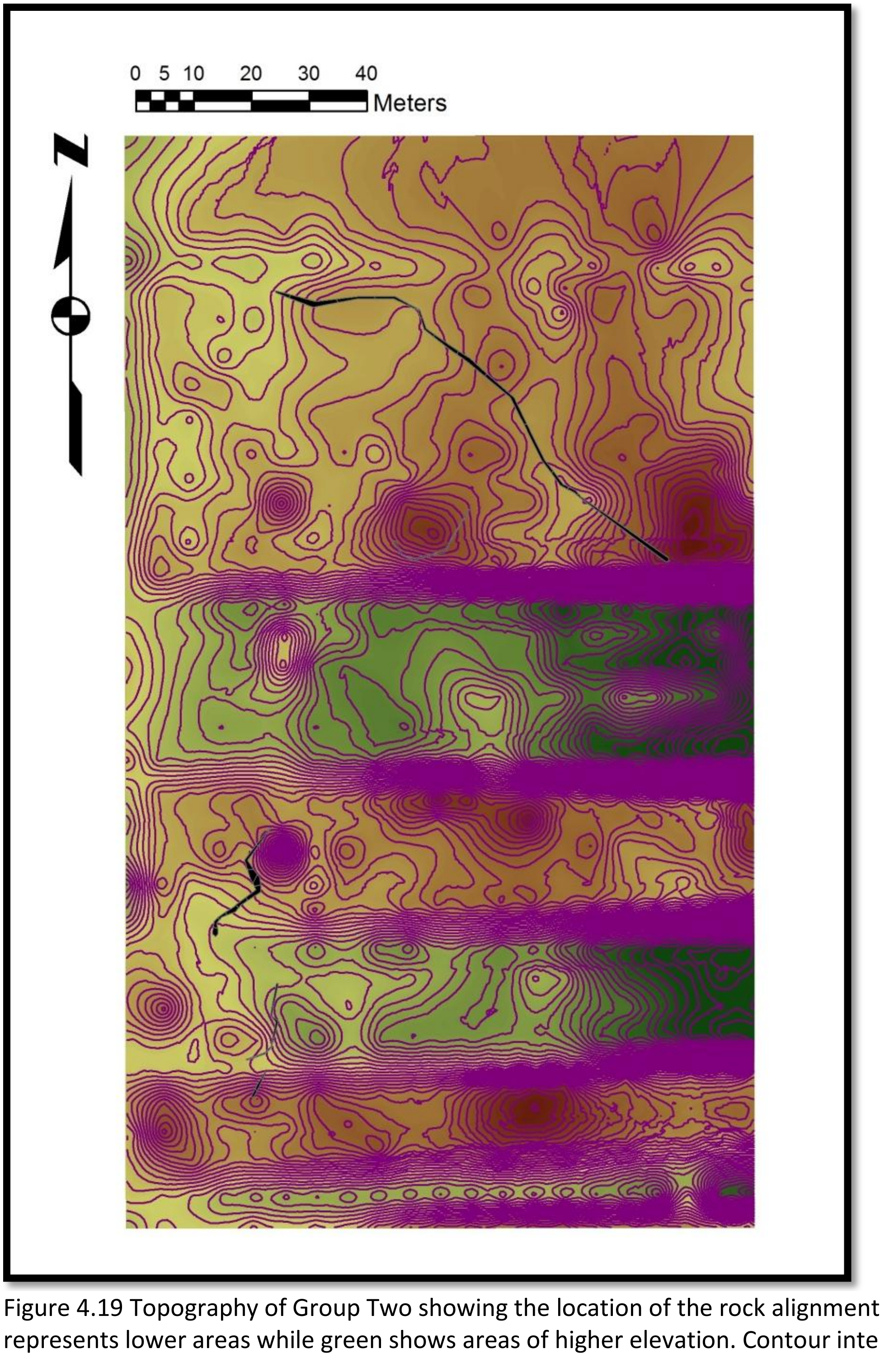

Figure 4.19 Topography of Group Two showing the location of the rock alignments. Brown represents lower areas while green shows areas of higher elevation. Contour interval is 5 cm.

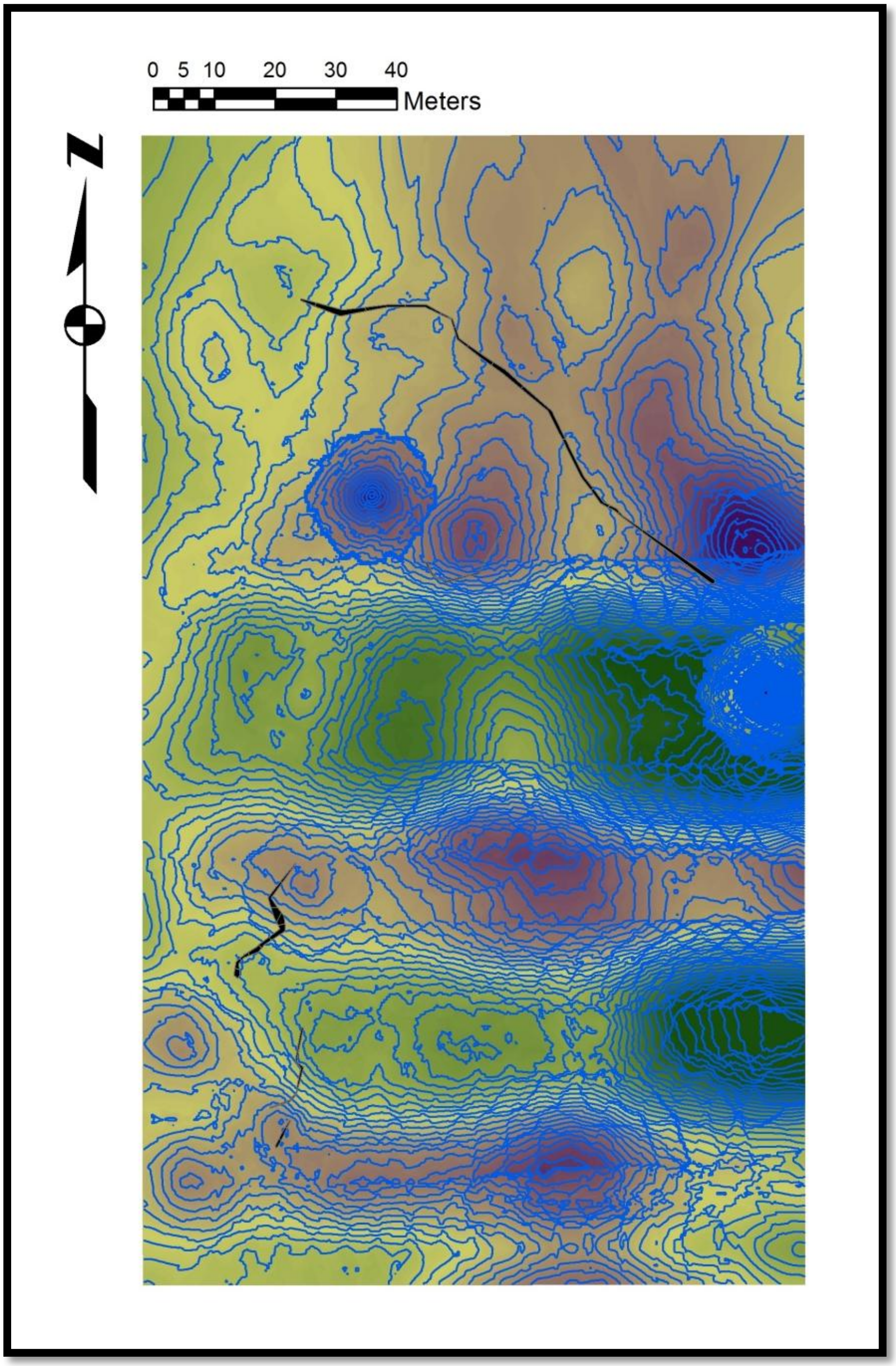

Figure 4.20 Group Two subsurface topography and the location of rock alignments. Purple represents low areas while green shows areas of higher elevation. Contour interval is 5 cm.

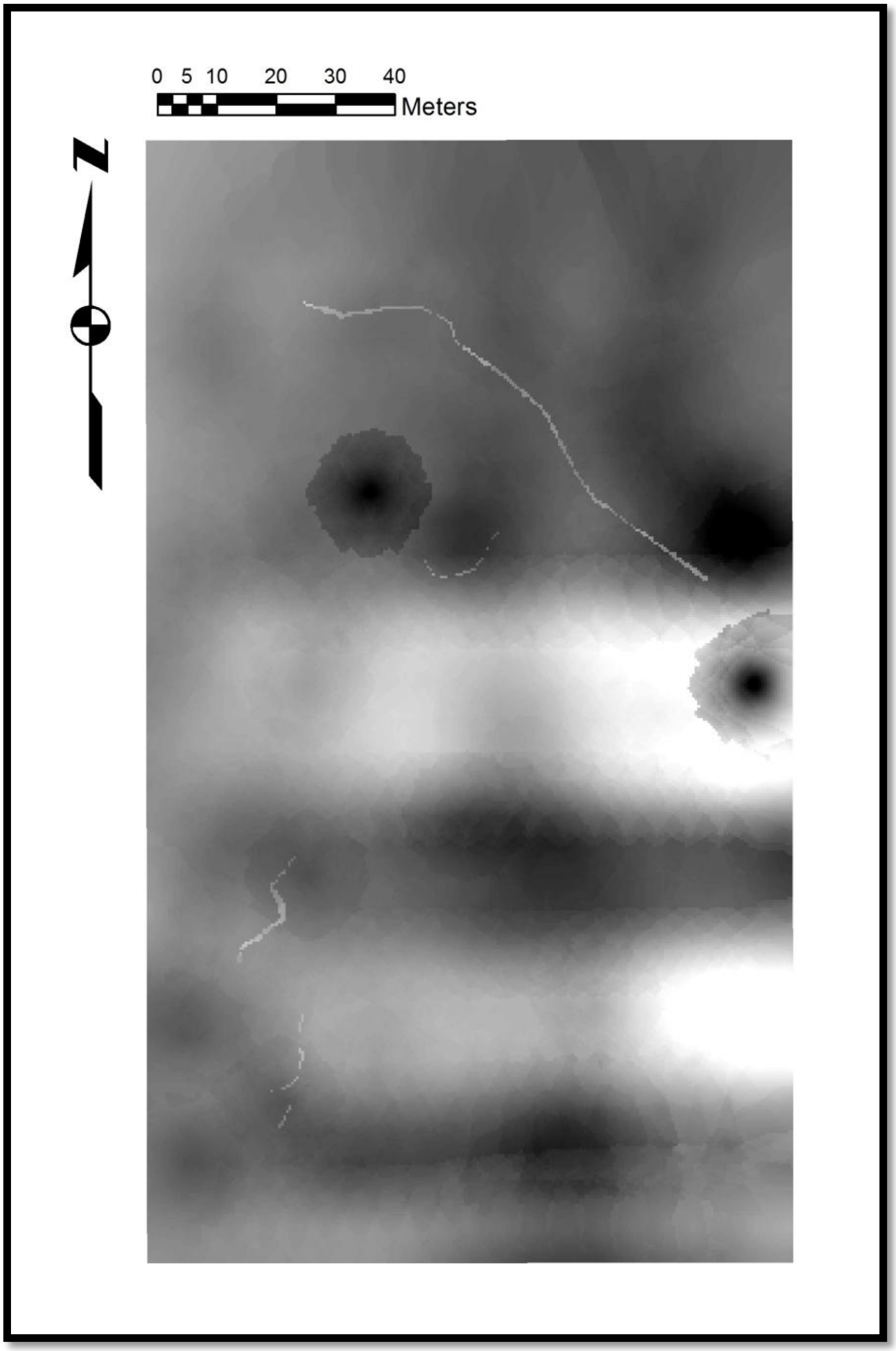

Figure 4.21 Group Two subsurface topography including rock alignments. Lighter areas are higher elevation while darker areas are lower.

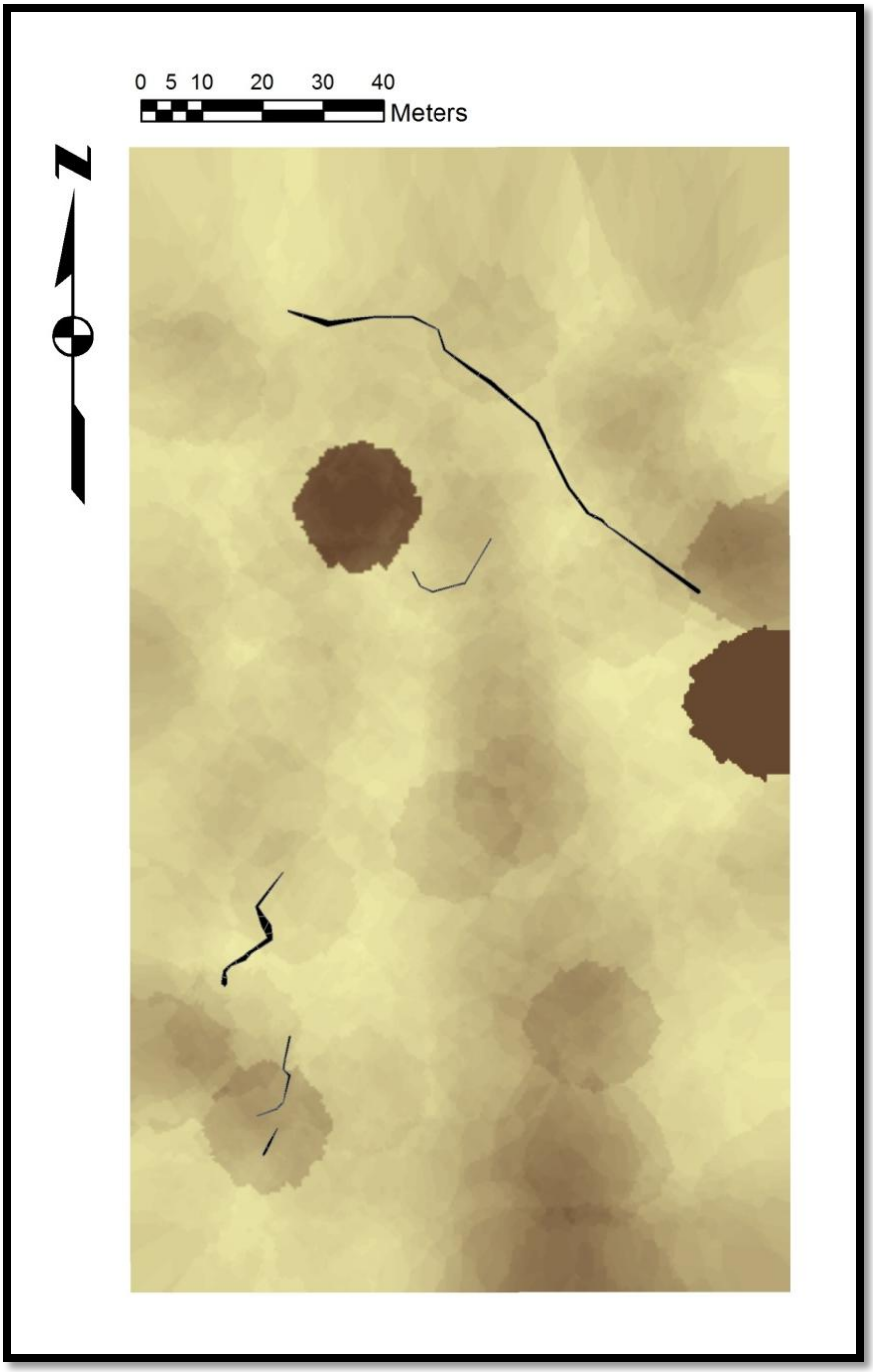

Figure 4.22 Soil and sediment accumulation in Group Two, darker areas indicate a deeper accumulation of sediment.

### *Rock Alignments*

Rock Alignment 14. Rock alignment 14 is composed of three sections, only one of which has been re-identified. It is approximately 12 m long, within a slight depression and leading up to a bedrock exposure. It is composed of a line of boulders, averaging 50 cm diameter. The surrounding terrain is quite level. Rock alignment 14 is an example of Fedick et al. (2000)'s Type Four alignment in that they occur perpendicular to slope in lower areas of the wetland and in areas transitioning from higher to lower elevations.

Rock Alignment 15. Rock alignment 15 is approximately 20 m long, running atop exposed bedrock. It is composed of a line of boulders, averaging 30 cm diameter. It is also an example of Fedick et al. (2000)'s Type Four alignment in that they occur perpendicular to slope in lower areas of the wetland and in areas transitioning from higher to lower elevations.

Rock Alignment 16. Rock alignment 16 is approximately 45 m long and runs from within the channel to the east side of the channel, terminating on a bedrock outcrop (Figure 4.23). There is a slight wave shape to this alignment. This is a Type Four alignment. The boulders used to construct alignment 16 are large, nearing 1 m on one side, and are constructed as a single row of boulders, less than 1 m wide. Unfortunately, no points were taken on this alignment, due to its full submersion in March 2012, to provide further information.

Rock Alignment 17. Rock alignment 17 is the longest alignment in Group Two, extending nearly 90 m (Figures 4.24 through 4.26). Its eastern edge is on raised bedrock and it continues, both on bedrock outcrops and through the depressed channel, northwest for approximately 65 m, until it meets higher ground and runs approximately 25 m east on top of bedrock. Some of the boulders used within this alignment are nearly 1 m on at least a single side, and often there

Figure 4.23 Rock alignment 16 jutting into the channel, looking west.

Figure 4.24 West end of Rock Alignment 17.

Figure 4.25 Rock Alignment 17 running through the channel.

Figure 4.26 Rock Alignment 17 from the same position as Figure 4.27 but in high water.

is more than a single line of stones constituting the alignment. Alignment 17 is a Type One or a Type Four alignment as it cordons off a large portion of the wetland while within lower terrain.

Rock Alignment 18. Rock alignment 18 is approximately 35 m. It is located approximately 20 m west of the lower portion of rock alignment 17, on the margins between the edge of the canal and higher ground (Figure 4.27). It has a slight U-shape. For the most part, rock alignment 18 is not situated directly on bedrock and is composed of slaps of limestone stood on end. It conforms to Fedick et al.'s (2000) Type Two alignment; surrounding and blocking the lowest portion of a depression.

### *Water Flow*

Unfortunately, both the direction of water flow and basin analysis within Group Two are heavily impacted by the skewed data Figures 4.28 and 4.29). Within Group Two there are 67 basins, both with and without the influence of rock alignments. However, the skewed data influences the formation of additional basins within the center of the channel. Water flow direction is into these basins. With the inclusion of the rock alignments, water flows away from or along the rock alignments and not through them. There is not a substantial difference in water flow with or without the rock alignments.

Figure 4.27 Rock Alignment 18 surrounding a depression.

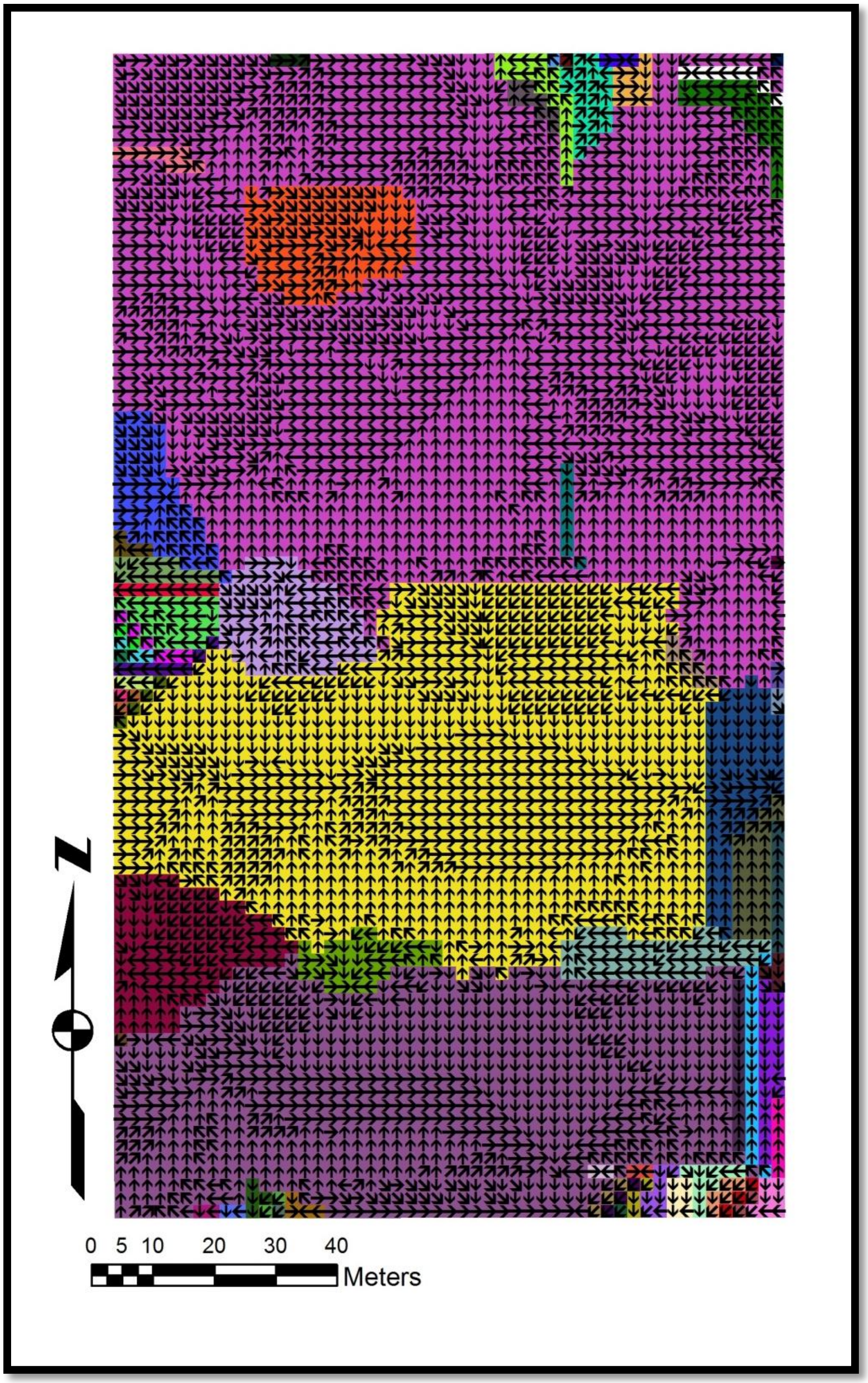

Figure 4.28 Group Two showing the direction of flow superimposed on the internal basins.

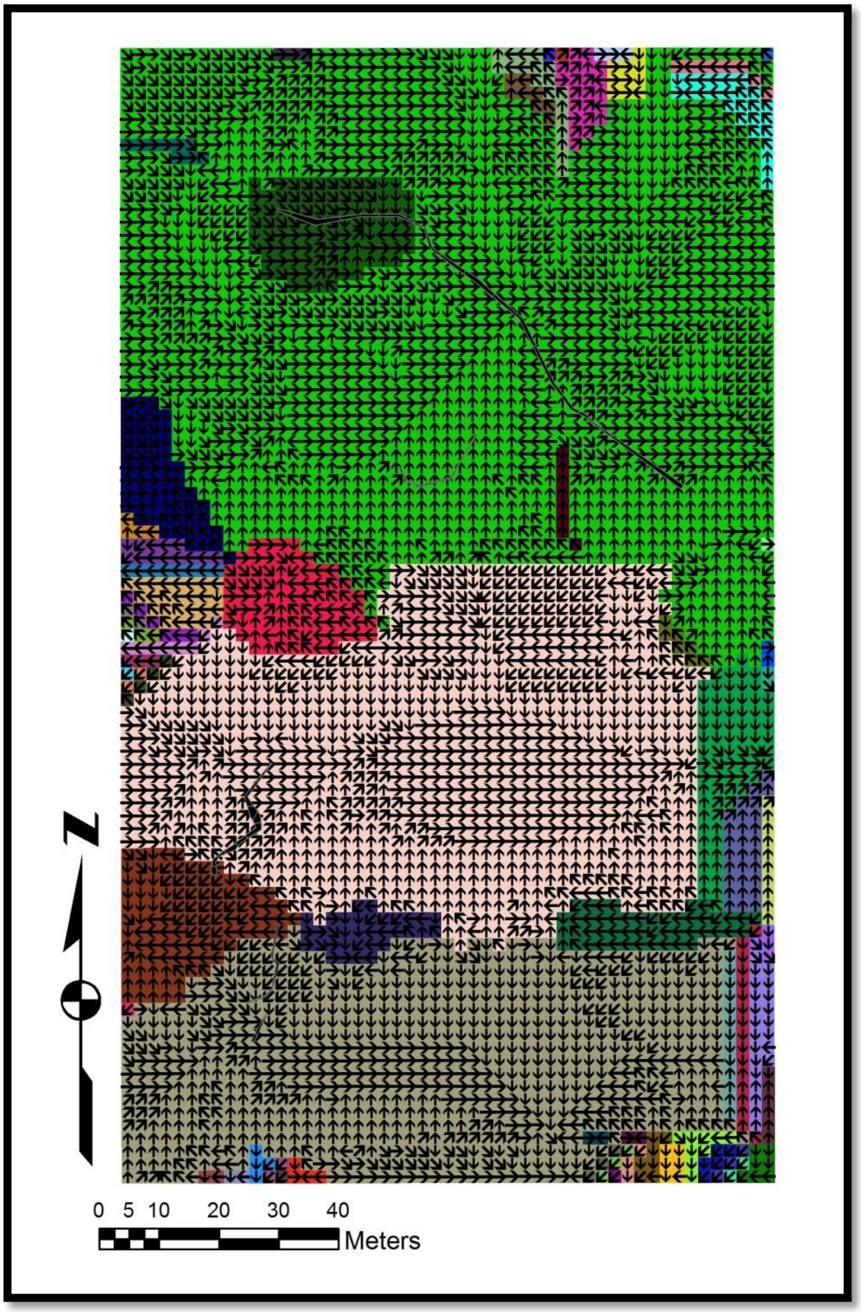

Figure 4.29 Water flow direction superimposed on the internal basins of Group Two with the effect of the rock alignments.

## MAPPING GROUP THREE

### *Group Three*

Group Three is located in the central portion of the wetland, 50 m to the north and 210 m to the east of Group One. Group Three measures 100 m by 100 m and contains two rock alignments, numbers 57 and 58.

### *Vegetation, Topography, Soils and Sediments*

Group Three exhibits vegetation zones of predominantly tintal with areas of open tintal Figures 4.30 and 4.31). Within the area of Group Three, there are some small depressions that hold water (Figure 4.32). Both the northwest corner and the eastern margin are particularly rocky and slightly higher areas. The lowest parts of Group Three occur along the mid western border as well as along the mid northern border.

Figure 4.33 shows the surface topography of Group Three. At the southwest corner, the elevation was measured at 22.78 masl. The highest points within the area reside on the mid east side, along the margin. Two other high areas are the north east and south east corners. Surface variation in elevation within this group is 1.14 m. The highest recorded elevation measures 22.48 masl while the lowest is 21.34 masl. Average surface elevation of group three is 21.88 masl, making this the lowest average elevation of any of the mapped groups and an average of 75 cm below Group Two.

Figure 4.30 An example of the extensive coverage of tintal in Group Three.

Figure 4.31 Open tintal in Group Three.

Figure 4.32 A depression filled with water on the north transect line of Group Three.

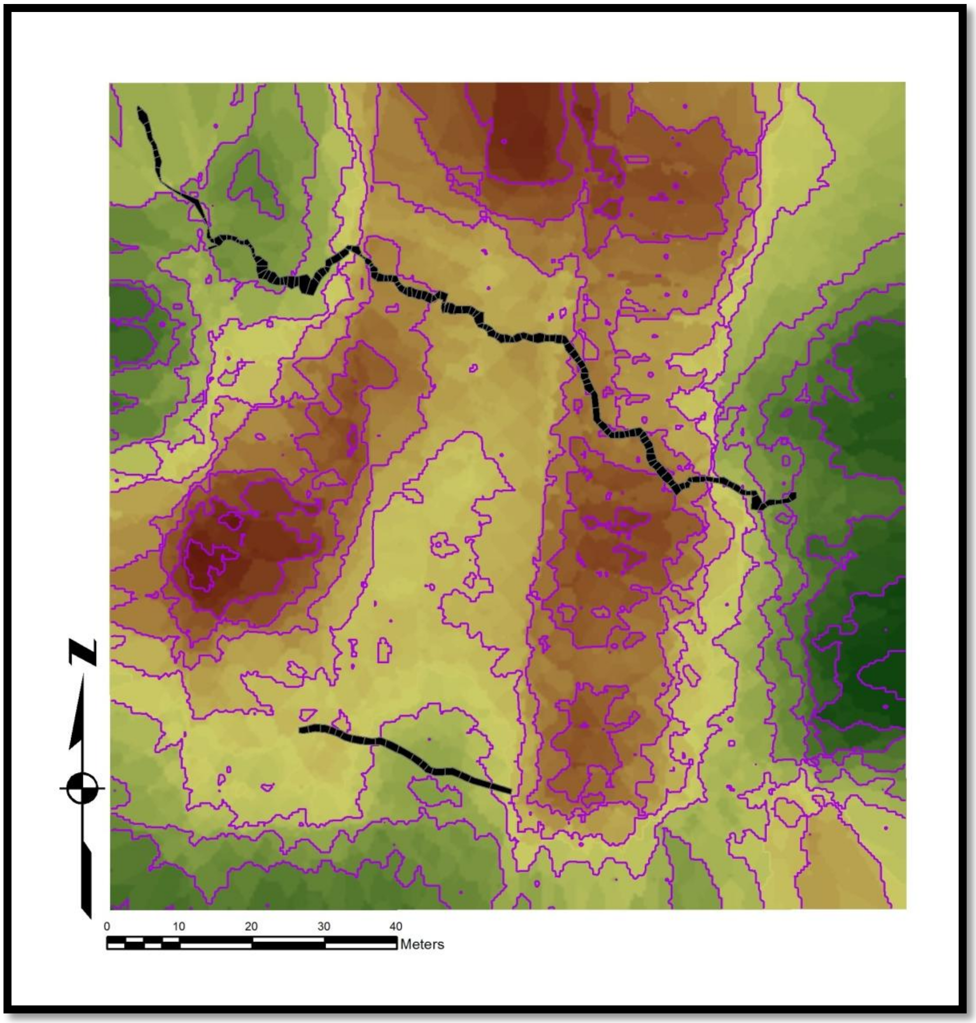

Figure 4.33 Surface topography of Group Three showing the location of rock alignments. Brown represents low areas while green shows areas of higher elevation. Contour interval is 5 cm.

Figures 4.34 and 4.35 shows the subsurface bedrock contours of Group Three and these mirror the contours of the surface. A difference of 1.15 m exists throughout the subsurface, with the highest measured point being 22.39 masl and the lowest being 21.24 m.

Group Three has the lowest average soil accumulation of all mapped groups at 4.00 cm. Figure 4.36) shows how the soil has accumulated on the surface, predominantly in the lowest areas of Group Three. Of the 440 surveyed points in group three, 233 - or 52.95 percent - have no sediment accumulation. The area of highest sediment accumulation was measured just south of a portion of rock alignment 57. The deepest sediment recorded was 36 cm.

*Rock Alignments*

Rock Alignment 57. Rock alignment 57 is approximately 100 m long and conforms to Fedick et al. (2000)'s Type Three alignment as it runs perpendicular to slight slope gradients in fairly open transitional vegetation zones (Figures 4.37 through 4.39). It connects two areas of higher elevation. Rock Alignment 57 also has a distinctive zig zag form and follows along the upper contours of a ridge around depressions that hold water. It should be noted, however, that even within the flat, central portion of group three that Rock Alignment 57 exhibits two 90 degree turns in its course (Figure 4.40).

For most of its length, Rock Alignment 57 is composed of large slaps of bedrock piled atop other slabs of bedrock. In other places, the alignment consists of a row of boulders. Many of the boulders within this alignment are very large, 1 m on one or more sides. Often, this alignment is wide, approaching 2 m in width.

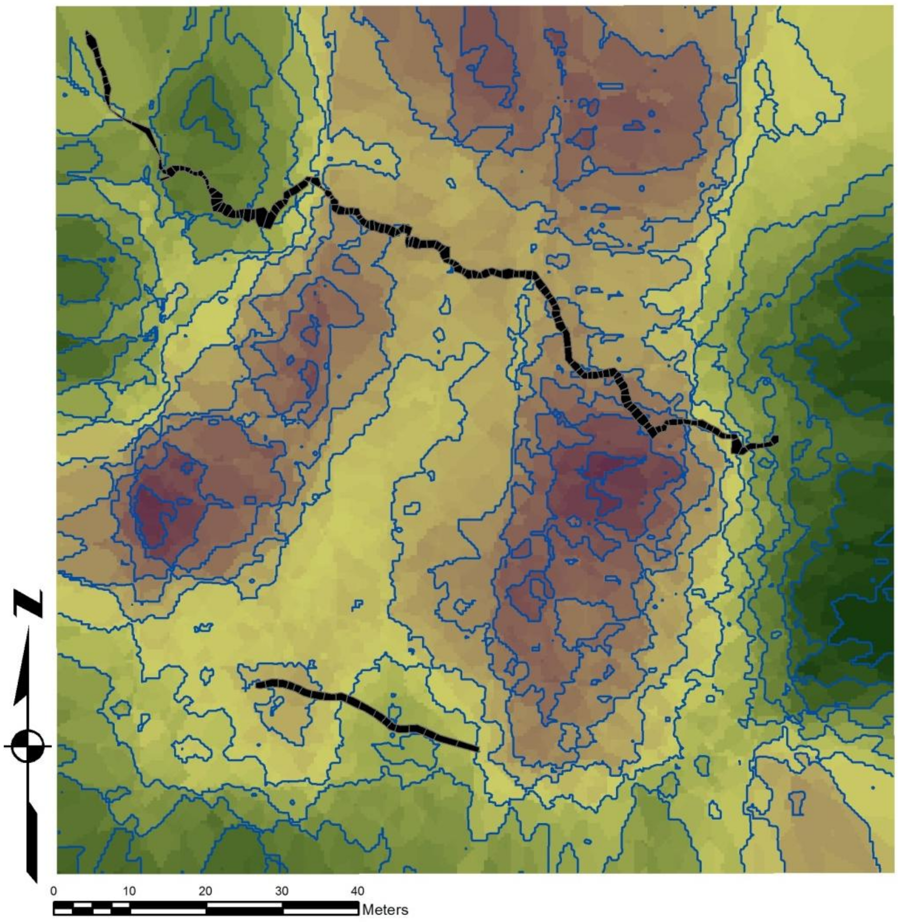

Figure 4.34 Subsurface topography of Group Three. Higher areas are represented by green whereas lower areas are purple. Contour interval is 5 cm.

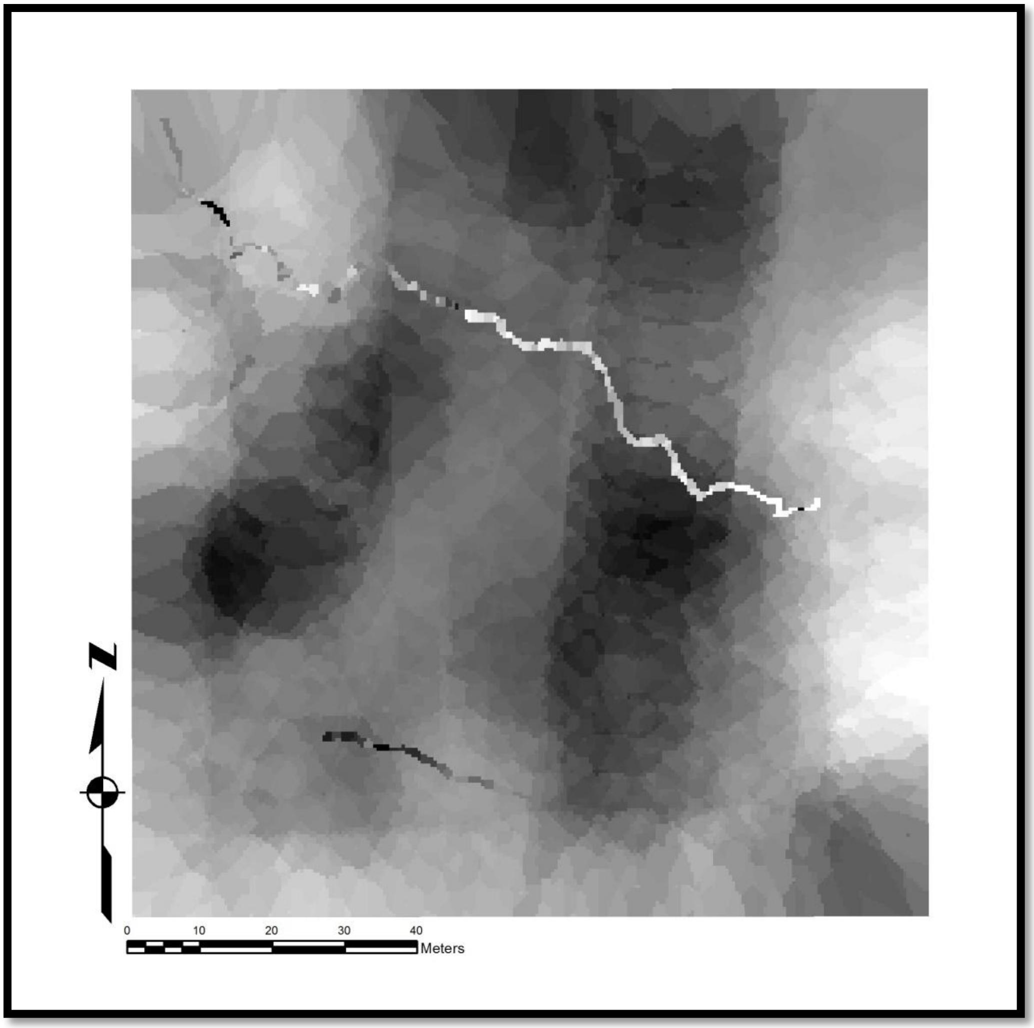

Figure 4.35 Subsurface topography of Group Three including the rock alignments. Higher areas are represented by white whereas lower areas are darker.

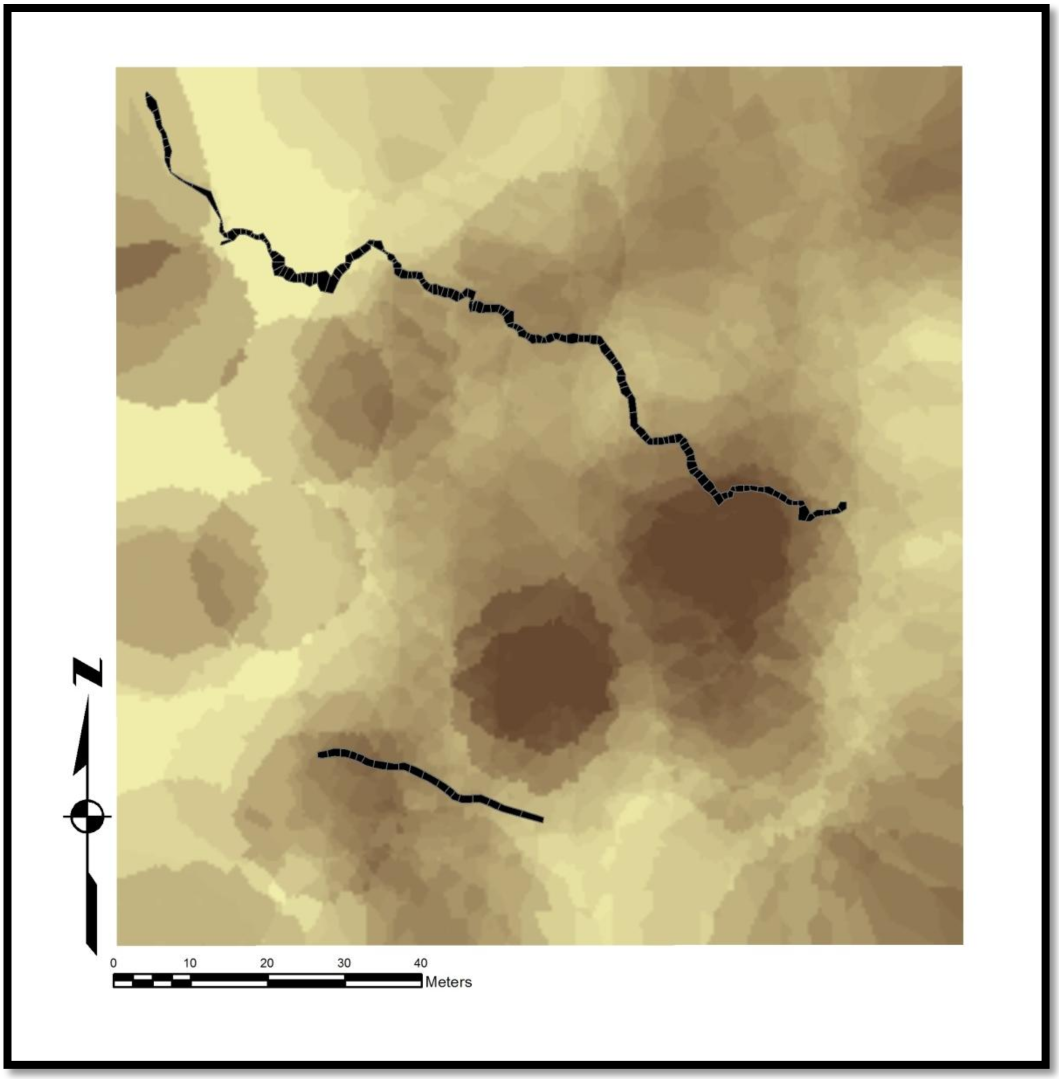

Figure 4.36 Soil accumulation in Group Three. Deeper areas of sediment are darker.

Figure 4.37 Section of Rock Alignment 57, notice the piled slab construction technique.

Figure 4.38 Rock Alignment 57 curving around a depression, to the right.

Figure 4.39 The northwest terminus of Rock Alignment 57.

Figure 4.40 One of the 90 degree curves of Rock Alignment 57.

Given the specific location of the rock alignment and the recovery of friable material that could have been undiagnostic ceramic sherds in Fedick et al. (2000)'s excavations that could have served as fish net weights, that this alignment served as a base for a fish weir is a consideration.

Rock Alignment 58. Rock alignment 58 is a short alignment, not even 10 meters long, that connects two bedrock exposures. It is composed of a single row of boulders, not more than 50 cm diameter. As there was standing water between the bedrock exposures, this alignment seems to be an example of Fedick et al. (2000)'s Type Five alignment: running across a narrow and relatively deep channel.

### *Water Flow*

Direction of water flow and internal basins are shown in Figures 4.41 and 4.42. Group Three has 706 basins that direct overall water flow. The majority of these basins are on the margins of the mapped group, with only seven or eight basins in the center. Of the two rock alignments in Group Three, rock alignment 57 has significant impact on overall direction of water flow. The portion of rock alignment 57 that extends through the flatter section of Group Three directs the immediate flow of water to the side and along its length, effectively creating a new basin. Rock alignment 58 has minimal impact on direction of water flow.

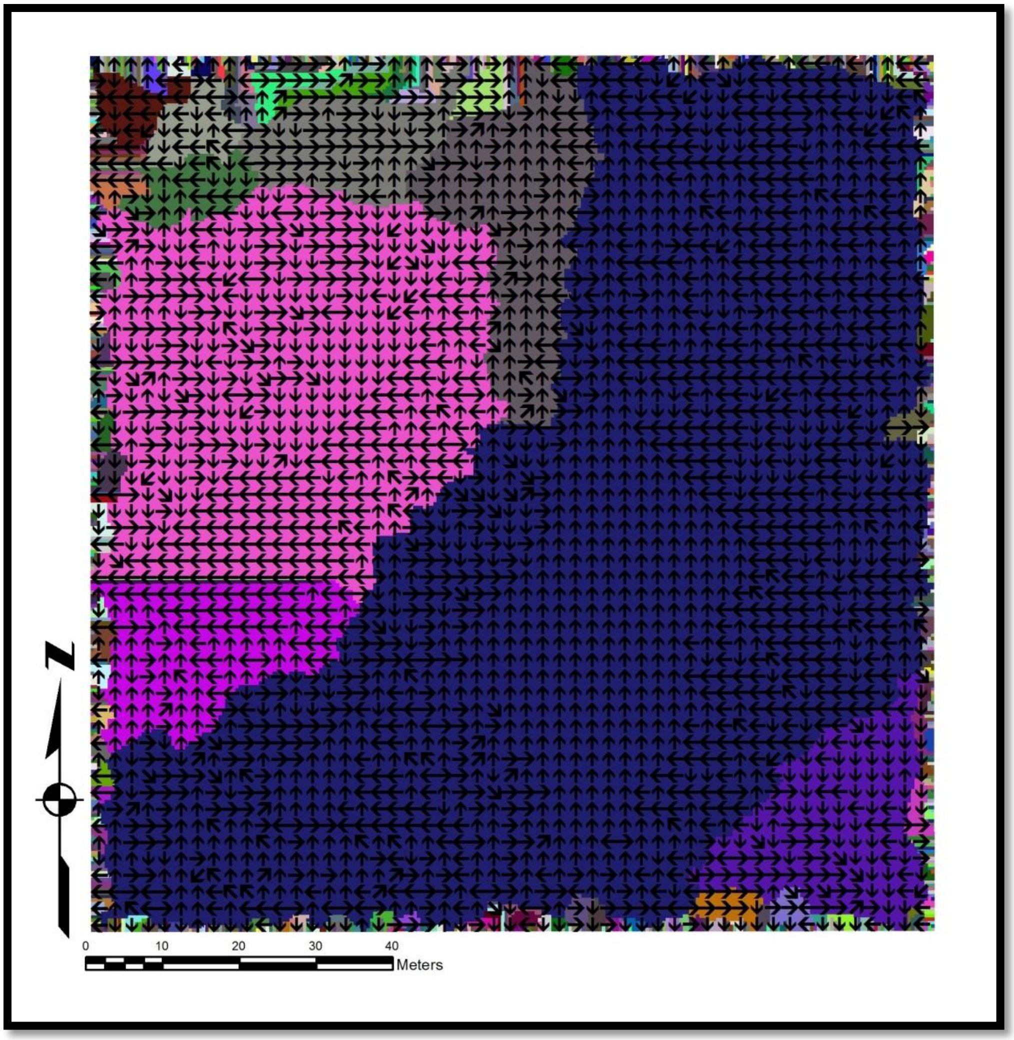

Figure 4.41 Internal basins and direction of water flow on the surface of Group Three, both without the influence of rock alignments.

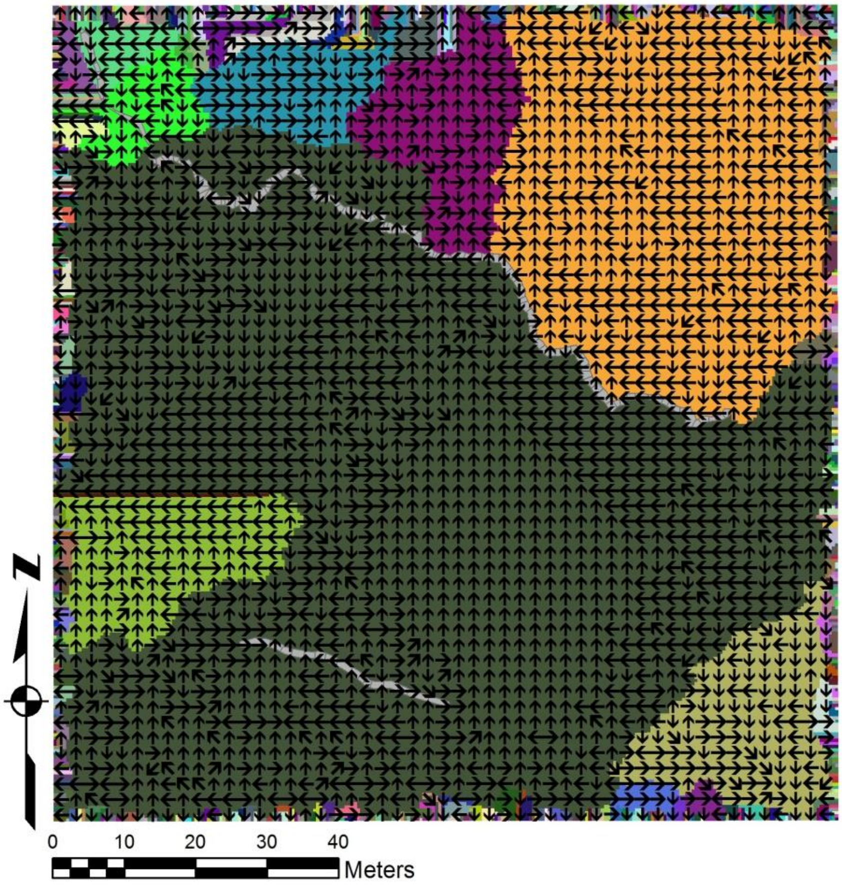

Figure 4.42 Internal basins and direction of water flow within Group Three, considering the influence of the rock alignments.

## MAPPING GROUP FOUR

### *Group Four*

Group Four is located in the northern portion of the wetland, to the north of the great 700 m alignment, Rock Alignment 41. Rock Alignment 41 cuts across nearly the entire wetland, arcing gently northwards. Group Four measures 95 m north to south and 110 m east to west and contains three rock alignments, alignments number 43, 44, and 45.

### *Topography, Vegetation, Soils and Sediments*

The area of the wetland where group four is located is on higher and rockier ground so subject to less frequent and sustained inundation. The northwest and southeast corners host the highest elevations (Figure 4.43). Within the central portion of Group Four is a small channel-like depression that extends east to west and supports very dense stands of sawgrass (Figure 4.44 and 4.45). Vegetation varies in this area and is indicative of transition to higher elevations, with palm savanna and open tintal vegetation zones dominating. Soils within the depression at times exceed 1.2 m depth – rather substantial for this wetland.

Figure 4.46 shows the surface topography of Group Four. Elevation at the southwest corner was measured at 22.15 masl. Throughout the group, there is 1.50 m of topographic variation, the highest recorded point is 23.02 masl and the lowest surface elevation is 21.53 masl. The highest point within Group Four is located on the northern margin, on the western

Figure 4.43 Area of tintal in Group Four.

Figure 4.44 The central depression in Group Four, in dry conditions.

Figure 4.45 Central depression in Group Four in wet conditions.

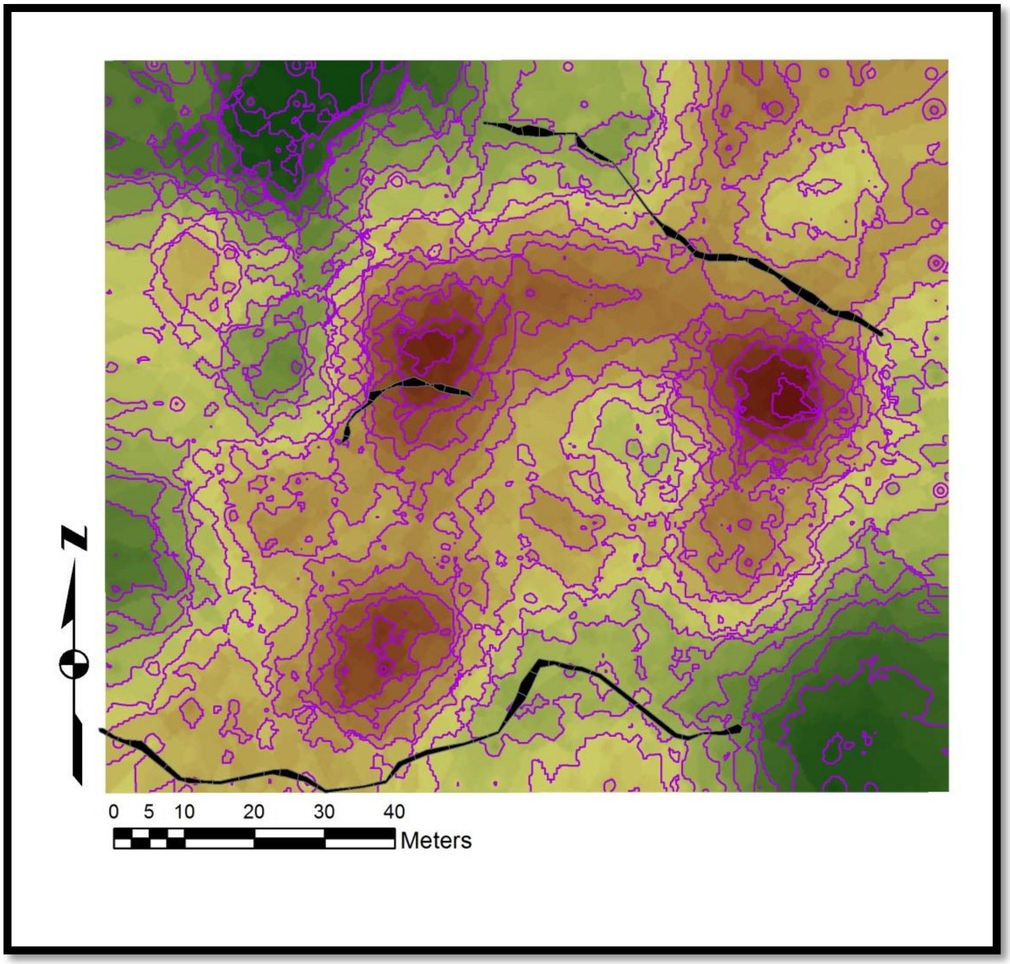

Figure 4.46 Surface topography of Group Four. Green areas represent high elevations, grade through yellow to low elevations shown in brown. Contour interval is 5 cm.

side. A second high area exists within the southeast corner of the group. The average elevation of Group Four is 22.20 masl, the second highest group, only 42 cm below Group Two.

The subsurface topography of Group Four is shown in Figures 4.47 and 4.48. The highest point was measured at 22.98 masl, the lowest at 20.38 masl, with an average subsurface elevation of 22.14 masl. Three separate depressions are highlighted in the central area of Group Four. The lowest subsurface point of Group Four is lower than the lowest point recorded in Group Two.

Of all the groups, Group Four boasts the deepest measured sediment at 1.28 m. The average depth, however, is only 6.84 cm and 28.26 percent (130 of 460) of the surveyed points reported no sediment accumulation. Figure 4.49 shows that the location of the majority of sediment accumulation was throughout a central depression in the group.

### *Rock Alignments*

All three alignments in Group Four correspond to Fedick et al. (2000)'s Type Two alignment: blocking the lowest areas of a natural depression. Rock Alignment 43 runs along the southern portion of Group Four, Rock Alignment 45 is in the north, and Rock Alignment 44 is in the central area of Group Four.

Rock Alignment 43. Rock alignment 43 is the most southern alignment and measures approximately 80 m (with breaks in its extent) running roughly east to west (Figures 4.50 through 4.52). It begins in a short depression, approximately 2 m wide, and continues much of its extent is along an outcrop that drops approximately half a meter to the south of the rock

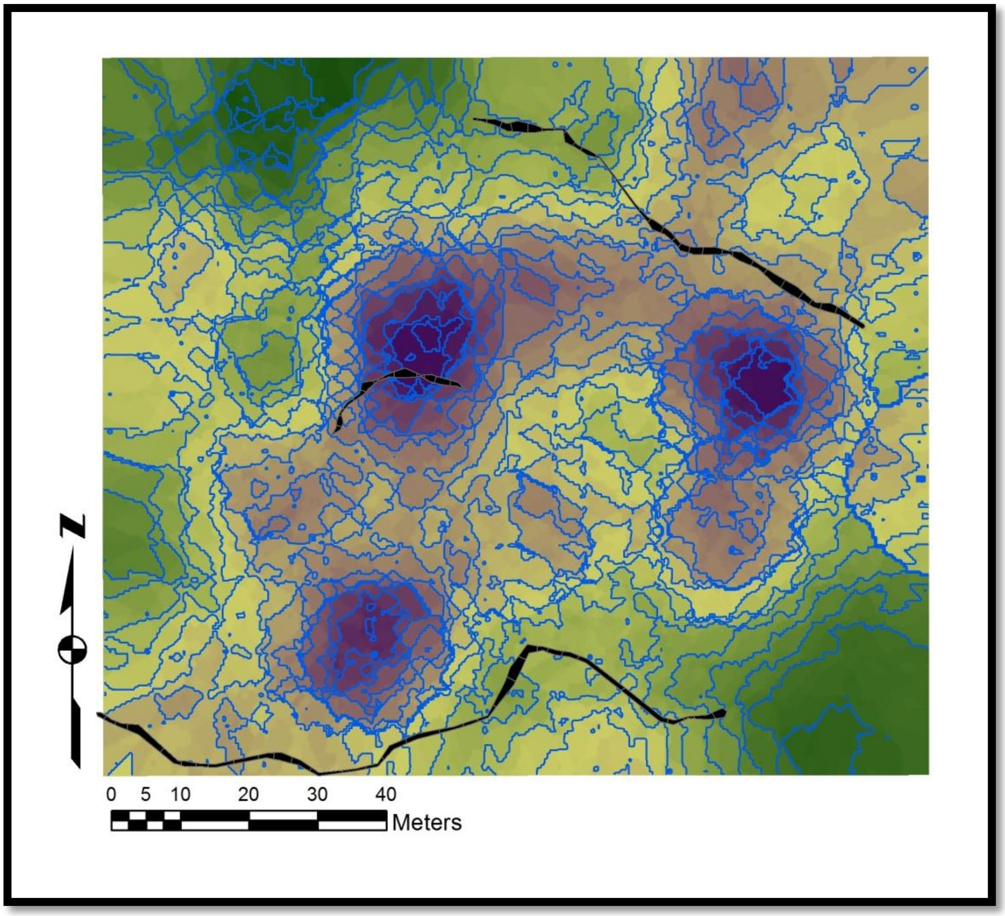

Figure 4.47 Subsurface topography of Group Four. Green represents high areas, purple represents low areas. Contour interval is 5 cm.

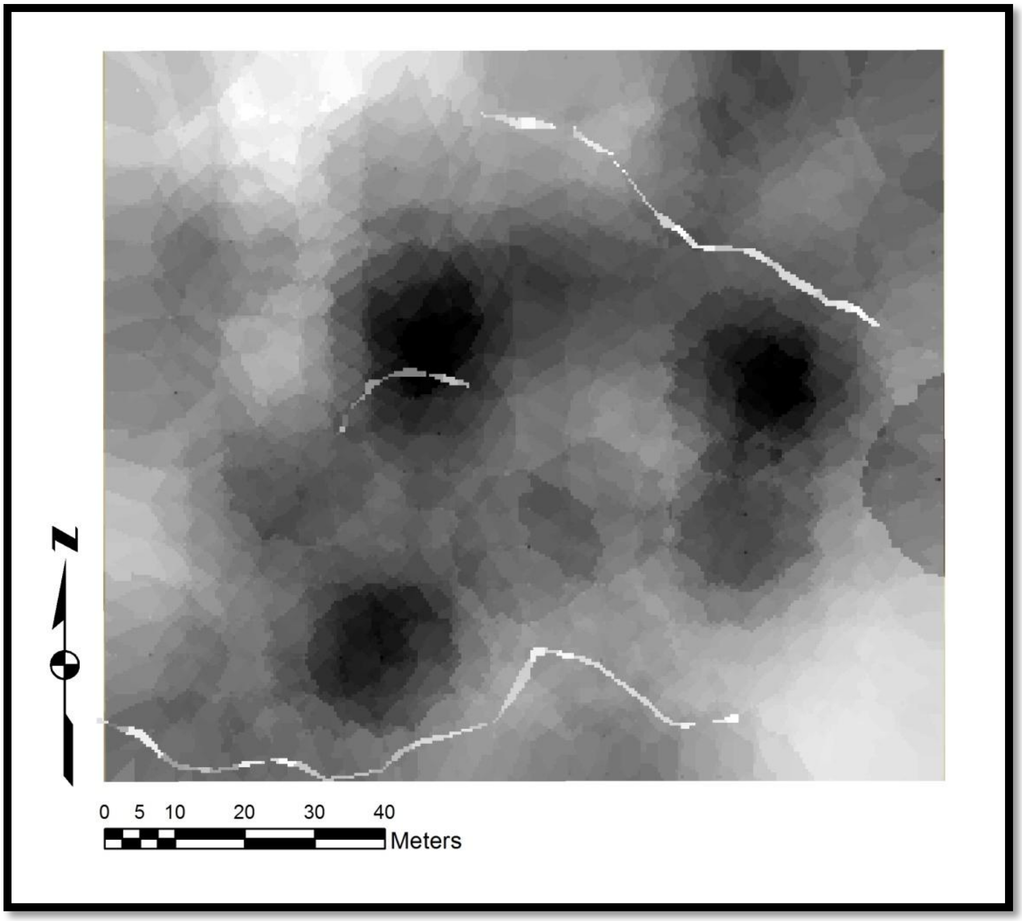

Figure 4.48 Subsurface topography of Group Four including the rock alignments. Light areas are of higher elevation while darker areas are lower elevation.

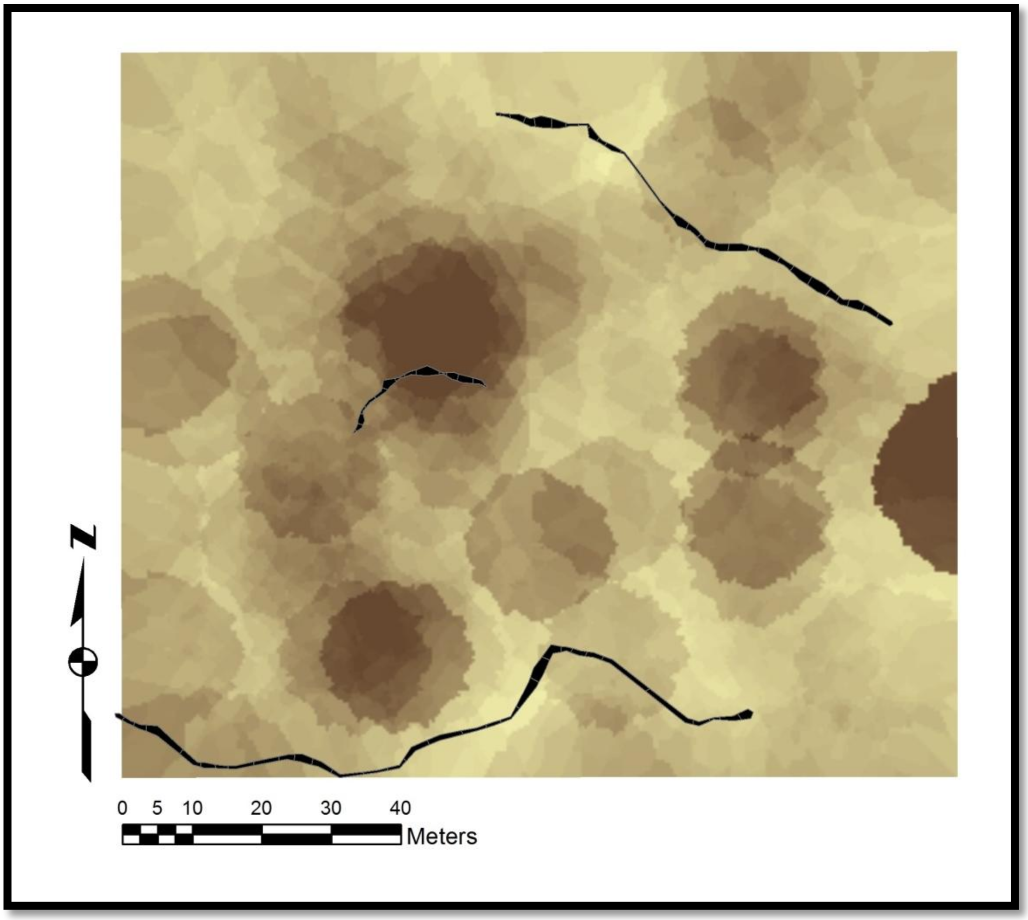

Figure 4.49 Sediment and soil accumulation in Group Four. Darker areas indicate locations of deeper sediments.

Figure 4.50 Rock Alignment 43 in wet conditions.

Figure 4.51 Rock Alignment 43 in dry conditions.

Figure 4.52 A section of Rock Alignment 43 showing slabs of limestone piled upon a bedrock outcrop.

alignment, before terminating after another large depression. Although rock alignment 43 runs along a raised area, it does link two areas of higher elevation. It is built up by slabs of limestone piled upon slabs of limestone. Some of the limestone slabs are large, nearing and exceeding 1 m on one side.

Rock Alignment 44. Rock alignment 44 is the shortest of the alignments in Group Four, measuring approximately 20 m (Figure 4.53). It borders a circular depression to the south, and meets up with a bedrock outcrop on the west. Immediately behind rock alignment 44 there is a depression that contains deeper sediments. A single row of boulders ranging in size from 20 - 40 cm form alignment 44.

Rock Alignment 45. Rock alignment 45 measures approximately 75 m, southeast to northwest (Figures 4.54 and 4.55). It is to the north of a depression, connects segments of exposed bedrock, and creates a ridge through this lower area. Rock alignment 45 is predominantly constructed of slabs of limestone, in some areas propped up against each other (Figure 4.56), and in other areas laid on the bedrock. Many of the slabs used in the construction of alignment 45 are very large, exceeding 1 m on one side (Figure 4.57).

### *Water Flow*

Of all the groups, the presence of the rock alignments within Group Four has the most impact on direction of flow (Figures 4.58 and 4.59). Without the presence of rock alignments, water would tend to flow north and east, resulting in a general northeastern flow of water. The rock alignments, however, appear to redirect water to predominantly a south and west flow.

Figure 4.53 Rock Alignment 44.

Figure 4.54 Rock Alignment 45 running through part of the depression in the dry season.

Figure 4.55 Rock Alignment 45, at approximately the same location, in the wet season.

Figure 4.56 An example of the upright slab construction technique of Rock Alignment 45.

Figure 4.57 One of the many slabs exceeding 1m used in the construction of Rock Alignment 45.

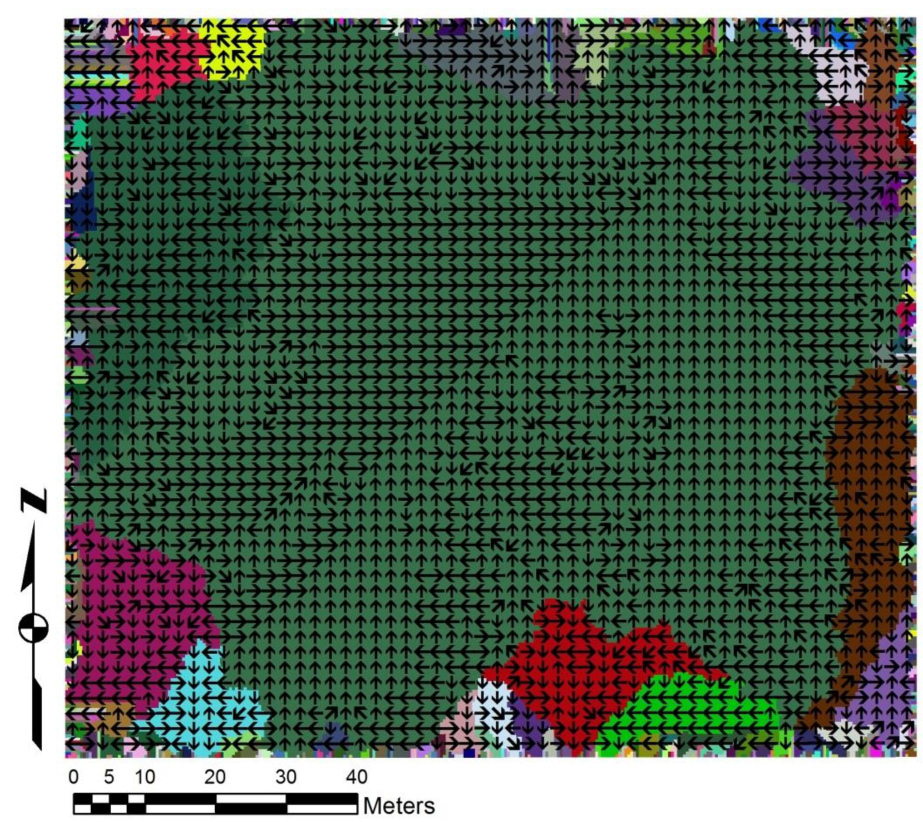

Figure 4.58 Direction of water flow in Group Four, not accounting for the rock alignments, shown on the surface topography.

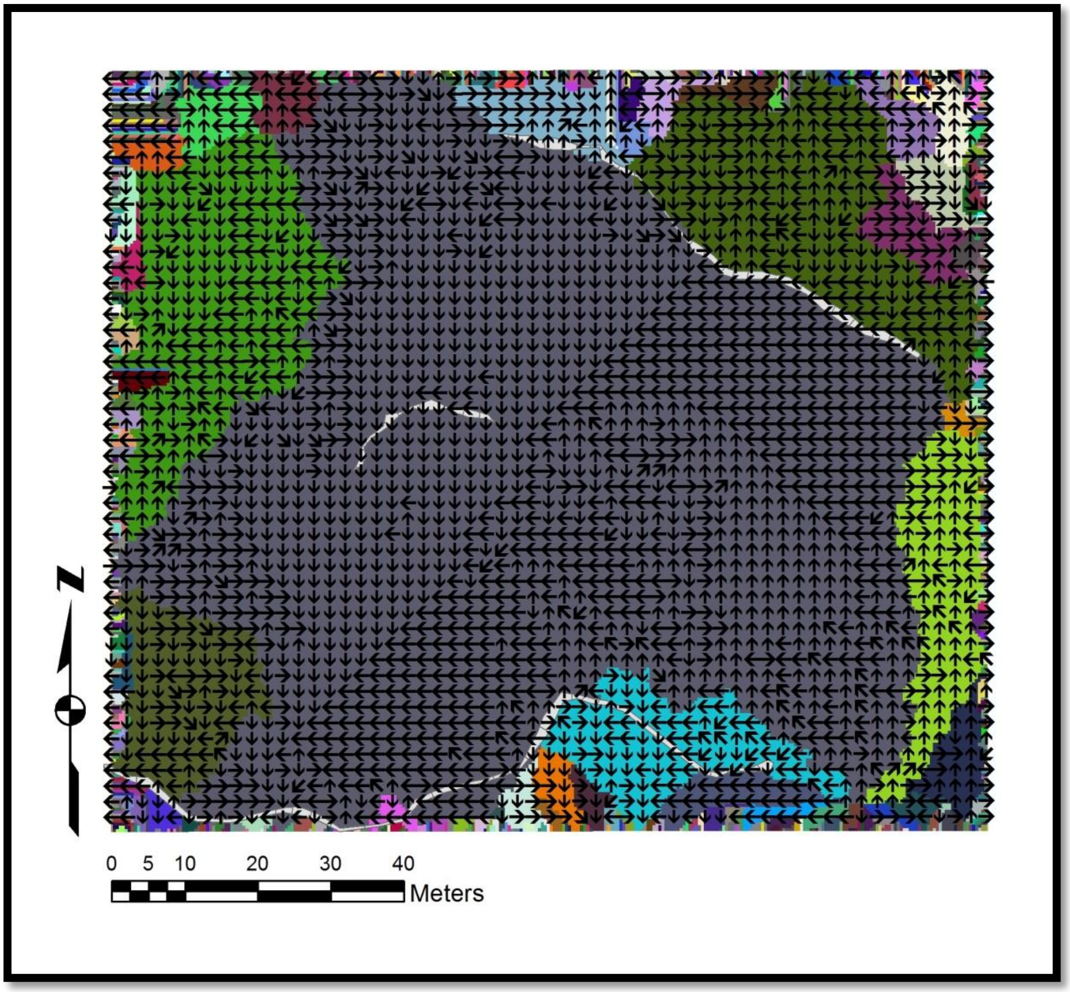

Figure 4.59 Surface flow in Group Four, accounting for the rock alignments, shown on the flow direction raster.

Toward the western side of rock alignment 43, the rock alignment redirects water so that it stays in shallow depressions in that area.  Rock alignment 44 redirects water so that would stay within that slight depression.  Rock alignment 45 has the most significant impact on the direction of water flow.  By cutting off access to a depression leading northeast, water can no longer flow in that direction.  Rock alignment 45 forces water that would otherwise flow to the northeast to flow west and south, changing the entire flow pattern in Group Four.  Given that rock alignment 43 runs through a depression in the southwest corner of the group, it may have served to hold water within this depression.

## CORING LOCATIONS

On November 24, 2010, Jennifer Chmilar joined Dr. Gerald Islebe, two of his students Pablo Ramírez Barajas and Pierre Charruan and his assistant Margarito Tuz Novelo, all from El Colegio Frontera Sur (Spanish acronym ECOSUR) on an expedition to extract seven sediment cores from areas throughout the wetland to be analyzed for change in pollen through time as well as AMS dates.  The day was sunny and warm, and the water was not too high, averaging approximately 30 cm depth throughout the wetland but at times deepening to 50 cm – not enough to hamper attempts at removing sediment cores (Figure 4.60).  Two cores extended to nearly 1 m in length, one from each the northern and southern portion of El Edén.

The first three sediment cores were taken at locations along the old north vegetation transect at the locations of 16 Q 0479846 2347126, 16 Q 0479861 2347144, and 16 Q 0479922 2347204, respectively.  The first core was less than 50 cm in extent, the second core was nearly 1.5 m, and the third core approached 2 m.

Figure 4.60 Sediment coring in water.

The fifth core was extracted within the northern portion of the wetland but south of the first three within a small depression. It measured nearly 50 cm in length. The sixth and seventh sediment cores were extracted from locations in the southern portion of the wetland, at 16 Q 0479537 2344807 and 16 Q 0479529 2344633, respectively. The sixth core was extracted from within the northeast portion of Group Two and extended to a length of nearly 2 m (Figure 4.61). The seventh core was extracted approximately 200 m south of the sixth core and just to the south of Group Two but still within the depressed channel that runs through the east portion of Group Two.

Due to its greater length, analysis has focused on just sediment Core 7. Initial radio carbon ages indicate a basal age of core three from a depth of 195 – 196 cm at 4040 ± 25 BP up to a recent radio carbon age of 2060 ± 15 BP at a depth of 60 – 61 cm. The radio carbon age from a depth of 158 – 159 cm seems problematic as it yielded an age of 2615 ±15 BP. The date of that sample is out of line with the subsequent two ages, at 123 – 124 cm and 91 – 92 cm respectively, are 3015 ± 15 BP and 2355 ± 15 BP.

Core 7 produced radio carbon ages ranging from at least 2045 ± 15 BP, at a depth of 89 – 90 cm (Sample UCIT26472), to 765 ± 15 BP, at a depth of 43 – 44 cm (Sample UCIT26474). Two of the ages derived from deeper samples in Core 7, at 140 – 141 cm (Sample UCIT26470) and 111 – 112 cm (Sample UCIT26471), appear to be out of line as they give ages of 1195 ± 15 BP and 1135 ± 15 BP, younger than 2045 ± 15 BP. A sample (UCIT26473) from a depth of 65 – 66 cm yielded an age of 1355 ± 15 BP.

When Core 7 was resampled it produced the following radio carbon ages for the two awry samples: 2850±15 BP between 141- 141 cm (Sample UCIT26470R) and 1290±15 BP at a depth between 111 - 112 cm (Sample UCIT26471).

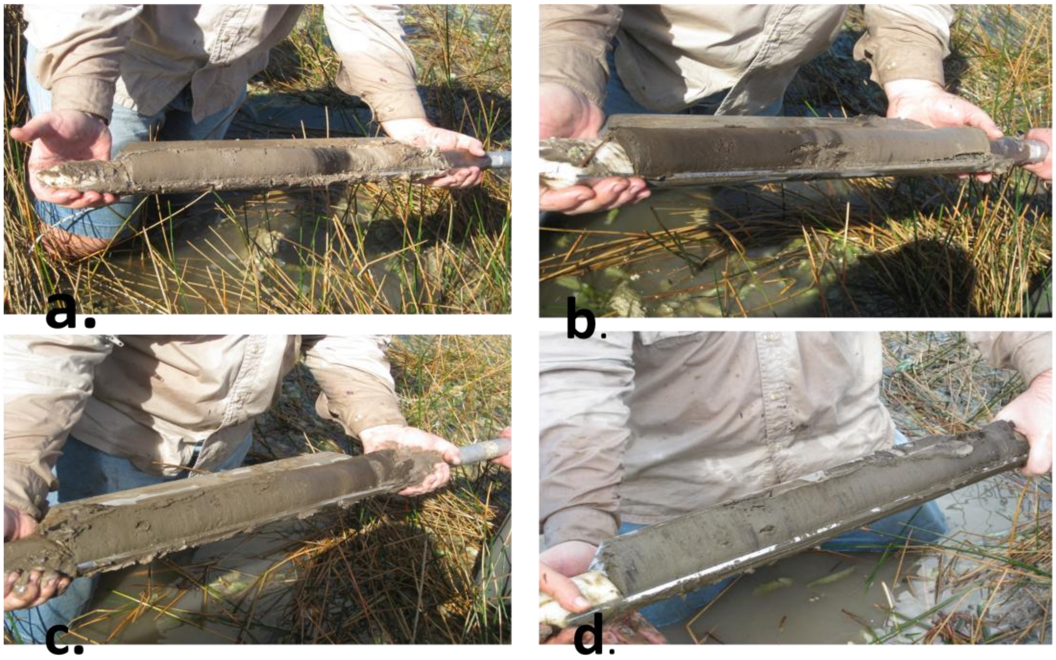

Figure 4.61 Extraction of the longest sediment core within Group Two. Images a - d show sections of the sediment core from top to bottom.

## POLLEN ANALYSIS

### *Sediment Cores*

Of all the cores extracted, only one has been analyzed to date. El Edén Core 7, the longest, was analyzed for ancient pollens. Five radio carbon dates along it provide a temporal correlation for the pollen (Figure 4.62). Very generally, through time there has been a dominance of forest pollens with varying periods of increasing disturbance pollens. Forest pollens include many species of trees, many of which were listed in Chapter One. Disturbance pollen includes many herbaceous species, shrubs, and smaller plants that rapidly colonize an area after it has been disturbed. Forest is a more stable and constant environment whereas disturbance species indicate a changing environment.

The pollen diagram shows that in the past the area of El Edén Ecological Reserve was more heavily forested, primarily by species from the *Ficus*, *Moraceae*, and *Fabaceae* families. At approximately 848±30 Cal BC *Borreria verticillata*, represented nearly half the pollen accounted for. There are two points, 96±30 Cal AD and 439±30 Cal AD, when *Monletes*, or ferns, spike in the pollen count, indicating a transitional environment. After approximately 697±30 Cal AD, although forest species still dominate the pollen count, there is a diversification of all plant species as well as an introduction of aquatic species and *Zea mays*.

The deepest and oldest portion of the core extends between 190 - 200 cm and 2221±30 - 2392±30 cal. The majority of the pollen (approximately 70 percent) is of tree species and the remaining pollen (approximately 30 percent) within that zone belongs to disturbance species,

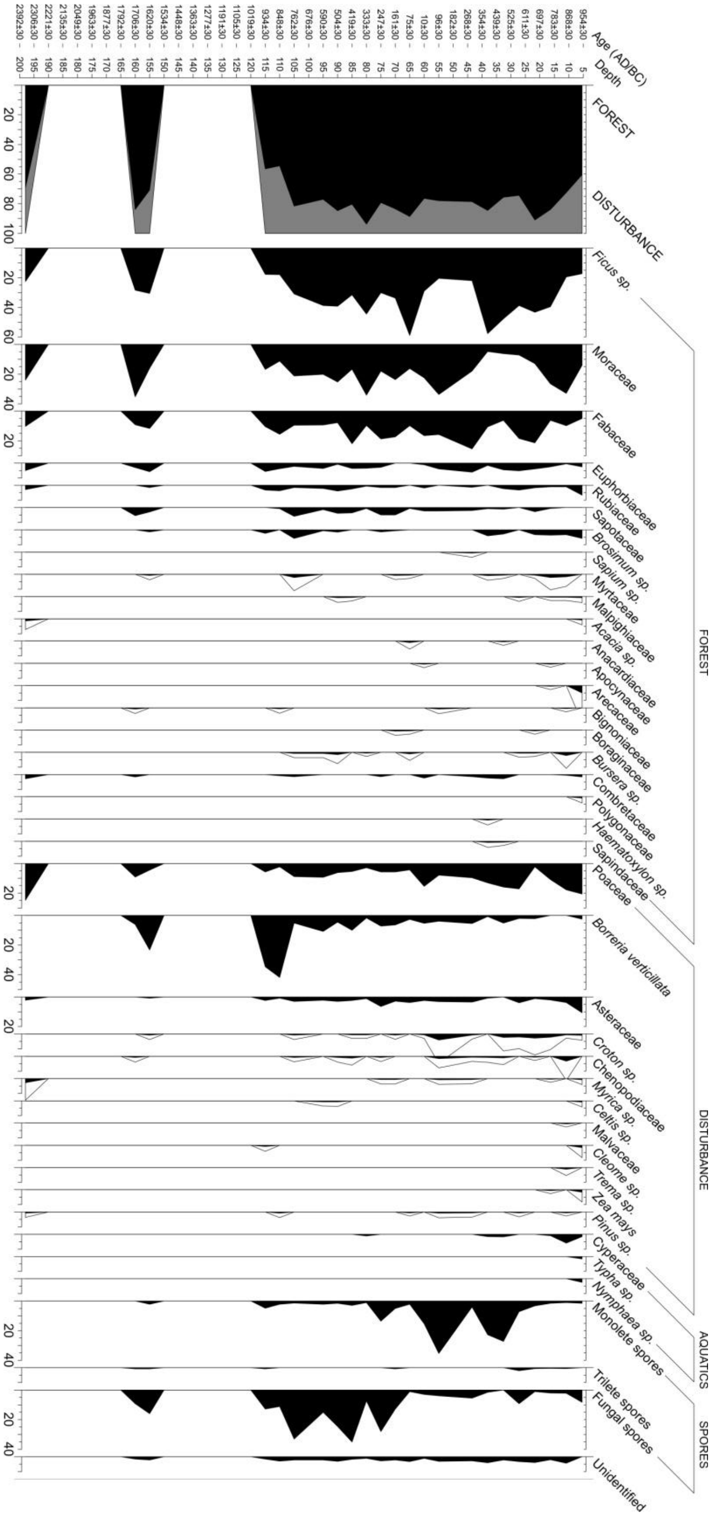

Figure 4.62 Pollen diagram for El Edén Core 7, including dates.

primarily grasses of *Poaceae*. Above that section, data is missing for the sediments between 165 - 190 cm.

The section of the core between 150 - 165 cm, 1792±30 - 1534±30 Cal BC, shows a similar distribution of approximately 80 percent forest species and 20 percent disturbance species. Unlike the older time period, however, the disturbance species is composed of approximately half *Poaceae* and half *Borreria verticillata*, and also unlike the previous existing section, there are some species of fungus. The section of the core between 120 - 150 cm, 1019±30 - 1534±30 Cal BC, is missing data.

Between 0 - 120 cm, Cal AD 954±30 - 1019±30 Cal BC, the pollen representative of forest species varies from a low of about 55 percent of the sample to a high of nearly 95 percent of the sample. Roughly, throughout this entire span, forest pollens account for 75 to 80 percent of the sample. The first spike of forest pollens occurs at 105 cm (762±30 Cal BC) and corresponds with a dramatic decrease (from 40 to 5 percent) of the pollen disturbance species *Borreria verticillata*.

At depths ranging from 105 - 120 cm, 762±30 - 1019±30 Cal BC, the pollen of forest species and disturbance species are nearly even, with disturbance species accounting for 20 to 45 percent of the total pollen. Compared to immediately above this period, there is up to 5 percent pollen from ferns. Interestingly, as well, the end of this period sees a spike in mushroom spores (up to 35 percent of the entire sample). Of the forest pollen, there is also a small spike in the *Sapotaceae* and *Brosimum* each occupying a total of 5 percent of the total pollen at 762±30 Cal BC.

Between 95 - 105 cm, 590±30 - 762±30 Cal BC, forest pollens remain stable comprising approximately 80 percent of the pollen assemblage and peaking at 90 percent of the assemblage at the start of the period. The predominant forest species are of *Ficus*, *Moraceae*, and *Fabaceae* (each comprising 40 percent, 20 percent, and 10 percent of the total pollen count, respectively). Also of note are *Sapotaceae* and *Brosimum* each increasing from nearly 0 percent at the beginning of this time to nearly 10 percent each. Of the disturbance species, *Poaceae* maintains a constant 10 percent while *Borreria verticillata* decreases from 10 percent to 5 percent of the pollen total. Pollen from ferns remains stable at 5 percent while fungus spores increase from 20 percent to 30 percent.

From 80 - 95 cm, 333±30 - 590±30 Cal BC, forest pollens vacillate between 75 - 90 percent of the pollen profile. At 85 cm, 419±30 Cal BC, the percentage representation of *Ficus* and *Moraceae* drop while *Fabaceae* increases.

Between the depths of 65 - 80 cm, 75±30 Cal BC - 333±30 Cal BC, the forest species begin at 85 percent, dip to 80 percent before reaching 90 percent of the pollen count. Both the *Moraceae* and *Fabaceae* remain relatively stable, each comprising approximately 20 percent of the pollen count, while the *Ficus* species range between 30 percent and up to 60 percent of the pollen. Other tree species are not highly represented except for *Sapotaceae* which makes up approximately 5 percent of the pollen total during this period. Disturbance species represent only 10 percent to 15 percent of the pollen total. Each *Poaceae* and *Borreria verticillata* comprise approximately 5 percent of the total pollen count. At 75 cm, 247±30 Cal BC, *Monoletes* peak at 15 percent of the total, otherwise comprising approximately 5 percent.

From 35 - 65 cm, 439±30 Cal AD - 75±30 Cal BC, the pollen of the forest species ranges from 80 percent, sinks to 75 percent, and then rises up to 90 percent of the total. The counts of pollen from the *Ficus* family is highest at both the beginning and end of this time, 60 percent each, but dips to 15 percent of the total during the mid times. Pollen from the *Moraceae* family spikes at 30 percent during that lull while pollen from *Fabaceae* remains relatively consistently between 10 percent to 20 percent with a spike to 25 percent at 354±30 Cal AD. Of the disturbance species, the grasses *Poaceae* and *Borreria verticillata* each occupy approximately 15 percent and 5 percent respectively. *Asteraceae*, *Croton*, *Chenopodiaceae*, *Celtis*, and *Pinus* also are represented. *Monoletes* spike to 30% at 96 ±30 Cal AD, up from zero percent at 354±30 Cal AD to 20 percent at 439±30 Cal AD.

Between 20 - 35 cm, 697±30 Cal AD - 439±30 Cal AD, forest pollens range between a low of 75 percent and a high of 90 percent of the pollen count. *Ficus* species decline through time, beginning at 60 percent and declining to 40 percent, whereas both *Moraceae* and *Fabaceae* increase through time, from 5 percent to 15 percent and 10 percent to 25 percent respectively. Each of *Euphoribiaceae*, *Rubiaceae*, *Sapotaceae*, and *Brosimum* comprise up to 5% of the pollen total. Of the disturbance species, *Poaceae* declines to 0 percent from approximately 20 percent of the total, and *Borreria verticillata* comprises 5 percent or less of the pollen total. The aquatic family of *Cyperaceae* begin this period comprising around 5 percent of the pollen total. *Monoletes* decline to nearly 0 percent at 697±30 Cal AD.

During the most recent period recorded in the sediment core from 5 - 20 cm, 697±30 Cal AD - 954±30 Cal AD, the forest pollens begin at 60 percent of the pollen profile and increase to 90 percent. Of the forest species, members from *Ficus* increase from 20 percent to 40 percent, *Moaceae* increases from 15 percent to 30 percent at 868±30 Cal AD before declining back to 15 percent, and *Fabaceae* increases from 5 percent to 20 percent. Other notable forest species include up to 5 percent from each of *Euphorbiaceae*, *Rubiaceae*, *Brosimum*, *Myrtaceae*, *Arecaceae*, and *Busera*. Of the disturbance species, *Poaceae* increases from 0 percent to 20 percent, *Borreria verticillata* comprises less than 5 percent, and other notable species include those from *Asteraceae*, *Croton*, *Chenopodiaceae*, and *Zea mays*. *Monoletes* and mushrooms are minimally represented.

The top 5 cm of sediment must have been too muddled to display botanical changes from the past thousand years.

## WATER MEASUREMENT

Two pressure transducers were set up at El Edén wetland, one in the south and one in the north, with a third established just outside of the flooded area in an old well (see previous chapter for full description). From establishment in July 2010 through May 2012, the pressure transducers were observed four times – November 2010, April – June 2011, March, and April 2012 – and the data downloaded in May 2011 and April 2012.

The most variation in water table levels was observed at the pressure transducer located in the south part of El Edén wetland, in essentially a pond or *aguada*. At the time the pressure transducer was established, the diameter of the pond spanned approximately 15 m and the pressure transducer extended approximately 1 m into the body of water. At the first revisit to the pressure transducer in November 2011, the pond had expanded to a diameter of approximately 20 – 25 m and the pressure transducer was inaccessible. During the period between April and June 2011, the pressure transducer was on the margin of the now nearly 10 m diameter pond but by May 2011 there was no water at all in the pond and the pressure transducer rested above dry sediments. In April 2012, once again, the water had risen substantially above the pressure transducer giving the pond a diameter of approximately 20 – 25 m.

Throughout the period of study, the water level at El Edén was observed at a variety of times throughout the year. Since pressure transducers were only installed in 2010, specific precipitation, temperature, and water level data are unavailable before July 2010. In 2007, the first visit to El Edén, extended two days in May. An introductory hike traversed the main paths in both the north and south portions of the wetland. At that time, the water level was approximately ankle deep, 15 cm, throughout the entire area of the wetland. The south pond was filled with water and had a diameter of approximately 15 m. The northern portion surrounding Alignment 41, however, was not visited.

A week was spent at El Edén Ecological Reserve in June - July of 2008. Surveying focused within the northern portion of the wetland, cutting a 600 m transect from a central portion of the wetland into surrounding upland forest. No visits were made to the south portion of the wetland was not visited. The interior wetland portion of the transect is in the area just to the south of Alignment 41. Water levels in the interior of the wetland did not rise above the knee, 50 cm. Unlike 2007, there was no water on the path leading up to the northern portion of the wetland.

Two separate weeks were spent at El Edén wetland in 2009, one in April and one in May. During the first week, 2008 north transect was re-cleared and then re-mapped using the Total Station. The water in the northern portion of the wetland was substantially lower, and in most places there was no surface water, just wet soils. The second week in 2009 involved cutting another 600 m transect in the southern portion of the wetland. Once again the transect extended through the central wet portion of the wetland into surrounding upland forest. During the intervening month, it had rained and water levels at El Edén were higher. Within the wet portion of the southern transect, the water was above knee level. The terrain raised but lowered again in a channel before rising into upland forest. Within the channel, water was at about mid-calf level, 30 cm, in the very center portion rising to knee level, 50 cm. Into the upland forest, there were pools of water extending to the end of the transect. Never did the water in the upland pools extend above knee level.

Extended fieldwork at El Edén Ecological Reserve began March 29, 2010 and lasted through June 23, 2010. 2010 was a wetter year than experienced with the previous two. Although the first two weeks of fieldwork were precipitation-free (though in many places the sediment towards the center of the wetland was saturated and gave way easily), rains arrived the start of the third week, and within several days, water levels in the wetland increased from no surface collection to, as measured in one location, 81 cm depth of water. The entirety of the season alternated between short rainy periods and a few continuous weeks of hot weather. The resulting water distribution was such that water was at least ankle deep in the northern interior portion of the wetland, surrounding Alignment 41. The central portion of the wetland, such as the area including the northwest portion of Group One, experienced an increase in water level at the start of the rainy season but it receded significantly by the end of June so that the ground was not wet within the mapping group. To the south, in Group Two, the water level spiked early during the rains so that the entire area was blanketed in knee level (much higher within the channel) water. Like elsewhere in the wetland, with an increase in hot and sunny days, the water receded through the field season but was still present in pools along the north transect of Group Two (thus preventing the Total Station from being set up at that location and having the elevation points shot in).

Pressure transducers were installed up at the end of the June 2010 to begin taking water level and temperature measurements beginning July 1, 2010. The first pressure transducer (ID# 1017039) was installed in the south pond. At that time the base of the pressure transducer was hovering 3 cm above the bottom surface, and the water extended 46 cm from the base of the pressure transducer. The permanent datum, established on the side into bedrock, was measured at 21.5 cm above the water level.

A second pressure transducer (ID #1017066) was installed in the mid - northern portion, just off the main walking path. The area is outside of the main savanna, and on a piece of bedrock between two *eleocharis* depressions. Within the bedrock is a cavity that extends 116.5 cm deep (before constricting to only allow water through). The pressure transducer was extended so it was 5 cm above the bottom measured surface. At the time, the water was 71 cm above the bottom of the pressure transducer and the datum cap was located 45.5 cm above the surface of the water.

The third pressure transducer (ID# 1030630) was inserted into a well located at Rancho El Edén, outside the flooding margin of the wetland. The depth to the bottom of the well is 7.105 m. The base of the pressure transducer is 8 cm above the base of the well and at the time the pressure transducer was installed, the surface of the water was 6.17 m below the datum cap (located on the lip of the well).

A visit was made to El Edén the last week of November, 2010 to extract sediment cores. Due to being in the middle end of the rainy season, the water level was higher than had been observed in late June. In the northern portion of the wetland, predominantly in the area just to the south of Alignment 41, the water level hovered around knee- height into the central portion of the wetland. At the south pond, the pressure transducer was completely obscured by water (Figure 4.63).

Figure 4.63 Water level in the south *aguada* in November 2010.

Figure 4.64 Water level in the south *aguada*, April 2011.

Figure 4.65 No water in the south *aguada*, May 2011.

In 2011, fieldwork began on April 5 and ended May 19. Rains were not experienced during this period, instead, fires often presented a problem. In the north end of the wetland, no water was in the interior portion of the wetland surrounding Alignment 41. Even the soils were not damp until deeper in the ground. The south portion of the wetland was also dry. No water was observed in the channel that runs through Group Two and by mid-May the south *aguada* had dried up completely (Figures 4.64 and 4.65).

Data was downloaded from the pressure transducers on May 6, 2011. At the south *aguada*, water had receded so that the pressure transducer was no longer in water, instead it was resting in 9 cm of sediment. At the north micro-*cenote*, the water level was 61 cm below the datum cap. At the well, the water level was 6.355 m below the datum cap. As will be discussed further below, there was a general decrease in water level of approximately 20 cm in each area a pressure transducer is measuring water level fluctuations.

Two visits were made to El Edén Reserve in 2012. The first ran from March 9 through March 23, and the second visit extended August 20 until August 22. Though March should have been marked by the early dry season, water had not receded and was comparable to, if not higher than, the levels seen at November 2010. Towards the northern portions of the wetland, water levels reached above the knee, often mid-thigh reaching 80 cm, when on the margins of the flooded area so likely were higher towards the interior portions. In the southern sections of the wetland, Group Two was completely flooded with water level exceeding crotch height when standing in the deepest part of the channel. Further south, water level was consistently at least knee level as one continued towards the south *aguada*, which, was again flooded to the point that it concealed the location of the pressure transducer (Figures 4.67).

Figure 4.67 Water level in the south *aguada*, March 2012.

By August 2012, the El Edén wetland had still not experienced the dry season. Water levels were approximately 10 cm higher than in March. In the northern portion of the wetland, around the vicinity of Alignment 41, water was at approximately knee height and obscured the location of the alignment. Further north, throughout Group Four, water gathered across nearly the entire group, particularly pooling in the central depressions. At the southwest corner datum, water was measured at 6 cm deep. Within the central portions of the north side of the wetland, in Groups One and Three were less inundated with the datum of Group One (the most south of both groups) being covered by 23.5 cm of water and the terrain rising so that the datum of Group Three was dry. Water in the southern portion of the wetland was deeper. The channel that lies between the path and the datum for Group 2 measured 13 cm higher than five months previously in March at 54 cm (Figure 4.68). At the datum point, the water level was 23 cm. Further south, toward the south *aguada*, water was consistently above the knee surpassing 60 cm, and upon reaching the *aguada* it was greatly expanded in size, approximately 20 m diameter. At the datum, the water extended to 15 cm above. Once again, the pressure transducer was entirely concealed by water (Figure 4.69).

All pressure transducers at El Edén were removed August 20 - 22, 2012. Plans are in place to replace the pressure transducers and track temperature and pressure data for a longer period of time beginning sometime in 2013 or 2014.

The specific data recorded by the pressure transducers at El Edén wetland reveals data for two very different years; a rather dry year and a rather wet year. General average precipitation data from the Yucatán Peninsula is between 1200 to 1500 mm per year (see Introduction chapter; Giddings and Soto 2001: 79) with the daily average temperature of 26C . From July 2010 through about July 26, 2011, the water levels are on a general decline.

Figure 4.68 The flagging tape measured the water level in the south channel in March 2012, in August 2012 it was measured to be 10 cm higher.

Figure 4.69 High water in the south *aguada*, August 2012, when high-res GPS were being collected.

Beginning around July 20, 2011 the water begins to climb and to an excessive amount beginning July 26, 2011. Data from all three pressure transducers are in agreement of the general trends of the area, as will be elaborated in the next section. Additionally, a pressure transducer installed at El Corchal, a wetland however far away, as part of the dissertation project of Daniel Leonard also reflects the same trends (Leonard 2012, personal communication).

### *Well at Rancho El Edén*

Data on the water level fluctuation from the pressure transducer installed at the well is illustrated in Figure 4.70. On July 6, 2010, five days after the pressure transducer began collecting data, it registered an increase in the water levels of approximately nearly one meter to 1.90 m. From that high point, there is a steady decline with a low point registered at .57 m on June 6, 2011. From July 26, 2011 through November 1, 2011 there was a general increase, punctuated by seven separate events that raised the water level. The first occurred July 26 - 28 and raised the water level to 1.86 m. The levels declined until July 9 - 11, 2011 when it raised to 1.66 m. After another longer decline, with a few minor periods of increase in the water table, the water increased August 31 through September 1, 2011 to a level of 1.81 m. September 23 - 26, 2011 and October 5 - 6, 2011 the water rose, respectively, to highs of 1.85 m and 2.21 m. A rather significant event October 16 - 17, 2011 caused the water to rise 87.59 cm on October 16, to a high of 2.85 m the following day. A prolonged event October 30 through November 3, 2011 caused water to raise to the seasonal high of 2.89 m. Subsequent to November, water level slowly declines until May 26 - 28, 2012 when it peaks at 1.73 m. Before raising again, on June 19, 2012, the water level registers a low at 1.35 m at which point it climbs to 1.81 m on June 27, 2012. Afterward, water once again began to recede until removal of the pressure transducer.

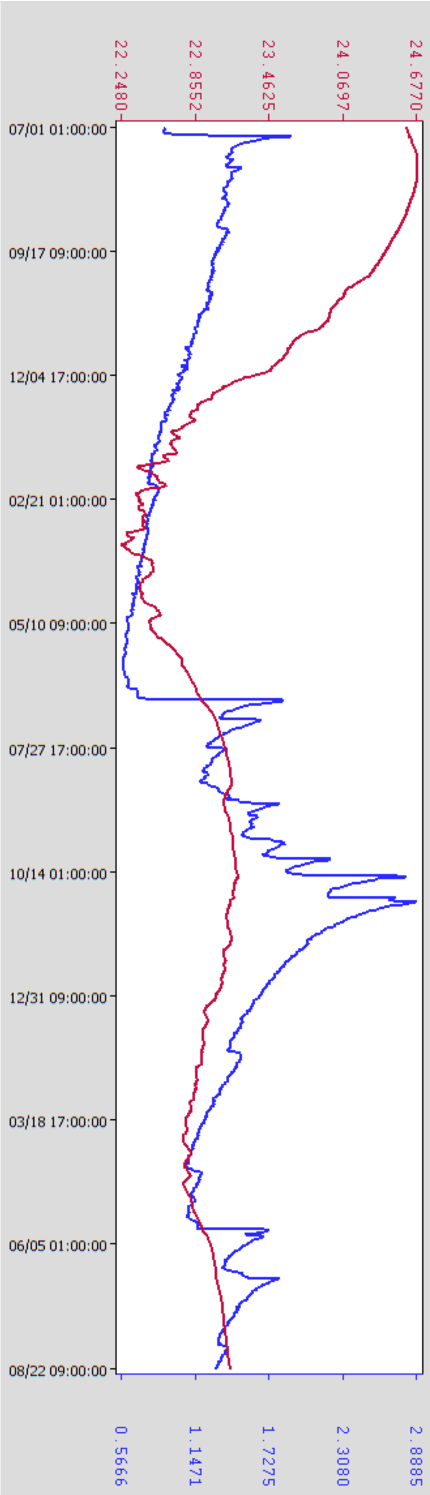

Figure 4.70 Graph showing the water table fluctuation in the Rancho El Edén well. Blue line represents the water level and the red line represents the temperature.

One small increase that occurred between August 7 - 10, 2012 is of note, however, as this rise in water was due to hurricane Ernesto. A low of 1.31 m was recorded on August 7 and a high of 1.40 m was recorded on August 10, documenting a 8.62 cm increase due to a hurricane that did not pass directly overhead.

### *South Aguada*

Water levels in the south *aguada* (Figure 4.71) rose abruptly beginning July 5, 2010, from .40 m depth to a maximum depth of 1.26 m. Until February 9, 2011 water levels declined to a minimum of .25 m before an event caused an increase to 0.59 m on February 13, 2011. Water levels again declined, reaching .20 m - the lowest point recorded - on April 20, 2011. Water was below the level of the pressure transducer between April 13 and June 1, 2011. On June 1, the water level increased from -0.03 m to 0.26 m, reaching a maximum of 0.33 m at 3 pm. Water levels remained stable at around that level until an episode from June 26 - 30, 2011 when the water increased to 1.47 on June 29, 2011. The water level stayed rather constant, decreasing only slightly through the end of August 2011. Through until November 3, 2011 the water level increased to 2.06 m, punctuated by four discreet events. November 2011 through the end of May 2012 the water level in the south *aguada* declined, reaching its lowest point of 1.00 m on May 5, 2012. On May 26, 2012 the water level increased 36.75 cm, from 1.03 m to 1.40 m, beginning an increase that peaked at 1.56 m on May 31, 2012. Water levels since May 31, 2012 receded, except for a spike of 8.54 cm between August 5 - 8, due to the near passing of hurricane Ernesto. When the pressure transducers were removed, water levels had declined to 1.23 m on August 21, 2012.

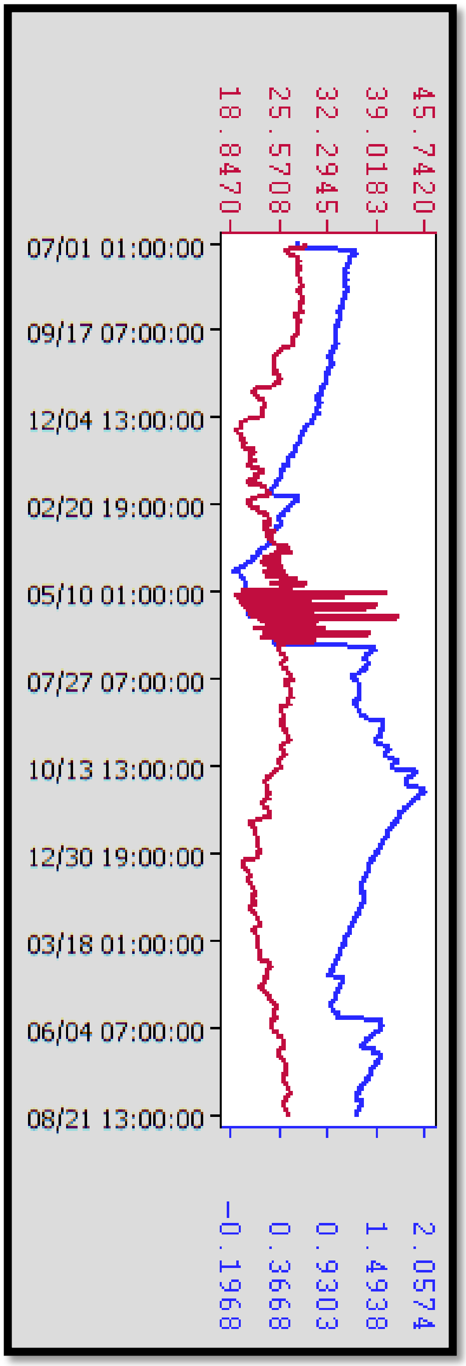

Figure 4.71 Graph showing the water table fluctuation in the south *aguada*. Blue line represents the water level and the red line represents the temperature. The red line between 5/10 and 10/27 shows when there was no water in the *aguada*.

### *North Micro-Cenote*

At the commencement of readings on July 1, 2010, water levels in the north micro-*cenote* were at .98 m (Figure 4.72). Between July 5 - 8, 2010 there was a rapid increase to 1.63 m on July 8, 2010. Although there was general drying trend through until June 2011, there were a few episodes where the water table increased. Of these, two are notable, including an episode between November 13 - 14, 2010 that raised the water level to 1.32 m from a low of 1.17 on November 12, 2010. Another episode in February 2011 raised the water from a low of 0.66 m on February 9 to 1.27 m on February 11; in just four hours the water level increased 58.39 cm. The peak in February 2011 fell to a low of .67 m on March 6 and spiked briefly on March 8, 2011 to .74 m before continuing a gradual decline through until early June 2011. On June 6, 2011 the water level reached its record recorded low of .48 m and had two small spikes on June 11 to .53 m and on June 20 to .94 m before quickly rising to 1.64 m on June 29, 2011. The period from June 29 through November 3, 2011 showed a long decrease and subsequent increase punctuated by ten peaks, including those on June 29 and November 3. The lowest point of this period was reached on August 11, 2011 at 1.27 m, with two minor high points on July 12 and August 12 at 1.57 m and 1.36 m, respectively.

After the low on August 18, 2011, the water rose and was characterized by six discreet water raising episodes. The first rise occurred between August 18 - 22, 2011 and brought the water level up to 1.45 m. Afterward, the water level slowly increased until between August 31 through September 2, 2011 when it jumped to 1.74 m. The next spike was experienced between September 23 - 26, 2011 when the water level reached 1.81 m and then

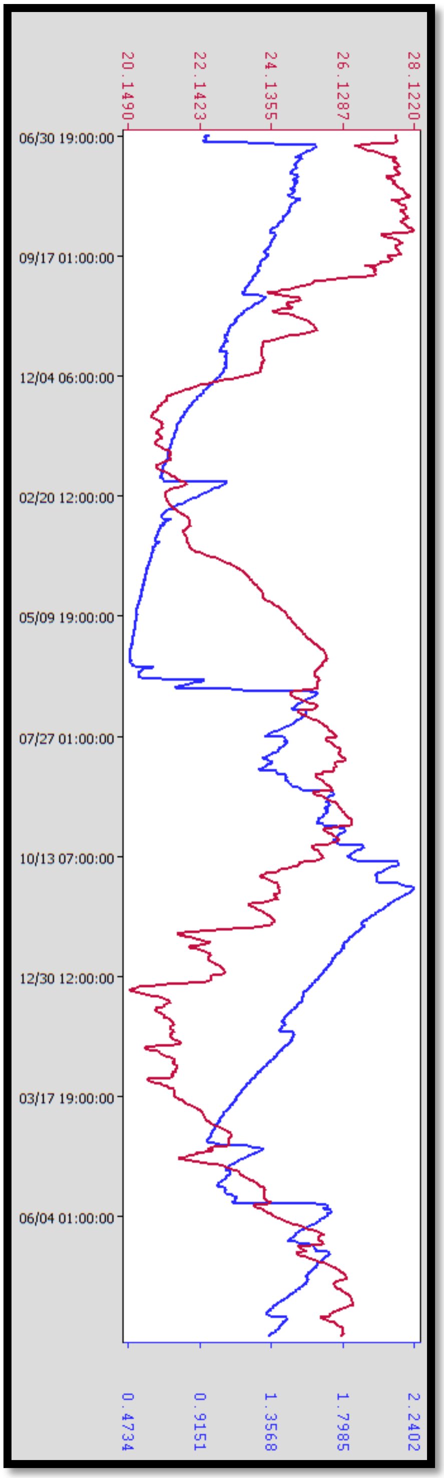

Figure 4.72 Graph showing the water table fluctuation in north micro *cenote*. Blue line represents the water level and the red line represents the temperature.

declined before raising to 1.92 m on October 5 - 7, 2011. On October 14, 2011 the water level declined to 1.82 m before a raise to 2.14 m during October 16 - 18, 2011. The water level subsequently receded to around 2 m through October 23 - 30 before an episode between October 30 and November 3, 2011 that raised the water to 2.24 m - the highest recorded value at this location. The water receded until mid- April 2012, except for a short peak between February 2 - 7, 2012 that raised the water level from a low of 1.40 m, recorded on February 2, to a high of 1.49 on February 6, 2012. On April 16, 2012, the water reached a low point of 0.95 m then rose to 1.30 m on April 21. April 18, 2012 experienced the majority of water table increase. Water level declined through until a low point of 1.01 m on May 15, 2012, and then maintained a level not exceeding 1.20 m until a jump on May 26 - 28 that brought the water level up to 1.70 m. A second peak of the water level occurred on May 31 where the water level was recorded at 1.73 m. The water table subsequently declined through until June 20, 2012 where a low of 1.44 m was reached. Once again, the water rose to 1.71 m on June 28, 2012. The water level declined until the pressure transducer was removed with the exception of one spike on August 9, 2012 of 1.45 m after a low on August 6 of 1.32 m. At the time of removal on August 21, 2012 at noon, the water level was measured at 1.33 m.

### *Water Level Summary*

All three locations that recorded water table levels showed similar fluctuations at corresponding times. Of interest is the rate of increase and decrease between the readings from the well, just outside of the proper wetland, and the readings from the south *aguada* and the north micro-*cenote*. The overall increase during water raising events was more marked in the well. The well may have received excess run off from the surrounding upland areas as well as direct rainfall. At the same time, however, water levels within the well declined at a more rapid pace than did the water levels within the wetland. More than likely, water from upland areas would flow to lower areas within the wetland and thus appear to drain faster.

Without a longer record at El Edén wetland, it is difficult to definitively call 2010 - 2011 a dry year and 2011 - 2012 a wet year. What has been recorded, however, is demonstrative of the range of variation precipitation may have for two consecutive years. Hurricane Ernesto in August 2012 did not pass near El Edén wetland but had the impact of raising the water level approximately 8 cm within a day. Hurricane Wilma in 2005 passed directly overhead and raised the water level at El Edén nearly 2 m above the surface level within Group Three (personal observation; Scott Fedick, personal communication 2007). Storms such as hurricanes would have had a severe impact on the hydrology of the wetland. The two years of data recorded are probably not extremes in either case, the possibility for a much wetter or a much drier year that would exceed these years. Only two years of water table fluctuations are currently available. Of these two years, however, a great deal of variation occurs. Given this range of fluctuation, based on the pollen in the sediment core, the environment at El Edén wetland appears to have been drier, on a normal year, and both permanent water and areas of flooding were likely confined to interior and deeper portions of the wetland.

# 5. INTERPRETATIONS and DISCUSSION

The following chapter will explore the implications of the data just presented in the previous chapter. Specifically, the issues that will be addressed include the origins and equifinality relating to the rock alignments; the chronology and dating of use; rock alignment function and physiographic setting; water flow, sediment accumulation, and surface elevations; crops, cultigens and other vegetation; resilience; and the integration of environment, culture, and landscape.

## DISCUSSION

### *Equifinality*

One concept that must be addressed is that of equifinality (Patterson and Hoalst- Pullen 2011; Phillips 1999). The basic idea of equifinality is that, given similar or different initial conditions, two phenomena may evolve into similar phenomena through different pathways . That being stated, what we see currently in the archaeological record is likely not what it looked like in the past. The rock alignments as seen today are not in the same form as they would have appeared and were constructed in the past. Although they appear similar today, not all the rock alignments described in the previous chapter necessarily had the same origin nor same function.

As to whether or not the rock alignments are natural, Fedick et al. (2000) addressed the issue of natural origin versus anthropogenic origin. Through excavations he was able to identify three building techniques (upright slabs supported by boulders on each side, stacked slabs of rock, or cobbles and boulders lined up), directly on bedrock. Short lines of stone might form naturally when exfoliating from an outcrop or due to tree fall, but that clearly is not the case here. The rock alignments within El Edén wetland are entirely human creations.

A remaining debate is how a finished rock alignment would have looked. If it were solely composed of stones, then what is visible now is very similar to what it would have existed. However, if the rock alignments were built up with sediment or vegetation, as is suggested by Fedick et al.'s (2000) recovery during excavation of weathered gravels between upright slabs, they would have appeared significantly different.

The current dissertation recreated the alignments given the most prominent readings, the highest points of the rock alignments. Such a recreation may overcompensate in some areas while still not fully representing the form of the alignment as it would have been. It also does not account for small but significant variations in size of the alignment. A modified configuration could have produced different results. However, the recreation as has been done here does allow for generalizations to be made as to how some or all of the rock alignments may have functioned.

Dynamic equifinality was introduced by Patterson and Hoalst-Pullen (2011) as a way to describe phenomena that had different origins or circumstances through time, that have resulted in a dynamic end state. The rock alignments at El Edén can be considered in a state of dynamic equifinality. The environment of the wetlands responds to many temporal and spatial influences and exhibits pulses based on these influences. Annually, the seasonal rains cause the water table to rise and fall. Less frequent hurricanes raise the water table for an extended period of time afterward. Long term fluctuations in sea level affect the base line of the water table in the wetland. Thus, the wetland is a pulse-based ecosystem and will vary through time.

The rock alignments were constructed within this climatic regime with the aim of taking advantage of the seasonal rise and fall of the water table surrounding them.

Depending on what time of year and where in the wetland, a rock alignment may have been on dry land, in shallow water, or completely submerged. The ancient Maya constructing the rock alignments knew and understood the seasonal rhythms and variations and positioned the rock alignments to function during shifts in the water table level. Both when the ground was completely dry or submerged, the rock alignments would be of little use. Also, because the water could rise quickly and cover the rock alignments within one or two days, periods of rapid water level rise was not the targeted time period for use. At the onset of the dry season, water would slowly seep underground, causing the overall water level to wane. As the water declined and sunk below the level of the rock alignments, the water immediately surrounding the rock alignments was influenced by the presence of the rock alignment. Some alignments maintained and directed water behind them, some alignments created a wall to impound water.

Dynamic equifinality is exhibited through the general function of directing water on a small scale, depending how the water levels were on a given year. The ancient Maya accounted for the fluctuation of the water table level seasonally as well as between years. Some years the water table rise and fall would correspond to the level of all or some the rock alignments and other years fewer.

### *Dating and Chronology of Use*

As discussed earlier in the background section, there is no way to definitively date a rock alignment. Association with a stratigraphic sediment profile and diagnostic artifacts could help, but neither are present at El Edén wetland. The best method to begin to consider the possible dates of rock alignment construction and use is by applying the dates of occupation of nearby sites that have been demonstrated to have used the wetland. In this case, the closest site to El Edén wetland is Makabil (Morrison 2000).

Two other sites located near wetlands, T'isil and Tumben-Naranjal. T'isil is located approximately three kilometers from a wetland approximately 10 km to the south of El Edén, and Tumben-Naranjal is located approximately 35 km south of El Edén and adjacent to a wetland. Both sites display corresponding date ranges. The main occupation of both sites dates to the Late Preclassic through Early Classic, 100 B.C. through A.D. 350, with a reoccupation in the Terminal Classic to Postclassic periods, A.D. 1000 - 1200 and A.D. 1200 - 1500 (Fedick et al. 2000; Morrison 2000).

Pollen data provides supplemental information about when the wetland might have been used by the ancient Maya. Considering crops and other plants that are known to have been important to and cultivated by the ancient Maya, time periods in which the pollen frequency of these plants increase (and potentially when the pollen of other, non-economically important plants decline) are potential periods of occupation and use. In the pollen data of the one El Edén core analyzed, there are two time periods of interest.

Makabil is known to have been occupied during the Late Preclassic and early Classic periods, between approximately A.D. 100 - 350. During that time, the frequency of forest pollen declines, a possible indication of human action to minimize the presence of forest at that time. Of the tree families represented in the pollen count, *Ficus* declines substantially. It is unclear or still to be decided if trees of this family represented an economically viable product. Pollen from grasses remains stable throughout this period. No pollen from *Zea mays*, corn, is present during this time period.

Interestingly, pollen of *Zea mays* is present in the sediment core beginning about 697±30 Cal AD. When the pollen in the sediment core terminates at approximately 954±30 Cal A.D., *Zea mays* pollen is still increasing. As pollen from *Zea mays* does not travel very far, the presence of this pollen indicates cultivation of *Zea mays* in the near vicinity, most likely within the wetland. However, since occupations have not been demonstrated earlier than the Postclassic period, it is possible that the *Zea mays* pollen from the Late Classic was brought in by hurricane action and was not, in fact, anthropogenic. The later *Zea mays* pollen, however, may be anthropogenic.

Previously, due to the investment of labor in the construction of sites such as Makabil and T'isil during the Late Preclassic, it was presumed that construction of rock alignments and use also dated predominantly, if not exclusively, to the Late Preclassic as well. However, given the presence of *Zea mays* pollen in the Terminal Classic and likely continuing into the Postclassic, it appears that the wetlands were utilized by the ancient Maya at that time and also raises the question of whether rock alignments were used, reconstructed, or constructed during that time.

### *Rock Alignment Function and Physiographic Setting*

Fedick et al. (2000) defined five types of alignments roughly based on their physiographic setting in the wetland. Function cannot be tied directly to this typology. Alignment 17 is the only Type One alignment within the sample; crosses and cuts off a large portion of the wetland.  It runs across the northern portion of the channel in Group Two, effectively isolating that area. Unfortunately, analysis does not demonstrate that it had a significant impact in changing the flow of water in this part of the wetland. Due to pollen of *Zea mays* recovered from the sediment core taken from this area, however,  it is probable that this area was isolated to maintain water within it for cultivation.

Four alignments belong to the Type Two category: alignments 18, 43, 44, and 45.  The main distinguishing factor in this type is that the alignments are in a lower elevation range. Alignments 18 and 44 are similar in that they both border almost entirely a circular depression.

Alignments 43 and 45, on the other hand, do not border a small depression, rather, they extend along the margins of a substantial depression in Group Four.  Alignment 45 also crosses through a lower point toward the northeast portion of the depression.  The portion of alignment 45 that crosses the depression effectively reduced or stopped water flowing to the north. Instead, water was redirected southwards and maintained within the immediate depression. Rock alignment 43 also appears to have redirected water back into the depression. Both rock alignments would have been ineffectual when water was significantly above their height, and so it was during periods of water levels recession that alignments 43 and 45 redirected water into the depression.

Even though alignments 18 and 44, and 43 and 45 seem to be of two types of formations, bordering a small depression or bordering a larger depression, the function appears to be similar.  The alignments just described acted to maintain water and moisture within a depression when water was on the rise, and acted to trap water behind its walls when water was receding.

Rock alignments 43, 44, and 45 are the highest rock alignments and located in the highest mapped group of the wetland. Their location within an area that, on an average year would still be further from the water table, bolsters the interpretation that they diverted moisture to be maintained within an internal depression.

Five alignments are Type Three; 53, 54, 14, 15, and 57. Characteristic of each of these alignments is that it runs perpendicular to slight slope variations within an area of relatively higher elevation. Most distinctive of all these alignments is 57 whose sinuous shape gives credence to the probable function as the base of a fish weir.

The functions of alignments 53 and 54, however, is quite different and rather clear. Similar to the functions of Type Two alignments, alignments 53 and 54 are intended to either maintain water in front of or behind them. They do not impact the flow of water except directly next to the rock alignment, so would have directed remaining water along the rock alignment instead of letting water seep into the ground. Given that they are the lowest rock alignments that were mapped and are also within the lowest mapped area of the wetland, strongly suggests their role of trapping water and sediment.

Alignments 14 and 15 in Group Two are away from the margins of the channel but parallel to it such that they acted to trap water or sediment behind them as water flowed into the channel.

Early on, Fedick et al. (2000) speculated that, due to its curvaceous nature, Rock Alignment 57 exhibited the potential to be the base of a fish weir. Based on both the flow and basin analyses, it is apparent that Rock Alignment 57 functioned to separate the central, flat portion of Group Three. Given that there is no perceptible flow and movement of water in El Edén wetland, the rock alignment did not need to interrupt the flow in order to net fish that would be ushered through by the current. Rock alignment 57 provided a base from which to net fish on either side. Rock Alignment 57 is located within the mid elevation range of the wetland.

Alignment 16 is the only Type Four alignment. It runs perpendicular to slope and runs into lower area, in this case the channel of Group Two. One characteristic of this rock alignment is that it has a wave to its shape, similar to that of alignment 57. Even though alignment 16 is in a different physiographic zone within the wetland, the function is the same as that of alignment 57; alignment 16 functioned as the base of a fish weir. Unfortunately no points were taken on this alignment as it was completely submerged. What can be gleaned from that, however, is that it would not have been in functional use during stand of water 1 m or higher.

Only one Type Five alignment exists and that is questionable. Alignment 58 in Group Two runs through a depression. Because the stones are nearly at surface level, it appears more likely that this alignment served as a walk way across the depression as opposed to acting to modify water movement. Water flow analysis showed that rock alignment 58 had no impact on the flow of water around it.

### *Water 'Flow', Soil Accumulation, and Surface Elevations*

Water flow at El Edén wetland is generally in a northward direction (Chavret 2009). The flow, however, is not akin to that of a river or stream. Water movement northward is imperceptible at a specific location and essentially only visible over a few days time as the water from the south will spread out and into the north.

Of the rock alignments, there does not seem to be a general alignment attempting to inhibit and check the northward flow of water. Even though alignments 41, 48, and even 17 are constructed with a slight northward arc it appears that such an orientation was related to the local topography and would have only impacted water immediately surrounding the rock alignment.

Within Group Four, however, Rock Alignment 45 does close off a depression and redirects water back into the depression. A portion of Rock Alignment 43 runs through a channel-like depression on the opposite side of the group, and also may have acted to impound water within the depression.

Also of interest is soil accumulation. Even with the general northward movement of water, there is not a significant deposition of soils and sediments on the south side of rock alignments. Once again, the orientation of the rock alignments is based on local topographic variations.

During rains when the water level rises, the primary direction that the water moves is up. Any depressions in the topography are the first areas to hold water. When all depressions are level, the water table rises throughout the wetland. Water recedes slowly, and similar to its rise, the main direction of recession is downward. However, as the flow direction analysis shows, the rock alignments have an impact on water directly surrounding the rock alignment when the water is lower.

All of the datum points have similar elevations, exhibiting a variation of only 81.3 cm. Similarly, the elevations that rock alignments are found at exhibit a maximum of 1.45 m difference. Given that minimal topographic variation, a substantial rainfall event would submerge most of El Edén wetland in a short period of time. Areas on the margin of the wetland, however, would be impacted slightly later and would be functional when internal areas are flooded. Likewise, as water levels receded, areas further in the wetland would be available.

Potentially, the rock alignments located in different areas of the wetland would be functional at various times, nearly continuously throughout the year, particularly if the water table was higher. Rock alignments in the slightly higher Group Four functioned slightly different than those in the low lying Group One.

*Cultivated Plants*

Numerous plant species that were valuable to the ancient Maya thrive in and surrounding the wetland. Of the pollen revealed in the sediment core, *Zea mays* was present. However, *Zea mays* was encountered in more recent Late Classic period sediments and not within the Preclassic sediments, when population was larger. Lack of evidence for *Zea mays* in the Late Preclassic does not suggest that El Edén wetland was not of economic importance to the ancient Maya. Rather, other plant resources were valued. The wetland hosts a range of vegetation that is edible, used in construction, medicinal, or ceremonial.

It is quite possible that whereas specific species of plants may not have been cultivated, that the growth of some species that naturally thrived in and around the wetland were encouraged. In such a scenario, any plants infringing on the growth would be taken out and the locations of growth expanded. Encouraging currently existing species to grow while minimizing others may have a minimal impact on the pollen deposition as the overall numbers would not change drastically.

Changes in the plant communities are evident during the periods of nearby occupation. Dating to the Late Preclassic, approximately 50 B.C., there was a spike in population, though people had been living in and modifying the landscape before this time. At 330±30 Cal. B.C.

there is a sudden spike in Monolete, or fern, pollen. Although that spike of fern pollen declines, from 75±30 Cal B.C. through Cal A.D. 96±30 it once again spikes, at this time much more prominently and sustained. Ferns tend to colonize recently cleared land and such spikes as seen in Core 7 are likely indicative of a recently cleared area. At the same time, grasses of *Poaceae* and *Borreria verticillata* remain constant. Fern pollen declines to nearly nothing at Cal A.D. 268±30 but immediately increases again. As settlement does not appear to have persisted at either T'isil or Makabil much past this time, it is possible that the second spike in fern pollen represents ferns colonizing areas that had been settlement. Regardless, beginning by Cal A.D. 525±30 there is a sharp decline of fern pollen, indicating that the environment had reached a point of stability and that there were no open areas to be colonized. In general, the pollens indicating forest decline and pollens of disturbed species increase, a pattern that is highly suggestive of intentional clearing.

Nearly 300 years later, Cal A.D. 697±30, there is evidence of further modification. At this time, the pollens of disturbed species increase from 10 percent of the total pollen count, to 40 percent of the pollen count in Cal A.D. 954±30 (the earliest extent of the pollen diagram). There is no change in the pollen from ferns, remaining constantly minimal, but there is a dramatic increase of *Poaceae*. *Poaceae* is a family of true grasses, and grass is another species that quickly colonizes newly opened areas. More intriguing, however, is the appearance of *Zea mays*, or maize, pollen. Pollen from maize does not travel far from the plant so its presence within core number seven is indicative of cultivation within the immediate vicinity. Conversely, however, appearance of maize pollen may be due to a hurricane.

Reoccupation of the Yalahau area is not reported until the Early Postclassic, approximately A.D. 1000, but there is maize pollen approximately 300 years before. Aside from the question of admixture from earlier sediments, the presence of maize pollen raises the question of earlier waves re-peopling the area slowly. Regardless, maize was cultivated in and around the wetland beginning around the Late Classic period.

It is also probable, as reported by Morrison (2000), that plants were cultivated closer to home but that the periphyton, whether in wet or dry form, was transported to home gardens to be used as fertilizer. Wet periphyton would also provide moisture to the sediments, but would be heavier and more awkward to carry. When dry, periphyton covers rocks and vegetation in a thin layer and is very easily picked up, and would be light and easy to transport.

### *Resilience*

The essential idea behind cultural resilience is that humans will adapt to changing conditions either by modifying what they are already doing or by doing something entirely new. Rock alignments were constructed through various physiographic settings within the wetland, most likely during the Middle to Late Preclassic period when the majority of settlements in the vicinity were built and occupied.

Rock alignments are scattered throughout the wetland, within different physiographic settings and at different topographic elevations. By exploiting a wide range of areas in the wetland, resilience is demonstrated through preparation for different hydrological conditions either throughout a given year or years of extreme rainfall or drought. The recorded water table fluctuation between 2010 and 2012 is quite significant but likely not representative of the extreme wet and dry years. Thus, rock alignments at higher elevations and towards the margin of the wetland were viable when the water table was high, and rock alignments in lower areas of the wetland were functional most years but necessary during drier years.

Of all the rock alignments, those in Group One show the lowest elevations, those in Group Four are among the highest elevations, and those in Group Three are within the mid elevation ranges. Considering the elevation ranges and the positioning of the rock alignments, slightly different functions based on their location may be suggested.

At some point around A.D. 350, local populations abandoned the area. The Preclassic period had been characterized as a wet period with adequate rain and a water table nearly 1 m below current levels (Wollwage 2008; Wollwage et al. 2012). A subsequent warmer and drier period may have forced populations from the area, demonstrating a lack of resilience. It is possible that the water table did not contact the rock alignments at lower elevations even at the height of the rainy season and the overall hydrologic regime had shifted substantially to encourage abandonment as opposed to adaptation. It is also possible, however, that other influences - such as political - were more attractive. Cobá, just south of the southern terminus of the Yalahau wetlands, experienced a surge in population at this time.

In the Terminal Classic and Postclassic, however, a reoccupation of the area occurs. Once again wetlands are important to the settlements and *Zea mays* is locally cultivated as indicated by its presence in the analyzed sediment core. At this time, however, it is difficult to determine if the rock alignments were once again in use, and if they were in use, whether they served the same function or if a new function had arisen for them. Also difficult to ascertain is whether the rock alignments were refurbished, rebuilt, or if new rock alignments were constructed at this time. It is interesting to note that the Terminal Classic and Postclassic periods were wetter than during the Classic period, the water table had risen to levels exceeding that during Preclassic times.

### *Environment, Culture, and Landscape*

It is evident that the ancient Maya around El Edén wetland understood the variation within the wetland environment. Construction of rock alignments within the wetland took advantage of small variation in topography and impacted the flow of water in the immediate vicinity. As rock alignments were constructed in different regions of the wetland, changes in the water table level through the year were taken advantage of; when water levels were higher, rock alignments on the margins and in higher areas of the wetland were accessible and conversely, rock alignments further into the wetland and in lower areas took advantage of the water level as it receded.

Changes in the environment were accounted for by the wide placement of rock alignments and thus, recognizing and incorporating this knowledge into culture.

Without a doubt, the ancient Maya created a productive landscape. In an area where surface water is often absent, the wetlands provided a vital resource. Due to the yearly flooding regime of the wetlands, a gradient of vegetation existed surrounding and throughout the wetland . Sites surrounding the wetland took advantage of its diversity. Larger sites beyond those locations directly involved in exploiting the wetland also benefited from its ecological richness.

At the end of the Preclassic, the ancient Maya left the area surrounding El Edén wetland. A few hundred years later, however, they returned. The landscape was reoccupied and the rock alignments reincorporated into cultural knowledge.

# 6. CONCLUSION

The intent of this dissertation was to test hypotheses and demonstrate that the anthropogenic rock alignments within El Edén Ecological Reserve had the function of modifying soil and water movement around them. The first four hypotheses specifically address the possible range of functions whereas the fifth through eight hypotheses are more concerned with decision making and resilience in the face of environmental fluctuation. The following and final chapter will review the data specifically to each hypothesis and summarize what is now verified about the functions of the rock alignments. Finally, the data gathered from the topographic survey and analysis using arcGIS, the pollen data from the soil cores, as well as the water level data, will be woven together to illustrate the ways in which the rock alignments functioned to modify soil and water movement through time. Possible future directions will be discussed before a final summary.

The first hypothesis concerned the position of the rock alignments in relation to surrounding topography. If in a system of cultivation, the rock alignments would be expected to modify soil and water movement, specifically function one - or more - of three ways: ***a***) slow and disperse water flowing into lower areas that would be appropriate for plant cultivation, or, ***b***) slow water in order to promote the deposition of suspended sediments behind rock alignments to create areas of deeper soil appropriate for plant cultivation, or, ***c***) slow water in order to promote the deposition of suspended sediments behind rock alignments that would be transported to another area.

Within Group One both rock alignments 53 and 54 potentially served this purpose. Bordering the margins of a depression and each other, these two rock alignments would have kept water towards the depression when levels were rising, as well as maintained water or moisture behind them as water levels receded. Within the water there would be a small amount of sediment that would settle around the rock alignment. Given that they are in the lowest portion of the wetland, they are ideally positioned to modify water and sediment movement in drier years - both when the water table was lower and with less precipitation.

In Group Two, alignment 17 also had this function as it shut in the northern portion of the channel. Within the bounded depression that the alignment created, water would be maintained.

In Group Three, the eastern sections of alignment 57 may have served this function as it extended through a relatively flat area. More sediment accumulation is encountered on the south side of the eastern portion of the alignment and this may have been encouraged.

Within Group Four, alignment 45 modified the movement of soil and water as it cut across the northeastern portion of the depression. Direction of water flow analysis demonstrated that it rock alignment 45 actively redirected water back into the depression. Soil moisture would be essential in this area as it is within the higher elevations of the wetland, further from the water table, so maintaining soil moisture would allow plants to flourish.

Hypothesis number two considered the possibility that the rock alignments acted as property boundary markers to delimit the extent of gardens or agricultural fields. If so, the alignments would be expected to: ***a***) delimit areas of preferable agricultural soils, without necessary regard to local slope characteristics, or, ***b***) divide areas of preferable agricultural soils, without necessary regard to local slope characteristics.

Given the data, it is difficult to assess whether the rock alignments acted to delimit specific areas. In no instance does a rock alignment completely surround something. At times, it will nearly encircle a depression or connect two outcrops of higher elevation where there will be an outcrop bordering one side.

Alignments 53 and 54 in Group One border the edge of a depression and run parallel to each other, both terminating on higher bedrock outcrops. The area between these alignments is roughly bounded, but given the lack of soil in this portion, it does not appear to be delimiting an area for cultivation.

In Group Two, alignment 17 crosses the channel, connecting higher areas of bedrock on either side, and is bordered on the northern portion by a natural rise in bedrock. Particularly given that the analyzed sediment core was taken from within this closed off portion of Group Two, that alignment 17 may have been delimiting a preferred area for cultivation is possible. Alignment 18 partially surrounds a depression holding deeper soils.

All alignments in Group Four may serve to delimit areas. Both alignments 43 and 45 run along the southern and northern margins of a depression and terminate approximately where the terrain raises. The east portion of alignment 45 cuts through the depression and may be delimiting a preferred area. Alignment 44 partially surrounds a depression within the main depression of Group Four.

The third hypothesis hypothesizes that, if the rock alignments served as engineering features or boundary markers in a plant cultivation system, then physical evidence for the cultivated crops will be present in associated soils or within sediment located near the cultivation area. Physical remains could take the form of pollen, phytoliths, and/or starch grains from plant species known to be of economic importance to the Maya.

Only one sediment core was analyzed for pollen analysis and it was from Group Two. Although no pollen from cultigens was present at the levels corresponding to the Late Preclassic and Early Classic periods, pollen from *Zea mays* was found in levels corresponding to 697±30 Cal AD. The early appearance of maize may not be anthropogenic, but rather the result of a hurricane bringing in more distant pollen. The pollen of *Zea mays* at the end of the pollen profile, however, is more likely anthropogenic in origin. It is also possible that the growth of some plant species were encouraged over others but this activity might not have left a perceptible change in the pollen record.

The fourth hypothesis explores the possibility that some of the rock alignments may have been constructed as the base for a fish weir. As bases for weir superstructures of wood pole and nets, rock alignments would not necessarily need to have a level upper elevation. If the rock alignments were indeed constructed as the base for fish weirs, they would be situated within the surrounding topography so as to: ***a***) cross channels of water flow below natural reservoirs of sufficient volume to support fish populations, and/or, ***b***) impound areas of water above a natural reservoir of sufficient volume to support fish populations that would be trapped behind the weir as seasonal water levels receded.

Two alignments, 16 in Group Two and 57 in Group Three, exhibit properties of fish weir bases. Alignment 16 runs from the eastern margin, across, and nearly to the opposite side of the channel. There is a gentle curvature of this alignment, like an 'S', highly characteristic of the bases for fish weirs. Also given that this channel does fill with water, the likelihood that this alignment acted as a fish weir base is high.

Alignment 57 in Group Three follows the upper contours of a more uneven area. On either side of this curvy alignment are depressions that hold standing water with fish. In 1997, Scott Fedick excavated a portion of Alignment 57 and recovered a few degraded pieces of ceramic that could have acted as fish net weights. Upon a direction of flow and a basin analysis, it is shown that within the flat, central section of Group Three Rock Alignment 57 interrupts a basin within the area. Within the wetland there is no significant flow, but when the water was high enough, Rock Alignment 57 would be a good base for a fish weir.

The fifth hypothesis considers if all rock alignments at El Edén Ecological Reserve were constructed for use at around the same time period, or for the same hydrologic regime. Ideally, if some or all of the proposed rock alignment functions were in operation within an average annual hydrologic regime (wet season – dry season), then all of the rock alignments should fall within an elevation range that would compliment a typical annual hydrological pulse. If this is the case, long-term changes of the wetland hydrologic system were not adapted to.

All mapped groups exhibit less than one meter of variation between them, based from their datum points but rock alignments have nearly 1.5 m variation. If the rock alignments are built for a single hydroperiod then no resilience or emergence is evident in the wetland management system. However, it is likely that the rock alignments were in contact with the water table level at different times throughout the year and they also acted to mediate any relatively minor differences between years. The occupation and abandonment of nearby sites, such as Makabil only occupied in the Late Preclassic through Early Classic, may be directly tied to a single hydroperiod.

Hypothesis six considers the adaptation and resilience of the ancient Maya in reconstructing rock alignments at locations and elevations that would have been subject to different hydrologic regimes, or water levels. If rock alignments of a given function are found to be situated in a range of elevations that fall outside of a typical annual hydrological regime (wet season – dry season), then the subsistence system exhibits evidence for resilience through the construction of management features of the same function, or functions, in new locations (up slope or down slope) in response to environmental change. If paleoenvironmental reconstructions of water-level changes can be physically correlated with elevations of rock alignments, and chronologically correlated with occupation and abandonment of nearby settlements, then settlements may have remained sustainable through of environmental change with little or no changes in the subsistence resources utilized.

At the El Edén wetland, rock alignments do cluster within the same elevation ranges. Group One and Group Four, however, are the lowest and highest groups, respectively. Rock alignments were engineered for different hydroperiods. Even though the rock alignments do fall into a narrow range of elevations, the possibility that they were designed to interact with the water table at different points of the season is likely. Group Four is further from the water table so moisture would need to be retained in this area whereas the rock alignments in Group One are much lower, on the margin of a depression, and in more sustained contact with fluctuating water table levels.

The seventh and final hypothesis considers the possibility of a change in function of the rock alignments, that through fluctuating water table levels, new or different functions for the rock alignments emerged as the ancient Maya modified their usage of them. If rock alignments of different proposed functions are situated in a range of elevation outside of an average annual hydrologic regime (wet season – dry season), but are restricted to narrow elevation ranges that represent the highs and lows of long-term changes in water-table level, then the subsistence system exhibits evidence for sustainability through emergence of new subsistence practices, such as shifting from cultivation of seasonally inundated wetlands to the harvesting of fish from shallow lakes. If paleoenvironmental reconstructions of water-level changes can be physically correlated with elevations of rock alignments, and chronologically correlated with occupation and abandonment of nearby settlements, then settlements may have remained sustainable through times of environmental change with shifting emphasis in the subsistence resources utilized.

Of interest at El Edén wetland is the appearance of *Zea mays* pollen beginning in the Late Classic period though there is no evidence of cultigens in the wetland during the Preclassic when the area was more heavily occupied. As the nearby sites of T'isil and Tumben-Naranjal were reoccupied in the Terminal Classic and Postclassic periods, it is possible that the Postclassic Maya used the wetlands and the rock alignments for different reasons.

## FUTURE DIRECTIONS

Although many questions were addressed with this research, still more research could be done to further elaborate on the role of rock alignments in El Edén wetland specifically, and all Yalahau wetlands in general.

Scott Fedick has spoken with Marco Lazcano, the director of the El Edén Ecological Reserve, about the possibility of purchasing LIDAR (Light Detecting and Ranging) imagery of the area. LIDAR uses a laser to scan and bounce off the ground and a sensor detects the returning laser beam. The resulting images are very high resolution and may detail the surface topography.

Depending on the resolution of the LIDAR image, less work in the field could be done as the image could be used as a digital elevation model (DEM). Some data, such as soil depth, would still need to be verified and accounted for in the field.

In terms of better understanding the paleoenvironment, sediment cores within and surrounding the wetland could be analyzed for oxygen isotopes within animal shells as well as for diatom frequencies. Oxygen isotopes hint as to variation in rainfall through time and would help to identify when in the past rainfall episodes during ancient Maya occupation. Diatoms live in water and their frequencies change based on amount of water and the salinity, so specific assemblages of diatoms are indicative of specific hydrologic conditions. Since water levels may rise due to a sea level rise or event aside from precipitation, diatom assemblage would indicate that.

A total of seven sediment cores were extracted from El Edén wetland but only one was analyzed for pollen. Analysis of the other six cores would be helpful to either corroborate or expand the results from the single sediment core. Additionally, new sediment cores should be extracted from the central area of Group Four where the soils are in excess of 1 m deep.

## SUMMARY

The sun was pale but bright early one winter morning. Two Maya farmers leave their home to walk three kilometers to the nearby wetland. Throughout the forest and into the vegetation transitioning to the wetland, plants are still thriving from the water of the recently passed rainy season. Upon coming closer to the wetland, the bare exposed bedrock was slippery underfoot. Further in, pools of clear water reflecting the blue sky and tasiste palms are muddied by a light brown grey cloud as the underlying soil is disturbed. In some places, the water obscures holes in the bedrock and the Maya falls into the water. The Maya passed a line of rocks that zig-zagged across a flat area and along a few high points. There, when the water was higher, nets would be floated around a divot in the rock wall, and pulled in and up to catch fish.

Finally they reach their destination. At this point in the wetland, two lines of rock had been constructed from slabs of limestone propped up against each other and stabilized by the placement of gravels and other stones around them. These rocks had been placed by members of the community so that water was redirected back in towards a depression as the water receded, allowing plants within the depression to continue to flourish longer into the dry season. They checked to ensure that the plants that needed to grow were unobstructed, when necessary they removed other plants that threatened their growth. On the return to the community, the Maya collected branches of other useful plants as well as some periphyton on the margin of the wetland, it had already mostly dried out but would still provide nutrients to the gardens near their home.

Rock alignments were first documented at El Edén Ecological Reserve in 1994. Initially, the functions, chronology, and cultural associations of these rock alignments came into question due to the fact that these rock alignment features were markedly different than what was seen in the better studied southern Maya lowlands. At that point, what was clear is that rock alignments were constructed by the ancient Maya to modify soil and water movement within the wetland.

Understanding the past environment and hydrology of the wetland environment was a crucial first step. The ecosystem is dynamic and governed by multiple pulses ranging from seasonal changes, decade-level events such as hurricanes, and long term changes such as the rise or fall of sea level. The conversion of these events influenced the distribution of vegetation. The past hydrology was different, notably the water table was much lower, but given the variation of precipitation recorded in two years it is likely the ancient Maya experienced similar, and greater, extremes. Water rose high enough to be affected by the placement of the rock alignments, and in some places, rises above the rock alignments. Rock alignments were constructed throughout the wetland in varying physiographic zones to take advantage of and account for seasonal variation and differences between years. Specifically, the receding water was redirected to maintain moisture in localized depressions where plants would continue to grow into the dry season.

During the Late Preclassic, favorable plants grew in and around the wetland and their growth was encouraged. Local populations maintained the rock alignments. Crops may have been grown but we have no evidence for this time period, as of yet. During what appears to have been a drought, population around El Edén wetland declines or is gone entirely. Quite possibly, conditions at the site of Cobá, to the south, were more favorable.

At least three hundred years later, at the Terminal Classic period, sites in the vicinity show a reoccupation. Water levels were more favorable to wetland cultivation as evidenced by *Zea mays* being recovered from a sediment core. El Edén wetland was being utilized again, though it is unclear if the rock alignments were directly in use, or passively continuing to modify soil and water movement for the benefit of the Postclassic population.

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