TERRACING, AGRICULTURAL STRATEGIES, AND RESILIENCE AT THE ANCIENT MAYA MINOR CENTER OF WAYBIL

By

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To Dr. Gyles Iannone: Friend, Colleague, and Mentor
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The study of past agricultural strategies has always drawn the attention of archaeologists across the globe in order to understand the development, florescence, and ultimately the demise of ancient societies. This dissertation asks the question: Were agricultural terraces a successful adaptive mechanism within the subsistence strategy of ancient Maya communities to a buffer against internal (social) and external (environmental) stress? This is addressed by examining the geo-intensive agricultural strategy of the ancient Maya minor center of Waybil, located in the hilly region of the North Vaca Plateau of west-central Belize. Waybil is a small agrarian based center within the larger polity of Minanha. Its occupation stretches from the Late Preclassic (400 B.C – A.D. 100) to Early Postclassic (900 – 1200 A.D.), with a history of agricultural terrace construction and use from the Early Classic (250 – 550 A.D.) to the Terminal Classic (810 – 900 A.D.). This dissertation draws on five years of mapping, excavation, remote sensing (LiDAR), soil analysis, GIS modeling of settlement and landscape, and combined analysis of the resulting multidisciplinary datasets to understanding the role terraces played in changing the agricultural potential of the landscape and strategy of the Waybil community. Using a socio-ecological framework, results are combined with regional archaeological and paleoclimatic data to reveal
insights on the social, economic, and political structure of the Minanha polity and the North Vaca Plateau from the agrarian perspective of a minor center subjected to internal social pressure from the growing political capital center and external pressure from fluctuating local precipitation.

Concepts drawn from resilience theory conceptualize and explain significant transitional periods within the development, extensification, and eventual abandonment of the agricultural terrace systems at Waybil. Results present the emergent properties of agricultural terraces in relation to hydrological flow and erosion as well as their ability to increase land suitability for production by decreasing variation in the face of climatic fluctuations. The increased stability of production allowed the Waybil community, and subsequently the Minanha polity, to develop the capital necessary to negotiate their socio-political and socio-economic position outside of the traditional hierarchical polity system.
CHAPTER 1
INTRODUCTION

Ancient geo-intensive agricultural strategies have captured the attention of archaeologists for nearly a century in the Maya area. This has led to a rich discourse describing the many different types of geointensive systems, interpreting their functional capabilities, and suggesting the socio-political and socio-economic implications of their use. This dissertation continues this discussion by examining the agricultural terraces of the minor center of Waybil, located in the hilly region of the North Vaca Plateau of west-central Belize. Waybil is a subsidiary minor center to the Minanha polity or “Little Kingdom” (Schwake and Iannone 2016) where the Social Archaeology Research Program (SARP) directed by Dr. Gyles Iannone has conducted research. Research has progressed since 1998 and has focused on understanding the role of Minanha within its greater socio-political and socio-economic sphere of the North Vaca Plateau and greater Maya area (Iannone and Schwake 2013). The study presented in this dissertation reflects five years of mapping, excavation, soil analysis, and GIS modeling of settlement and landscape, and combined analysis of the resulting multidisciplinary datasets at Waybil. Together these provide a detailed understanding of the role of terraces in the agricultural strategy of the Waybil minor center. This information is combined with regional archaeological data and global climate data to reveal further insights on the social, economic, and political structure of the Minanha polity and the North Vaca Plateau from the perspective of a minor center. A minor center subjected to internal social pressure from the growing political capital center and external pressure from local precipitation impacts from changing global climate. Specifically, this dissertation examines the function and distribution of the relic agricultural terraces at Waybil and their associated planting surfaces and assesses the impact of this terracing on the agricultural potential of the region in terms of hydrological, erosional, and agricultural suitability qualities.
These qualities are modeled alongside information on changing social and climate pressures to compare functionality under different conditions. This assessment is used to reconstruct the complex association between landscape modifications, climate change, as well as the politics and economics of a growing Classic period polity. In order to articulate the changes and assess adaptations exhibited in the Waybil agricultural strategies concepts found within resiliency theory will be drawn on. This dissertation will address such questions as: How did terraces function in terms of soil and water management? How were agricultural terraces integrated into the agricultural strategy and community of Waybil? Why were the agricultural terraces adopted into the agricultural strategy, did the relationship change over time, and were they a beneficial or detrimental decision? What larger inferences can be drawn from this case study to the larger North Vaca Plateau and the ancient Maya as a whole?

The study combines settlement survey and mapping of the epicenter, settlement units, agricultural terraces and water management features (Demarte and Alfano 2013; Iannone et al. 2011c; Macrae and Demarte 2012), LiDAR remote scanning (Chase et al. 2014a), and GIS modeling to create a high-resolution DEM of the entirety of the Waybil’s agricultural terrace systems and settlement units (Macrae and Iannone 2016). Excavation over five field seasons, focusing on the epicenter (Schwake et al. 2013a), surrounding settlement units (Demarte et al. 2013:59), and agricultural terraces and water management features (Macrae and Demarte 2012; Macrae 2013) provide a settlement chronology based on radiocarbon accelerated mass spectrometry (AMS) dating, ceramic dating, and stratigraphic association between settlement and landscape features to reveal an occupational history that stretches from the Late Preclassic (400 B.C.E – 100 C.E.) to Early Postclassic (900–1200 C.E.; [(Hills et al. 2012:51-52; Schwake et al. 2013a:140-141)])}, and a history of agricultural terrace construction and use from the Early
Classic (250 – 550 C.E.) to the Terminal Classic (810-900 C.E.). Excavation also reveals the variation in terrace and water management structure, and through association with settlement construction patterns, insight into the function and likely management of the terraces. The analysis of soils from the planting beds of the terraces allows for a description of the soil characteristics in terms of nutrient level as well as susceptibility to erosion and agricultural suitability. Finally, interviews conducted amongst the surrounding farmers will provide a local analogy from contemporary farming in the North Vaca Plateau.

The various data types are combined into a functional assessment of the agricultural terraces based on a series of GIS models that allow quantification of essential elements of the Waybil agricultural system including hydrological flow, watershed delineation, susceptibility to erosion, and agricultural suitability. These provide a means to assess the influence of agricultural terraces in maintaining suitability of the landscape and soils for crop production under different conditions. In addition to providing a detailed assessment of the agricultural landscape of the Waybil area between the Preclassic (1200 – 900 B.C.) and Postclassic (1200 – 1525 A.D.) periods, these models allow a comparison of landscape during periods of different climate regimes as reconstructed for the region by paleoenvironmental research (RW.ERROR - Unable to find reference:1160; Akers et al. 2016; Akers 2011; Beach et al. 2015; Brenner et al. 2002; Brenner et al. 2003; Brook and Akers 2010; Curtis et al. 1996; Dahlin and Chase 2014; Hansen et al. 2002; Hodell et al. 1995; Hodell et al. 2005; Iannone, ed. 2014; Leyden et al. 1996; Mueller et al. 2009; Polk et al. 2007; Polk 2010; Polk et al. 2013; Rice 1996; Rosenmeier et al. 2002; Webster 2000; Webster et al. 2007), and during changes in social, economic, and political pressure from the Minanha polity of which Waybil was a part.
This study of the history and role of the Waybil minor center is discussed from an agrarian perspective using a socio-ecological framework. In this manner it provides a data driven understanding of the role that agricultural terraces played in changing the agricultural potential of the landscape, as well as the role that ancient Maya minor centers played within the greater socio-political and socio-economic organization. This is presented as a multi-scalar study: assessing first the agricultural strategy at Waybil, second the role of Waybil and its agricultural production as a subsidiary center to the Little Kingdom of Minanha, and finally the role of Waybil within the greater socio-political and socio-economic sphere of the North Vaca Plateau and its neighboring polities (Schwake and Iannone 2016). These relationships will be mapped out within the conceptual framework of socio-ecological systems, and the relationships between residents, terraces, agricultural systems, landscapes, social systems, and the local impacts of climate will be examined using select concepts from resilience theory.

**The Questions**

The fundamental research question in this dissertation is: Were agricultural terraces a successful adaptive mechanism within the subsistence strategy of Maya communities to a buffer against internal (social) and external (environmental) stress?

I have broken down this broad question into a series of specific questions that I will approach using combine data from: (1) LiDAR and archaeological survey, (2) excavation of agricultural terraces, analyses of related artifacts and soils, (3) ethnographic research, and (4) environmental modeling using Geographical Information Systems (GIS) to address the effects of relic terraces on the agricultural landscape in term of hydrological, erosional, and suitability qualities. These questions include:

1. How did the Waybil terraces function in terms of soil and water management? Did the Waybil terraces increase the agricultural resilience of the community?
2. How did the Waybil terraces function in terms of community activities (regardless of whether they did or did not increase resilience)? By whom and in what manner were they organized, constructed, and maintained?

3. What initiated the adoption of terraced agriculture and their increased use over time? As a response to perceived risk or demand (increasing resilience)? As a reaction to continued or episodic stress (required resilience)? As a gradual, accretive, improvement in farming (not as part of risk management)?

4. Were the Waybil terraces useful only in the face of pressures, or once adopted did they create a permanent dependence within and between the agricultural and social systems at Waybil? Were the Waybil terraces ultimately “resilient”, or in other words, did the Waybil community continue through periods of pressure they would otherwise not have survived?

5. What does this interpretation of the Waybil agricultural strategy mean for the extensive anthropogenic landscape of the North Vaca Plateau? What extrapolations can be made from understanding the Waybil agricultural strategy to the resiliency of the ancient Maya agriculture?

I use these questions to link Early Classic and Late Classic terrace attributes (building technique, function, and terrace bed soil condition) to (i) local environmental conditions (topography, ecology, and hydrology), (ii) social situation (settlement distribution and socio-economic factors such as community status and occupation), and finally to (iii) broader external factors including local precipitation (based on reconstructions of global climate) and regional political factors within the broader polity and beyond. These are combined to evaluate the role of terrace practices in the face of changing external environmental pressures (local weather conditions created by climate changes) and internal social pressures (political and economic demands of the broader Minanha polity). This holistic, multi-component approach is essential to understanding the coupled nature of the variables of the agricultural strategy and the socio-ecological system within which it lies.
The Dissertation Organization

In this dissertation Chapters 2-4 provide background information fundamental to understanding the results of the various analyses presented in Chapters 5-9 and which are used in the larger discussion and conclusion in Chapters 10-11.

Chapter 2, Ancient Maya Settlement and Agricultural Studies, presents a discussion of the history of study and changing theoretical perspective of ancient Maya settlement patterns and agricultural strategies. This emphasizes the long history of investigation of agricultural terrace systems that transitioned from the early beginnings of identification, description of geo-intensive function, and recognition of the vast spatial distribution, to the more recent research that targets detailed functional characteristics, relationship with the natural processes of the landscape, and organization of these agricultural features within the context of socio-political and socio-economic organization at various scales in ancient Maya society. This provides the necessary information to understand how this component of ancient Maya research has developed and lays the foundations for the approach taken in this dissertation. The chapter is concluded with a discussion of both the framework and theories applied in my dissertation. This defines the socio-ecological systems approach, linking it to the earlier studies (systems theory and historical ecology) that laid the groundwork for its application. This is followed by a discussion of resiliency theory, including the fundamental principles and their application within the context of agricultural strategies. This not only describes the current state of agricultural studies in the Maya area but also defines the framework within which this dissertation is written.

Chapter 3, Environment of the Maya Area and North Vaca Plateau, provides background information about the environment of the Maya area and North Vaca Plateau, as well as paleoclimatic reconstructions for the period of Maya occupation of the region. Environmental variables considered include geographical delineation, climate, and soils of the Maya area. The
North Vaca Plateau is discussed in terms of the soil classification as well as the geological, hydrological, and geographical characteristics. This discussion provides the characteristics of the Maya area and North Vaca Plateau that may have influenced the resident's decision to incorporate terraces within the Waybil agricultural strategy and the unique qualities of the tropical Maya area and North Vaca Plateau that the Waybil agricultural strategy had to address.

Chapter 4, A Review of the Archaeological Sites of the North Vaca Plateau and Regional Cultural History, discusses the history of research conducted by the Social Archaeology Research Program (SARP) as background to contextualize how this dissertation and the research I conducted at Waybil fits within the larger research program. This is followed by a short site description of the four centers (Minanha, Ixchel, Martinez, and Waybil) targeted by SARP research in the North Vaca Plateau. The Waybil information presented in this background section includes the results of investigations by Iannone, Schwake, Demarte, and Hills, conducted at the same time as my own work at the site. These overlap somewhat, but where my data is presented in association with that of other team-members in the results section, the other analysts are acknowledged. This cultural history lays the foundation for the chronological sequence of the archaeological sites of the North Vaca Plateau including a discussion of the social, economic, and political history of the region. This chapter outlines the archaeological background as well as the socio-political and socio-economic organization of the North Vaca Plateau, both necessary to contextualize the role played by Waybil minor center.

Chapter 5, Results of the Survey and Excavations, is the first of the results chapters and provides a description of the methods and results of the settlement and terrace survey and mapping, the agricultural terrace excavations and analysis of terrace-associated ceramics and terrace planting bed soils including both ceramic analysis and AMS dates of the soil organic
matter. This is followed by the description and interpretation of the archaeopedological analysis conducted on the soil samples collected from the terrace planting surfaces.

Chapter 6, Contemporary Farming in the North Vaca Plateau, analyzes data from a series of interviews conducted with the local farmers found within the North Vaca Plateau, which provide analogy to past agricultural strategies. Specifically, interviews provide a discussion of management decisions in terms of field distribution, reactions to changing precipitation regimes, and current and future production concerns. Data drawn from these interviews are used to support and expand on the description and rational behind the changes found within the Waybil agricultural strategy.

Chapter 7, Establishing Evidence for Local Precipitation Variation as a Source of Pressure on the Waybil Agricultural System, provides an important reconstruction of precipitation in the Waybil region that is based on paleoenvironmental and modeled data from various sources and my evaluation of the suitability of these data for the Waybil environs. This reconstruction data is essential to the modeling presented in the chapters 8 and 9.

Chapter 8, Defining Social Pressure at Waybil, evaluates the extent to which politics and economics of the broader polity had an impact on the Waybil inhabitants. The chapter presents the occupation history of Waybil in relation to the other developing ancient Maya communities in the North Vaca Plateau. Drawing on the terrace characteristics (types and construction style) and density of distribution at Waybil the degree of pressure exerted from the Minanha polity on the subsidiary minor center Waybil is assessed. Interpretation draws on physical characteristics that can define centralized and decentralized organization behind the construction and maintenance of terrace systems. Results are used to describe the influence of the effects of the
relationship between Waybil and Minanha on agricultural strategy and ultimately the terrace systems.

Chapter 9, Geographical Information Systems (GIS) Modeling, pulls together the background material with results of excavation and ethnographic analysis, analyses of environmental (precipitation), and social (demand for production) pressures, to inform three landscape functionality models which quantify the hydrology, erosion susceptibility, and overall agricultural suitability of the terraced agricultural lands. All three models incorporate variations in precipitation regimes to assess the impact of the terraces on hydrology, erosion, and suitability under varying climatic regimes. The final comprehensive suitability model provides information on production also under varying climate regimes. These models are tested against a modified surface model of Waybil with the terraces removed.

Chapter 10, Discussion, brings together excavation results, the chronology of the North Vaca Plateau, climatic and social pressure evaluations, and results from the three GIS models to discuss the adoption of agricultural terraces within the agricultural strategy of Waybil. This is accomplished through a temporal narrative, describing the fluctuating external (climatic) and internal (social) pressures exerted on Waybil. This chapter concludes by examining key transitional points with concepts from resilience theory. Exploring both the applicability of these concepts and how they inform on the changes identified in the Waybil agricultural strategy.

In the conclusion, Chapter 11, answers to the research questions are provided and the future direction of this research is presented.
CHAPTER 2
ANCIENT MAYA SETTLEMENT AND AGRICULTURE STRATEGIES: A HISTORY OF STUDY AND THEORETICAL PERSPECTIVES

Coupled human-natural systems models, based on complex systems and historical ecology, provide the framework for this dissertation and its research questions. I use archaeological terraces, their construction, and use as proxies for both environmental practice and social organization. This chapter provides background information to explain the development of the coupled human-natural systems model, the history of research on the links between agricultural and social structures, and how these links are manifest in the material record of terraces in the Maya area. The study of agricultural strategies in the Maya area is often intertwined with the investigation of settlement patterns and governed by the theoretical positions of the researcher. In the first section of this chapter, I explore these past interpretations of agricultural practices and settlement studies in the Maya area, highlighting the influences that developing methodological approaches as well as changing population and subsistence theories have on interpretations. In order to understand how the interpretive framework used in this dissertation is applicable I need to address how perceptions of the connections between ancient Maya settlement and agricultural strategies changed over time. This chapter will not only identify these changing perceptions, but present the associated discourse and data on agricultural strategies in order to show how the Waybil case study can influence the greater conversation of ancient Maya agricultural strategies. This discussion will begin with the 19th century influences of Wittfogel, Malthus, and Boserup on agriculture and environmental use models from archaeological and paleoenvironmental data. It will then introduce the use of settlement and construction data as proxies for reconstructing ancient social organization. In particular, control over settlement and agriculture decision making within Waybil may have been decentralized (meaning decision-making was held at the household and local site level), centralized (meaning
decision-making was at the polity level and thus, at Waybil, was strongly linked to the demands of the polity capital), or heterarchical (some combination of the two). The extent to which control of terrace construction and use was centralized is used as a proxy for the pressure that would have been exerted on the Waybil residents to produce surplus goods for the larger polity rather than just for household or local community consumption. This provides the basis for the consideration of contemporary discussions of resiliency theory that will be addressed in this dissertation. In the second section of this chapter, the concept of coupled socio-ecological systems is introduced. This begins with a discussion of theories of ecological systems and historical ecology, outlining their independent development yet shared goals and trajectory. This describes how complex systems and historical ecology function to provide the basis for socio-ecological systems and ultimately the framework for this dissertation and its research questions.

Studies of Maya Settlement and Agriculture

Perspectives of ancient Maya subsistence strategies have changed over the decades of archaeological investigations, often paralleled by a contemporaneous understanding of settlement patterns. Starting in the 19th century, and becoming firmly entrenched by the 20th century, was the theory that the ancient Maya sustained themselves solely on milpa slash and burn (swidden agriculture), emphasizing the production of maize, beans, and squash (Turner 1978b:13). This was based on ethnographic analogies to the modern Maya who practice this subsistence technique and archaeological evidence of carbonized maize pollen and various vegetation disturbances indicative of large scale burning (Dahlin et al. 2005:231; Morley 1946:141; Steggerda 1941; Tsukada 1966; Tsukada and Deevey 1967; Turner 1978b:14). The settlement model associated with milpa farming consisted of dispersed ceremonial centers with few permanent residents, while rural settlements were widely dispersed to facilitate the long fallow period required for swidden practices (Dahlin et al. 2005:231; Linton 1940:40; Sanders
Archaeological evidence, or lack of evidence, that was used to support the dispersed, low population levels, was based on surveys that focused mainly on epicenters, with little to no information about the rural landscape. This approach produced very small settlement counts, and low population numbers, which fit within the limited carrying capacity of swidden agricultural practices (Cowgill 1960; Puleston 1978:229; Turner 1976:74; Volgerler 1974:110-11).

At this time the theory fell in line with the contemporary “hydraulic hypothesis” presented by Wittfogel (1957) and past population dynamics proposed by Thomas Malthus (1798; 1878). Wittfogel (1957) argued that the centralized control of hydraulic or other geointensive agricultural systems was essential for the development and maintenance of state level society. This was a level of social and political organization not attributed to the ancient Maya at this time. Through a number of publications, Malthus (1798; 1878) proposed that population levels always increase faster than the rate of agricultural production, resulting in misery when one surpasses the other. Thus, population levels and density were dependent on agricultural production, lands, and technology as well as cultural and environmental settings. At the time, the low population estimates of the ancient Maya and swidden agricultural production met with the Malthusian and Wittfogel theories.

It was during the 1960s that the validity of the swidden thesis came into question. These inquires originated from the insights of several early settlement studies that highlight a more dispersed and varied settlement pattern. This was initiated by researchers such as J. Eric S. Thompson (1931) who produced the first systematic settlement survey strategy in the Maya lowlands, within a 12 km² survey zone in the Mountain Cow region of Belize. Thompson identified three levels of residential structures which he contrasted with larger centers, noting
distances, and implying social systems (Ashmore and Willey 1981:8; Thompson 1931; 1939). Around the same time O. G. Ricketson, Jr. conducted a settlement survey at Uaxactun. The strategy created a cruciform survey zone, centered on the epicenter with arms that stretched out in four directions. This covered 1.94 km², and including 78 small mounds and platform units (Ashmore and Willey 1981:9; Kurjack 1974:24-25; Ricketson 1937). While concepts of the city, presence and nature of domestic structures, and relationships of major centers were still examined, research addressed population estimates, integrative patterns, sociopolitical organization, and social hierarchies. Results suggested that Maya cities contained dense urban populations calling into question swidden practices and limits of the sustaining areas (Ashmore, ed. 1981; Dahlin et al. 2005; Haviland 1963; 1966; 1970; Kurjack and Andrews 1976; Puleston 1974; 1978; Turner 1976; Vogt and Leventhal 1983; Wilken 1971; Willey et al. 1955; Willey et al. 1965; Willey 1956; 1978).

In opposition to the swidden thesis, Bennett Bronson (1966), and Dennis Puleston (1968), proposed alternative root crops and arboriculture respectively to the triad of corn, beans, and squashes. Simultaneously, many researchers realized that previous conceptions did not take into account any variables that may have changed over the 4000+ years of Maya occupation, such as soils, climate, and population (Dahlin et al. 2005:231). The next step was the discovery that Maya cities contained dense urban populations, which could not sustain themselves strictly by swidden practices (Dahlin et al. 2005:231; Wilken 1971:432). This realization was assisted by an increasing number of settlement studies that included a focus on regions rather than sites with major projects expanding their survey zones around epicenters. In 1954, Gordon Willey spearheaded the Belize Valley settlement project in a 2 km² survey zone at Barton Ramie (Vogt and Leventhal 1983:xvi; Willey 1953; 1956; 1978; Willey and Bullard Jr 1965; Willey et al.
1955; Willey et al. 1965). This was the first full-scale project aimed specifically at settlement patterns, exploring size and composition of ancient communities in order to understand where the ancient Maya lived in relation to the environment as well as the social and cultural composition (Haviland 1966:28; Vogt and Leventhal 1983:xvi). At this time, Bullard (1960) presented his seminal article, within which he laid the foundations for differing Maya settlement types. Directly relevant to this dissertation is the description of Minor Ceremonial Centers, which fall between household units and Major Ceremonial Centers in terms of size. Further, Minor Centers are defined by the incorporation of one or more large structures, typically pyramidal in nature, with one to three adjacent plazas and occasionally the vaulted architecture of “palatial” residences are in direct or indirect relation to the central compound (Bullard 1960:361-360). Studies such as this produced much larger population estimates that called into question the limits of the sustaining areas and methods of farming (Haviland 1963; 1970:193; Kurjack and Andrews 1976:319; Puleston 1974:309; 1978:229; Turner 1976:73).

The identification of higher population levels increased the awareness that the superficial ethnographic analogies to the small population of modern Maya were inappropriate for they did not take into account the demographic and environmental changes (Wilken 1971:433). Influential publications of this era by the Danish agroeconomist Esther Boserup (1965) appeared to fit nicely with the notion of a much more diverse Maya area, with an increased awareness of agricultural potentials at a local level. Boserup (1965) proposed that agricultural intensification was stimulated by population pressure and land shortage, and that it evolved in tandem with population needs (Dahlin et al. 2005:231; Trigger 2006:412; Turner and Harrison, eds. 1983; Turner and Harrison 1983:248, 266). This prompted scholars to turn their attention to theoretical models of social organization (Ashmore and Willey 1981:14).
This change in focus spurred William Haviland (1966) to argue that theoretical interpretations were outstripping the available data; he called for increased technical surveys and excavations to produce strong definitions of settlement patterns and types (Haviland 1966:23, 42). In response, surveys began to target areas outside of the traditional site core, while also became problem oriented with specific and diversified goals. Projects strove to define different levels of Maya settlement addressing large areas for micro and macro patterning amongst major centers, intervening minor centers, and households (Ashmore and Willey 1981:16-17). With these increased Maya settlement studies came evidence for greater variations in not only population, but also agricultural strategies. This suggested a variety of developmental sequences that did not fit into Boserup’s proposed process of agricultural intensification (Dahlin et al. 2005:231).

Settlement studies had outrun the “center bias” by the 1980s, which dramatically expanded the scale of inquiry (Ashmore and Willey 1981:16; Vogt and Leventhal 1983:xix). The subsequent publications up to and into the 1980’s had reversed the situation Haviland described, presenting an enormous collection of field data indicating high population and density estimates that supported urbanism (Ashmore and Willey 1981). Archaeological evidence for diversity within agricultural practices were found to include a large suite of intensive practices such as terracing, raised fields, fertilized kitchen gardens, and water management schemes that involved canals, ditches, dams, and reservoirs. The evidence showed that all these were in addition to extensive practices of milpa farming. Much of the work towards finding and understanding these alternative subsistence methods was accomplished by individuals such as Peter Harrison, Billy Lee Turner (Harrison and Turner 1978; Turner and Harrison, eds. 1983), Gordon Willey (1978), Dennis E. Puleston (1968; 1974; 1978), Paul Healy (1986; Healy et al. 1983), and Norman
Hammond (1978), although these are but a few of the active researchers at the time. Although these intensive systems are now well accepted, there was a great deal of debate in the 1970’s, exemplified by Sanders’ (1979) review of Pre-Hispanic Maya Agriculture (Harrison and Turner 1978). Sanders’ (1979:497) disagreements stemmed from the belief that intensive agriculture and irrigation would have to imply that the Maya had an understanding of ecological processes, practiced planned colonization, and made decisions based on long-term problems, all of which were perceived by Sanders as an impossibility for the ancient Maya (Fletcher 1978; Morley 1946; Puleston 1978:234; Sabloff and Rathje 1975; Steggerda 1941). Other factors in the widespread adoption of more intensive agricultural strategies were also identified in the archaeological literature, such as contemporaneous trends in expanding interregional interactions and shared cultural practices, as well as increases in large-scale construction projects and other evidence for the development of a hierarchical social system with an established kingship system. These revelations suggested a variety of developmental sequences that did not fit in Boserup’s proposed process of agricultural intensification (Dahlin et al. 2005:231). Rather, a complexity in development sequences were presented, highlighting intensification without population pressure (Antoine et al. 1982; Pohl et al. 1990; Pope et al. 1996) and the lack of intensification with population pressure (Dahlin and Dahlin 1994; Pope and Dahlin 1989; 1993).

By the mid 1990s field investigation had concretely revealed the wide spatial distribution and the variety of intensive and extensive agricultural practices in the Maya area, ending any debate over their presence and use (Antoine et al. 1982; Harrison 1996; Healy 1983; Healy et al. 1983; Pohl et al. 1990; Pope et al. 1996; Turner 1983a; Whitmore and Turner 1992). At this time, the Maya area exploded with fieldwork and publications that continues today. Large projects utilized holistic approaches to not only examine epicenters but also incorporate
community level analysis exploring support populations and agricultural strategies (see Iannone 2006b; Yaeger and Canuto 2000). Further, a number of independent and associated projects addressed specific questions using a variety of methodologies incorporating interdisciplinary components. Survey work was revolutionized with the increased use of total stations and highly accurate GPS devices, complemented by high-resolution satellite imagery. Geographic Information Systems transformed the production of maps providing the capacity to run a diversity of analyses. These tools expedited survey work increasing the scale at which it could be conceptualized and carried out at. Numerous dissertations and theses exemplified this phase; Fedick (1988) in the Upper Belize Valley, Murtha (2002) at Caracol, Wyatt (2008) at Chan, Pollock (2007) in the Contreras Valley, Hoggarth (2012) at Baking Pot, Peuramaki-Brown (2012) at Buenavista, just to name a few.

There were then, and still are today, a large number of studies within the Maya area that focus on intensive agricultural practices (Healy et al. 1983; Kunen 2001; Murtha 2002; Neff 2008; Pollock 2007; Turner and Harrison, eds. 1983; Wyatt 2008). These projects revealed the diversity and massive scale at which intensive practices were sometimes used by the Maya over the years. Studies have focused on intensive practices and the natural ecology (see Beach et al. 2008; Beach et al. 2009; Beach et al. 2006; Dunning and Beach 1994; Harrison 1996). Intensive practices and water management have been examined in terms of the role of water and social control (see Scarborough 1998; Scarborough 2003; Scarborough and Valdez 2003). In particular, and of interest in our discussion, relic terrace systems were being used to deduce the social organization behind their construction and maintenance and to infer the greater socio-political and socio-economic organization of the ancient Maya (see Chase and Chase 1998; Macrae 2010; Murtha 2002; Pollock 2007; Wyatt 2008).
The level of investment in intensive agricultural practices has been a tantalizing line of evidence that archaeologists have used to interpret ancient Maya social organization, specifically the degree to which economic and political organization of production was centralized or decentralized. The centralized organization of agricultural production suggests a tighter and direct control over landownership, labor, and ultimately surplus, with agricultural surplus extracted to play a role in a centralized economy (Chase and Chase 1998; Chase and Chase 2001; Chase et al. 1990). Agricultural production under a decentralized organization is reflective of local organization by households, lineages, or small communities, with little relationship to, or control of, central rulership. Production is lower than the centralized process and is distributed outside of the formality of larger economic sphere and trade systems (Dunning 2004; Dunning et al. 1997; Dunning and Beach 1994; Fedick 1994; Hageman 2004; Kunen 2001; Neff et al. 1995; Turner 1983b).

At the forefront of this approach is the study of agricultural terraces. Terrace research not only provides information on the conditions and use of geointensive agricultural systems for food production, but also links the process of creating food and surplus to the social organization of the community that built, maintained, and used the terraces. The link between terrace construction and community social organization has been much debated. Terrace systems that exhibit large-scale landscape modifications through the vast distribution of high quality terraces, are suggested to have been organized under the direct guidance of the political elites in control of surplus. These urban fields or vast rural field systems exhibit a large-scale organization scheme with surrounding, evenly distributed settlement compounds or high density pockets of settlement (Chase and Chase 1998; Demarest 1992; Doolittle 1984; Dunning 2004; Healy et al. 1983; Healy 1986). Both agricultural field systems and associated settlement need a temporal consideration.

Terrace systems that exhibit irregular patterns of terraces that lack constructional uniformity are proposed to have been created through long-term, small labor investments. This piecemeal process is associated with gradual investments on agricultural return from a bottom-up, nonhierarchal process locally controlled without the guidance of state administration. Researchers suggest that these field systems were constructed by individual farming households, lineages, or communities composed of clustered and dispersed settlements units (Beach et al. 2002; Chase and Chase 1998; Doolittle 1984; Dunning 2004; see Dunning and Beach 1994; Haviland 1970; Healy et al. 1983; Kunen 2001; McAnany 2000; Netting 1993; Wyatt 2005). In the Maya area, examples of decentralized organization can be drawn for the ancient Maya centers and surrounding settlement of Mountain Cow, Caracol, Chan, Dos Chombitos Cik’in, Barba Group, Las Terrazas, La Milpa Drainage 1, the upper Belize River valley, Petexbatun region, and within the Three River region of northwestern Belize (Beach et al. 2002:386-287; Chase and Chase 1998:73; Demarest 2004:146; Dunning et al. 1997; Fedick 1996a; Fedick 1994; Healy et al. 1983:402; Murtha 2002; Robin 1999; Wyatt 2008:11).
Beyond the examination of the physical properties and labor investments in the creation and maintenance of these geointensive agricultural features is the analysis of their value for production of crops. Crop choice has been proposed to be linked to social organization as either domestic or surplus production. The prevailing model suggests that the top-heavy hierarchical structure of the ancient Maya, especially during the Late Classic, placed increasing demands on surplus agricultural production to support the large aggregated populations of the urban centers (Kennett and Beach 2013). Beginning in the Preclassic, in order to alleviate growing pressure, farmers are hypothesized to have expanded field size for primarily maize monocropping, causing deforestation which lead to increased erosion and the ultimate adoption of agricultural intensification (Beach et al. 2009; Dunning et al. 2002; Kennett and Beach 2013). This process of deforestation is documented in pollen records as a reduction of tree species and increase of pioneer species, and an emphasis on maize production, seen in the pollen record as an increase in grass pollens (see Abrams and Rue 1988; Anselmetti et al. 2007; Binford et al. 1987; Deevey et al. 1979; Jones 1994; Mueller et al. 2009; Neff et al. 2006b; Pohl et al. 1996; Rosenmeier et al. 2002; Wahl et al. 2013). It has been argued that the increased maize production and reduced taxonomic diversity (with low richness and evenness based on the dominance of a single species) can act as a trade-off for forest ecosystems (Kennett and Beach 2013). However, alternative polycultivation systems have also been suggested based on modern analogies and a much higher taxonomic richness identified in more recent archaeobotanical studies (Hageman and Goldstein 2009). The archaeobotanical record is a better proxy for crops since it reflects actual archaeological remains while palynological data reflects primarily only wind-pollinated species, of which there are very few (according to Ford, really only ramon which is not a good indicator species since it is attracted to limestone constructions and thus may reflect only increasing
settlement, not decreasing tree species), and which are often dominated by a few high-rate pollinators (such as maize). This alternative suggests greater species diversity and a more complex level of management and organization that maintains the natural processes of a forest garden (Ford 2008; Ford and Nigh 2015; Ford and Nigh 2009). These alternative agricultural strategies have included intensive milpa farming or the use of “Maya Forest Gardens”. Forest gardens are defined as an intensive milpa cycle that preferentially leaves economically important species standing in order for the field to transition into a managed orchard and eventually closed canopy after annual crops have been harvested (Ford and Nigh 2009:216). While the degree of diversity in crop production and none-agricultural plant exploitation varies, there is direct evidence that indicates differential deforestation and management of useful trees and palms (Dunning et al. 1999; Dunning et al. 2014; Gómez-Pompa 2003; Hageman and Goldstein 2009; McNeil et al. 2010; Pohl et al. 1996). Regardless of the agricultural diversity, the archaeological record clearly shows that both extensive and intensive agricultural systems expanded in tandem with growing population sizes and with the development of a non-agricultural population in the urban centers.

The stark dichotomy of centralized and decentralized organization schemes of agricultural production almost immediately produced concerns over the simplification of the complexities found in both agricultural production and its socio-economic and socio-political oversight (Chase et al. 2009; Fash 1994; Liendo Stuardo 1999). This can be apparent when considering the temporal changes that occur within the agricultural strategies throughout the occupation history of a site, a factor compounded by difficulties associated with assigning specific dates to geointensive features. Over time disagreements between the dichotomy of centralized and decentralized organizational schemes formed from both classification criteria and
occurrences at specific sites. For example, it has been proposed that a decentralized construction of intensive field systems can accumulate over time from small terrace systems into an entire agroecosystem, similar to an incremental construction process (Doolittle 1984:124), reminiscent of what a centralized systematic terraced landscape would resemble. With the understanding that classifications based on centralized or decentralized organization formed an arbitrary dichotomy, researchers attempted to break this by introducing the new classification of heterarchy (Brumfiel 1995; Crumley 1995; Potter and King 1995).

Heterarchy is understood as an alternative to the hierarchical and non-hierarchical understanding of systems that dominated up to this point in time. Heterarchy is based on the unrankable or potential for differential ranking of dissimilar variables in a system (McCulloch 1945). When considered in terms of social organization, heterarchy describes a unique position and a degree of independence within the hierarchical organization in which social entities (community members, communities within a polity, etc.) possess the ability to be ranked in a number of different ways or even to be unrankable within the social structure (Crumley 1995:3; Scarborough 2003:XIV). So defined, social structures were more reflective of the complex organization, adaptability, and flexibility of typical human societies (Crumley 1995:3; Scarborough 2003:XIV). This complex management system works on all levels of society, from agricultural production, to settlement organization, to social structuring, involving both vertical and horizontal power relationships (Crumley 1995:3; Potter and King 1995:17). Horizontal relations include societal elements perceived to be unranked and equivalent to each other (Potter and King 1995:17). Vertical relations occur on a tiered, ranked organization (Potter and King 1995:17). Heterarchical social organization networks assume different roles of ranking depending upon their context of use (Brumfiel 1995:128). This flexibility makes elements within
society unrankable in comparison to each other or, when possible, they are thought to contain the ability to be ranked in a variety of different ways based on participation in individual systems (Brumfiel 1995:125). Heterarchy suggested an alternative to how humans understand structures across time and space, allowing researchers to address interactions across and outside the scales defined in the traditional parameters of their study (Crumley 1994:13).

This type of organization has rarely been attributed to agricultural systems in the Maya area (Macrae 2010). Examples include the reassessment of the Three Rivers region, which posits the existence of several communities, each of which had the advantage of different resource extraction and production specialties, which allowed them to negotiate their relationship with neighboring and larger centers. This includes communities focused on terrace farming, such as Las Abejas, My Lady, El Arroyo, and Dos Barbaras (Scarborough et al. 2003; Scarborough and Valdez 2003:12) which are presumed to have specialized in crop production. There are also bajo communities within several sites west of La Milpa that are hypothesized to have exploited the high quality soils of these low lying, seasonal swamps for specialized agricultural production (Creamer and Haas 1985:740; Dunning et al. 2002; Hammond 1978:33; Hansen 1998:53; Rice 1976a:445; Scarborough and Valdez 2003:12; Siemens 1978:136). Aguada communities are also apparent to the east of Dos Hombres, where the site residents are hypothesized to have specialized in exploiting artificial and natural water resources (Scarborough and Valdez 2003:13).

Today is an exciting time for the archaeological investigations into ancient Maya subsistence strategies. New technologies, seen in the new interest in the use of LiDAR in tropical environments, are identifying the vast scale of past agricultural systems (see Chase et al. 2014a; Chase et al. 2014b; Chase et al. 2012). In addition, advances in scientific methodologies in the
fields of archeobotany and pedological studies are starting to identify the diversity of crop production and use as well as relationships with soil characteristics (see Bathurst et al. 2010; Dickau et al. 2007; Ford and Nigh 2009; Holliday and Gartner 2007; Nielsen and Kristiansen 2014; Pearsall 2000; Pearsall et al. 2003; Perry 2004; Piperno 2009; Wingard and Hayes 2013). Research is starting to describe how these agricultural strategies were designed to exploit the heterogeneous nature of the Maya area.

The greater understanding of the diversity and extent of these ancient Maya agricultural strategies has begun to reveal their hidden complexities. These complexities describe how the foundations of these agricultural practices are based on interconnections and dependencies between the natural and cultural worlds (discussed below). This is best reflected in the framework of socio-ecological systems. The next section discusses how this approach was developed in archaeology and how it will be used in this dissertation.

**Complex Socio-Ecological Systems and Resilience Theory**

The concept of socio-ecological systems rests on the theory that humans lives in a linked social and ecological system (Abel 1998; Balée 1998; 2002; Berkes and Folke, eds. 1998; 2003; Crumley 1994; Gunderson and Holling, eds. 2001). This notion that humanity and nature are intrinsically linked is not a new concept. Studies by European scholars began to explore this concept in the 18th century using an early style of historical ecology. The first study to focus on historical ecology was conducted by Grainger (1946). Then in 1948, the term historical ecology was first defined (Conway 1948). In this instance, it was used to refer to the “profound effects that man has exerted on vegetation at any time during the post-glacial period when the population of a district has reached a sufficient density” (Conway 1948:220). The first self-conscious use of historical ecology in a North American anthropological setting is attributed by
Don S. Rice (1976a) and William Balée (1998) to Edward S. Deevey who at the time was directing the Historical Ecology Project at the University of Florida in the early 1970’s.

It was around the 1970s when conception of the system in which these human-environment interactions occurred began to change. Prior to this, these systems in anthropology were viewed as being in equilibrium, drawing on ecologists’ view of a balance to nature (Scoones 1999:480). This understanding bled into anthropology as seen by the works in cultural ecology (Steward 1955), the ecosystems approach (Rappaport 1967), and cultural materialism (Marquardt 1985). This premise gave rise to the belief that like nature, society was internally regulated to maintain a state of equilibrium, and could be explained through deterministic models (Hastings et al. 1993). Shortly after the 1970s there was a substantial shift in how systems were understood, a change that would have ramification not only in complex systems but also anthropology. To understand the application of socio-ecological systems in archaeology I need to look at both the contemporary understanding of complex systems and historical ecology.

**Complex Adaptive Systems**

The change in how systems were understood during the early 1970s first occurred amongst ecologists, with the emergence of nonequilibrium theory (Scoones 1999:482). This drive for a new view of systems came from a concern about studies that “ignore questions of dynamics and variability across time and space, often excluding from the analysis the key themes of uncertainty, dynamics, and history” (Scoones 1999:482). Nonequilibrium theory focuses on systems as nonlinear due to their unpredictable nature and differing effects of both short and long-term change (Berkes and Folke, eds. 1998:12; Costanza et al. 1993:546; Levin 1999:431). This placed an emphasis on both spatial and temporal variability and three primary concepts were suggested: systems can exist in multiple stable states (Noy-Meir 1973); systems are chaotic, exhibiting historical dependency while lacking long term predictability (Ellner and Turchin
1995; Hastings et al. 1993; May 1989; 1990); and systems are complex (Chesson and Case 1986). This new paradigm was labeled the “new ecology” (Abel and Stepp 2003:12; Scoones 1999:481-483).

While the acceptance of nonequilibrium systems occurred rapidly in ecology, there was a delay before social scientists incorporated these new concepts as part of the movement to ecological anthropology. The rather scathing review of ecological anthropology by Vayda and McCay (1975) highlighted this delay and issues of the time. These criticisms focused on the persistent concentration on equilibrium systems with a focus on self-regulation and homeostasis which neglected the possibility of “nonhomeostatic changes, system disruptions, and ‘unbalanced’ relations between people and their environments” (Vayda and McCay 1975:294). Further, Vayda and McCay (1975:295) suggested that studies were using “ill-chosen or ill-defined” units of analysis, which refers to issues in the spatial and temporal considerations of these systems. During this period, there was a disassociation between ecology and anthropology even though at the same time there were important exchanges occurring between a diverse set of disciplines that encompassed ecologists, economists, and other social scientists at the Beijer Institute in Stockholm. This collaboration initiated the “Linking Social and Ecological Systems for Resilience and Sustainability” project in 1993 and the “Dynamics of Ecosystem–Institution Linkages for Building Resilience” project in 2000 which resulted in two important publications (Berkes and Folke, eds. 1998; 2003). These edited volumes focused on outlining socio-ecological systems in the new framework provided by the “new ecology” and complex systems, dismissing past equilibrium models for systems.

As stated above, contemporary complex systems are defined by several attributes: non-linearity, self-organization, and multiple stable states (Berkes and Folke, eds. 1998:12; Levin
Complex systems are non-linear in that their development is unpredictable due to combined slow, long-term fluctuations and fast, short-term fluctuations, and a historical dependency between their variables (Berkes and Folke, eds. 1998:12, 352; Costanza et al. 1993:546; Levin 1999:431). “Non-linearity refers to the fact that effect and cause are disproportionate, so that small changes in critical variables... can lead to disproportionate, perhaps irreversible, changes in system properties” (Levin 1999:14). Thus, systems need to be understood in terms of changing behavior over time and space as the interaction between variables change, and the system evolves and develops (Berkes and Folke, eds. 1998:352, 354; Levin 1999:433). Contrary to the diversity created by non-linearity (Levin 1999:12), complex systems are self-organizing in response to feedbacks between interconnected variables (Berkes and Folke, eds. 1998:357), re-organizing themselves at critical points when pressures are exerted upon the system (Berkes et al., ed. 2003:6). However, it is vital to stress that the direction of organization in a system results from the entanglement of a small number of controlling variables that are path dependent due to accidents of history (Berkes et al., ed. 2003; Holling 2001:391; Levin 1999:12). Complex systems remain in specific states or regimes as the variables self-organize and adapt to fluctuations. At certain points when the system can no longer mitigate these fluctuations it crosses a threshold, changing into a new regime (Berkes et al., ed. 2003:5). Thus, complex systems exist in series of nested tiers, smaller systems within larger ones, each with the potential for existing in multiple stable states (Berkes et al., ed. 2003:6).

**Historical Ecology**

From the anthropological front, starting in the mid-1990s Carole Crumley and William Balée were invested in understanding the relationships between society and nature in different ways from past anthropological studies, which focused on environmental determinism, cultural ecology as adaptation to environmental condition (Steward 1955), and equilibrium-based
systems models (Flannery 1968). They were using similar concepts as those used in the “new ecology” to create a foundation for their perspective of dynamic systems that human and nature interactions created as a form of co-written environmental "history". Crumley spearheaded this revolution in Historical Ecology with her work in Burgundy (Crumley and Marquardt, eds. 1987). Her most famous publication “Historical Ecology: Cultural Knowledge and Changing Landscapes” (Crumley 1994), is well known for defining the new direction of Historical Ecology. In these early works, multi-scalar approaches are emphasized suggesting that research should be conducted from small locational studies to larger regional and interregional scales, finally being incorporated at a global level (Crumley 1993:377). Temporally, research is suggested to focus from the specific to the long term (Crumley 1993:378). The incorporation of these temporal and spatial scales was viewed as imperative in the definition of the parameters for the study of the human – nature relationship, degrees of interactions, and consequences. These multi-scalar and multi-temporal analytical strategy were designed

…to examine, at specific temporal and spatial scales, factors of duration, intensity, and periodicity, which cannot be defined in simply arithmetic terms. These parameters must be considered as relative to a particular environment because a small change in one environment could be perceived as a major change in another. (Crumley 1993:378)

Historical ecology was developed as a multidisciplinary research program that explores the dynamic and synergistic interrelationship between humans and the environment they live in (Balée 1998:14; Crumley 2006). Balée (1998) advanced Crumley's definitions during the late 1990s and presented four postulates:

(1) Much, if not all, of the non-human biosphere has been affected by human activity. (2) Human activity does not necessarily lead to degradation of the nonhuman biosphere and the extinction of species, nor does it necessarily create a more hospitable biosphere for humans and other life forms by increasing the abundance and speciosity of these. (3) Different kinds of sociopolitical and economic (political economies) in particular regional contexts tend to result in qualitatively unlike effects on the biosphere, on the abundance and speciosity of
nonhuman life forms, and on the historical trajectory of subsequent human sociopolitical and economic (or political economies) in the same regions. (4) Human communities and cultures together with the landscape and regions with which they interact over time can be understood as total phenomena.

These postulates were presented so that historical ecology could be interpreted not as a method or field but rather a viewpoint (Balée 1998). Crumley (1993:377) noted that the coexisting development in social, natural, and biological sciences of a multi-scalar, spatial and temporal, framework that would comprehensively address the complex, multi-causation nature of human and environment interaction. To address this, terms were presented by Crumley and colleagues as integral for the application of historical ecology. Thresholds, or crisis level, are known as a point in which environment and “other disturbances” trigger a cultural response (Crumley 1993:378; 1994:10). Thus, the threshold is defined and varies based on the cultural knowledge that defines the society’s resilience to disturbances (Crumley 1993:378; 1994:10). Temporally, this knowledge is transferable and has the ability to increase over time (Crumley 1993:378; 1994:10). The historical ecology research program also emphasized the importance of cultural diversity in terms of society’s ability to mitigate the human-environment interactions, particularly in terms of potential fluctuations and the ability to be both detrimental and beneficial to the environment and its resources (Crumley 1994:12).

Researchers focused on historical ecology believed that it encompassed too little and too much at the same time, suggesting that it means more than one thing to different researchers (Kidder and Balée 1998:405). They ultimately believed that historical ecology should be seen “as part of a broader, far more consequential transformation in science as a whole” (Kidder and Balée 1998:405).
Coupled Socio-Ecological Systems

While it may seem apparent that the two approaches of complex systems and historical ecology are linked, their development was independent. The research program of historical ecology, and the framework of linked cultural and natural systems, have several clear connections seen in their goals and terminology. It has been made clear that both approaches are based on the concept of humanity and nature being inextricably interconnected. However, despite this commonality there has been little to no conversation between the two fields, up until very recently (Abel and Stepp 2003; Redman and Kinzig 2003; Redman et al. 2007; Tainter and Crumley 2007). Why there was no interaction between the fields is still open for debate; it is likely that the same disciplinary divide between ecology and anthropology that both approaches were trying to cross caused this lack of discourse. Yet, in examining these fields beyond their social and environmental foundations, there are several similarities.

The self-conscious use and definition of historical ecology by Crumley was used to create a common vocabulary to facilitate the discussion of the subject of complexity from both the “natural scientific and historical approaches” (1994:XIV; see Balée 1998). Similarly, the development of linked cultural and natural systems in ecological and resource management was to establish a series of definitions to create a common vocabulary (Berkes and Folke, eds. 1998:4). Unfortunately, due to the lack of communication there was a series of concepts developed to describe the human-nature systems that essentially explained the same thing but are described in different vocabularies. I find that the ecosystem vocabulary places a higher emphasis on clear terminology to describe socio-ecological systems while historical ecology tends to rely on larger more fluidly defined concepts. A clear instance of these similarities is found in the use of thresholds (Crumley 1993:378; 1994; Walker and Salt 2006:76; 2012:215). In addition, the use of heterarchy in the social sciences is similar to panarchy and nested/coupled
hierarchies. Determining which of these two vocabularies to use when analyzing the relationship between the humanity and nature in my dissertation extends beyond a simple selection of one or the other, but rather needs to be based on how these fields portray themselves and their epistemological foundations.

While the concept of socio-ecological systems was presented from the ecological side of the argument, it has fostered a significant amount of interest in anthropology and especially archaeology (Costanza 2014; Costanza et al., ed. 2007; Iannone 2015). This interest and subsequent discourse has facilitated an avenue to unify these two approaches (complex systems and historical ecology) not only in terms of terminology, but also in methodology (Iannone 2014; Iannone 2016a; Iannone 2016b). A coupled socio-ecological approach requires holistic, multi-component research that integrates aspects of natural and cultural variables. It acts as the foundation within which these typically isolated variables can be combined within a singular system in order to evaluate and model changes and reactions between them.

Returning to the postulates of historical ecology outlined by Balée (1998), they call for an approach that recognizes that humans have affected the nonhuman biosphere in both destructive and nondestructive ways, and that variation in the manner in which humans interact with the biosphere is diverse and dependent on the socio-political and socio-economic context of the society. The effects of these human nature interactions are not only restricted to the nonhuman biosphere, but can also affect the historical trajectory of the society in question. The study of this would require a multi-scalar (temporal and spatial) approach to understand the total phenomena. Lacking a unifying approach, the study of historical ecology has been designated a research program (Kidder and Balée 1998:405). Complex systems of the “new ecology” not only embodies many of the qualities found in this approach to science, but also provides methods to
achieve the postulates outlined in historical ecology. Both complex systems and historical ecology are encapsulated in the framework of coupled socio-ecological systems.

The study of socio-ecological systems embraces the self-organizing and non-linear characteristics of complex systems as representative of the diversity found in human-nature interactions and their consequences. Applying a temporal perspective when describing complex systems accounts for the historical contingencies that shape both society and its interactions with the environment. The temporal component that archaeology and other historical disciplines provide in the study of complex systems is integral to the understanding of system resilience (Dearing 2007:27-29; Thompson 2016:314). This is essential in that it presents systems as a continuum, rather than a historical episode, facilitating a much clearer understanding of their dynamic nature by presenting both short-term and long-term fluctuations amongst the variables over time (Gunderson and Folke 2003:15; Holling et al. 2002:11; Redman et al. 2007:116-117).

The multi-scalar approach prescribed in historical ecology (Crumley 1993:377) is satisfied by the ability to target a singular system within a series of nested systems, i.e. panarchy (see Gunderson and Holling, eds. 2001). This method facilitates the ability to study phenomenon at a local level and expand into regional and interregional scales. Further, examining smaller systems produce a more manageable number of variables to select from. This assemblage of variables can be simplified by the concept of “requisite simplicity”, which refers to the process of identifying the minimal number of variables necessary to effectively define the system of study (Walker and Salt 2012:23). By applying these methods, researchers can study a system at a local scale, identify essential variables for analysis, and describe how the system functions over time. This approach copes with the complicated feat of identifying the “totality” (system) of the human-nature landscape (Balée 1998:24; Balée and Erickson 2006:2-3; Ingold 2011:221). The
results from small scale studies can be extrapolated into larger more regional systems, examining how small scale phenomena and changes in local systems can influence larger processes at a regional scale (Thompson 2016:314).

Coupled socio-economic systems have been utilized in archaeology in a variety of different applications and scales, with varying degrees of success. In the Maya area, applications tend to focus on the broader interregional scale of polities or society wide analysis. Scarborough (2007) explores the relationship between the ancient Maya of the southern lowlands and their tropical environment. He outlines self-organizing social complexity (heterarchy) in terms of the interconnections between groups and sustainable means of agricultural production. Results describe a system within which the increasing speed of landscape modification and rigidity in social stratification, due to historical contingencies, ultimately lead to the degradation of the landscape and reorganization/relocation of its population (Scarborough 2007:55). Dunning et al. (2014) examines changes in hydrological and erosion patterns, as well as vegetation disturbances in order to identify the role of human and/or environmentally induced change throughout the Preclassic occupation of east-central Yucatan and the Mirador Basin. Isendahl et al. (2014) discusses the Classic period Maya sites in the Puuc region. They explore the agro-urban settlements in terms of agricultural production and intensification, water management, environmental benefits and limitations, as well as increasing social and political stratification. Ultimately, results describe the rapid florescence and decline of Puuc cities due to a failure to adapt the socio-political and socio-economic organization to the diminishing returns of the agricultural strategy (Isendahl et al. 2014:50). Alternatively, studies have focused on more specific human-nature interactions and their climatic and environmental consequences. For example, Griffin et al. (2014) explores the role of local climatic variability and its
interconnectivity to increasing and decreasing levels of deforestation for agricultural purposes in the Maya area. This human-nature interaction is examined in order to question its influence on the frequency and severity of droughts (Griffin et al. 2014:85).

More relevant case studies to this dissertation can be found outside the Maya area. In recent years, there have been several studies that focus the resilience of agricultural strategies through the lens of socio-ecological systems. Altaweel and Wantanabe (2012) as well as Altaweel (2008) study the agricultural strategy employed to exploit marginal lands and minimize the effects of salinization in Mesopotamia by modeling the past socio-ecological system. Their analysis incorporated environmental variables with simulated agricultural strategies, informed from the archaeological record, into a socio-ecological systems model in order to describe the subsequent consequences of the decisions made by the inhabitants. Results reported on both the successes and failures within the agricultural strategy and ability to avoid salinization. Barton et al. (2010) describes the interaction of water and land-use amongst the agro-pastoral systems in the Mediterranean. As part of The Mediterranean Landscape Dynamic Project (MedLanD (Barton et al. 2012:43-44) the landscape and hydrological process are mapped and explored using agent-based modeling. The consequences of human-nature interaction are discussed in terms of the varying effects of growing settlements in the landscape (Barton et al. 2010:5286-5291). Within the Maya area, while agricultural studies are prevalent, there have been limited applications of coupled socio-ecological systems at the scale of analysis conducted in this dissertation.

This dissertation is written within the framework of coupled socio-ecological systems and fundamental accepts its underlying theory. Specifically, in this dissertation this perspective will provide the framework to evaluate whether terracing was a successful adaptive strategy for Maya communities to continue agricultural production in the face of fluctuating internal (social) and
external (environmental) stresses. This framework rests on combining data on terrace structure, terrace microclimate, settlement, soil physical and chemical properties, temporal information on regional climate conditions and polity-wide socio-political and economic conditions, to identify interacting variables that create the complex system of the agricultural strategy during the occupation of Waybil. This will provide insight into the resilient and vulnerable qualities of this agricultural strategy. The social variables identified in the production and political pressures exerted on the Waybil minor center and the decision to adopt agricultural terracing will be evaluated with the environmental variables associated with agricultural production and climatic change. Environmental variables will be evaluated by modeling the relationship of terraced and terrace-removed landscapes with hydrological processes, erosion susceptibility, as well as agricultural suitability. Describing the Waybil agricultural terraces through these models during a single time period, the Late Classic, as well as the variability over time (Preclassic through Terminal Classic), provides the ability to address the changing social and environmental variables. This dissertation provides an essential component within the broader understanding of the resilience and vulnerabilities (see Carpenter et al. 2001; Cumming and Collier 2005; Holling 1973; Redman et al. 2007; Schoon et al. 2011; Walker and Salt 2006; 2012) associated with the adoption of geointensive agricultural practices amongst ancient Maya communities in the North Vaca Plateau (Iannone et al. 2014b).

**Resilience Theory**

Resilience is the capacity of a complex system to adjust to fluctuations while maintaining its purpose and identity (Holling 1973; Redman et al. 2007; Walker and Salt 2006:76; 2012). In opposition "vulnerability" can be described as the rigidity that develops within a system and the inertia that maintains specific structural components, despite a need to adapt (Schoon et al. 2011). Another approach to describing resiliency relates to the robusticity of a system to withstand perturbation amongst the variables, and when necessary, being flexible enough to
change structural components in order to maintain system integrity. Evidence for a lack of flexibility in decision making and/or an inelasticity in certain structure components, brought on by increasing rigidity, indicates vulnerability (Berkes et al. 2003:22; Davidson-Hunt and Berkes 2003:60; Lamson 1986:272; McCay 1981:371; Vayda and McCay 1975:299; Walker and Salt 2006:84, 121, 138). Thus, resilience does not equate with a level of resistance to change, but rather the effective management and adaptation to change, referred to as adaptive capacity (Walker and Salt 2006:119; 2012:24). Resiliency needs to be understood in terms of scale and perspective. As discussed, systems are found in nested hierarchies, and as such they are often discussed in terms of reactions and consequences between the larger and smaller systems as they change over time (Gunderson and Holling, eds. 2001; Walker et al. 2004). However, these tiered systems can also be understood in terms of exhibiting varying degrees of resilience and vulnerability, or alternatively varying thresholds (see Kinzig et al. 2006). For example, the smaller subsystem of a local farmer may be more flexible in terms of crop placement and timing and thus more resilient, while at a larger social and political scale there may be demands for agricultural surplus that cannot be changed without system collapse, which is therefore a less resilient system. Further, examining a systems from different perspectives can identify an unevenness in the desirability of resiliency (Walker et al. 2004:4; Walker and Salt 2006:37). The ability of a system to persist despite a desire to change it, such as totalitarian regimes, is beneficial for the head of state while at the same time potentially detrimental for its subjects. Outlining the complexities behind understanding the resiliency of a particular system or case study, highlights the importance of carefully crafting and defining the subject of study.

In terms of agricultural strategies, resiliency equates to the ability to continue sufficient agricultural production using select suite of techniques (strategy) to meet subsistence and social
demands, despite changing natural and cultural variables. Identifying and testing resilience and vulnerability, beyond that of a theoretical realm, requires one to identify the “resilience (and vulnerability) of what, to what” (Carpenter et al. 2001:767; Redman et al. 2007:119). Thus, this dissertation examines the resiliency of ancient Maya agricultural strategy at Waybil to the changing food security brought on by climatic change and demands of the Minanha royal court.

Central to understanding the resiliency of a system is the identification of the system identity, regime, and thresholds. Identity is the essential nature of the system determined by the dynamical relationship among the structural components as it functions through time and space (Cumming and Collier 2005; Walker and Salt 2012). In the case of ancient Maya agricultural strategies, identity is defined as the suite of techniques employed to develop the agricultural strategy. Thresholds are understood as the points at which a system has changed and reorganized so much so that it constituted a different system with a different behavior and structure, thus changing its identity. This change is referred to as a regime shift (Walker and Salt 2006:76). Regimes are defined as “a locally stable or self-reinforcing set of conditions that cause a system to vary around a local attractor (identity); the dominant set of drivers and feedbacks that lead a system behaviour” (Cumming 2011:14; see Scheffer and Carpenter 2003). Thus, when a regime shift occurs, the system is reorganized in a manner that it no longer behaves in the same way resulting in a new identity. In consideration of agricultural production, the regime, within which system identity is nested, encompasses both the social and environmental variables that direct the system. In the case of ancient Maya, the continued use of any, or a select combination of, different strategies of food procuration, i.e., slash and burn, terracing, raised fields, etc., defines the agricultural strategy and thus outlines system identity, while the ability of the agricultural strategy (identity) to maintain a defined level of production, delineated by food security and
surplus demands, within the external and internal variables of social pressure and climatic conditions describes the regime. Stresses or fluctuations, from within or outside of the system, on the variables composing the regime can cause it to change to a point that a threshold is crossed and a regime shift occurs placing the system into a different state, giving it a new identity.

Regime shifts are often associated with “collapse”. To clarify, when “collapse” is discussed in this dissertation it refers to the definition provided by Tainter: “A society has collapsed when it displays a rapid, significant loss of an established level of sociopolitical complexity” (Tainter 1988:4). Similarly paraphrased by Faulseit: “a rapid (over a few generations) decline in sociopolitical complexity or the demise of a particular political system” (2016:5). When taken from an agricultural perspective, collapse is related to the unmanaged abandonment of a particular agricultural strategy (identity) resulting in the changing or abandonment of the suite of production techniques which also impacts production levels. Thus, a regime shift, or “collapse”, within the agricultural strategy of a community is identified when it is no longer capable of maintaining the demands in production defined by a particular regime.

Critical in interpreting collapse, or regime shifts, is the previously discussed notion of perspective. The inability to support a certain system and the transition into a new regime can open opportunities, beneficial to certain structural components, that were previously restricted by the systems rigidity. Alternatively, a change from a disruptive or degrading identity, such as unmanaged milpa farming, followed by the subsequent regime and shift to a more stable identity, terraces production, can bring greater resilience to the system. Thus, not all regime shifts and changes in identity are necessarily negative processes. The managed transition from one identity to another can be an intentional action to increase the adaptive capacity of the system.
Chapter Summary: Complex Socio-Ecological Systems and Resilience Theory

Within this chapter I have described the significant changes in how ancient Maya agricultural strategies were perceived over the decades of research. Throughout which I explored the influence different population and subsistence theories as well as methodological approaches had on these interpretations. This approach highlighted a general trend, as archaeologists refined methodological approaches to settlement and agricultural analysis, often increasing the scale of analysis, they were continually outstripping the restricted views of their contemporaneous theoretical paradigms. Archaeologists not only identified higher population levels than expected and trends towards urbanism, but also revealed a greater scale and diversity in intensive and extensive agricultural practices. The diversity and prolific nature of the geointensive agricultural features provided an opportunity for archaeologists to question the social organization behind their construction and maintenance. These early interpretation of social organization offered the dichotomy of centralized versus decentralized when considering the development and maintenance of agricultural strategies and the social hierarchy behind them. However, in recognition of the restricted nature of this dichotomy, heterarchical organization was introduced as a model to address the complexities in time, scale, and human nature. Beneficial in breaking down the traditional dichotomy and its flexibility in descriptive capabilities, heterarchy lacked the framework for analyzing the complexities that the differing agricultural systems were revealing. In order to address the complexities behind the agricultural strategies I introduce the discussion of social organization within the socio-ecological systems, and its roots in new complex systems and historical ecology, which provides the opportunity to not only merge natural and social variables, but facilitates a more fluid interpretation of the changing social organization experienced by the Waybil community. I concluded the chapter by explaining how coupled socio-ecological systems will be used in this dissertation to combine and analyze both
cultural and natural variables. In this manner, it will act as the framework within which the role of agricultural terracing as an adaptive mechanism within the subsistence strategy of Maya communities can be evaluated as a buffer against internal (social) and external (environmental) stress.
CHAPTER 3
ENVIRONMENT OF THE MAYA AREA AND THE NORTH VACA PLATEAU

In this section, I review the environment of the Maya area and Vaca Plateau including the geographical delineation, climate, and soils. I present two different scales: the general characteristics of tropical environments and the more specific characteristics that differentiate the North Vaca Plateau from the larger Vaca Plateau and its neighboring geological and environmental zones. Given the highly heterogeneous nature of both tropical areas and the Maya area, I highlight the relevant characteristics of Waybil. The more general characters of tropical landscapes serve to illuminate the past agricultural strategy of the Waybil community and the decision of the residents to invest in agricultural terracing. This chapter describes the geological processes that formed the topography and hydrology that made agricultural terracing a practical application. The larger climatic patterns of the Maya area are described in order to address the local weather patterns and paleoclimatic reconstructions of the ancient Maya climate, which are later incorporated into the GIS modeling of external pressures exerted on the Waybil community. The unique qualities of tropical soils are presented in order to understand the larger soil processes and classification of the North Vaca Plateau soils that encapsulates the local soil properties, which is necessary for understanding agricultural production on tropical soils and the interpretation of the soils excavated from the terrace planting surfaces at Waybil.

**Geography of the Maya Area**

Defining the geographic boundaries of the ancient Maya world is a difficult endeavor given the fluid nature and diffuse limits of the cultural characteristics classically associated with the ancient Maya (Blanton and Kowalewski 1993:16). Accepted boundaries are defined by the distribution of distinctive architectural features, monuments, language, as well as geologic and environmental features (Willey 1982). The Maya area is composed of 324,000 km² extending
from the Rio Grijalva in southeastern Mexico and south to the Pacific Ocean, and stretching east to the Rio Lempa in central El Salvador and the Rio Ulua in western Honduras (Lucero 2006; Martin and Grube 2008:6; Sharer and Traxler 2006:26; West 1964:33). This area can be subdivided into three large geographical zones: Pacific Coastal Plain, Highlands, and Lowlands, with the lowlands divided into northern and southern sections (see Coe 2011; Demarest 2004; Sharer and Traxler 2006). The Vaca Plateau of Belize lies in the southern lowland zone of northern Guatemala, Belize, and northern Chiapas (Figure 3-1) (see Sharer and Traxler 2006; Turner 1979).

Figure 3-1. The Maya area identifying the Southern Maya Lowlands.

Lying at a lower elevation than the mountainous highlands, this area exhibits significant relief in the Maya Mountains, Pine Ridge, and Vaca Plateau, with lower relief occurring within the central portions and along the coastal margins. Temperatures range from 25 – 35°C and the area is often called tierra caliente (Sharer and Traxler 2006:45). Average rainfall is 2,000 – 3,000
mm (Turner 1979). Several large rivers that flow northeast through this region into the Caribbean include the New River, the Belize, and the Hondo. The Usumacinta along the southeastern highland flows northwest into the Pacific.

**The Tropical Climate of the Maya Area**

The climatic conditions of the Maya area are classified as dry tropical, including equatorial fully humid (Af), equatorial monsoon (Am), and equatorial savanna with dry winter (Aw) regions according to the Koppen-Geiger system (Kottek et al. 2006; Rubel and Kottek 2010; see Geiger 1954; Geiger 1961; Köppen 1900). The Minanha polity lies within the equatorial monsoon region, which is typified by hot summers (annual temperature > +22°C) (Kottek et al. 2006: Figure 1, Table 1). This region is characterized by annual precipitation ranges between 62.5 and 8,000 mm, with rainfall during the wet season peaking between June and July (Kricher 2011:21). As a tropical equatorial environment, Central America is subjected to a distinct wet season (June – November/December) and dry season (December/January – May) to varying degrees (Hastenrath 1967; Kricher 2011:21). Locally in the region surrounding Waybil the average annual rainfall is typically 2,400 mm with 1,700 mm in a dry year and 3,000 mm in wet year.

The weather patterns of Central America are influenced, as are all weather patterns, by the migration of the Intertropical Convergence Zone (ITCZ) (Yan 2005:429). The ITCZ is a low-pressure system that is oriented east-west located near the equator where the surface northeast and southeast trade winds converge. At this meeting the moist air is driven upwards creating heavy rains (Yan 2005:429). The ITCZ is fluid, migrating north away from the equator during the winter season in the northern hemisphere and south during the summer season (Krishnamurti et al. 2013:35). Its movements are based on its interaction with global atmospheric and oceanic circulations (Yan 2005:430). Specifically, the movement of the ITCZ is drawn to areas of solar
heating, and is thus impacted by increased sea surface temperature (SST) and higher solar emissions (Burn and Palmer 2014:835; Sandweiss et al. 2001:605; Yan 2005:430). This leaves the ITZC movements subject to the actions of the El Niño-Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) (George and Saunders 2001; Giannini et al. 2000; Hordon 2005; Wahl et al. 2014; Yocom et al. 2010) resulting in annual variability in precipitation, temperature, and resultant droughts. El Niño events are characterized by the decrease in cold waters along the central and eastern equatorial Pacific as warmer waters move in from the west, ultimately increasing both the SST and air temperature (Bigg 2005; Glantz 2005; Haug et al. 2001). This causes the southward movement of the ITZC, resulting in drier conditions in the Caribbean region (Haug et al. 2001; Kennett et al. 2012; Wahl et al. 2014; Yocom et al. 2010). El Niño events occur on average every 4.5 years, but can be as frequent as every 2 years or as infrequent as every 10 years (Glantz 2001; 2005:350). La Niña is known as the counter part of the El Niño and it has the opposite effects. La Niña effects occur with an increase in cold water along the central and eastern equatorial Pacific, coupled with a decrease in temperature across the Pacific (Glantz 2001). As a result, the ITZC is shifted northwards, bringing wetter and moister weather patterns to the Caribbean. Dramatic fluctuations in the ITZC have been linked to the prevalence of tropical depressions and droughts (Giannini et al. 2000; Kennett et al. 2012). Both long-term changes in the ITZC and short-term fluctuation of ENSO have been suggested as causal to various archaeological patterns in the Maya area (Haug et al. 2001; Iannone, ed. 2014; Kennett et al. 2012; Moy et al. 2002; Peterson and Haug 2005; Rein et al. 2005; Sandweiss et al. 2001; Wahl et al. 2014). The specifics of these links are discussed later in this section.

**Tropical Soils**

Tropical soils present a suite of characteristics that have a direct effect on agricultural production. Two soil properties, temperature and moisture, have a direct consequence on rates of
erosion, levels of moisture retention, and supply of essential nutrients. Although not a direct soil property, vegetation cover plays a significant role in soil temperature and moisture. All these factors need to be taken into consideration when assessing the agricultural strategy of the ancient Maya as well as the analysis of the soils collected from the terrace planting surfaces at Waybil.

**Soil Temperature**

The higher levels of solar radiation in the tropics increase the soil temperature, which affects both soil behavior and plant growth. The low seasonal temperature fluctuation in the tropics keeps annual soil temperatures high (Wambeke 1992:8). Soil temperatures can be affected by local topography, soil texture, and vegetation cover. The varied topography, specifically the changes in altitudes across the Maya area, plays a role in soil temperature. However, the effects of local variations of slope and aspect on soil temperatures are diminished due to the lower latitudes of the tropics. For example, the north and south-facing slope aspects’ effect on soil temperatures are minimized by morning sunshine and afternoon cloudiness (Wambeke 1992:6-7).

Soil texture also influences soil temperatures. Sandy surfaces are more prone to suffer the effects of solar radiation than clayey soils (Wambeke 1992:7). This relation is also identifiable in the soil profile and depth of soil heating. This is not unique to the tropics, but does play a role in the overall moisture regime of tropical soils (Wambeke 1992:8). The high clay content recorded in the soils of the North Vaca Plateau reduces soil temperatures.

Vegetation cover and the resultant organic matter play an important role on the effect of soil temperature. When soils are not directly influenced by solar radiation, often due to vegetation cover, soils adjust their temperatures to match the above ground air temperature (Wambeke 1992:8; Weischet and Caviedes 1993:110). The higher temperatures of the tropics induce more rapid turnover of organic matter, which results in lower soil humus content.
It has been noted that regions with mean annual temperatures above 25 - 35°C exhibit a decomposition rate that surpasses plant growth, resulting in the rapid release of nutrients and smaller accumulated vegetation (Brady and Weil 2007:523). This is expedited in regions prone to periods of excessive dryness, like those experienced in the tropics, due to the increase of microbial activity with the return of wet conditions (Brady and Weil 2007:503). Microbial activity is greatly increased with a rise in temperature, with an optimal range between 35 – 40°C (Brady and Weil 2007:291). However, in the tropics the majority of plant matter decomposition is first carried out by the comminution practices of insects rather than the emphasized decomposition by the production of leachates by microbial activity common in temperate regions. As a result, decomposition of organic matter in tropical soils has reduced eluvial and illuvial horizons (Wambeke 1992:17). However, rainfall regimes tend to dominate these decomposition trends.

**Soil Moisture**

Seasonal variations in precipitation and soil moisture have the greatest impact on variability in tropical soils (Wambeke 1992:19). Rainfall and temperature act as important external factors when considering the intensity of soil weathering (Wambeke 1992:16, 39). While temperature regulates the intensity of chemical reaction, increasing two- to three-fold with every increase of 10°C, this decomposition of minerals and mineralization of organic matter only occurs in the presence of water (Kalpagé 1976:21; Wambeke 1992:16, 39). The rate of decomposition and mineralization is also a function of the length and intensity of the rainy season (Wambeke 1992:19). The retention of soil moisture is based on losses due to evapotranspiration, runoff, and percolation.

In the tropics, the consistent low incidence angle of the sun and day lengths result in the level of cloudiness, which acts as a major regulator of evapotranspiration (Wambeke 1992:19).
As a result, the direct angle of the sun during the rainy season creates clouds, reducing both temperatures and evapotranspiration to their lowest (Wambeke 1992:19).

The percolation of water through soils is a factor of intensity and duration of precipitation. This acts to leach away products created during weathering and mineralization, ultimately opening up the possibility and encouraging the further transformation of minerals and organic matter (Wambeke 1992:16, 39). Although not unique to the tropics, the rate of leaching is also a function of soil composition and particle size (Kricher 2011:362). The consistently high temperatures as well as the intensity and duration of rainfall exhibited in tropical environments results in a rigorous and advanced stage of mineral and organic matter decomposition amongst soils (Kalpagé 1976:21; Kricher 2011:363; Wambeke 1992:39).

While runoff is not exclusive to the tropics the rainfall regimes of the tropics increases the effect. Hudson (1995) describes the high-energy load of tropical storms accounting for a 16% increase in the erosive power of tropical rainfall over that of temperate rainfall. This is a result of greater intensity, amount of rain per unit of time, larger droplets, and faster terminal velocity (Hudson 1995; Wambeke 1992:20, 23). These characteristics of tropical rainfall not only affect the amount of water lost in runoff and erosion but also how much moisture enters the soils.

**Vegetation Cover**

Vegetation reflects and absorbs large portions of solar radiation reducing the amount that reaches the soils. It provides the biomass that forms the organic faction of the soils. It also plays a role in retaining and covering soils. With the majority of soil nutrients found in the upper 20 to 30 cm of the tropical soils, it is common for tropical plants to have dispersed, yet shallow, buttress roots (Weischet and Caviedes 1993:124, 133).

The deforestation and removal of vegetation for agriculture leaves the thin layer of nutrient rich soils open to surface erosion and additional leaching through percolation (Weischet
and Caviedes 1993:124). Further, with the vegetation cover removed, the full force of available solar radiation is now in direct contact with the soils, raising soil temperature and increasing soil moisture evaporation (Weischet and Caviedes 1993:109). This is compounded by the excess solar radiation, solar radiation previously consumed by the vegetation during transpiration within the vegetation. Further, the removal of vegetation cover decreases surface roughness, increasing the movement of humid air masses at the ground level, further elevating the level the evaporation of soil moisture (Griffin et al. 2014:75-76). These ramifications increase the mineralization of organic matter; organic matter that is already limited by the lack of direct vegetation sources. This results in an increasingly declining source of nutrients (Weischet and Caviedes 1993:109). Under the increased leaching conditions caused by vegetation removal, these declining nutrients are compounded.

**Geology, Hydrology & Natural Geography of the Vaca Plateau**

The Vaca Plateau is located in west-central Belize and eastern Guatemala, bounded by the Mountain Pine Ridge (south), the Rio Macal (east), the Chiquibul River (west), and the Belize River Valley (north) (Figure 3-2). Until the early 1990’s, there had been no focused study of the physical geology and geography of the Vaca Plateau. Early studies that do mention the region generally focused on Belize as a whole or the neighboring Mountain Pine Ridge and Maya Mountains. However, since 1990, the Northern Vaca Plateau Geoarchaeology Project (NVPGP), and its affiliated researchers, have made significant contributions to understanding the physical landscapes and paleoenvironmental reconstructions of the North Vaca Plateau (see Akers et al. 2016; Akers 2011; Brook and Akers 2010; Polk et al. 2007; Polk 2010; Reeder et al. 1996; Reeder 2011; Webster 2000; Webster et al. 2007). Much of this section is indebted to the meticulous work these dedicated individual have completed over the last 35 years. Drawing on the research conducted by the NVPGP the geological formation and hydrological processes of
the North Vaca Plateau describes how agricultural terracing could have been an attractive option for the ancient Maya farmers at Waybil.

Figure 3-2. Map of the Vaca Plateau and archaeological site.

The Vaca Plateau is one of the largest karst landscapes in Belize covering 1,000 km² (Miller 1996:110). The North Vaca Plateau is differentiated from the southern portions of the Vaca Plateau as known as the Chiquibul. The karst limestone bedrock of the North Vaca Plateau is constructed from the uplifted Campur Formation that extends from central Guatemala (Miller
The Cretaceous carbonates of the Campur Formation were deposited in a shallow sea, reef-associated limestone environment and are composed of gray, gray-brown, and tan limestone (Vinson 1962). Within the limestone are thin, localized, beds of shale, siltstone, and depositional breccia limestone (Reeder et al. 1996:122, 130).

The northern and southern zones of the Vaca Plateau are differentiated by a drainage divide, with distinct differences identified in the hydrological recharge and its effects on karst development (see Reeder et al. 1996). While the Chiquibul receives almost all its water from neighboring non-karst catchment areas in the Maya Mountains (called allogenic recharge), the recharge in the North Vaca Plateau is almost exclusively autogenic (defined as derived almost entirely from precipitation (Ford and Williams 1989:78; Reeder et al. 1996:127). The North Vaca Plateau is classified as fluviokarst, exhibiting above and below ground hydrology that is a result of both dissolution and mechanical erosion of the running water (Ford and Williams 1989:4). The rugged landscape visible today in the North Vaca Plateau was formed by combined solutional dissolution and mechanical erosion. Solutional dissolution occurs as precipitation causes the chemical dissolution of the limestone calcite (Brady and Weil 2007:39; Ford and Williams 1989:39-65; Jennings 1985), typically along structural faults, forming small catchments. Due to the autogenic recharge of the North Vaca Plateau chemical dissolution occurs in a diffuse pattern across the landscape (Reeder et al. 1996:127-128). The diffused dissolution creates fractures and void spaces in the carbonate bedrock that became interconnected, developing a subterranean drainage system (White 1988:9-11). As surface permeability increased and drainage features enlarged, surface drainage eventually disappeared, leaving behind the valleys that are visible today that were then filled by mechanical erosion (Reeder et al. 1996:128). After the surface water retreated to the subsurface, mechanical erosion functioned
in conjunction with the sloping sides of valleys to fill abandoned streambeds, valley bottoms, and former drainage channels (Reeder et al. 1996:128).

The fluviokarst nature of the North Vaca Plateau has therefore produced an exaggerated topography interspaced with “dry karst valleys separated by residual limestone hills and interfluves” (Reeder et al. 1996:121) and interspaced by a deranged valley network of residual hills and interfluvial ridges sculpted by the solutional processes and subsurface flow (Miller 1996:111; Reeder et al. 1996:128). The deranged valley networks are defined by the lack of coherent patterns resulting from the autogenic processes. Residual hills are composed of parts of the bedrock that dissolve less readily than the surrounding bedrock and are ultimately left standing (White 1988:101-102). These residual hills have slopes that range from 30° to vertical with progressively more bedrock exposed as the angle increases. Typically, there is a 100 m change in relief from valley bottom to hilltop (Miller 1996:110; Reeder et al. 1996:125).

Soils of the Vaca Plateau

Soil formation processes are affected by several interrelated factors: climate, parent material, relief, hydrology, organisms (including humans), and time (Young 1976:5), the most important of which are the parent material and climate (Wyatt 2008:70). The soils of the Vaca Plateau have developed from the impurities left behind after the dissolution of the limestone parent material (Reeder et al. 1996:122) and are high in clay content and stony (Baillie et al. 1993; Pollock 2007:103-104). The Vaca Plateau has been subjected to few targeted soil surveys. However, it was included in the studies of Belizean soils by the Natural Resource Institute (NRI) who initiated the Land Resource Assessment (LRA) in the 1980’s. The work by Wright et al. (1959) in Belize was later advanced by Baillie et al. (1993), who described the soils of the Vaca Plateau using a similar classification scheme of soil suites, sub-suites, and series, unique to Belize and independent from the more common schemes produced by the FAO (1988; 1999) and
the USDA (1975; 1999). This independent classification scheme was created prior to the accepted use of international standards in Belize and is now familiar to, and used by, local farmers and foresters in Belize and is argued to be more tailored to the specificity and diversity of tropical soils in Belize (Baillie et al. 1993:57). This dissertation will also use the local nomenclature while making references to the more standardized systems.

The soils of the Vaca Plateau are classified within the Chacalte suite, which includes the sub-suites of Cabro, Xpicilha, Cuxu (Baillie et al. 1993:25). These encompass the FAO Soil Map of the Worlds (1988; 1999) orders/suborders Leptosol, Cambisol, Vertisol, and Phaeozem with 13 combinations of soil-units (Baillie et al. 1993:58-59). These Chacalte soils developed on Cretaceous limestone in the undulating topography of the Vaca Plateau and are reddish and brownish when shallow and dull brown or yellowish when deep enough to exhibit a subsoil (Baillie et al. 1993:11). Subsoils tend to be heavy and sticky clays with pockets of iron and manganese. The clays are neutral or slightly acidic and susceptible to shrinking and cracking while maintaining a string structure (Baillie et al. 1993:11). The three sub-suites share these similar traits but are separated based on “texture, colour, topographic location and natural vegetation” (Baillie et al. 1993:15).

Chacalte Cabro are stony shallow soils >50 cm, often thinner when found between bedrock outcrops and boulders. These are clayey soil of black or dark grey, although brown and reddish colors occur often in the Vaca Plateau. The soils are fairly stable, slightly acid to neutral in pH with a crumb structure and much faunal activity. Both the shallowness and the underlying limestone of these soils make them vulnerable to moisture depletion and erosion, characteristics that are further amplified if vegetation is cleared (Baillie et al. 1993:25).
Chacalte Cuxu is very similar to the Cabro sub-suite in all ways except its iron oxide content and resultant change in color. The high levels of iron oxide in these soils, with subsurface geological features that increase subsurface drainage, increase the oxidization of iron and manganese which changes soil color to a reddish or brown (Kricher 2011:122). The high number of iron oxide inclusions are released as impurities during the dissolution of the limestone parent material. Further, these impurities decrease potassium and nitrogen levels while increasing the phosphate fixation, giving the soils a more flexible and tractable feel (Baillie et al. 1993:26). The rate of soil drainage is variable between the soil sub-suites limited by the clay content of the soils (see Chacalte Xpicilha soil sub-suit).

Chacalte Xpicilha are the deepest of the Chacalte soil sub-suites, reaching a depth between 50 – 100 cm and are found along the interfluvial valley floors. In terms of plant growth, these soils present sufficient nitrogen with moderate contents of phosphorous and potassium, while maintaining a neutral or slightly acidic pH level (Baillie et al. 1993:25). They exhibit a subsoil that can range from dark grey to reddish and brownish and on occasion transition into an olive yellow in the lower soils (Baillie et al. 1993:25). The color changes are indicative of intermittently slowed drainage, identified by black iron-manganese stains and concentrations (Baillie et al. 1993:25). This is due to the reduced drainage and higher moisture content of soil with a high clay content. These clayey soils are plastic when wet, yet shrink and crack when dry.

The soil suite of Chacalte and its sub-suites have been identified based on a broad area of the Vaca Plateau, flanking hills of the Maya Mountains, and foothills leading to the Belize River Valley. Given the changes in topography and vegetation cover in the North Vaca Plateau, it is likely that this area exhibits a high frequency of soil change spatially across the landscape, justifying the classification of these sub-suites into series. The North Vaca Plateau differs
slightly, geologically and hydrologically, from the southern Vaca Plateau. The fluviokarst properties of the North Vaca Plateau indicate both complex topographic variation and a higher level of surface permeability. This increases the soil drainage, decreasing the amount of saturation time, and ultimately reducing soil moisture. However, given the pattern of isolated drainage features across the North Vaca Plateau, surface permeability is not homogenous across the landscape and areas not subjected to this aggressive drainage pattern likely retain a higher moisture content.

Generally, the soils of the North Vaca Plateau have been described as highly fertile, and, given proper agricultural management, extremely productive (Wyatt 2008:71), yet their natural characteristics and local environment create crop production issues. These soils are known to be deficient in several important nutrients, such as nitrogen and phosphorous, while abundant in calcium. However, the neutral to slightly acidic pH level supports optimum nutrient uptake. Soil depth is a function of erosion and ultimately topography and slope. The karst landscape creates thin and often non-existent soils on the tops and sides of the steep residual hills, while accumulating deep soil beds along the valley bottoms and gentle slopes (Pollock 2007:103). The high clay content in the collected deeper soils causes water drainage problems while the shallowness of the eroding soils, as well as porosity of underlying bedrock, all cause water retention problems. This makes managing both soil moisture and erosion the largest constraint for production in the North Vaca Plateau.

**Weather and Climate**

The weather patterns of the Vaca Plateau are greatly influenced by the general climatic trends of tropical environments and global climate variations, discussed above, and are locally characterized by high temperatures and precipitation, and well-defined wet and dry seasons. Temperatures range between approximately 10 to 35°C with a mean temperature of 25°C and the
hottest temperatures occurring in May (Polk et al. 2007:56; Webster et al. 2007:3). Several weather stations are located in the Vaca Plateau (see http://www.hydromet.gov.bz/climatology-stations-locations), but Akers and colleagues argue that, because of the high local variability across the broad Vaca Plateau, these weather stations do not provide enough accuracy to understand any area except the local conditions around each station. They argue that the most accurate estimates of rainfall in this region are those of the NVGP which provide 5km resolution and thus a more specific local precipitation estimate (Akers et al. 2016; Akers 2011). These estimates were created using Tropical Rainfall Measuring Mission (TRMM) satellite data derived by the National Aeronautics and Space Administration (NASA) Goddard Earth Sciences Data and Information Services Center (GES DISC) Giovanni tool (http://disc.sci.gsfc.nasa.gov/giovanni) (Acker and Leptoukh 2007; Huffman et al. 2010; Huffman et al. 2007; Kummerow et al. 1998). Their estimates show that, over the past decade, during the wet season, when the ITCZ is drawn north, approximately 1,809 mm of precipitation fell between June and November in the region nearest Waybil. Most of this fell during June to October at a monthly average of 250 mm (Akers et al. 2016:269; Akers 2011:5; Polk et al. 2007:56). On occasion this wet season was disrupted after an early wet season peak, by a short midsummer dry spell called the canicula (Magaña et al. 1999), the timing, duration, and magnitude of which fluctuates annually (Akers et al. 2016:269). During the dry season, when the ITCZ is drawn south, an average of 588 mm of precipitation fell between December and May (Akers 2011:5; Furley and Newey 1979:3; Polk et al. 2007:56). The driest period was between February and December with a monthly average precipitation of 65 mm (Akers et al. 2016). These recorded precipitation values fluctuate spatially and temporally. Across the North Vaca Plateau precipitation fluctuates between valleys (Penn et al. 2004:23) as a result of the
heterogenic topography of the North Vaca Plateau, with hilltops influencing localized weather patterns. In the Waybil area, this translates to relatively unreliable weather forecasting using broad weather models even from weather stations within the country. Temporally, Akers and colleagues (2016; 2011) identified significant interannual variation in rainfall and short-term droughts influenced by El Niño events within the period 1998-2014. These fluctuations are perhaps representative of similar fluctuations at the site in the past (see Chapter 7 for further discussion).

This modern data provides a possible analog for past weather patterns in the North Vaca Plateau, but it is necessary to understand whether this 10-year period is an accurate representation of the full range of wet and dry years and seasonal variation within those years over the several thousand-year prehistory of the area. Paleoclimatic reconstructions provide a second analog for possible weather conditions and precipitation in the Waybil area.

**Paleoclimate Reconstructions**

When discussing paleoclimatic changes in the Maya area it is important to consider the difficulties in developing an accurate reconstruction. Discrepancies between reconstructions may be the result of natural variation of climatic data, specific methods employed, or quality of raw data, but they are primarily the result of specific local weather expressions of the broader climate trends. Thus, I will briefly present a regional perspective on paleoclimate based on sequences developed in three regions close to the North Vaca Plateau, and then I will present the specific reconstructions now available for the North Vaca Plateau.

**Paleoclimate reconstruction methods**

To set the stage for these regional reconstructions, I will first discuss the methods used in the two primary sources of proxy data used in the Maya area reconstructions: sediment cores (lake and cave) and speleothems. Since the direct measurements of climate change, here
specifically precipitation levels, is a developing field, archaeologists rely heavily on proxy signatures (Brenner et al. 2003:47). A large suite of tests can be used to derive proxy signatures within sediments and speleothems including geochemical changes (sedimentation process), sediment lithology (sediment composition), or the analysis of carbon and oxygen isotopic variation, marine and freshwater diatoms, phytoliths, and pollen (Brenner et al. 2003:46-47; Leyden et al. 1996:31).

Several types of paleoenvironmental analyses can provide data about ancient precipitation variations and ranges. Precipitation records are particularly important to the North Vaca Plateau, with little to no source of irrigation other than rainfall. Thus, understanding the climatic sequence of wetter and drier periods is of paramount importance for this study when considering the timing of agricultural terrace construction and use as well as the role terraces play in terms of erosion and land suitability.

Sediment cores from both caves and lakes can be tested for many of the proxies for climatic change, although lake sediments are more commonly used for climatic reconstruction (Ford and Nigh 2014:90). These proxies can include carbon and oxygen isotopes, pollen, diatoms, phytolith, shell carbonate, geochemical, magnetic susceptibility, organic matter, minerology, microfossils, sediment influx, and limnochronology (Brenner et al. 2003; Douglas et al. 2016b; Dunning et al. 2014:116; Ford and Nigh 2014:90; Hodell et al. 1995; Hodell et al. 2005; Leyden et al. 1996:30-31; Rice 1996; Wahl et al. 2006; Wahl et al. 2013; Wahl et al. 2014; Wahl et al. 2016).

Sediment cores from caves are particularly attuned to identifying vegetation changes and intensity of agricultural production due to the allogenic creation of soil stratigraphy (Iannone et al. 2014a:276; Polk et al. 2013). The allogenic deposition of the cave soils facilitates the analysis
of sediments originating above ground. These sediments are examined to identify the ratio of \( \delta^{13}\text{C} \) to \( \delta^{12}\text{C} \) \cite{Bender1968,O'Leary1981,Polk2007,Polk2010,Tieszen1991}. In the tropical environment of the Maya subarea most wild, non-grass plants are C\(_{3}\) (\( \delta^{13}\text{C}: -23\text{\%o} \) to -34\text{\%o}), while maize, one of the few tropical grasses, is a C\(_{4}\) (\( \delta^{13}\text{C}: -9\text{\%o} \) to 17\text{\%o}) plant. Research has focused on the identification of maize production and production intensity through the presence of C\(_{4}\) photosynthetic pathways \cite{Beach2011,Fernández2005,Solís-Castillo2014,Webb2004,Webb2002,Webb2007}. Paleoclimatic studies have extended this interpretation to link dry periods to increased \( \delta^{13}\text{C} \) levels due to the reduction of more water sensitive C\(_{3}\) plants. The reduced of photosynthetic CO\(_{2}\) assimilation within C\(_{3}\) plants during dry periods results in a decrease in the low levels of \( \delta^{13}\text{C} \) within the soils \cite{McDermott2004:905,Polk2013:6,Turney2001:782,vanBeynen2008:80}. However, cave sediments are often subject to mixing. Closed (non-circulating) lake sediments provide a less disturbed and sometimes continuous history of past climatic and environmental conditions within the targeted lake and its surrounding drainage basin \cite{Leyden1996:30-31}. Specific to climatic change, the hydrological cycle can be studied in terms of changes in water level (pollen curves of aquatic plants), potable water and salinity levels (microfossils), as well as evaporation and precipitation ratio (gypsum/calcite ratio and oxygen isotope signatures in microfossils) \cite{Hodell1995:391-392,Hodell2005,Leyden1996:30-31}.

The use of cave speleothems has recently developed into another important source for high-resolution paleoenvironmental reconstruction, especially in terms of local expressions of climate change \cite{Akers2016,Akers2011,Hoggarth2016,Iannone2014a:272,Kennett2012,Medina-Elizalde2010,Medina-Elizalde2016,Pollock2016,Webster2007}. The formation process of speleothems creates discernible annual and
occasionally sub-annual layers, facilitating high-resolution analysis of proxies that indicate fluctuation in wet and dry climatic regimes, in addition to local vegetation conditions (Iannone et al. 2014a:273-274). Speleothem climatic data includes visible banding (dust and water flow change), stable isotope geochemistry (evaporation/precipitation levels), and luminescence (moisture conditions of soil organic matter (Webster 2000:37). This analysis can provide estimates of precipitation (relative wet and dry conditions), and adjacent vegetation activity (relative proportions of C3/C4 plants (Akers et al. 2016; Akers 2011; Iannone et al. 2014a:274; Webster 2000; Webster et al. 2007).

Speleothems are first dated using uranium–thorium (U-Th) disequilibrium method (Cheng et al. 2000; Cheng et al. 2013; Shen et al. 2002). This analysis uses a mass-spectrometer to measure the degree that $^{234}$U and isotope $^{230}$Th have achieved secular equilibrium though radioactive decay, after the absorption of soluble uranium (Cheng et al. 2013:83; Douglas et al. 2016b:6). This is based on the principal that the slowly absorbed thorium is more abundant at the time of speleothem formation then the quickly absorbed Uranium (Douglas et al. 2016b:7).

Analysis of visible bands in speleothems can be conducted by examining luminescence, color, and reflectance (Douglas et al. 2016b:8). The ultra-violet luminescence (UVL) can provide insight into the organic acids (humic substance) within the speleothem, which are influenced by moisture conditions of the organic matter in soils surrounding the cave (Baker et al. 1998; Webster 2000). Moisture conditions of the overlying soils relate to soil productivity and vegetation surrounding the cave (Douglas et al. 2016b:8; McGarry and Baker 2000; Shopov et al. 1994; Webster et al. 2007:9). The color index and reflectance of speleothem thin sections can support luminescence proxies by suggesting increases or decreases in dust and water flow (van Beynen et al. 2001; Webster et al. 2007:9).
Stable isotope geochemical analysis of speleothems focuses primarily on δ^{18}O and δ^{13}C found within the development of calcium carbonate (CaCO₃). The values δ^{18}O are understood as a reflection of past precipitation, evaporation, and temperature regimes (Akers et al. 2016:273; Akers 2011:96-99; Douglas et al. 2016b:7; Kennett et al. 2012:789; Lachniet et al. 2012:259-261; McDermott 2004; Medina-Elizalde et al. 2010:257; Medina-Elizalde et al. 2016:95-97; Pollock et al. 2016:105; Webster 2000:140-156; Webster et al. 2007:9-12), particularly in the tropics where temperature fluctuation is minimal (see Hodell et al. 2012). The study of oxygen isotopes in the paleoclimatic reconstructions is based on the differential concentrations of δ^{18}O and δ^{16}O in water as it moves through the stages of its global water cycle and primarily influenced by temperature (Lachniet 2009:414). As a result of the differing atomic weight of δ^{18}O (heavier) and δ^{16}O (lighter) they behave differently as water changes in structure. As water vapor, O^{18} is extracted more quickly than O^{16} (Akers 2011:25). Further, O^{16} is preferentially evaporated over O^{18} leading to greater concentrations of δ^{18}O in remaining water. Thus, with the high levels and more expedient evaporation that occur with higher temperatures results in elevated levels of O^{18} in the earth’s surface water (Akers 2011:45). This is a process that can be further escalated by reducing the cover vegetation, which acts to increasing evaporation (Lachniet 2009:419). The study of modern δ^{18}O, temperatures, and precipitation can then be used to correlate δ^{18}O levels and past temperature, precipitation, and evaporation regimes.

Researchers have used δ^{18}O data from present precipitation levels across Central America to determine the relationship between δ^{18}O in rainfall and surface water (Lachniet 2009). Referred to as the amount effect this reports the relationship between precipitation amount (P) and precipitation δ^{18}O (dP). Medina-Elizalde et al. (2016) reports the equation for the Yucatan as δP/ΔP = -0.0137 ±0.00031%₀ per mm (80% confidence interval, r = 0.87). Archaeologists have
used this relationship to correlate historical rainfall levels of a specific region to $\delta^{18}$O found in speleothems of similar age (Medina-Elizalde et al. 2010; Medina-Elizalde et al. 2016). This has been calibrated by quantitative estimates of the transformations (or fractionations) that occur in rainwater $\delta^{18}$O as it passes from the ground surface to drip-water and eventually deposition in speleothems (Lachniet et al. 2012; McDermott 2004; Medina-Elizalde and Rohling 2012; Medina-Elizalde et al. 2010; Medina-Elizalde et al. 2016). These calibrations take into account specific site characteristics including soil types, epikarst, humidity, evaporation, kinetic isotope effects, recharge, storm magnitude, and anthropogenic changes to the landscape (Akers et al. 2016:261; Douglas et al. 2016b:7; Lachniet et al. 2012:259-261; McDermott 2004:904-906; Moquet et al. 2016; Pape et al. 2010; Pu et al. 2016) and are thus most appropriate for local reconstructions rather than broad regional reconstructions.

To test the interpretive value of $\delta^{18}$O as a proxy for rainfall, several archaeologists have correlated this isotope to $\delta^{13}$C variations in the same samples (Akers et al. 2016; Kennett et al. 2012; Webster 2000; Webster et al. 2007). The "Hendy test" is one test of $\delta^{18}$O rainfall or temperature predictive accuracy (see Hendy 1971) which uses the relationship between $\delta^{18}$O and $\delta^{13}$C to evaluate the extent to which $\delta^{18}$O variability reflects the impact of climatic factors (external to the cave) vs kinetic factors (those of the cave environs). Hendy argued that, in a state of equilibrium, $\delta^{18}$O and $\delta^{13}$C will be affected by different factors and thus will not correlate, but when $\delta^{18}$O and $\delta^{13}$C are affected by internal factors they will co-vary. This test has been refuted and various alternatives have been suggested, since in many situations the co-variance between the two isotopic ratios is not a measure of the extent to which internal or external factors have affected fractionation (see Dorale and Liu 2009)
Maya world paleoclimate reconstructions

One of the most broadly used paleoclimate reconstructions is from outside the Maya world, the Venezuelan Cariaco Basin inshore marine sediments, that provide unique, almost annual precipitation variation estimates based on bulk sediment chemistry (titanium) (Haug et al. 2003:1732; Haug et al. 2001:1304-1306). Other early reconstructions, primarily from the Petén Lakes region of Guatemala, were also used to suggest broad Maya-world patterns (Brenner et al. 2002; Brenner et al. 2003; Hodell et al. 1995; Hodell et al. 2001; Hodell et al. 2005; Rosenmeier et al. 2002). However, over the years of exploring the paleoenvironmental conditions throughout the Maya area archaeologists are beginning to present regionally specific sequences (Dunning et al. 1999:654; Dunning et al. 2014:116) including in the North Vaca Plateau (Akers et al. 2016; Pollock et al. 2016), realizing that these provide stronger interpretive power for neighboring sites than do the broad reconstructions. However, it can be extremely difficult to differentiate between climatic and anthropogenic impacts on local weather conditions (Dunning et al. 2014:116; Ford and Nigh 2014:90).

The three regions of the Maya world that have seen the most research on paleoclimate reconstructions are the northern lowlands, and central (Guatemalan Petén) and eastern (Belize and Honduras) southern lowlands. The Guatemalan Petén has seen a long history of geochemical and palynological investigations on lake sediments. To the north, the Mirador Basin and surrounding lowlands contain numerous low-lying seasonal swamps and perennial wetlands, where drainage is internal (Dunning et al. 2014:109) and thus the area presents a closed system ideal for paleoenvironmental reconstruction. Here, sediment cores were analyzed from the wetlands and two lakes, Lago Paixban, and Lago Puerto Arturo, for isotopes (\(\delta^{13}C\) and \(\delta^{18}O\)) and pollen (Dunning et al. 2014; Hansen et al. 2002; Wahl et al. 2006; Wahl et al. 2014; Wahl et al. 2016). In the central Petén, another fairly closed drainage system, although one with
considerable permanent surface water, isotopic, magnetic susceptibility, and botanical data from sediment cores have been analyzed from the lakes of Yaxha, Sacnab, Macanche, Petén Itza, Quexil, Salpeten, Petenxil, Oquevix, Ija, Chilonche, Chimaj, and Laguna Yaloch (Rice 1996:193; Rosenmeier et al. 2002; Rosenmeier et al. 2016; Wahl et al. 2013). To date, no studies in this region have targeted speleothem data to the authors’ knowledge.

In the eastern Maya Lowlands, many sites have been the focus of paleoclimatic reconstructions. These include three sites at which speleothem studies have been done including two sites in the Vaca Plateau: Macal Chasm and Chen Ha (Akers et al. 2016; Akers 2011; Brook and Akers 2010; Pollock et al. 2016; Webster 2000; Webster et al. 2007). A third site, Yok Balum, is found in southern Belize (Kennett et al. 2012). Beyond these speleothem studies, there are a number that address lake sediments including the lakes and swamps surrounding Copan (McNeil et al. 2010; Rue et al. 2002; Rue 1986), Agua Caliente in southern Belize (Walsh et al. 2014), the Sierra de Apaneca in western El Salvador (Dull 2004), the mangroves found along the pacific coast of Guatemala (Neff et al. 2006a), and New River Lagoon, Hondo River, Laguna de Cocos, as well as Albion Island in Northern Belize (Bradbury et al. 1990; Hansen 1990; Pohl et al. 1996; Rushton et al. 2013).

In the Northern Yucatan, paleoclimatic reconstruction has targeted sediment cores from several lakes: Chichancanab, Punta Laguna, Miragoane, and Cenote San Jose Chulchaca (Brenner et al. 2003:61; Curtis et al. 1996; Hodell et al. 1995; Hodell et al. 2005; Leyden et al. 1996:30-31). These lakes were studied because they are closed systems (basins) with no free flowing water (above or below ground), losing most water through evaporation (Leyden et al. 1996:30-31). Lake sediment climate proxies included δ¹⁸O, calcite gypsum ratio, sulphur content, organic matter, pollen, sediment bulk density, and microfossils. These studies have
assisted in understanding the role of the water bodies in terms of human use (potable water), vegetation disturbance, as well as precipitation/evaporation ratios. Archaeologists working on paleoclimatic reconstructions within the Northern Yucatan and Quintana Roo have also targeted speleothems as a source of proxy data. This research has focused on the Tzabnah Cave and the Rio Secreto Natural Reserve (Medina-Elizalde and Rohling 2012; Medina-Elizalde et al. 2010; Medina-Elizalde et al. 2016). From these speleothems, proxies include $\delta^{18}$O, cave monitoring (humidity, temperature, and drip water), as well as historical precipitation record. Researchers drew on these proxies to quantify past precipitation estimates and percentage of change.

**Chapter Summary: Environment of the Maya Area and North Vaca Plateau**

In this chapter, I reviewed geological, climatic, and pedological characteristics of the Maya area and on a smaller scale the Vaca Plateau. This presented the complex characteristics, found in both the tropical environment of the Maya area as well as the more pointed features of the Vaca Plateau. The geography and climate of the Maya area presents the guiding principles of the tropical environment within which the ancient Maya are found, and outlines the guiding principles of the environment in the North Vaca Plateau. This is followed by a discussion of the tropical soil, which are characterized by unique soil moisture and temperature regimes and strongly influenced by the vegetation cover, providing important considerations to draw on when discussing the more specific soils of the North Vaca Plateau and the interpretation of the Waybil agricultural fields. Latter in this dissertation the results from the soil analysis of the terrace planting surfaces will draw on these processes to understand the ramification of agricultural production. This section was followed by a discussion of the geological and hydrological formation of the North Vaca Plateau, which describes the geographical setting that proved to be conducive for agricultural terracing. Further, in order to understand and interpret the soils found in the Waybil terraces, a description of soil suites present in the North Vaca Plateau, including
the three soils sub-suites that varied based on their geological foundation and locations in the landscape, is presented. The final section of this chapter presents the contemporary weather patterns in the North Vaca plateau which will be drawn on within the GIS models as precipitation estimates. This is followed by a discussion of paleoclimatic reconstruction in the Maya area. These topics are presented in order to address methodology, regional climatic trends, paleoclimatic conditions of the North Vaca Plateau, and as a justification for the estimates used throughout this dissertation. This background provides the necessary insights and data for future discussions surrounding the rationale behind adopting agricultural terraces, the consequences and hurdles of agricultural production, and the role terraces played in the larger environmental backdrop of the North Vaca Plateau.
CHAPTER 4
A REVIEW OF THE ARCHAEOLOGICAL SITES OF THE NORTH VACA PLATEAU AND REGIONAL CULTURAL HISTORY

Fundamental to socio-ecological systems is the mutualistic interconnection of human – nature variables. To address the human variable in this relationship, this chapter describes the larger social, political, and economic circumstances of the North Vaca Plateau. There were two major polities in the North Vaca Plateau, Minanha and Ixchel, and seven minor centers, Martinez, Waybil, Mile 4, Oxmuul, Camp 6, Kolchikiin, and Ixkuk (Figure 4-1).

Figure 4-1. Archaeological sites of the North Vaca Plateau.
This chapter will introduce Minanha, Ixchel, Martinez, and Waybil, providing brief site
descriptions and the sequence of occupation for each site, focusing on important construction
events and archaeological feature that highlight key historical changes at each site. The minor
centers of Mile 4, Oxmuul, Camp 6, Kolchikiin, and Ixkuk, have only received preliminary
survey and identification, thus lack the chronological sequencing necessary for this discussion.
For more information on these sites refer to Barry (2014).

**History of Research: Social Archaeology Research Project**

In order to situate the Social Archaeology Research Program in place at Waybil within
the greater Minanha polity a brief background for the research is required. Over the past 16
years, Minanha has been subjected to three phases of research. During this time, there has been a
variety of different excavation and survey strategies, progressively increasing the scale of
analysis and influencing research questions.

In 1922, a chiclero stumbled upon the ruins of the ancient Maya center of Minanha. This
initiated two early expeditions by the British Museum in 1927, resulting in the initial excavations
and survey of the site (Iannone 2004:3; Joyce et al. 1927). Over the following decades, the
location of the center was subsequently lost. In 1997, Dr. Gyles Iannone was asked to locate the
lost city of Minanha and assess the feasibility of excavations. In 1998, after three arduous
reconnaissance trips, members of SARP rediscovered the site as well as several nearby minor
centers (Iannone 2006c:155).

Phase One research occurred from 1999 to 2005, during which excavations concentrated
on the Minanha epicenter (Iannone and Schwake 2010:22). Research was designed to address the
structure, development, apogee, and abandonment of this ancient royal court (Iannone 2009:2).
Survey work focused on the epicenter and site core using both intensive theodolite methods and
extensive pedestrian reconnaissance. During this phase, three survey projects outside of the site
core focused on the support population. First, in 1998 Dr. Killpack began to explore the surrounding sustaining area, identifying and documenting relic agricultural terrace systems (Killpack 1997:69; 1998). Second, in 2000 Dr. Samuel V. Connell initiated the Minanha Regional Survey (MRS), a community perspective on settlement and terrace reconnaissance (Connell and Neff 1999; Connell 2000; 2001:113). This survey recorded sites with GPS and tape and compass, classifying them in a multi-tiered system focused on the number and size of mounds in each settlement group. Third, in 2001 Ryan Primrose (2003) conducted an intensive survey within a 1.5 km radius of the Minanha epicenter, recording and documenting all water management features. Phase One produced a multitude of results concerning the sociopolitical and socioeconomic processes at work within the epicentral court complex, as well as its occupation and collapse sequence (Iannone 2006a:1). Nevertheless, questions about Minanhas’ history remained, requiring the development of Phase Two.

Phase Two operations occurred between 2006 and 2009. It included settlement and agricultural terrace surveys as well as detailed excavation of a stratified settlement sample in two 1 km² study zones (Figure 4-2). One incorporated the epicenter and surrounding site core settlement zone, the other encompassed the Contreras Valley, a heavily settled and terrace valley situated 1.5 km southeast of the epicenter. The objectives were to analyze the settlement, compare densities and composition of the two study zones, as well as map agricultural terrace systems within the Contreras Valley (Iannone et al. 2008:149). Research was guided by questions that emphasized the changing relationships to, and integration with, the Minanha royal court during its development, florescence, and denouement (Iannone et al. 2008:149). Site core excavations were comprised of a 20% stratified random sample of the 39 identified settlement
groups in order to compare settlement composition, density, and development between the three distinct study zones (Iannone et al. 2014a:283; Longstaffe 2011:50).

Figure 4-2. Research zones of Social Archaeological Research Program; Phase One and Two.

Excavations in the Contreras Valley were based on a 15% stratified random sample of all 100 settlement units discovered during reconnaissance (Iannone 2008a:149; McCane et al. 2009). Survey work combined and added to two earlier projects. These included Pollock’s (2003; 2004; 2006; 2007) intensive survey and excavation of terraces and settlement within a 5 ha subzone and Phillips’s continued systematic GPS settlement survey, adding to Connell’s earlier
MRS research (Iannone et al. 2006). Contributing to these early works was Macrae’s Phase Two intensive survey and detailed assessment of the terrace systems and settlement across the Contreras Valley survey zone (Macrae and Stringer 2007; Macrae and Longstaffe 2008; Macrae and Iannone 2009; Macrae 2010). The Phase Two findings reflected the changes and continuance of the communities over time in reaction to political shifts as well as the degree communities were integrated into the sociopolitical and socioeconomic hierarchies (Iannone et al. 2008:149). However, to fully understand related minor centers and the sub-regional component of the Minanha community necessitated Phase Three.

In 2009, Dr. Iannone began to collaborate with a series of specialists to develop a comprehensive socio-ecological dataset for the North Vaca Plateau. In this sub-regional research phase, there was a concentrated effort to excavate and re-survey the major center of Ixchel, situated 10 km southwest of Minanha. Excavations were conducted in order to assess the chronology of this center in comparison to that of Minanha (Iannone and Schwake 2013:6). Collaboration with the Northern Vaca Plateau Geoarchaeological Project (NVPGAP) facilitated the investigation of geologic, geomorphic, and speleologic data (Iannone et al. 2010; Reeder 2010). This collaboration resulted in one of the most comprehensive and robust climatic datasets in the Maya subarea (Akers et al. 2016). In addition, numerous caves were explored to identify changing ritual practices throughout the sub-regional study zone (Moyes and Awe 2010).

Further, in 2013 SARP became involved with a multi-project research grant to acquire 1057 km² of LiDAR, at the time creating the largest surveyed area within the Maya lowlands (Chase et al. 2014a:8673). This survey encompassed the entirety of the North Vaca Plateau. The incorporation of LiDAR imagery into archaeological research has been groundbreaking. It has changed the discipline to the point that is has even been stated that “advances in the remote geospatial
imaging of cultural landscapes, including ancient communities and their anthropogenic hinterlands, constitute(s)… an archeological paradigm shift” (Chase et al. 2012:12916). Currently, the new LiDAR studies are identifying vast expanses of agricultural terraces (Chase et al. 2011a; Chase et al. 2014a; Chase et al. 2014b; Chase et al. 2012; Chase et al. 2013; Chase et al. 2011b; Weishampel et al. 2011).

Over the many years of study at Minanha, there were exploratory investigations into the surrounding sub-region comprising the North Vaca Plateau. During SARP Phase Three, this stimulated the initiation of research that focused on the minor centers of Martinez and Waybil. The objectives of these investigations were to develop a chronological sequence for these centers, create a functional understanding of their changing roles within the greater Minanha polity, and generally to investigate their dynamic relationship with the Minanha royal court (Iannone 2008b; Iannone and Schwake 2013). This research involved the full coverage survey of the site core settlement zones surrounding both Martinez and Waybil, and detailed excavations within each epicenter. The Martinez site was subjected to a targeted survey that mapped the surrounding valley floor as well as several surrounding hills within a 500 x 500 m zone.

Excavations targeted the eastern shrine complex, centrally located in the sites main plaza. Research at Waybil has included extensive excavations and survey within a 500 x 500 m survey zone. Excavations were conducted over five field seasons, focusing on the epicenter (Hills et al. 2012; Schwake et al. 2013a), surrounding settlement units (Demarte et al. 2013:59), and relic agricultural terraces (Macrae and Demarte 2012; Macrae 2013). Agricultural terrace and water management features were mapped in 50% of the survey zone (Demarte and Alfano 2013). With the addition of LiDAR-generated, high-resolution DEM with the settlement and terrace survey have facilitated the digitization of the entirety of Waybil’s agricultural terrace systems and
settlement units. Settlement chronology has been determined by 100% settlement sampling through courtyard and patio-focused excavations in settlement units and strategic structure excavation in the epicenter and large settlement groups in order to explore settlement demographics (Demarte et al. 2013). The Waybil and Martinez investigations completed the Phase Three research in the Minanha community.

The Archaeological Sites of the North Vaca Plateau

Minanha

Minanha is centrally situated in the North Vaca Plateau. This site has been referred to as a small polity capital encircled by a number of similarly sized polities in the Belize river valley to the north, the polities of southeastern Petén region to the west and southwest, the large polity of Caracol to the south, and Naranjo, another large kingdom, to the northwest (Schwake and Iannone 2016:135). The evidence for occupation at Minanha dates from the Middle Preclassic (600-400 B.C.) to the Early Post Classic (A.D. 900 – 1200 (Schwake and Iannone 2016:135). The site of Minanha can be divided into three zones; epicenter, site core, periphery (Contreras Valley). The Minanha epicenter covers approximately 9.5 hectares and is composed of 14 structural groups with a total of 54 structures (Hills 2012:46). At its height, Minanha can be referred to as a “full-service” center with a complete set of architectural features that accommodate residential, ritual, civic-ceremonial, and service functions (Iannone 2005:29-30). The epicenter is composed of two distinct components. To the north is the royal acropolis and royal residence with its associated private and semi-private courtyard groups as well as service groups. To the south is found the more public architecture with open plazas, less restricted courtyard groups, temples, range structures, eastern shrine, and ball court (Hills 2012; Iannone 2005; Longstaffe 2011).
The Minanha site core settlement zone, immediately surrounding the epicenter, is composed of administrative, ritual, and residential features. Residential units exhibit a degree of wealth disparity, ranging from more wealthy to lower status commoners (Longstaffe 2011:8, 207-208). While the exact boundaries of the site core were fluid, analysis was focused on a 1

Figure 4-4. Three-Dimensional topographical map of Minanha (vertical exaggeration x1.5).

Further, away from the Minanha epicenter is a study zone referred to as the Contreras Valley. This peripheral community is situated 1 km from the epicenter, and is a representative of the residential and agricultural zone that was home to some of Minanha’s support population. This zone exhibits extensive terracing and 100 settlement units (Longstaffe 2011:50; Macrae 2010). Recent analysis of the settlement groups within the Contreras Valley suggests that they exhibit some of the longest lasting settlements at Minanha, with occupation beginning in the
Terminal Preclassic (A.D. 100 – 250) and enduring into the Early Postclassic (A.D. 900 – 1050) (Lamoureux-St-Hilaire et al. 2015; Macrae and Iannone 2010; McCormick 2007).

Figure 4-5. Contreras Valley, North Vaca Plateau, west-central Belize.
Ixchel

Ixchel is a major center strategically located 10 km southwest of Minanha and 14 km north of Caracol (Figure 4-7, 4-8). The site exhibits an occupation sequence that stretches from the Late Preclassic (400 B.C. - A.D. 100) to the Terminal Classic (810 - 910 B.C.; (Hills et al. 2013; Iannone et al. 2014a; Schwake et al. 2013b). However, like many archaeological sites in the North Vaca Plateau, and elsewhere, this occupation fluctuated over time. The Ixchel epicenter is composed of nine formal groups and two solitary mounds for a total of 70 structures, in addition to three sacbeob (causeways) (Iannone et al. 2011b). All excavations at Ixchel focused on the epicenter, including the main public plaza, its eastern shrine complex, and ball court (Group A), and the royal residential acropolis (Group B, C, and D (Hills et al. 2013; Iannone et al. 2011b; Iannone et al. 2012; Schwake et al. 2013b). Adjacent to the site core is the
Macal Chasm sinkhole, a locus for paleoenvironmental studies. Researchers from NVPGP discovered Ixchel when conducting reconnaissance for paleoclimatic data in the Macal Chasm (Reeder 2010:174). NVPGP conducted a preliminary study at Ixchel, during which they collected surface finds, explored looter trenches, and roughly mapped the site (Colas et al. 2008; Colas et al. 2006).

Figure 4-7. Ixchel, North Vaca Plateau, west-central Belize.
Martinez

The Martinez site is a minor center located 5.8 km northeast of Minanha (Figure 4-9, 4-10). The site dates from the Middle to Late Classic (A.D. 675 – 810) period and was likely built in a single construction phase (Schwake et al. 2011). The site runs north-south along the valley bottom of several interfluvial hills. Found directly adjacent to the epicenter is a small well and a spring fed stream that flows along the same valley. The site is composed of seven formal settlement groups and four solitary structures. As a relatively small site, the majority of the architecture is found surrounding the epicenter with a small number of isolated groups and single mounds scattered in the periphery. There is also a sacbe that is found running NNW-SSE between the central eastern shrine complex in the Group A plaza and the adjacent the residential group, Group B. A possible stela monument was found at the point that this sacbe entered Group.
A. All excavation at this site has focused on Group A, the eastern shrine complex (Schwake et al. 2011).

Figure 4-9. Martinez, North Vaca Plateau, west-central Belize.
Waybil

Waybil is a subsidiary site of the Minanha polity, located 1.92 km southeast of the Minanha epicenter (Figure 4-11, 4-12). The epicenter and surrounding settlement zone are composed of 15 settlement groups, 8 solitary buildings, and 591 agricultural/water management features. The Waybil epicenter is composed of Group A, with the adjacent Group B and C considered to be part of the surrounding site core settlement zone. Surrounding the epicenter and sitecore are a series of settlement units, isolated structures, and agricultural terraces. A large component of the research conducted at Waybil was aimed at understanding the role of agriculture terracing in the economic and social system of the Minanha polity from the perspective of a minor center. This includes understanding the function and distribution of the
agricultural terraces and their associated planting surfaces. Excavation and subsequent ceramic analysis has revealed an occupational history for Waybil that stretches from the Late Preclassic (400 B.C. – 100 A.D.) to Terminal Classic (A.D. 810 – 900) (Demarte et al. 2013; Hills et al. 2012; Schwake et al. 2013a). Agricultural terrace construction and use at Waybil began during the Late Terminal Preclassic (A.D. 100 – 250) and ended during the Terminal Classic (A.D. 810-900).

Figure 4-11. Waybil, North Vaca Plateau, west-central Belize.
Figure 4-12. Three-dimensional topographic map of Waybil (vertical exaggeration x1.5).

**Occupation Sequence of the North Vaca Plateau**

Permanent occupation within the North Vaca Plateau is not visible in the archaeological record until the Middle Preclassic period (900 – 400 B.C.). This occupation is documented to continue until the Early Postclassic (A.D. 900 – 1200). The changing settlement patterns and occupation of Minanha, Ixchel, Martinez, and Waybil lay the foundations for the temporal understanding of the changing socio-political and socio-economic circumstances in the North Vaca Plateau. Assessment of the changes at the major and minor centers surrounding Waybil facilitates the evaluation of both the occupation history of Waybil and influences on its agricultural strategy. An emphasis will also be placed on the Minanha support population in the Contreras Valley as it provides a comparative device to discuss the development, maintenance, and abandonment of the agricultural terracing at Waybil. For more detailed descriptions of the
excavations and archaeological material refer to the numerous site reports, thesis, and publications by the members of the SARP project cited throughout this chapter.

**Middle Preclassic (900 – 400 B.C.)**

**Minanha.** Occupation during this period within the North Vaca Plateau is very scarce. Evidence is often ephemeral and no standing structures have yet been identified. Minanha is the only site as of yet to exhibit ceramics from this period. These ceramics date to the later part of the Middle Preclassic (600 – 400 B.C.) and were found in mixed-fill deposits of later constructions (Iannone et al. 2014a:287; Iannone 2005:29; Schwake and Iannone 2016:135).

**Late Preclassic (400 B.C. – 100 A.D.)**

**Minanha.** During the latter portion of this period and transition into the Terminal Preclassic, Minanha experiences its first construction phase. This is evident in the form of a number of tamped earth floors beneath the epicenter’s main public plaza and one of its associated administrative range structures (Structure 12A), as well as a small sub-structure beneath the stairs leading up to the royal residential courtyard (Group J), and a multiple entry chultun burial found in Group M (Hills 2012:46, 57, 64; Iannone and Longstaffe 2010:65; Iannone et al. 2014a:288; Turuk et al. 2005:51). This finds attested to a relatively low, but nonetheless growing population within what will become the Minanha epicenter.

**Ixchel.** Ixchel exhibits its earliest occupation during this period, identified beneath both the eastern shrine complex in the main public plaza (Group A), and the royal residential acropolis (Group B). Beneath Group B, this early occupation coincides with the leveling and filling of the natural bedrock to construct a plaster floor courtyard surface (Hills et al. 2013; Schwake et al. 2013b). Associated with this courtyard there is evidence for at least one structure, B24. B24 is very ornate, exhibiting an armature likely would have supported a stucco mask (Hills et al. 2013). Evidence of stucco masks in the Maya lowlands has been strongly associated
with the Late Preclassic, with early examples dating to the Middle Preclassic (900 – 400 B.C. [(Coe 1967; Freidel and Schele 1988; Iannone et al. 2011c; Lucero 2007; Marcus 2003; Pendergast 1981; Ricketson and Ricketson 1937)].

**Waybil.** While there is limited evidence for occupation at Waybil during the Late Preclassic it is clear that the site held at least a degree of importance in terms of civic-ceremonial functions. This is evident in the epicenter by the construction of a large plastered shrine structure, Structure AI, which also exhibited a stucco mask (Hills et al. 2012:47-52; Iannone et al. 2011c:101-107). Besides this antepenultimate construction there is no other evidence for occupation dating to this period.

**Terminal Preclassic (100 – 250 A.D.)**

**Minanha.** The transition from the Late to Terminal Preclassic period at Minanha exhibits the multi-phase construction of the Minanha eastern shrine complex, Structure 3A. Within Structure 3A are three axial aligned offerings dating to this period (Hills 2012:69; Schwake 2001; Schwake 2008; Schwake and Iannone 2010:335). During this period, the Contreras Valley presents the construction of tamped earth floors at the settlement unit MRS 4, which will become one of the most complex and largest settlement group in the valley and persist until the valleys abandonment. Further evidence of occupation in the Contreras Valley is evident by the penultimate building at MRS 96 (Macrae and Iannone 2010:189-190; Macrae 2010:112-113). It is also during the Terminal Preclassic where I have the first evidence for agricultural terracing, with two terrace planting surfaces revealed during the structure excavations of MRS 15 and MRS 96 (Macrae and Iannone 2010:189-190; Macrae 2010:112-113). The gradual construction of terraces starts during this period. This was carried out by early households, attempting to conserve and improve their local agricultural lands. The exploitation of prime agricultural lands by these original inhabitants was supported by the development of isolated pockets of denser,
more complex, higher quality terraces within the interfluvial valleys near their house lots (Macrae 2010:129-130). These small terrace systems were produced in a piecemeal fashion, and employed labor saving methods, such as the use of the natural bedrock features both above and below ground, which demonstrates a well-founded knowledge of the Contreras Valley (Macrae 2010:127; Pollock 2006:222-223).

These investments in constructing an agroecosystem follow similar trends foreshadowed across the Maya area. This is evident by centers placing an increasing emphasis on low-lying seasonal swamps (bajos), focusing on water management. These practices were especially prevalent in the north-central Petén and northern Belize. The increasing population and centralized control of labor facilitated production on a larger scale. Evidence of increased deforestation, modification of natural water features such as bajos and aguadas, the construction of canal systems, and raised fields, are found along the Hondo River and within the dry environment of the Yucatan Peninsula. Sites identified include Becan, Dzibilchaltun, Santa Rosa, Xtampak, Dzibilnocac, and Edzna (Creamer and Haas 1985:740; Dunning et al. 1999:652; Hammond 1978:34; Hansen 1998:88; Leyden et al. 1996:44; Matheny 1976:639-642; 1978:199, 207; Pohl and Bloom 1996:153; Pohl et al. 1996:369; Rice 1976b:445; Rice 1996:203).

**Ixchel.** During the Terminal Preclassic Ixchel underwent a period of increased civic-ceremonial construction. Within the Royal Residence there was the application of a new plaster floor, construction of the penultimate structures B21 and B24, as well as the antepenultimate re-use of structure B22 (Hills et al. 2013:42; Schwake et al. 2013b:12). Further evidence is drawn from the construction fill and plaster flooring event in Group A, the eastern shrine complex, that dates to the transition from the Terminal Preclassic to Early Classic (Iannone et al. 2011b:41). This is evident in Structures A1, A2, A3, A4, and A5. During the transition from Terminal
Preclassic to Early Classic there was a brief hiatus and disruption in construction practices punctuated by the burning of several temples (Akers et al. 2016; Hills et al. 2013; Iannone et al. 2011b; Iannone et al. 2012:12; Iannone et al. 2014a:287; Schwake et al. 2013b). This is supported by the removal of the stucco mask and careful burial of the antepenultimate structure B21 as well as evidence for burning in the E-group complex, structure A1 and A3. This has been connected to a drought occurring at the same time (Akers et al. 2016; Hills et al. 2013; Iannone et al. 2011b; Iannone et al. 2012:12; Iannone et al. 2014a:287; Schwake et al. 2013b).

**Matinez.** During this period the Martinez site exhibited only a small collection of Late Preclassic and Terminal Preclassic ceramics found on top of the sterile paleosol. The lack of any construction suggests a more transient population, but does confirm that people were in the area (Schwake et al. 2011:73, 90-91).

**Waybil.** This period presents evidence for the increasing presence of people at Waybil, yet still no solid evidence for long-term occupation. Within the epicenter the antepenultimate Structure AI is entombed by a Terminal Preclassic building. During this construction phase there was a dedicatory cache placed within the fill (Hills et al. 2012:47-52; Iannone et al. 2011c:101-107). More circumstantial evidence is found within the floor fill of what would become a small settlement unit, within the construction fill of a terrace wall, and a terrace planting surface (Demarte et al. 2013:84; Macrae and Demarte 2012:94). This ceramic evidence is likely incorporated into these contexts accidentally through the use of local material during a later construction phase.

**Early Classic (250 – 550 A.D.)**

**Minanha.** This period exhibits the continuation of a modest expansion of epicentral construction program. A notable addition to the epicenter was the construction of the causeway termini structure (Zehrt and Iannone 2005:65), as well as the burial within, and expansion of, the
Great Southern Plaza (Hills 2012:47; Iannone et al. 2006:118-119). It is during this period that the site core exhibits its first settlement units and penultimate structures at Groups AQ and S (Snetsinger 2013:30) as well as a platform at Group U (Longstaffe 2009:61). Similar to the Contreras Valley these early settlement groups were also some of the longest occupied. Within the Contreras Valley the settlement occupation remains fairly constant, although there is an increase in the number of structures built and occupied within the persisting settlement groups (Macrae and Iannone 2015; Macrae 2010). The agricultural terraces appear to remain a constant from the Terminal Preclassic period. For even though there was an increase of structures there were no new settlement groups constructed.

Ixchel. After the brief hiatus and burring event, the site again experiences a significant construction event, evident amongst the civic-ceremonial structures. There is another plaster floor laid in the eastern shrine complex (Iannone et al. 2011b). As well as the terminal construction of B24 and modification to B21 within the Royal Acropolis (Hills et al. 2013:43).

Waybil. During the Early Classic period, Waybil experiences an increased investment into the epicenter. This is evident by the penultimate construction a large range structure, Structure AV, and the construction of the Group A courtyard with an associated burial. The penultimate range structure, structure AV, provided no evidence for the multiple superstructures or masonry footing that would be indicative of multiple rooms used for administrative functions (Schwake et al. 2013a:140). The lack of superstructures or masonry footings suggest that there was a large open platform on top of the structure, potentially enclosed by a single perishable superstructure (Iannone 2017; Schwake et al. 2013a:140). Structure AV represents the first non-ritual architecture constructed at Waybil. Finally, terrace excavation identify the first terrace wall constructed at Waybil.
**Middle Classic (550 – 675 A.D.)**

**Minanha.** Little construction occurs within the epicenter during this period. However, there is an additional burial placed in association with the Early Classic plaza burial (Hills 2012:47). The Minanha site core also maintained a consistent occupation, with the exception of the new construction of Group X (Longstaffe 2009:59; Longstaffe 2011:105-107). Within the Contreras Valley, the settlement patterns changed abruptly; not only were there more settlement units, many increased in size, and most of these were clearly oriented towards the maximization of agricultural lands, which lead to the location of settlements units on hilltops and slopes (Fedick 1995:31; Iannone et al. 2007:154; Iannone et al. 2008:152; McAnany 2000:72).

Elsewhere in the valley at this time, other lineages and extended family expanded into more marginal lands, and improved their agricultural productivity by using intensive farming techniques, in this case terracing (McAnany 2000:97). There is an increase in single mounds, trojas or field houses, suggesting the use of fields further away from the primary residences (Iannone et al. 2007:154; Iannone et al. 2008:152). These structures may also have worked to lay claim to, and maintain ownership of land, their increasing prevalence may imply increasing competition, and stress on agricultural resources. The terrace systems at this time see dramatic expansion. Terraces were produced in a very uniform manner and they developed into clear sets based on topographical situations and association with settlement units. The interconnectivity with surrounding terrace sub-systems, high number, and protracted length of several of these terraces suggest a level of interaction that extends beyond the household, and involves a large-scale construction process. However, within the larger terrace system there is evidence of localized construction methods and knowledge (Macrae 2010:123-137).

**Ixchel.** This period exhibits another disruption event that interrupted the expansion of the Ixchel epicenter (Hills et al. 2013; Iannone et al. 2014a). Evidence is drawn from the burning of
a number of temples in the eastern shrine complex, A1 and A2, as well as the Royal Residence, B21 (Iannone et al. 2011b:63; Schwake et al. 2013b:14-15). However, shortly following this disruption event, Ixchel again swung into a period of affluence with renewed construction projects in both Royal Residence and eastern shrine complex, including associated dedicatory caches (Hills et al. 2013:43).

**Martinez.** During the late facet of this period Martinez begins to experience its first and only identified construction phase. This involves the construction of the eastern shrine complex with an associated burial (Schwake et al. 2011).

**Waybil.** There is limited evidence for the Middle Classic occupation at Waybil. The evidence is found in Group B, a formal residential group directly beside the Group A epicenter. Within Group B, there are two flooring events and simple crypt burial (BIII-B/1) under what will become structure BIII (Schwake et al. 2012:73). The excavation of a sealed chultun, Op.W100-1, revealed Middle to Late Classic ceramics (Iannone et al. 2011c:108-111).

**Late Classic (675 – 810 A.D.)**

**Minanha.** The Late Classic period was a dramatic time for Minanha. During the early facet of the Late Classic period there was the emergence of the Minanha Royal Court. This coincides with a rapid construction program and population growth after 693 A.D. but before 775 A.D. (Iannone 2005:29; Schwake and Iannone 2016:139). The construction program included all the trappings that describe Minanha as a “full-service” site, which notably includes the restricted access royal residence with its vaulted entry way and rooms, in addition to a painted performance plaza (Iannone and Longstaffe 2010:72; Iannone 2005:30; Schwake and Iannone 2016:140). Further, in order to legitimate their power the Minanha kings tapped into the ancestral memory of the epicenter and constructed an eastern shrine placing associated caches and burials in the public Great Southern Plaza (Schwake and Iannone 2016:140; Schwake and
Iannone 2010). Despite this relative success, Minanha suffered a destruction event during the late facet Late Classic period, likely briefly after 775 A.D. (Iannone and Longstaffe 2010:72; Schwake and Iannone 2016:142). During this period parts of the royal residences were demolished and caches robbed while burials in E-Group were similarly looted (Iannone and Longstaffe 2010:72; Schwake 2001:19; Schwake and Iannone 2016:142). This destruction event was followed by a brief “new building program” which reformed the Royal Residence, installing a new shrine, and within the Great Southern Plaza two new monuments were erected and a staircase built over the eastern shine which led to a new pyramidal structure (Schwake and Iannone 2016:145). Following this rebuilding phase, Minanha experienced yet another destruction event between 800 and 810 A.D. This destruction event targeted both the royal residence and E-Group Complex, yet differed by carefully sweeping and infilling in portions of the royal residence and reusing the stone for a much less elaborate residence. However, specific aspects were targeted for destruction, including the stucco freeze(s), stela monuments, and administrative structures (Schwake and Iannone 2016:146-149). This turbulent history in the Minanha epicenter appears to be relatively restricted to the royal trappings of the king as the site core at the time expands to its highest occupation with all investigated settlement units occupied, several of which continue into the Terminal Classic. During this period, there was an investment in water management features, including at least one aguada (Philpot 2012:90-91).

In the Contreras Valley settlement units spread prolifically. The large MRS4 courtyard expands to its greatest size. These founding settlements who laid claim to the prime resources develop an elevated level of wealth above later occupants, apparent in the overall size of MRS4 (see McAnany 2000:98-99). The changes in the location and frequency of settlement types in Contreras Valley suggests a hierarchical organization during the Middle and Late Classic period.
The increase in population is not surprising, given the “gravitational pull” of the “full-service center” that Minanha had become. The spread of settlement units appears to correlate with the majority of the visible terraces suggesting a considerable investment, this is supported by the evidence that all terraces excavations exhibit a Late Classic component (Macrae 2010; Pollock 2007).

**Ixchel.** The prosperity of the latter half of the Middle Classic period at Ixchel continued into the early facet Late Classic, as a substantial effort was given to the construction of new buildings and resurfacing of plastered floors in both Group A and B. This included the single construction phase of a ball court in Group A (Iannone et al. 2012:25). Within the eastern shrine complex, a burial was discoverd that exhibited a defaced stela monument used as a cap stone, possibly from the earlier destruction event (Iannone et al. 2012:11). In the Royal Acropolis the B21 terminal structure and courtyard were constructed. There is no evidence for construction or resurfacing during late facet Late Classic (Iannone et al. 2014a:290).

**Waybil.** There is a drastic change in occupation at Waybil during this period. This may represent the first true full-time occupation at the site. All the settlement units and solitary structures exhibit a Late Classic component (Demarte et al. 2013:106). The site core exhibited the construction of a new shrine structure AIII (Hills et al. 2012:53-54) and the terminal structure and staircase of structure AV (Schwake et al. 2013a:130-141). Similar to the penultimate structure AV, the terminal construction of this structure lacks the typical multi-room composition of a range structure and rather presents evidence for a singular large room or open space that is interpreted as a large storage structure (Iannone 2017; Schwake et al. 2013a:130-141). There was also, at this time, a terminal construction phase at the epicentral shrine structure AI. When structure AI experienced its terminal construction, two simple crypt burials were placed within
the structure (AI-B/1) and within the new central courtyard (WAP-B/1) (Hills et al. 2012:42-45; Iannone et al. 2011a:105-108). The ceramic analysis and radiocarbon dates retrieved from burial A1-B/1 [655-770 Cal A.D. (95%) with an intercept of 675 A.D.], indicate that terminal construction of this epicentral shrine structure occurred during the early facet of the Late Classic period, or potentially earlier given that later facet Middle Classic ceramics were encountered during excavation (Dr. Iannone, Personal Communication).

In addition, of the five terrace walls and thirteen planting surfaces were investigated, all but one wall and its adjacent two planting surfaces, exhibit a Late Classic component. Thus, it can be confidently stated that all terrace systems were in use during the Late Classic.

Martinez. The eastern shrine complex founded in the Middle Classic continues to be occupied during this period. Overall, the construction quality of this group is relatively high suggesting a substantial investment in the well-made walls, fill, and plaster (Schwake et al. 2011:90).

**Terminal Classic (810 – 900 A.D.)**

Minanha. During this period, there is only a limited occupation within the Minanha epicenter and site core. This is evident by the smaller and less elaborate residential units (Iannone and Longstaffe 2010:72). However, several of the earlier, long-standing, residential settlements do persist (Iannone and Longstaffe 2010; Lamoureux-St-Hilaire et al. 2015). Within the Contreras Valley some of the founding lineages inhabiting the larger settlement units still flourished, including the long-standing MRS4 courtyard. New construction does occurs with the new MRS63 settlement unit and expansion MRS15 (Macrae 2010:140). All but two single mound, trojas, are abandoned, which may indicate that the landless groups of the Contreras Valley were either pushed out, or left with the influence and wealth of the royal court. This suggests, to some extent, that there was a continuation of the previously held socio-political and
socio-economic organization of the Middle and Late Classic periods (Macrae 2010:140). The terraces during this period are more difficult to decipher. The location of the continuing settlement units in areas adjacent to improved terrace lands suggests continued use.

**Ixchel.** There is no evidence for construction at Ixchel during this period. However, the discovery of Terminal Classic ceramics throughout the slump and humus levels in every excavation unit suggest a continued occupation/visitation at a diminished level (Colas et al. 2006:9; Hills et al. 2013:36, 41; Iannone et al. 2014:290; Schwake et al. 2013:17, 22, 26).

**Waybil.** During this period the dramatic construction and occupation at Waybil ends, suggesting a significant contraction within the Waybil population. Only the epicenter and Group B exhibit Terminal Classic ceramics, all of which are found within the top levels, slump and humus (Hills et al. 2012:47-52; Schwake et al. 2012:67, 71, 80; Schwake et al. 2013a:133-134, 140). The only exception is a feature and burial placed within Structure BIII (Schwake et al. 2012:79). The radiocarbon dating of the BIII-B/1 burial provided a relatively weak signal for the Late to Terminal Classic (775-885 [68%]) (Dr. Iannone, Personal Communication). After the Terminal Classic, there is no more evidence for occupation or visitation at Waybil.

**Early Postclassic (900 – 1200 A.D.)**

**Minanha.** During this period, the Minanha epicenter appears to be only a place for visitation and ritual, evident by rare ceramics and a chultun burial. Meanwhile the site core exhibits the only continued occupation at Group X with the addition of two new structures (Iannone et al. 2014:295; Longstaffe 2011:106-110). In the Contreras Valley, all the structures within MRS4 are in use, attesting to the longevity of this primary settlement (Macrae 2010:141). The only other settlement unit in use is MRS15, which was reduced to a single structure. It appears that the Early Postclassic occupation exhibits a return to a decentralized, lineage based, settlement pattern, with a smaller population, similar to that exhibited by the Terminal Preclassic.
and Early Classic periods. During the Early Postclassic, there is no evidence for agricultural terrace construction. However, similar to the previous period, older terrace systems near occupied settlement units can be safely be assumed to be in use.

**Martinez.** There is no construction during this period at the Martinez site. However, there was a side-notched point chert flake discovered near the surface as well as a single Postclassic ceramic sherd (Iannone et al. 2014a:295; Schwake et al. 2011:80). This may suggest a return to a transient population similar to the Preclassic period. Although, it must be noted that these point have been dated to the Terminal Classic at Caracol (Iannone et al. 2014a:295).

**Chapter Summary: A Review of the Archaeological Sites of the North Vaca Plateau and Regional Cultural History**

In this chapter, I have presented the history of research conducted by SARP in the North Vaca Plateau. This was followed by brief site description of Minanha, Ixchel, Martinez, and Waybil which are the four key sites targeted by the SARP research program. Beyond the site descriptions, the occupation history of these centers was presented, addressing the social, economic, and political history of the North Vaca Plateau. Analyzing the occupation history of the North Vaca Plateau from the Middle Preclassic to the Early Postclassic provides the temporal data to map the changing socio-economic and socio-political circumstances and ultimately question how these may have affected the Waybil community. Further, the chronological sequence of the North Vaca Plateau and Waybil in particular is required to correlate changes within these centers to the paleoclimatic reconstruction and to understand how the relationship between Minanha and Waybil influenced the agricultural strategy of the minor center. This will play a significant role in both the discussion and Chapter 8: Defining Social Pressures at Waybil.
CHAPTER 5
RESULTS OF THE SURVEY AND EXCAVATIONS

In this chapter, I will describe the methods and results of the Waybil archaeological survey of settlement and terraces, excavation and analysis of agricultural terraces, and archaeopedological analysis of the terrace planting surface. This chapter provides results that will lay the foundations assessing the effect changing social pressures had on the agricultural strategy in place at Waybil as well as the necessary raw data for incorporation into the GIS models of the ancient landscape of Waybil. Results will also contextualize the Waybil agricultural strategy in terms of how agricultural terracing was incorporated and changed with the changing external (climate) and internal (social) fluctuating pressures.

Waybil Settlement and Terrace Survey

Survey Methods

Waybil is located within the North Vaca Plateau. The epicenter, site core, and its immediate periphery encompass several hills that exhibit complex terrace systems. The settlement survey and mapping program conducted at Waybil had modest roots beginning with preliminary reconnaissance and limited survey. Later, as part of the Trent University Belize field school program, I used Waybil to instruct students on how to use a theodolite to survey and map structures. This preliminary work was carried out within Group A, the largest courtyard at the site. During the 2011 field season, SARP survey efforts at Waybil were intensified and a small survey team, under my direction, used a theodolite to mapping the immediate area surrounding the epicenter and associated large architecture (Iannone 2011:98-101). The goal of mapping the core area was accomplished, providing valuable spatial data and a better understanding of the site plan at the minor center. During the 2012 field season, the SARP settlement survey at Waybil was expanded with the new goal of mapping a 500 x 500m survey zone centered on
Group A. This ambitious full-coverage survey mapping program was performed by a small survey team, under the direction of Pete Demarte, who utilized a total station and spent 19 days in the field mapping all mounds, relic agricultural terraces, and water management features found within the prescribed survey area. All total station survey data was loaded onto a project laptop, analyzed and presented using ArcGIS software. By the end of the 2012 field season the SARP survey team successful mapped the western half of the survey zone. During the 2013 field season, Demarte mapped all the remaining settlement units using tape and compass with a GPS, after a total station failure. Further, in 2013, a LiDAR dataset was acquired as part of a consortium of archaeologists working in west-central Belize and was conducted by the National Center for Airborne Laser Mapping (NCALM) between April 27th and May 10th, 2013. Classification of the raw LiDAR data was completed in the software platform TerraScan version 13.009 (Terrasolid Inc, Finland) and distributed as las files and a DEM. Waybil was included within this dataset. Totality of this survey identified 15 settlement groups, comprising 46 structures, 8 solitary buildings, and 615 agricultural/water management features (Figure 5-1).

The terraces that were surveyed in the Northwest and Southwest quadrants of the Waybil survey zone using traditional methods were entered into GIS and digitized. These provided a mechanism to confirm the visual identification of the terrace using LiDAR. When examining the surface model of Waybil it was found that the best way to visually present the agricultural terraces and settlement was to overlay the DEM with a raster image depicting both slope and hillshade. During the digitization process these two images could be combined or examined independently. Further, when areas in the survey zone were difficult to decipher a horizontal cross-section of the trouble area could be produced and examined for aggressive elevation changes.
Figure 5-1. Waybil settlement and agricultural terrace survey.

**Light Detection and Ranging (LiDAR) & Surface Modeling.** Light Detection and Ranging (LiDAR) generates high-resolution elevation data. The technique primarily involves
mounting an Airborne sensor to a plane and flying transects across the landscape, during which time the sensor bombards the earth with laser pulses. Using GPS, the plane is able to correlate received data with coordinates, as well as map transects and confirm total coverage. The Point-LiDAR utilized in our survey uses continuous, short bursts of laser pulses that are small enough to filter through the small holes in canopy cover. In this manner, a series of numbered returns can be assigned. The lowest returns are pulses that reached the ground, followed by intermediate returns that include the canopy structure; finally, the last reached the forest canopy surface (Chase et al. 2012:12920). Collected data is classified into these return categories, in addition to others that researchers are interested in, and presented as a point-cloud. The resolution of the ground, referred to as bare earth, can range from 5 to 30 cm depending on the density of canopy cover (Chase et al. 2012:12920; Hightower et al. 2014).

Surface modelling, especially elevation modelling, is an important analytical tool due to its ability to reconstruct landscapes. Often, these result in the production of a digital elevation model (DEM) constructed from primary or secondary sources. In this case, the LiDAR database will act as the primary source. However, datasets need to be manipulated through interpolation techniques to create a continuous DEM surface (see Conolly and Lake 2006). Interpolation techniques are used to fill gaps between observations, predicting the missing data. There are several methods of interpolation including, as examples, Natural Neighbor, Kriging, Splining, and Inverse Distance Weighting (Arun 2013; Childs 2004; Conolly and Lake 2006; Polat et al. 2015). I use the local operator technique, inverse distance weighting (IDW), to examine the immediate neighboring cells to create the interpolated data. IDW, introduced by Shepard (1968), functions by examining a large sample of neighboring observations surrounding the missing data point, with each observation being assigned a specific power that is inversely weighted based on
its linear distance (Conolly and Lake 2006:95). In this manner, points further away will contribute less, while at the same time points immediately adjacent do not contribute wholly. During analysis, technicians have the ability to select the number of neighboring observations to be included. The influence that each neighboring cell has on the interpolated data can be modified by changing its weight. Based on the large number of point returns that occur within a LiDAR dataset, this method proves accurate and falls within the computational ability of most computers (Joseph and Kang 2011).

At Waybil, the LiDAR point-cloud consists of 6,738,078 point returns. Of these, 426,698 are classified as ground returns, with ~1.7 ground returns per square meter. However, these points are not evenly distributed across the survey zone. The DEM of the Waybil survey was created by converting the LiDAR point-cloud into a multi-point feature using only ground return points. The IDW interpolator technique was used to create a raster image, setting the number of neighboring points examined to 12, with a weight of two. Horizontal resolution was set to 1 m. Although greater resolution of .5 m or even .25 m was possible, I determined that they produce too much noise for accurate subtler analyses such as hydrology, erosion, and potential productivity. Vertical accuracy of the DEM is approximately 5-30 cm (Chase et al. 2014:220; Chase et al. 2011:64).

Further, imperfections, often present within DEMs, need to be accounted for. This requires a sink fill (Pit Removal) to remove surface depressions, known as sink or pits, which are usually present in the DEM. Surface depressions can be the result of data errors created during the surface modeling, while others can be the result of both natural and anthropogenic processes (Deursen 1995:47; Jenson and Domingue 1988:1593-1594; Wang and Liu 2006:195). They are a local minimum that does not have a downslope flow path, composed of a single or group of cells
of the same elevation and surrounded by cells of a higher elevation (Conolly and Lake 2006:257; Wang and Liu 2006:195). Sinks can be detrimental to hydrological modeling, causing water flow to terminate or accumulate until the sink is filled, prior to reaching the edge of the study area. Traditionally, several analytical procedures can be used to condition the DEM by applying smoothing filters to raise the sink or lower the surrounding neighboring cells, making the DEM depressionless (Conolly and Lake 2006:257; Deursen 1995:47; Olivera et al. 2002:71). These procedures have developed from earlier approaches (see Band 1986; Jenson and Domingue 1988; Marks et al. 1984; Morris and Heerdegen 1988) to more complicated algorithms that take into account specific sizes based on area, depth, and volume (see Deursen 1995). Arc Hydro provides several tools to address sinks; Sink Prescreening, Sink Evaluation, Sink Selection, and Fill Sink. These tools allow the user to develop a sink criterion, evaluate potential sinks, deselect true sinks, and finally filling the sinks. There were 1,127 sinks identified and filled across the Waybil survey zone.

Waybil Settlement Survey

The following section summarizes the various settlement units and agricultural and water management features surveyed at Waybil. Settlement units were classified using the Xunantunich system of classification (Table 5-1) (Ashmore et al. 1994). This section will highlight key settlement units that provide particular importance when describing the occupation history of Waybil. Dates prescribed to settlement groups are derived from excavations and resultant ceramic analysis. More details on both excavations and ceramic analysis will be available in Pete Demartes’ forthcoming Masters thesis.
Table 5-1. Type classification and distribution of settlement units within the Waybil survey zone. Group classifications are provided by Demarte.

<table>
<thead>
<tr>
<th>Type</th>
<th>Total #</th>
<th>% of Types</th>
<th>Identified Settlement Units Within Waybil Survey Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>I: isolated mound (less than 2 m high)</td>
<td>8</td>
<td>35</td>
<td>WAI, WAII, WAIII, WAIV, WAV, WAVI, WAVII, WAVIII</td>
</tr>
<tr>
<td>II: 2-4 mounds (informally arranged; all less than 2 m high)</td>
<td>1</td>
<td>4</td>
<td>Group O</td>
</tr>
<tr>
<td>III: 2-4 mounds (orthogonally arranged; all less than 2 m high)</td>
<td>10</td>
<td>43</td>
<td>Group B, D, E, F, G, H, I, J, M, N</td>
</tr>
<tr>
<td>IV: 5 or more mounds (informally arranged; all less than 2 m high)</td>
<td>0</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>V: 5 or more mounds (at least 2 arranged orthogonally; all less than 2 m high)</td>
<td>1</td>
<td>4</td>
<td>Group L</td>
</tr>
<tr>
<td>VI: 1 or more mounds (at least 1 being 2-5 m high)</td>
<td>1</td>
<td>4</td>
<td>Group K</td>
</tr>
<tr>
<td>VII: 1 or more mounds (at least 1 being higher than 5 m)</td>
<td>2</td>
<td>9</td>
<td>Group A, C</td>
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<td>TOTALS</td>
<td>23</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Aggregated structures

The Waybil epicenter is composed of Group A. This is a plazuela group consisting of six structures. Structure AI is a temple-pyramid and since it is the largest and only structure to have an outset staircase, it is considered the focal point for this group (Cohodas 1980:208). Structure AV is a long linear building, which may imply that it is a range structure. Although it lacks the individual rooms that would confirm this classification (see Cohodas 1980:208; Rice and Puleston 1981:296), as a result it is suggested to have acted as a storage structure. The structures of Group A sit upon a large construction platform that constitutes the plaza floor. There is one official entrance found south of Structure AVI that exhibits a staircase leading onto the construction platform just south of the plaza. Structure AVII is a low, rectangular structure. While a rather unassuming building its placement appears to have enclosed the group. Access to the courtyard group would have been limited to the stairway leading up from Group B and the terraced slope running to the southwest of the group, to Structure AI and Group C. Group A
exhibits dates that stretch from the Late Preclassic to Late Classic period (Hills et al. 2012:51-52; Schwake et al. 2013a:140-141).

The Waybil sitecore is composed of two residential courtyard, Group B and Group C. Group B is associated with Group A and located 63m east. The four structures within this group are arranged in an "n" shape built on a construction platform that tapers off in the southwestern corner where it reaches ground level creating the entrance to the courtyard. BII presents itself as a long structure with two rooms. The rooms are separated by a well preserved staircase that extends up and over the middle section of the structure. Based on its linear nature and the presence of two rooms, BII could be interpreted as a range structure (see Cohodas 1980:208; Rice and Puleston 1981:296). Group C is located 170m SSW of Group A and connected by a raised causeway. This group sits atop a tall construction platform which is progressively built up with structural terraces. There are two structures within this group. Structure CI is built upon a low construction platform. On the western side of the construction platform is a staircase that leads away from the group.

Surrounding the epicenter and sitecore are 12 settlement units. These aggregated structures are composed of various numbers of structures, orientation, and heights (Table 3-1). All of the settlement units are located within the agricultural terraces systems that comprise the Waybil anthropogenic landscape. The excavations conducted within the plazas and courtyards of all these settlement groups date to the Late Classic (Demarte Forthcoming).

**Solitary structures**

There are eight solitary structures found within the Waybil survey zone. All of these structures are comparatively small in comparison to the more formal groups, ranging from 3 to 6 m in diameter and rarely reaching over 0.5 m in height (Demarte and Alfano 2013; Iannone et al. 2011c; Macrae and Demarte 2012). The majority of these isolated mounds are found within
terraced field systems. In the neighboring Contreras Valley, a support population for Minanha, these single mounds have been referred to as trojas, or field houses, which suggest the use of fields further away from the primary residences (Iannone et al. 2007:154; Iannone et al. 2008:152). The only exception to these trojas is Structure WAI which can be considered a causeway terminus structure (see Chase and Chase 1996:215; Chase and Chase 2001:277).

**Chultunob**

Within the Waybil survey zone there are two identified chultunob. While one of these chultunob was open, the other remained sealed. The sealed chultun was subjected to excavation, Op. W100-1, to determine chronology of use and contents (Iannone et al. 2011c:108-111). Excavations revealed no ritual or burial material, suggesting that this sealed chultun was likely used to store perishable contents that deteriorated over time (Iannone et al. 2011c:108). Although the stratigraphy was complicated by taphonomic processes, the ceramics collected in the chultun date to the Middle and Late Classic period (Iannone et al. 2011c:108-111).

**Waybil Agricultural Terrace and Water Management Survey**

Within the Waybil survey zone almost every aspect of the landscape exhibits anthropogenic modification to some extent. The most extensive and visible modification at Waybil are the agricultural terraces. The impressive amount of labor, construction material, and time that the inhabitants of Waybil invested in their agroecosystem caught the attention of the SARP team early in their visits to the site. This spurred the first terrace and water management survey. This survey was conducted both on the ground with traditional methods and remotely using LiDAR. With the addition of LiDAR, high-resolution DEM combined with settlement and terrace survey have facilitated the digitization of the entirety of Waybil’s agricultural terrace systems and settlement units. The combined traditional and LiDAR survey identified 615 agricultural terraces.
Identifying agricultural terraces

Traditional survey and LiDAR digitization have identified 615 terraces. During digitization several terrace walls were identified that were missed by the traditional survey. This is a reflection of the dense vegetation that covers parts of the survey zone. Settlement units and water management features, aguadas, were also digitized from traditional survey and visual analysis. No new settlement units or aguadas were discovered in the LiDAR that had not already been identified on the ground. The terraces identified primarily consisted of contour and cross-channel types. Contour terraces are found along the gentle slopes in the northern and southeast portions of the survey zone and are generally the most common terrace type. These function to disperse water parallel across the hillsides, while reducing slope to create level planting surfaces. Cross-channel terraces, found in the constricted topography in the southwest and eastern portions of the survey zone, capture the sediment and water that flows down these narrow valley bottoms creating deep planting surfaces (Beach et al. 2002:386; Kunen 2001:326). Similar to the Contreras Valley, terraces often compliment natural bedrock outcroppings, and incorporate to reduce labor requirements (Macrae 2010:127; Pollock 2006:222-223). The number and distribution of terrace walls at Waybil indicates a significant investment in the modification and management of the landscape through a geointensive agricultural strategy. More detail concerning the typology and distribution of the terraces at Waybil is provided in Chapter 8.

Aguadas

Four aguadas were located at Waybil. The 2012 survey program coincided with the start of the rainy season and these aguadas contained a substantial amount of standing water. Aguadas are known to be both natural and artificial occurrences of semi-permanent to permanent ponds with solid clay bottoms (Bullard 1960:363; Siemens 1978:137; Tamayo 1964:97, 100, 138). Many of these systems are known to exhibit human manipulation, as evident in their construction
or enlargement, the construction of a terrace like rim, and a clay or river cobble base (Bullard 1960:363). None of these water management features at Waybil have been subjected to excavation, thus there are no confirming dates. Two adjacent aguadas are found in the western side of the survey zone and have no close connections to any settlement units. The third aguada is much smaller and is found near the base of the Group C staircase.

**Section Summary: Waybil Settlement and Terrace Survey**

As results for the traditional survey and LiDAR data are accumulated, an accurate depiction of the anthropogenic landscape inhabited by the Waybil community is formed. The original settlement survey prior to my work identified 15 settlement units composed of 46 structures with an additional eight solitary structures. While traditional on-the-ground survey only mapped 50% of the survey zone, the acquired LiDAR dataset facilitated the visual mapping of the remaining areas. Survey work not only identified settlement units but also targeted water management features and the agricultural terraces found prolifically throughout the survey zone. After combining both datasets, survey and LiDAR, 615 terraces were mapped, including four aguadas.

**Waybil Terrace Excavations**

Over two field seasons a series of excavations that targeted agricultural terrace walls and their associated planting surfaces were conducted at Waybil (Macrae and Demarte 2012; Macrae 2013). The primary excavation goals were to confirm their agricultural use, develop a chronology of use, examine constructional qualities, and acquire soils samples for further pedological analysis. Four excavations were conducted and designated as Op.W102-1, Op.W103-1, Op.W104-1, and Op.W105-1 (Figure 5-2). These were divided between the four subzones of the 500 x 500m survey zone: Northeast, Northwest, Southeast, and Southwest.
Terraces targeted for excavations were selected based on their proximity to settlement units and their structural diversity in terms of terrace diversity and function (Macrae and Demarte 2012; Macrae 2013). This approach allows for direct comparison of the terrace dates with those from settlement units sampled as part of the larger settlement study. Correlation of chronology and structural association between the terrace and settlement units further
substantiates the dates for each terrace. My analysis of excavated ceramics from these units identified a long series of terrace construction that stretches from the Early Classic to Terminal Classic (Macrae 2013). Beyond developing this chronology, the goal was to collect soil samples for pedological analysis. Excavations were conducted in traditional trowel and brush fashion following both architecture and soil horizons.

Dating agricultural terraces is notoriously difficult (Healy et al. 1983; Turner 1983a, 1983b), because they often exhibit low numbers of highly weathered diagnostic ceramics. Further, terraces are understood as objects constructed once, but used continuously over long periods, obscuring the earlier construction and use. Periods of use for the Waybil terraces are determined based on assessment of the ceramic dates within terrace walls and associated planting surfaces, terrace construction sequences, association of dated settlement units and adjacent terrace operations, and the radiocarbon dating of the soil organic matter (SOM) collected from soil samples from the planting beds.

Analysis of all recovered ceramics from the agricultural terraces was conducted at the end of every field season, under the guidance of Dr. Iannone. Ceramics obtained from excavated terrace walls provide dates for the construction of the terraces, while those from the excavated planting surfaces provide dates for their use. Given the difficulties in deciphering ceramic sequences in these geointensive features, the ceramics were analyzed in terms of chronological frequency. Each excavation revealed a substantial peak in ceramics dating to singular period, often with significantly lower numbers dating before and after. The incorporation of a small number of earlier ceramics has been interpreted as the use of surrounding local material as fill in the construction of the terrace wall and planting surfaces. Further, the ceramics dated to latter
periods are attributed to evidence of terrace maintenance or continued use after initial construction.

The association between terrace walls and the matrix of the terrace-planting surface was used to indicate if the agricultural terrace walls and planting surfaces were constructed in a single phase ("expedient" surfaces) or incrementally over a long period. Incremental surfaces are created by gradual accumulation of eroded soils from above the terrace behind freestanding walls (Beach et al. 2002:380; Dunning and Beach 1994:58, 64). Expedient surfaces were created by stripping soil from above the underlying bedrock to lay terrace wall anchoring stones, and subsequently refilling with anthrosols to form the planting surface (Chase and Chase 1998:70; Healy et al. 1983; Kunen 2001:339; Robin 2015:44). Elsewhere, this process is identified by a lack of naturally occurring soil horizons, unique soil classifications, and lack of stones in the planting surface (Chase and Chase 1998:70; Hansen et al. 2002:283; Matheny 1976:643; Turner 1978a:170). The terrace excavations at Waybil revealed terrace planting beds that were single, identifiable, soil horizons different than any other soil horizons found outside terraces. These terrace planting bed horizons were similar to those described at Caracol (Chase and Chase 1998) as expedient constructions. Chase and Chase (1998) have operationalized this type of terrace construction. It begins by stripping the soils to bedrock, then constructs the terrace wall, and then refills the planting bed. Refilling the planting surface in one process, potentially using previously excavated or transplanted soils, created the uniform anthropogenic soil horizon. The construction method suggests that terrace wall and planting surface were either contemporaneous, or the bed postdates the terrace wall. This pattern has been identified in three of the four terrace excavations, Op.W102, Op.W103, Op.W105, while Op.W104 shows a slight variation. During excavations the terminal, and only, construction level of these terraces was defined as Level 3.
Due to the fact both terrace wall and planting surface were constructed at the same time our ceramic analysis will focus on Level 3 as a singular unit of analysis.

The settlement chronology is also used to verify the ceramic dates derived from the terrace excavation. Terrace excavations were placed close to associated settlement groups, to corroborate the dates of the terraces and to identify pre- or post-occupational use (for example if the terrace wall ran underneath or over the structure and plaza). This technique has also been used at Caracol (Chase and Chase 1998:71).

Radiocarbon dating of the SOM matter was also conducted to confirm the ceramic dates. In the Maya subarea this dating method has been used to explore formation processes behind natural features, often bajos, identifying the role ancient Maya had in increasing and decreasing erosion rates through agricultural practices (Beach et al. 2003; Beach et al. 2008; Beach et al. 2002; Dunning et al. 1998; Dunning and Beach 1994; Gunn et al. 2002; Jacob 1995a; 1995b). Radiocarbon dates were acquired from Direct AMS. Results were calibrated using Oxcal version 4.2 and IntCal 13 (Ramsey and Lee 2013; Reimer et al. 2013). The bulk organic fraction from soils collected from the four excavations were dated after an acid wash to remove the carbonates.

**Operation Op.W102**

Operation Op.W102 focused on the larger agricultural terrace systems. The terrace system selected for excavation was in close proximity to Group E, which exhibited a series of surrounding contour terraces (Figure 5-3). Construction of these contour terraces has been suggested to be short, requiring a high level of labor investment with fast expansion of their terrace system (Fedick 1994:120; Pollock 2006:184). This provides important insights into the organization and function of the terrace system and the specific terrace being excavated.
Unit Op.W102-1 was a 9 x 1m unit and consisted of three distinct levels. It was excavated to a depth of 164 cm Below Unit Datum (B.U.D.) Unit Op.W102-1 was oriented 28° west of north and aligned with the terminal architecture of the terrace (Figure 5-4, 5-5). In addition to being situated within the terrace system, it was oriented to expose two terrace walls and three planting surfaces. The levels were sub-divided into six sections based on the distinction between planting surfaces, terrace walls, and construction fill. The excavations of this unit were completed down to the bedrock.

Figure 5-3. Rectified isometric plan of Op.W102, showing association with Group E.

Figure 5-4. East-west profile of Unit Op.W102-1, facing south.
Figure 5-5. Excavation photos of Unit Op.W102-1, Level 3.

Unit Op.W102-1

Level 1. Level 1 was designated humus - non - domestic (secondary) and was situated at approximately 6- 212 cm B.U.D. and was excavated to a depth of 21- 227 cm B.U.D. The humus layer (Level 1) exhibited a matrix composition of 80% aggregate, 5% pebbles, and 15% roots and rootlets. The decision to stop this level and begin the Level 2 slump layer was based on the exposure of the terrace walls and the appearance of a new soil horizon within the terrace beds. Ceramic analysis of this level dates to the Late Classic period (AD 675 - 810). Artifacts recovered from this level include a ceramic bulk lot (27/187-005:199) and a lithic bulk lot (27/187-005:201).

Level 2. Level 2 was designated slump - non - domestic (secondary) and was situated at approximately 21- 227 cm B.U.D. It was excavated to a depth of 25- 227 cm B.U.D. This level was concentrated throughout the center of the unit. The slump layer (Level 2) consisted of mostly
larger pebbles and cobbles that had fallen from the terrace walls. Level 2 exhibited a matrix composition of 40% aggregate and 60% cobbles. During this process, it became apparent that the terrace had undergone a significant amount of erosion and dismantling over time. This level was excavated very slowly as to not dismantle or acquire ceramics from within the terrace walls. Ceramic analysis of this level dates to the Late Classic period (AD 675-810). Artifacts recovered from this level include a ceramic bulk lot (27/187-005:200). Following the removal of the slump layer, the unit was sub-divided into five sections of construction; Level 3a, Level3b, Level3c, Level 3d, and Level3e. Each of these levels represented either a terrace wall or terrace-planting surface. Since they were likely all constructed at the same time they remain within the same Level3. The terrace planting surfaces were distinguished by a change in the soil horizon and were located between the terrace walls. Soil samples were collected from each of these layers for macro-analysis using flotation. Ceramic analysis of these levels has indicated a Late Classic period (AD 675-810) date.

**Level 3a.** Level 3a was designated terrace planting surface- non- domestic (secondary) and began 21-30 cm B.U.D. It was excavated to a depth of 35-51 cm B.U.D. This level was located in the eastern portion of the unit above the first terrace (Level 3d). The terrace-planting surface (Level 3a) was distinguished by a change in the soil horizon. The soil consisted of light brown clay. Level 3a exhibited a matrix composition of 95% aggregate and 5% pebbles. Although a ceramic bulk lot (27/187-005:220) was recovered from this level, ceramic analysis of this level could not be completed, as there were no diagnostic ceramic sherds. Soils were collected from this level for macrobotanical and pedological analysis.

**Level 3b.** Level 3b was designated terrace planting surface - non - domestic (secondary) and began 82-132 cm B.U.D. It was excavated to a depth of 109-145 cm B.U.D. This level was
located in the central portion of the unit between two terrace walls (Level 3d and Level3e). The terrace-planting surface (Level3a) was distinguished by a change in the soil horizon. The soil consisted of thick light brown clay. Level3b exhibited a matrix composition of 90% aggregate, 5% pebbles, and 5% cobbles. Ceramic analysis dates this level to the Late Classic period (AD 675 - 810). Artifacts recovered from this level include a ceramic bulk lot (27/187-005:221) and a lithic bulk lot (27/187-005:222). Soils were collected from this level for macrobotanical and pedological analysis.

**Level 3c.** Level 3c was designated terrace planting surface - non- domestic (secondary) and began 197-214 cm B.U.D. It was excavated to a depth of231 - 244 cm B.U.D. This level was located in the western portion of the unit below the second terrace (Level3e). The terrace-planting surface (Level3a) was distinguished by a change in the soil horizon. The soil consisted of thick light brown clay. Level3c exhibited a matrix composition of 90% aggregate, 5% pebbles, and 5% cobbles. Ceramic analysis of this level dates to the Late Classic period (AD 675- 810 A.D.). Artifacts recovered from this level include a ceramic bulk lot (27/187-005:257). The terrace walls (Level 3d and Level 3e) were designated construction fill with rubble- non – domestic (secondary). These levels exhibited stone terrace walls that exhibit various degrees of deterioration. Ceramic analysis of these levels has dated them to the Late Classic period (AD 675- 810). Soils were collected from this level for macrobotanical and pedological analysis.

**Level 3d.** Level 3d was designated construction fill with rubble - non - domestic (secondary) and was situated at approximately 48-88 cm B.U.D. It was excavated to a depth of 55 - 97 cm B.U.D. This level is a terrace wall located in the eastern portion of the unit between the terrace-planting surface, Level3a and Level3b. These levels exhibited stone terrace walls that had been partially deteriorated. Level 3d exhibited a matrix composition of 60% cobbles, 30%
pebbles, and 10% boulders. Ceramic analysis of this level dates to the Late Classic period (AD 675 - 810). Artifacts recovered from this level include a ceramic bulk lot (27/187-005:280), a lithic bulk lot (27/187-005:281), and two groundstone-manó fragments (27/187-005:314, 27/187-005:282).

**Level 3e.** Level 3e was designated construction fill with rubble-non-domestic (secondary) and was situated at approximately 139-164 cm B.U.D. It was excavated to a depth of 163 - 207 cm B.U.D. This level is a terrace wall located in the eastern portion of the unit between the terrace-planting surface, Level 3b and Level 3d. Level 3e exhibited a matrix composition of 60% cobbles, 30% pebbles, and 10% boulders. Ceramic analysis of this level dates to the Late Classic period (AD 675-810). Artifacts recovered from this level include a ceramic bulk lot (27/187-005:278) and a lithic bulk lot (27/187-005:281).

**Level 3f.** Level 3f was designated construction fill with rubble-non-domestic (secondary) and was situated at approximately 127-136 cm B.U.D. It was excavated to a depth of 148 - 172 cm B.U.D. During the excavation of the planting surface, Level 3b, it was clear that under the western portion of the planting surface the bedrock dropped off creating a space between it and the terrace wall (Level 3e). This area was designated level 3f and exhibited a higher density of pebbles and cobbles within the aggregate. This level exhibited a great deal of pebbles on the west side with large boulders along the eastern side. Level 3f exhibited a matrix composition of 30% aggregate, 65% pebbles, and 5% boulders. This level had been packed between the bedrock and terrace wall (Level 3e) supporting the terrace wall. Ceramic analysis of this level has been dated to the Late Classic period (AD 675-810). Artifacts recovered from this level include a ceramic bulk lot (27/187-005:294).
Results. Operation Op.W102-1 presented an example of a Late Classic contour agricultural terraces. Chronologically, the two terrace walls and three planting surfaces can be securely dated to the Late Classic based on the ceramics excavated (Figure 5-6).

There was evidence for a small number of ceramics that date to the Terminal Preclassic period (AD 100-250). These early dates were disregarded based on their context within Level 2 from the most eastern terrace wall and planting surface. They are hypothesized to have been the result of bioturbation, and originated from the nearby Group E settlement unit. Alternatively, these early ceramics may have been originally located within early field systems or construction materials used to build the terrace. Insight into the construction of both terrace walls was difficult to decipher due to the high level of deterioration and slump exhibited. Op.W102 was placed close to Group E. The plaza excavation conducted within this group was also dated solely to the Late Classic. This date suggests that the Terminal Preclassic ceramics recovered during terrace excavations did not come from the adjacent group. However, given the early dates for the
epicenter, Group A, suggests that people were at the very least visiting Waybil during this period. The Late Classic correlation between the terrace excavation and adjacent settlement group confirm the Late Classic dates. The AMS of SOM of Op.102-1 was returned as modern, likely a result of contemporary *milpa* farming.

The planting surfaces excavated indicated a clear agricultural use due to the distinct soil horizon identified between the terrace walls. The two terrace walls excavated can be classified as single wall constructions as described by Kunen (2001:328). Single walled terrace wall construction has been associated with contour terraces (Murtha 2002:161-162). It is also clear that the terrace walls utilized the underlying bedrock by taking advantage of the step like nature of the limestone bedrock. This has been noted in other excavations suggesting that the Maya who constructed these terrace walls had a well-founded knowledge of the local topography (Macrae 2010:127; Pollock 2006:222-223). The terrace walls were constructed in front of the bedrock step risers. Boulders were placed against the riser creating a facing that reached higher than the step itself. A fill of smaller pebbles and cobbles were used between the boulder facing and the bedrock or planting surface. In the case of Level 3f, pebbles and cobbles were used to fill the space between the terrace wall and the step in the bedrock. This was likely done to smooth out the undulating bedrock without having to drastically modify the curvature of the terrace wall to follow the natural form of the bedrock. Excavators also retrieved soil samples from all three planting surfaces for macrobotanical analysis and exported them to the University of Florida for pedological analysis. Collection of macrobotanical remains was conducted using floatation method locally in a Belize lab. Although a number of charcoal flakes and seeds were recovered, several germinating seeds were identified. Flotation attempts were ceased shortly after. These contemporary seeds attest to the modern AMS date prescribed to the SOM.
Operation Op.W103

Op.W103 was located in the northwest sub-zone, placed within an agricultural terrace system near Group F. The agricultural terrace selected for excavation was a contour terrace that ran around Group F (Figure 5-7).

![Rectified isometric plan of Op.W103, showing association with Group F.](image)

Unit Op.W103-1 was a 2 x 1 m unit oriented 121° east of north. The unit was excavated to a depth of 126 cm B.U.D, and consisted of two distinct levels. This unit was situated over one terrace wall and one planting surface, and placed in accordance with the terminal architecture of the terrace wall (Figure 5-8, 5-9). During excavation, a second planting surface was revealed adjoining the retaining wall. Following the excavation of the humus and slump, the excavation unit was sub-divided into two sections. Level3a constituted the terrace-planting surface while Level 3b was the terrace wall itself. Since they were both likely constructed at the same time they all remained Level 3. This unit was excavated down to bedrock.
Figure 5-8. North-south profile of Unit Op.W103-1, facing West.

Figure 5-9. Excavation photos of Unit Op.W103-1, Level 3. Left Front wall, Right retaining wall.
Unit Op.W103-I

**Level 1 & 2.** Level 1 and 2 were designated humus- non- domestic (secondary) and was situated at approximately 21 - 55 cm B.U.D. It was excavated to a depth of 48- 82 cm B.U.D. The decision to stop this level was based on the exposure of the terrace wall as well as a change in the soil horizon indicating the terrace-planting surface. The matrix consisted of a great deal of 60% dense moist dark aggregate, 15% roots and rootlets, 10% pebbles, and 5% cobbles. Ceramic analysis of this level dates to between the Late Classic (675 - 810 A.D.) to Terminal Classic (810-900 A.D.) periods. Artifacts recovered from this level included a ceramic bulk lot (27/187-005:369) and a lithic bulk lot (27/187-005:368).

**Level 3a.** Level 3a was designated terrace-planting surface non-domestic (secondary) and was situated 48 - 64 cm B.U.D. It was excavated to a depth of 73 - 87 cm B.U.D. This level was a sub-unit located in the southern end of the excavation unit located above the terrace wall (Level3b). The terrace-planting surface (Level3a) was distinguished by a change in the soil horizon and was located above the terrace wall (Level3b). Level 3a exhibited a matrix that was primarily a very dense and moist dark chocolate brown clayey soil with a composition of 90% aggregate, 5% rootlets, and 5% pebbles. Soil samples were collected from this layer between 50-60 cm B.U.D. for pedological analysis. Ceramic analysis dates this level to the Late Terminal Preclassic (100 - 250 A.D.) to the Early Classic (250- 500 A.D.) periods. Artifacts recovered from this level include a ceramic bulk lot (27/187-005:376).

**Level 3b.** Level 3b was designated construction fill with rubble - non - domestic (secondary) and was situated at approximately 55 - 102 cm B.U.D. It was excavated to a depth of 120 - 126 cm B.U.D. This level was a sub-unit that included a terrace wall located in the northern portion of the excavation unit retaining the terrace-planting surface (Level 3a). This
level exhibited a stone terrace wall that had been partially deteriorated. The terrace wall consisted of a double facing wall of boulders that acted to retain a small fill of pebbles and cobbles. Further, there was a retaining wall of larger cobbles that bounded the interior fill to the facing wall. Level 3b exhibited a matrix of similar aggregate as Level 3a, except only composing 15% of the total matrix. The construction fill was composed of 20% pebbles, 40% cobbles, and 15% boulders. At the very bottom of the excavation unit was a fine tan colored aggregate (composing 10%), that likely developed from deteriorated limestone bedrock. Ceramic analysis dates this level to the Late Terminal Preclassic (100 - 250 A.D.) to the Early Classic periods (250- 500 A.D.). Artifacts recovered from this level include a ceramic bulk lot (27/187-005:374) and a lithic bulk lot (27/187-005:375).

**Results.** Operation W103 is the exception to the Late Classic pattern of use, revealing a terrace wall with 43% of the ceramics dating to the Early Classic (250-550 AD) and a smaller percentage dating to the Terminal Preclassic and Late Preclassic (Figure 5-10). The planting surface also exhibits an Early Classic date. However, within the covering humus level there is evidence for Terminal to Late Classic ceramics suggesting its continued use or possible late reuse. Op.W103 was placed adjacent to Group F. Plaza excavations within the Group F courtyard are dated to the Late Classic. Thus, earlier dates of both the terrace wall and planting surface do not correlate with the nearby settlement. However, when examining Group F, it appeared that this Late Classic settlement group may have been built on top of the Early Classic terrace, expanding their patio by creating a horseshoe shaped structural terrace. Op.W103-1 exhibited an Early Preclassic date (conventional date [B.P] 2744 +/- 21, 1 σ cal B.C. [908 – 889], [881 – 884], 2 σ B.C. [927 – 830]), this clearly falls before our range of interest (Figure 5-11).
Examining the dates in conjunction with the terrace construction technique produces several interesting observations. The terrace was constructed without incorporating the natural step-like nature of the underlying bedrock (Macrae 2010:127, 165-167; Pollock 2006:222-223).
Utilizing the natural formations of the bedrock has often been interpreted as a means of reducing the labor requirements by using a localized and intrinsic knowledge of the landscape. I would argue here, that the lack of utilizing the bedrock is related to the early dates of this terrace. While Pollock (2007) notes the consolidation of bedrock into the terraces construction, the dates exhibited fell within the Middle to Late Classic period. Unit Op.W103-I dates heavily to the Early Classic and potentially the Terminal Preclassic suggesting one of the initial uses of agricultural terracing at Waybil and the immediate surrounding area. This terrace could be exhibiting a learning curve within which inhabitants were developing methods of terrace construction. The terrace wall construction itself falls within the classification of a double wall (Dunning et al. 1997:258; Kunen 2001:327). Double wall construction exhibits two walls that contain a fill of pebbles and cobbles between (Donkin 1979:32; Kunen 2001:327). Unit Op.W103-I exhibits this technique but also shows a degree of investment in the stability of the facing wall by the placement of two courses of stones. I believe that this technique shows a degree of a prior understanding of the methods and requirements of terrace construction. Thus, to summarize, Unit Op.W103-I uncovered an early terrace construction likely conducted by the inhabitants of Waybil or new arrivals who had a previous understanding of terrace construction, but lacked the local knowledge of the subsurface landscape.

**Operation Op.W104**

Op.W104-1 was located in the northeast sub-zone, placed within an agricultural terrace system located between two settlement groups, Group L and Group M (Figure 5-12). The agricultural terrace selected for excavation was a cross-channel terrace, also known as weir or check dams. This terrace runs within an inter-fluvial valley between two residual hills. Cross-channel terraces are usually short and found running perpendicular to gullies, drainages, and other locations that exhibit constricted features (Donkin 1979:32; Kunen 2001:326; Treacy and
Denevan 1994:96). This style of terrace is designed to restrict runoff, catch soils, and retain and regulate water in areas of erosion (Beach et al. 2002:379; Dunning and Beach 1994:59; Kunen 2001:326; Treacy and Denevan 1994:96). While they tend to be rather short in length, they do constitute some of the tallest terraces (Macrae 2010:105).

Figure 5-12. Rectified isometric plan of Op.W104, showing association with Group L.

Unit W104-1 was a 2 x 1 m unit oriented 15° east of north. It was excavated to a depth of 164 cm B.U.D, and consisted of three distinct levels. This unit was situated over a single terrace-planting surface with one terrace wall, and placed in accordance with the terminal architecture of the terrace wall (Figure 5-13, 5-14). During excavation a second planting surface was revealed adjoining the retaining wall. Following the excavation of the humus and slump, the excavation unit was sub-divided into two sections. Level 3a constituted the terrace planting surface while Level 3b was the terrace wall itself. Since they were both likely constructed at the same time they all remained Level 3. This unit was excavated down to bedrock.
Figure 5-13. South-north profile of Unit Op.W104-1, facing west.

Figure 5-14. Excavation photo of Unit Op.W104-1: Left unexcavated terrace wall (Level 3), Right excavated terrace wall depicting retaining wall (level 3).

**Unit Op.W104-1**

**Level 1.** Level 1 was designated humus - non - domestic (secondary) and was situated at approximately 9 - 86 cm B.U.D. It was excavated to a depth of 22 - 93 cm B.U.D. This level was
found throughout the unit. The humus layer (Level 1) consisted of 84% fairly dry dark brown aggregate, 15% roots and rootlets, and 1% pebbles. The decision to stop this level and begin the slump was based on the exposure of the terrace walls and the appearance of a new soil horizon within the terrace beds. Ceramic analysis of this level dates to the Late Classic period (675 - 810 A.D.). Artifacts recovered from this level included a ceramic bulk lot (27/187 -005:41 I) and a lithic bulk lot (27/187-005:413).

**Level 2.** Level 2 was designated slump non- domestic (secondary) and was situated at approximately 22 - 93 cm B.U.D. It was excavated to a depth of 29 - 109 cm B.U.D. This level was concentrated around the terrace wall for there was no slump on top of the planting surface. The slump layer (Level 2) consisted of mostly 10% larger pebbles, 30% cobbles, and 20% boulders, which had fallen from the terrace walls. The matrix consisted of 25% dark brown moist compact clay, and 15% roots and rootlets. During this process, it became apparent that the terrace had undergone very little erosion and appeared in good shape. This level was excavated very slowly as to not dismantle or acquire ceramics from within the terrace walls. A very small ceramic bulk lot (27/187-005:412) was collected from this level with none of it showing any appearance of being diagnostic therefore, a date cannot be ascribed to this level.

Following the excavation of the humus and slump, the excavation unit was sub-divided into two sections. Level 3a constituted the terrace-planting surface while Level 3b was the terrace wall itself. Since they were both likely constructed at the same time they all remained Level 3.

**Level 3a.** Level 3a was designated terrace planting surface- non - domestic (secondary) and began 105 - 109 cm B.U.D. It was excavated to a depth of 121 - 126 cm B.U.D. This level was located in the northern portion of the excavation unit below the terrace wall (Level3b). The
terrace-planting surface (Level 3a) was distinguished by a change in the soil horizon and is located above the terrace wall. The matrix consisted of 90% dry dark brown soil, and 10% root and rootlets. Soil samples were collected from approximately between 115-120cm B.U.D of this layer for pedological analysis. The ceramic bulk lot (27/187-005:430) exhibited only four non-diagnostic ceramics from this layer, making it impossible to date the planting surface.

**Level 3b.** Level 3b was designated construction fill with rubble - non-domestic (secondary) and was situated at approximately 25-33 cm B.U.D. It was excavated to a depth of 85-103 cm B.U.D. This level is a terrace wall located in the southern portion of the excavation unit above the terrace-planting surface, Level 3a. This level exhibited a stone terrace wall that had only been partially deteriorated. The terrace wall consisted of a facing wall with a layer of boulders that acted to retain small fill of pebbles and cobbles. Further, there was a retaining wall of larger cobbles that bounded the interior fill to the facing wall. The matrix of this level consisted of 25% of a similar aggregate from Level 3a, with 10% roots and rootlets, 10% pebbles, 35% cobbles, and 20% boulders. Ceramic analysis of this level has prescribed the date to be within the Late Classic (675-810 A.D.) to the Terminal Classic periods (810-900 A.D.). Artifacts recovered from this level include a ceramic bulk lot (27/187-005:546), a lithic bulk lot (27/187-005:384), a groundstone - pounding stone (271187-005:423), and a groundstone- metate fragment (27/187-005:429).

**Results.** The terrace wall (Level 3b) excavated in Unit Op.W104-1 can be solidly dated to Late Classic with 54 - 58% of the ceramics dating to this period (Figure 5-15). There is also a significant amount of Terminal Classic ceramics, 23 - 24%. Operation W104 revealed Late Classic ceramics in the terrace wall. However, due to the relatively poor preservation of ceramics in planting surface of Op. W104, they were non-diagnostic and provided no chronological
information. Op.W104 was placed between Group L and Group M, both of which date solely to the Late Classic. However, this terrace excavation is also in relatively close proximity with Group B. Group B is the only settlement unit to exhibit Terminal Classic ceramics. This proximity and number of Terminal Classic ceramics from the excavation unit suggest a later and continuous use of this agricultural terrace. Op.W104-1 returned a date range within the Late Post Classic (conventional date [B.P] 458 +/- 23, 1 σ cal A.D. [1418 – 1456], 2 σ A.D. [1430 – 1448]), this falls well after the occupation of Waybil (Figure 5-16).

Figure 5-15. Ceramic frequency and Estimated Vessel Equivalent of Op.W104-1, Level 3.
Op.W104-1 presented the most well preserved terrace wall excavated at Waybil. This facilitated a distinction between the humus and slump, which is usually indistinguishable amongst the other terraces. The terrace wall construction followed the same double wall techniques. It differed from Op.W103-1 in that the double-layered facing wall utilizes much larger boulders. Further, the rear retaining wall was of a much higher construction quality with cobbles of similar size creating a well-defined, straight, wall. This was not the only aesthetic quality of the terrace wall. Upon removing the humus layer (Level 1) one of the larger facing boulders showed signs of attempts to shape the stone to create a flatter face. This supports the idea that although later, the higher degree of investment into this terrace wall was likely due to its close proximity to the site core. Operation W104 revealed Late Classic ceramics in the terrace wall. The dates of this terrace wall did not match our original hypothesis. The location of the excavation unit, close to the site core and the high quality of its appearance, suggested an early terrace construction. This hypothesis proved incorrect. However, the appearance of a small
number of ceramics that date from the Late Preclassic to Middle Classic suggests that the area was in use. This could be representative of an earlier use of the area for none terraced agricultural purposes, such as milpa practices.

**Operation Op.W105**

Op.W105 was located in the southeast sub-zone, placed within an agricultural terrace system in close association with a settlement group, Group J (Figure 5-17). This operation was located on the eastern edge of a very large contour terrace that stretched across a gently sloping valley wall. In addition to being situated within the terrace system, it was oriented to expose one terrace wall and two planting surfaces.

![Figure 5-17. Rectified isometric plan of Op.W105, showing association with Group J.](image-url)
Unit Op.W105-I was a 2 x 1 m unit oriented 228° west of north. It was excavated to a depth of 161 cm B.U.D, and consisted of two distinct levels. This unit was situated over two planting surfaces with one terrace wall, and placed in accordance with the terminal architecture of the terrace walls (Figure 5-18, 5-19). Following the excavation of the humus and slump, the excavation unit was sub-divided into four sections. Level 3a constituted the terrace-planting surface behind the terrace wall. Level 3b was the terrace wall itself. Level 3c was composed of larger fill found under Level 3a and Level 3b. Finally, Level 3d constituted a terrace-planting surface uncovered in front of the terrace wall. Since all levels were likely constructed at the same time they all remained Level 3. This unit was excavated down to bedrock.

Figure 5-18. East-west profile of Unit Op.W105-1, facing north.
Figure 5-19. Excavation photo of Unit Op.W105-1. Left, unexcavated terrace wall (Level 3), Right, excavated terrace wall, exhibiting drainage feature (Level 3c)

**Unit Op.W105-1**

**Level 1 & 2.** Level 1 & 2 was designated humus - non-domestic (secondary) and was situated at approximately 8-77 cm B.U.D. It was excavated to a depth of 19 - 89 cm B.U.D. This level was concentrated throughout the excavation unit. The humus and slump layer (Level 1 & 2) consisted of 80% fairly dry compact brown aggregate, 10% roots and rootlets, 5% pebbles, and 5% cobbles. The decision to stop this level was based on the exposure of the terrace wall as well as a change in the soil horizon indicating the terrace-planting surface. This was a very shallow level, which exhibited no ceramics and a groundstone - mono fragment (27/187-005:450). Due to the lack of ceramics, no date can be assigned to the level.

Following the excavation of the humus and slump, the excavation unit was sub-divided into four sections. Level 3a constituted the terrace-planting surface, located above the terrace
wall in the northern portion of the excavation unit. Level 3b was designated the terrace wall. Level 3c, construction fill with rubble, constituted a level of fill uncovered below the terrace-planning surface (Level 3a). Level 3d was a terrace-planning surface uncovered in front of the terrace wall (Level 3b). Since they were likely all constructed at the same time they all remained Level 3.

**Level 3a.** Level 3a was designated terrace planting surface - non - domestic (secondary) and began 18-29 cm B.U.D. It was excavated to a depth of 76-83 cm B.U.D. This level was located in the northern portion of the excavation unit above the terrace wall (Level 3b). The terrace planting surfaces (Level 3a) were distinguished by a change in the soil horizon and are located above the terrace wall. The matrix of this level consisted primarily (90%) of a dark brown moist clay, 8% roots and rootlets, and 2% pebbles. Soil samples were collected from this layer at between 60-70 cm B.U.D. for pedological analysis. Ceramic analysis has dated this level to the Late Classic (675-810 A.D.) to the Terminal Classic (810-900 A.D.) periods. Artifacts recovered from this level include a ceramic bulk lot (27/187-005:451).

**Level 3b.** Level 3b was designated construction fill with rubble - non - domestic (secondary) and was situated at approximately 27-88 cm B.U.D. It was excavated to a depth of 83-96 cm B.U.D. This level is a terrace wall located in the southern portion of the excavation unit retaining the terrace-planning surface (Level 3a). The terrace wall (Level 3b) exhibited a stone facing wall that had been deteriorated, leaving only the two course of stone sitting on the bedrock. The terrace wall consisted of this facing wall with a layer of boulders that acted to retain small fill of pebbles and cobbles. Further, there was a retaining wall of larger cobbles that bounded the interior fill to the facing wall. The matrix consisted of 20% similar clay to Level3a, 15% pebbles, 35% cobbles, 20% boulders, and 15% roots and rootlets. Ceramic analysis has
dated this level to the Late Classic (675 - 810 A.D.) to Terminal Classic (810 - 900 A.D.) periods. Artifacts recovered from this level include a ceramic bulk lot (27/187-005:462) and a lithic bulk lot (27/187-005:463).

**Level 3c.** Level 3c was designated construction fill with rubble - non- domestic (secondary) and was situated at approximately 76 - 83 cm B.U.D. It was excavated to a depth of 131 - 139 cm B.U.D. This level constitutes a layer of construction fill underneath the terrace planting surface (Level 3a) and terminated at the rear retaining wall of the terrace wall (Level 3b). It continued again after the retaining wall until the facing wall. Level 3c was uncovered after the excavation of the terrace-planting surface (Level 3a). This level consisted of a relatively shallow layer, approximately 40 - 50 cm of cobbles that lay on top of the bedrock and terminated at the back retaining wall of the terrace wall (Level 3b). The matrix consisted of 20% of a similar aggregate as Level 3a, 15% pebbles, 30% cobbles, 25% boulders, and 10% roots and rootlets. Ceramic analysis has dated this level to the Late Classic (675-810 A.D.). The artifacts recovered from this level include a ceramic bulk lot (27/187-005:377).

**Level 3d.** Level 3d was designated terrace planting surface- non - domestic (secondary) and began 144 - 152 cm B.U.D. It was excavated to a depth of 155 - 161 cm B.U.D. This level was located in the southern portion of the excavation unit below the terrace wall (Level 3b). The terrace-planting surface (Level 3d) was distinguished by a change in the soil horizon and is located in front the terrace wall (Level 3b). This was only a small portion of the excavation unit at the base of Level 3b. Soil samples were collected from this layer at approximately 155cm B.U.D. for pedological analysis. No date could be assigned to this level for the ceramic bulk lot (27/187-005:482), as only one highly weathered diagnostic ceramic sherd was uncovered.
Results. The total accumulation of excavated ceramics from Level 3 in Unit Op.W105-1 can be dated to Late Classic, with 50-56% of the ceramics dating to this period (Figure 5-20). There is also a significant amount of Terminal Classic ceramics, 29 - 32%. Although, many of the Terminal Classic ceramics can be associated with Late to Terminal Classic transition. Op.W105 was excavated in close proximity to Group N. Excavations of Group N revealed no patio floor, but did uncover a terrace-planting surface. This planting surface was dated to the Terminal Preclassic. The Group J excavations were not the only settlement excavation that revealed an underlying terrace-planting surface; these are discussed in the next section. The only result that may be considered is from the late facet Late Preclassic (conventional date [B.P] 458 +/- 23, 1 σ cal A.D. [52 – 130], 2 σ A.D. [65 – 90] [100 – 123] (Figure 5-21). However, the ceramics from Op.W105-1 date to the Late Classic with no evidence of Terminal Preclassic. Further, while the Waybil epicenter exhibits construction during this period, there is no solid evidence for terrace construction at this time. This may reflect earlier milpa farming prior to the construction of agricultural terraces or the incorporation of older material during the expedient construction of the planting surface, but this is currently lacking strong evidence.

![Ceramic Frequency Op.W105-1, Level 3](image)

Figure 5-20. Ceramic frequency of Op.W105-1, Level 3.
Figure 5-21. AMS of SOM for terrace-planting surface, Op.W103-1, Level 3.

Operation W105, revealed Late Classic ceramics in the terrace wall, planting bed, and a level of construction fill underneath the planting bed, separating it from the bedrock. The excavations exposed a double walled construction technique. In contrast to Op.W103-1 and Op.W104-1 the facing wall only exhibited a single course of stones. This is likely responsible for the high degree of slumping exhibited in front of the terrace wall. During the excavations, this slump began to restrict access to the Level 3d planting surface. However, the rear retaining wall exhibited a much stronger construction, especially near the base. This highlights the most interesting aspect of this excavation, Level 3c. Level 3c constitutes construction fill, it is found underlying the Level 3a planting surface and underlying the fill found between the two walls that comprise the terrace, Level 3b. Level 3c is composed primarily of cobbles. While excavating there was concern that this may represent an earlier terrace. However, its continuance under the terrace fill of Level 3b discouraged this hypothesis. I propose that Level 3c is representative of a drainage and water management technique. Many people are familiar with the practice of including a layer of gravel in their planting pots; this level would function in a similar fashion. As rainwater is introduced to the planting surface, Level 3a., it would percolate through the unsaturated soils creating a wetting front, often with the downward movement being no greater...
than the horizontal spread (Brady and Weil 2007:198-200). Once the water reaches the larger cobble fill, Level3c, it stops and begins to expand. This is due to the smaller micropores of the finer aggregate of the planting surface, which provides a lower matrix potential. The larger macropores of cobbles in the construction fill are full of air and produce a higher matrix potential (Brady and Weil 2007:198-200). Water in unsaturated conditions will move from a higher potential to a lower potential (Brady and Weil 2007:198-200). However, when the soil becomes saturated the matrix potential is negligible and the gravity potential rules. Thus, as the wetting front reaches Level 3c its downward movement is slowed until enough water enters the soils that it reaches a state of saturation producing similar water potential between the levels, at which point it will move into Level 3c. The inclusion of Level 3c would benefit the terrace-planting surface in three fashions. First, it will function to retain water in the planting surface. Second, it will function to increase the movement of water away from the planting surface and through the terrace wall in saturated conditions. Third, during dry periods, if water is present in Level 3c, it will facilitate its upward movement into the planting surface. This ingenious terrace management does not come without a cost. To construct level 3c would have required a significant labor investment to remove all the overlying soil to place the cobble layer.

**Additional Terrace Excavations**

As discussed, during the settlement excavations terrace-planting surfaces were occasionally revealed below the patio or in place of an identifiable plaza. In total four terrace, planting surfaces were encountered during the plaza excavations of two groups and two solitary structures. Planting surfaces were identified by clear changes in soil horizon on the same elevation as nearby terrace walls. Terrace walls were not excavated. Excavation unit WJP-1 in Group J exhibited a planting surface that dates to the Late Classic. Excavation unit WNP-1 in Group N uncovered a terrace-planting surface dated to the Terminal Preclassic. The excavation
strategy of solitary structures differed from settlement groups. Specifically, group excavations placed excavation units directly in patio. When a patio was not readily visible excavations were place adjacent to the solitary mound, occasionally in-between terrace walls. However, only one small terrace wall was excavated. The solitary structure excavations, WAV-1, exhibited a micro-terrace wall and planting surface underneath a patio that dated to the Late Classic. Unfortunately, neither the underlying terrace wall nor planting surface produced reliable diagnostic ceramics. The solitary structure excavations, WAV-1, exhibited a planting surface that dated to the Late Classic.

**Section Summary: Waybil Terrace Excavation**

The 2012 and 2013 field season provided the opportunity to conduct four separate operations that targeted both terrace walls and planting surfaces. Excavations exposed a clear planting surface behind and in front of all terrace walls confirming their agricultural use. The examination of these planting surfaces revealed that these terraces were constructed in an expedient fashion. The ceramics recovered, comparisons to associated settlement units, and terrace-planting surfaces uncovered during the settlement study provided a strong chronological framework. This revealed that the terrace systems were in operation from as early as the Early Classic to as late as the Terminal Classic period. During this long period of time, it appears that there has been a progression in the techniques for the construction and management of these systems. This begins with terraces that were clearly constructed by people with a strong understanding of the methods but lacking the intrinsic knowledge of the underlying landscape (Op.W103), and evolved to terrace systems that not only exploited the underlying bedrock but incorporated complex drainage mechanism to accommodate both the wet and dry seasons (Op.W102, Op.W.103, Op.W105). While the dates returned from the AMS of SOM were correct for the material under analysis, they did not correlate with any of the archaeological data. This
describes an issues in this method, specifically input and output rates of soil carbon and ranges in dates provided (Trumbore 2000; Wang et al. 1996). These dates are likely the result of forest fires or contamination. Overall, the AMS of SOM highlight the difficulties in dating these geointensive agricultural features and emphasize why the reliance on ceramics is so important. An assessment of terrace construction style (single or double wall) and function (terrace type) suggests little correlation with dates, suggesting a prior knowledge of agricultural terraces before construction at Waybil. In three of the four terrace excavations, Op.W102, Op.W104, and Op.W105, dates are confirmed with directly associated settlement units. Op.W103 exhibits a divergence from this trend, however, the later Group F suggests may have been constructed over the terrace wall. The further assessment of both terrace distribution and association with settlement units is explored in chapter 8. In all excavation units, soil samples were collected from the exposed planting surfaces. These soil samples were subjected to pedological tests to help understand the soil fertility and productivity.

**Archaeopedological Analysis**

The goal of the Waybil soil analysis is to evaluate the key soil qualities for agricultural production. Soil samples were all collected from clearly identified planting surfaces during excavation. Planting surfaces were defined as the soil horizon retained and accumulated by the terrace wall and used in cultivation. The anthropogenic qualities of these planting surfaces were identified lacking any construction fill and reduced stone content. All samples were removed directly from pre-cleaned excavation walls using a cleaned trowel at a level below 20 cm to avoid bioturbation effects (Wyatt et al. 2012). Samples were taken into new whirlpak bags and immediately sealed to avoid cross-contamination.

My analysis will target the soil qualities important for agricultural production including soil taxonomy, textural classes, organic matter, and trace element concentration, as well as
chemical constituents such as pH, electrical conductivity, and estimated cation-exchange capacity. Together these will help interpret interdependent soil characteristics such as soil fertility, soil moisture retention capability, and vulnerability to soil erosion. These characteristics will be incorporated in the analysis section to inform models describing hydrology, susceptibility to erosion, and crop suitability and productivity potential. All pedological analysis was conducted by the University of Florida Institute of Food and Agriculture (IFAS).

**Soil Classification**

Soil taxonomy provides a starting point to draw inferences from the generalized characteristics of the soil horizons that are found across the landscape. As discussed previously, traditionally the soils found on the Vaca Plateau have been classified within the Chacalte suite, which includes the sub-suites of Cabro, Xpicilha, and Cuxu (Baillie et al. 1993:25). These soils have been described as relatively equivalent to *Inceptisol*, *Vertisol*, and *Mollisol* in the USDA classification scheme. These classifications provide background information on soils (see Environmental Background). However, in this dissertation I am discussing the soils excavated from the terrace planting surfaces. As previously discussed, these soils have been modified during terrace construction and more than likely also during the farming practices conducted across these terrace systems. Thus, the classification of these soils under the order of anthrosols is more appropriate (Krasilnikov et al., ed. 2009:240-241). Anthrosols are described as soils that develop from significant human induced alteration and redistribution of earthen and surficial material (IUSS Working Group 2014:148; Woods 2003:3). Alterations can include, but are not limited to, irrigation and cultivation as well as the addition of organic and mineral material through waste and charcoal incorporation (IUSS Working Group 2014:147). These alterations are founded on the qualities of the original soil suites. Anthrosols can be sub-divided based on the different anthropogenic horizons that give them their classification. The soils of Waybil
exhibit a Pretic horizon. These soils are primarily formed from human activity by adding charcoal, plant residues and kitchen refuse. This result in characteristics that exhibit dark colors with high levels of organic matter and phosphorous, high contents of exchangeable calcium and magnesium, while including charcoal and/or artifacts. This description is justified by the further soil analysis detailed below.

**Texture Analysis**

Soil textural classes were analyzed using a hydrometer to describe the different sized particles in the soil; specifically, the percentages of clay, silt, and sand. Understanding soil texture, partical size and surface area, is a fundamental component of comprehending all soil processes (Brady and Weil 2007).

![Soil Texture Triangle](image)

The Waybil textural analysis revealed two independent soil textures (Figure 5-22). The terrace planting surfaces of Op.W102, Op.W103, and Op.W105 were classified as clay while the soil sample collected from Op.W104 was classified as sandy loam. The approximate bulk density of the clay soil (50 – 65%) is between 1.25 to 1.35. The sandy loam has an approximate bulk density between 1.50 to 1.60.

**pH-testing**

Soil acidity is often referred to as a Master Variable because of the broad range of influences it has on soil systems (Brady and Weil 2007:358). Soil acidity is expressed in the concentration of H⁺ within the soil solution, and expressed as active pH. The buffer pH is the value of the sample after a standard buffer solution of lime is added and describes the amount of lime that would have to be added to change the pH value of the soil sample. Understanding the pH levels is important in terms of plant growth, but also the effects it has on the soil solution and the exchangeable nutrients. Both the active and buffer pH levels of the soil samples are provided (Table 5-2).


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The soils of the planting surfaces can all be classified as slightly alkaline (pH 7.5-8), with Op.W102 and Op.W104 found just outside of the classification. Several factors contribute to this higher pH level. The high level of accumulated organic matter results in an elevated pH level because it can create soluble complexes with Ca²⁺ and Mg²⁺ and can release H⁺ ions that contain numerous acid functional groups that these ions can dissociate from (Brady and Weil 2007:359).
The less aerobic conditions of high clay content soils reduce the oxidation of nitrogen, which consumes $H^+$ ions and also increases the soil pH.

Examining the buffer pH suggests, based on proximity to pH level, that it would take a significant investment to change the pH levels of the soils. Within slightly alkaline soils, this relates to buffering capabilities of the cation exchange capacity (CEC) and precipitation absorption of calcium carbonates (Brady and Weil 2007:369). This suggests that there is either a high CEC capacity or high levels of carbonate mineral. In the Waybil soils, this relates to the high clay content and elevated levels of calcium and magnesium.

**Trace Element Concentration**

The trace element concentration within the soil samples were analyzed at the University of Florida using the EPA 200.7 chemical digestion method (EPA 2001) and an inductively coupled plasma spectrometer (ICPS) for constituent quantification. This identified the trace and ultra-trace elements within the soil. Results provide both the total available quantities and the readily available, or extractable, quantities of these nutrients (the more common values used by agricultural scientists to understand just what a crop can access under ideal circumstances). ICP analysis identified the following trace elements; Phosphorous (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Zinc (Zn), Manganese (Mn), Copper (Cu), Iron (Fe), Aluminum (Al), Boron (B), Cadmium (Cd), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Silicon (Si), Sodium (Na), Barium (Ba), Chromium (Cr) (Table 5-3; 5-4).


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</table>

*Exchangeable phosphorous ICP-EPA Method 200.7

The results of trace element concentrations can provide an avenue to question the crop production capabilities of the Waybil terrace planting surfaces. Comparing the results with general crop production requirements (Table 5-5) provides the means to identify whether the quantity of these macro and micronutrients are present in sufficient levels (Table 5-6).

Table 5-5. General Crop Production Requirements. (Servi-Tech Laboratoreis (http://servitechlabs.com/Portals/0/Submission%20Forms/interpretingreports1.pdf).

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Very Low (VL)</th>
<th>Low (L)</th>
<th>Medium (M)</th>
<th>Optimum (OP)</th>
<th>High (H)</th>
<th>Very High (VH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium (K)</td>
<td>&lt; 60</td>
<td>60-120</td>
<td>121-160</td>
<td>161-220</td>
<td>221-280</td>
<td>&gt; 280</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>&lt; 100</td>
<td>100-200</td>
<td>201-300</td>
<td>301-2500</td>
<td>&gt; 2500</td>
<td>&gt; 5000</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>&lt; 25</td>
<td>25-50</td>
<td>51-75</td>
<td>76-100</td>
<td>100-200</td>
<td>&gt; 200</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>&lt; 0.3</td>
<td>0.3-0.5</td>
<td>0.6-0.8</td>
<td>0.9-1.2</td>
<td>1.3-2</td>
<td>&gt; 2</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>&lt; 1</td>
<td>1-2.5</td>
<td>2.6-5</td>
<td>5.1-15</td>
<td>15-30</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>&lt; 0.1</td>
<td>0.1-0.2</td>
<td>0.3-0.4</td>
<td>0.5-0.8</td>
<td>0.9-1.5</td>
<td>&gt; 1.5</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>&lt; 0.5</td>
<td>0.5-1</td>
<td>1.1-3.0</td>
<td>3.1-6</td>
<td>6-10</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>&lt; 0.2</td>
<td>0.3-0.5</td>
<td>0.6-0.8</td>
<td>0.9-1.5</td>
<td>1.6-2.5</td>
<td>&gt; 2.5</td>
</tr>
</tbody>
</table>

Mobile Nutrients

NO3-N | < 5 | 6-10 | 11-25 | N/A | 26-50 | > 50 |

Phosphorus

Mehlich-3 (ICP-P) | < 7 | 8-15 | 16-26 | 27-35 | 36-50 | > 50 |
When considering the role of nutrients in terms of plant growth it is important to consider the limiting role of individual nutrients as well as their interactions (Rubio et al. 2003). Further, nutrient availability can take on two forms, acute deficiency as well as acute toxicity (Roy et al. 2006:38). To address these concerns the adherence to general crop requirements has highlighted both the very low and very high levels of specific element concentrations.

**Deficiency.** There are is significant deficiency found in the phosphorus levels across the terrace planting surfaces, although Op.W104-1 is considered low. Phosphorus is the second most limiting element on crop productivity next to nitrogen. These low phosphorus result in stunted, thin stemmed plants that exhibit delayed maturity as well as low levels of flowering and seed production (Brady and Weil 2007:596). Phosphorous has a reduced availability when compared to other nutrients, partly due to the strong aluminum and iron combinations that dominate phosphorous in lower pH levels (< 5.5) and calcium in higher pH levels (> 7.3) (Brady and Weil 2007:596; Krishna 2002:68). This is a process further compounded by higher levels of clay content (Brady and Weil 2007:618). This is supported by lower levels of these three elements in the sandy loam of Op.W104-1, which also exhibits the highest phosphorus levels. Similar, low

### Table 5-6. Level of adherence to general crop production requirements.

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium (K)</td>
<td>L</td>
<td>L</td>
<td>VL</td>
<td>VL</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>OP</td>
<td>VH</td>
<td>OP</td>
<td>OP</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>VH</td>
<td>H</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>VH</td>
<td>OP</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>VH</td>
<td>VH</td>
<td>H</td>
<td>VH</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>H</td>
<td>OP</td>
<td>OP</td>
<td>H</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>VH</td>
<td>VH</td>
<td>VL</td>
<td>VH</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>VH</td>
<td>OP</td>
<td>H</td>
<td>OP</td>
</tr>
<tr>
<td><strong>Mobile Nutrients</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate-nitrogen (NO3-N)</td>
<td>VH</td>
<td>L</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td><strong>Phosphorus</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mehlich-3 (ICP-P)</td>
<td>VL</td>
<td>VL</td>
<td>L</td>
<td>VL</td>
</tr>
</tbody>
</table>
phosphorous values (0 – 10 mg/kg) have been reported in 99% of the soil analyses conducted amongst the Caracol terraces (Murtha 2002:189).

Another element that is recorded as being low in terms of crop production is potassium, the third most influential nutrient on crop productivity. This is especially apparent in OpW104-1 and Op.W105-1, both of which are considered very low. The role of potassium within the scheme of plant productivity is to activate enzymes that are responsible for energy metabolism, starch synthesis, nitrate reduction, photosynthesis, and sugar degradation (Brady and Weil 2007:623). Without these processes plants become less resilient to external stressors, of particular importance is droughts (Brady and Weil 2007:624). Potassium is vulnerable to factors of leaching, weathering, and runoff, which can explain the lower values in sandy-loam of Op.W104-1. Further, intensive farming, with the removal of above ground parts of the plants can also significantly reduce the level of potassium in the soil, a process further exacerbated by plants removing more potassium then required for their growth (Brady and Weil 2007:628; O'Callaghan 2010:7). The potassium deficiency at Waybil stands in contrast to the Caracol terraces where new research (Murtha 2002:190) reports acceptable levels, although a degree of variation.

**Overabundance.** There are two elements that are found in very high levels within the terrace planting surfaces, iron and manganese. Both of these element become more available and develop concentration in soils that are poorly drained. Soils with high acidity and poor drainage can develop toxic quantities of these elements. The better drainage of Op.W104-1 accounts for the lower levels in Op.W104-1. Further, phosphates can act to depress iron levels in the soils, Op.W104-1 exhibits the highest phosphorous levels and the lowest Iron levels, although still
considered high. These elevated levels may be a response to the moisture retaining qualities of the agricultural terraces.

**Terraces and Trace Element Concentration.** Agricultural terracing functions to divert water laterally across planting surface which functions to disperse water amongst the field system as well as slow the downward flow, which increases soil moisture (Beach et al. 2002:379; Brooks 1998:130; Dunning and Beach 1994:56; Kunen 2001:326; Liendo Stuardo, Rodrigo Ruben Gregorio 1999; Morgan 1995:138; Rackham and Moody 1996:142; Treacy 1989:39; Turner 1974:120; Wyatt 2014:459; Wyatt 2008:56). Terraces also function to trap and retain eroded sediments to both increase and maintain the soil depth of the planting surface (Brooks 1998:125; Donkin 1979:34; Dunning and Beach 1994:58; Field 1966:11, 510; Hudson 1992:150-163; Kunen 2001:326; Rackham and Moody 1996:142; Spencer and Hale 1961:3; Treacy 1989:22; Treacy and Denevan 1994:95; Turner 1974:120). These functional characteristics of terraces bring clear benefits to farming amongst tropical soils known for their shallowness and proneness to leaching. However, the potential problems involved in this geointensive agricultural practice needs consideration.

First, increasing the depth of the planting surface provides the necessary root zone from which crops draw oxygen, water, and essential nutrients. However, with the increased depth of these planting surfaces the potential for leaching nutrients beyond crop zone is possible. This problem is potentially escalated in soils that have reduced clay content and essential nutrients prone to leaching, i.e. nitrates, sulphates, manganese, boron, and dissolved organic phosphorus (Djodjic et al. 2004; Lehmann and Schroth 2003:152-153). This process would be more prevalent during the scattered, yet heavy, rains during the dry season.
Second, constructing terrace walls to retain and increase the soils act to retain soil moisture of the planting surface by increasing the hydraulic conductivity of the soils compared to the more porous terrace wall. The double wall constructing technique evident at Waybil would further magnify this factor. The higher capillary powers of the planting surface would have encouraged the accumulation of soil moisture until near saturation, at which point it would flow into the retaining terrace wall. While clearly beneficial to provide water to crops during dryer periods, it can be problematic during the wet season with its associated frequent heavy rains. With soil subjected to consistent saturation there is increased facultative anaerobic bacteria that convert nitrate ions into gaseous forms of nitrogen, a process referred to as denitrification (Brady and Weil 2007:557). Further, with the higher clay content found amongst the planting surfaces rain water infiltration is reduced and more water accumulation on the surface occurs, compacting the planting soils. The incorporation of drainage mechanism into the construction of terrace walls suggests that the farms had an understanding of the harmful process of an overabundance of water amongst in their field systems. This is evident in other agricultural terrace excavations (Beach et al. 2002:379; Brooks 1998:132; Chase and Chase 1998:70; Denevan 2001:179; Kunen 2001:326; Morgan 1995:137; Neff 2008:52; Treacy 1989:80; Treacy and Denevan 1994:105), as well as the excavations of Op.W105 at Waybil.

**Organic Matter**

Organic matter was calculated at the University of Florida using Loss-on-Ignition (Table 3-6). Loss-on-Ignition is based on the weight difference that occurs when the soil sample is oven dried then subjected to high heat, burning off all the organic matter, divided by the original sample weight (Mylavarapu et al. 2002:11). This process generates the percentage of soil organic matter.
Understanding the amount of organic carbon has important implications for soil quality and function, especially water movement (Brady and Weil 2007:495). Soil organic matter at Waybil ranged from 2.93% to 11.35% (Table 5-7). Results suggest a high degree of variability in soil organic matter from one planting surface to another. This is confirmed when examining the results of the values presented from the nearby Caracol terrace systems at the same depth that ranged from 19 to 10% (Healy et al. 1983: Table 4) and 4.64 to 5.76% (Corrected to SOM; (Coultas et al. 1993: Table 3). Coultas et al. (1994: Table 3.4) also tested a non-terraced flat area and non-terraced steep hillside for organic carbon which presented a 1.2 to 3.8% in organic matter, considerably lower than any of the terraced soil results. These results suggest the soil organic matter at Waybil is on the higher end of the organic matter values for the region. As discussed earlier, high temperatures and seasonal precipitation can promote microbial activity and ultimately decomposition although soils that exhibit high clay and silt content such as those at Waybil increase the percentage of organic matter by promoting biomass growth, containing higher soil moisture levels (less aerobic), and by binding organic material in clay-humus complexes (Brady and Weil 2007:524-525). However, the similarities of soil organic carbon and organic matter among the terraces tested at Waybil and Caracol, and the difference between the Waybil terrace values and those from the Caracol non-terraced flat areas and hillsides are strong indicators that the terrace planting surfaces were an accumulation point for organic carbon at Waybil as elsewhere. This may have been a natural result of reduced erosion or an intentional mulching practice.

<table>
<thead>
<tr>
<th>Context</th>
<th>Lab#</th>
<th>Organic Matter (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W102-1</td>
<td>R162542</td>
<td>11.35</td>
</tr>
<tr>
<td>W103-1</td>
<td>R162543</td>
<td>5.52</td>
</tr>
<tr>
<td>W104-1</td>
<td>R162544</td>
<td>2.93</td>
</tr>
<tr>
<td>W105-1</td>
<td>R162545</td>
<td>8.42</td>
</tr>
</tbody>
</table>

Section Summary: Archaeopedological Analysis

These archaeopedological tests present the basic properties of the soils collected from the terrace planting surfaces excavated at Waybil. These soils are Anthrosols with a distinct Pretic horizon, and all exhibit a high clay and sand content with varying levels of silt. The organic matter in the terrace-planting surfaces are high compared to other non-terraced areas. These levels suggest the accumulation of organic matter amongst the terrace planting surfaces, as a result of either reduced slope or human action. Analysis of the pH level and buffer pH describe slightly alkaline soils which require a significant amount of effort to change. These characteristics described are correlated to the result of the ICP analysis of trace elements, emphasized by the relationship between the high calcium levels and pH causing a reduced level of available phosphorus. These soils are resistant to nutrient leaching due to the high clay content and organic content, confirmed by evidence of a high CEC. These same qualities would have assisted in reducing the high levels of evaporation and soil temperature that characterize tropical soils. However, if agricultural practices conducted over these soils removed the overlaying vegetation, these qualities may have been diminished and the rate of nutrient mineralization may have escalated (See Chapter 3). Thus, these soils are typically less aerobic with a high soil moisture content, but susceptible to water evaporation and nutrient deficiency if vegetation cover
is not managed appropriately. These characteristics will be expanded and play an important role when modeling soil erosion and soil suitability.

**Chapter Summary: Results of the Survey and Excavations**

This chapter presents the methods and results of the archaeological survey of settlement and terraces, terrace excavations, and archeopedological analysis of terrace soils. The archaeological survey at Waybil utilized both traditional methods as well as LiDAR to completely map all the settlement units, agricultural terraces, and water management features. The results of this survey identified 15 settlement units with eight solitary structures, a total of 615 agricultural terraces, and four aguadas. In the following chapters these results will be used to model hydrological and erosional characteristics as well as land suitability for agriculture. Further, characteristics drawn from the agricultural terrace survey will be used to identify the social organization that can be inferred from their construction and maintenance, allowing an interpretation of the fluctuation in social pressures that would have been felt by the creators and users of the Waybil agricultural terrace system.

The methods and results of four excavations that targeted terrace walls and associated planting surfaces are presented alongside their ceramic analysis and AMS of SOM. The results present the dominance of Late Classic terraces, dates confirmed by associated settlement units. However, evidence suggests the presence of a few earlier terraces that date to the Early Classic. The results from AMS dating of the SOM appear to be inconsistent with the ceramic and chronology of Waybil in general, indicative of the problems associated with applying this method amongst geointensive features. The construction methods of both the terrace walls and planting surfaces were also examined, revealing significant consistency amongst the terraces, with the further identification of a possible learning curve between the early and later terrace constructions. The results from these excavations will also be applied in the later chapters to
assess the social organization behind the construction and maintenance of the agricultural terrace systems at Waybil and the effect that the social pressure exerted from Minanha may have had on various terrace qualities.

Archaeopedological analysis of the terrace planting surfaces report the basic properties of the soils collected from the terrace planting surfaces excavated at Waybil. Soils were classified as Anthrosolos with a Pretic horizon. Although they retained the characteristic qualities of Chacalte suite. Tests also included textural analysis, organic matter content, pH levels, total elements. The result of these test present an alkaline soil that is fairly well constructed for agricultural production with a high clay and sand content that would arrest erosion, evapotranspiration, nutrient depletion, and moisture loss. These characteristics are important given that they also revealed low levels of phosphorous and potassium. When compared to the soil analysis conducted amongst the agricultural terraces surrounding Caracol, these results are fairly comparable except for an elevated organic matter content in the Waybil terraces. These results will be incorporated in the GIS modeling of susceptibility to erosion and land suitability.
CHAPTER 6
CONTEMPORARY FARMING IN THE NORTH VACA PLATEAU

Information on the contemporary farming practices and land use in the Vaca Plateau is relatively limited. In the Vaca Plateau there are 1,286 km$^2$ of nominally protected lands (Day 1993:125). Scattered around the preserves are farmlands and pastures. In 1991, over 35 km$^2$ had been deforested for citrus production and pasture (Day 1993:125); this number has only been increasing. The majority of farm lands within the Vaca Plateau are family owned and farmed making estimates of land use difficult. The growing population in west-central Belize (Day 1993:127) further complicated this.

To gain a more nuanced understanding of agricultural production in the North Vaca Plateau and identify potential analogies to the ancient Maya agricultural strategy in the Waybil region, I conducted a series of semi-structured, IRB approved (UFIRB#2014-U-0659) interviews with local farmers. Interviews were conducted by visiting the farms found around Waybil and larger polity of Minanha. While an extensive list of questions was originally derived for these interviews, they were truncated to facilitate a higher level of engagement with the interviewees.

Thus interviews were initiated with a series of basic questions:

1. Do you live on your farm?
2. How big is your family?
3. Does anyone help you on the farm?
4. How big is your farm?
5. What crops do you grow?
6. Do you leave any parts of your land untouched?
7. How do you decide where to plant every year?
8. When do you plant and harvest your crops?
9. What do you keep for yourself and what do you sell?
10. Have you had any problems with drought?
11. What problems do you have farming here?
12. Do you foresee any problems in the future?
13. Do you have any terraces in your farm?
14. Have you built any terraces?
15. Do you maintain any of the terraces?
Many questions asked were intentionally left open-ended to encourage conversation and discussion. Being able to engage in discussion with the interviewees helped to indirectly answer many of the initial list of questions. My interviews explored contemporary farming strategies, emphasizing the ancient terraces found throughout contemporary field systems. Interviews were conducted with individuals with whom relationships have been formed during their active participation and affiliation with SARP for many years. The interviewees all reported varied experience in farming from five to 35 years on farms that varied from 20 to 250 acres. They also reported different objectives and plans that informed their farming strategies. Despite this diverse interview group and responses, several important trends and notes can be identified. These are broken into agricultural strategy, production concerns and problems, and information about the relic terraces.

**Agricultural Strategy**

Interviews revealed two complementary agricultural strategies. First, all of the farmers had a parcel of land set aside for the production of a suite of corn, beans, and/or squash (Table 6-1). The yields from which were in all cases saved for family consumption. All interviewees reported a degree of field rotation due to increasing degradation of soil and reduced production. However, the scheduling, pattern, and length of fallow of milpa movement varied. Further, most of the seeds were collected from the past year’s crop.

Second, six of the eight farmers had a separate plot of land dedicated to the production of vegetables or *Colocasia esculenta*, locally known as taro, destined for sale. When discussing labor distribution between the milpa and household garden every interviewee reported having to invest a significant amount of time working within the garden, more than the milpa. The two farmers who did not have a dedicated vegetable garden stated that it was too much work. For the most part all the seeds for garden production were bought in town.
In addition to these two plots, all but one of the interviewees reported to varying degrees the use of arboriculture, in order to producing a large suite of fruits for sale and consumption. These plots included banana, plantain, mango, avocado, soursop, and sapodilla. Further, two interviewees also reported planting timber products. Further, all interviewees that lived full time or for extended periods on the farm reported leaving areas free of farming to collect natural products, primarily wood for household consumption and building material. However, one of these interviewees’ was hired to work the farm in the place of the owner.

Table 6-1. Reported agricultural production by field system.

<table>
<thead>
<tr>
<th>Milpa</th>
<th>Household Garden</th>
<th>Arboriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>Taro</td>
<td>Palm</td>
</tr>
<tr>
<td>Beans</td>
<td>Sweet Pepper</td>
<td>Banana</td>
</tr>
<tr>
<td>Squash</td>
<td>Tomatoes</td>
<td>Soursop</td>
</tr>
<tr>
<td>Yams</td>
<td>Cabbage</td>
<td>Coconut</td>
</tr>
<tr>
<td></td>
<td>Cauliflower</td>
<td>Avocado</td>
</tr>
<tr>
<td></td>
<td>Onion</td>
<td>Plantain</td>
</tr>
<tr>
<td></td>
<td>Okra</td>
<td>Orange</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mahogany</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Teak</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cedar</td>
</tr>
</tbody>
</table>

Production Concerns and Problems

Typically, farmers are using milpa, slash and burn, techniques to clear the land. Two interviewees expressed concerns about the increasing deforestation that has resulted throughout the region because of lumber harvesting, and clearing land for livestock pasture and to a lesser degree farms. Two interviewees that lacked access to the flatter lands of the valley bottoms were concerned with erosion. One of these individuals was currently testing his fields by planting and clearing in different areas to test erosion levels. Another farmer reported leaving clumps of standing vegetation along steep areas to help prevent erosion. Four individuals voiced concerns over the annual fluctuations of the dry and wet season, particularly in regards to planting.
All farmers described a significant variation precipitation from year to year. This was not limited to the lack of rain, but also too much rain. These concerns were directed at both planting and harvest loss. It was reported that if it was too dry, seedlings would wilt and die, especially if located along the hillsides. Alternatively, if there was too much rain seedlings would also suffer, especially if planted in the lowlands and valley bottoms. Several solutions were discussed to deal with climatic and weather fluctuations. When there was too little water, seven farmers reported hand irrigation drawing on their local spring that held water year round. When there was too much water, two farmers reported digging trenches to assist with drainage. While three farmers reported avoiding low-lying areas during the especially wet years. Second to these concerns were difficulties encountered trying to bring surplus to the markets and disputes over land ownership with other farmers and the government.

**Relic Terraces**

Discussing the relic agricultural terraces that are found throughout the contemporary field systems with the local farmers revealed several insights. Six farmers stated that they targeted these areas for *milpa* fields, because they are able to plant in those fields for multiple seasons before leaving it to fallow and because these fields provided a degree of water security. Two farmer that did not follow this trend were located in flat areas and reported only small terraces scattered in their property. The interviewee that was testing for erosion across his fields described how terraces usually had much better soils with higher moisture content then other areas, so much, so that he could see the difference in production and based his crop distribution on it. This is collaborated by the farmers who assisted in the terrace excavations, occasionally taking home the excavated for household gardens. Interviewees also noted some drawbacks, stating that they never maintained or constructed terraces due to the lack of available labor and time to make such an investment. One farmer reported exploiting terraced lands but never had to
maintain them. Only one interviewee was an exception, and he had built up several terrace walls on hillsides to stop erosion. Another interviewee summed up his opinion of the relic terraces “Thank the Maya for coming ahead and building them all”.

Chapter Summary: Contemporary Farming in the North Vaca Plateau

This chapter describes the methods and results of a small series of interviews conducted amongst the local farmers of the North Vaca Plateau. The results describe contemporary farming practices that include targeting low-lying valleys for farms, elevated concern over too much and too little water then long term droughts, and the division between commercial gardens and consumption milpas. Interviewees showed interest in agricultural terraces but rarely reported building or maintaining due to a lack of labor. These results will be incorporated into this dissertation in terms of both analogy, but also to assess the feasibility of terrace farming in the North Vaca Plateau.

The results from these interviews provide the insight to allow better interpretations of the archaeological record. Several results are particularly interesting. First, while most researchers have described the in-field/out-field farming practice, these generally argue that the in-field supported household consumption while the out-field production was for commerce. Surrounding Waybil the farmers reported instead that the household garden is used for commercial purposes and the outfield for household consumption. Second, interviewed farmers were primarily concerned with the seasonal variation of water availability - and were just as concerned with dry periods as wet periods as well as the seasonal predictability of water. This suggests that, unusual year-to-year patterns in precipitation are an important consideration for farmers cropping in the past. As discussed the interviewees took advantage of local springs, topography, and planting techniques to combat annual fluctuations. However, in contrast to the concerns to annual fluctuations, little was mentioned in terms of long-term droughts or climate
change. The next greatest concern for the modern farmers were also likely the same as for the ancient farmers - the difficulties of cropping for a surplus to support commercial activities.

Third, nearly all the farms were found within the low-lying flat lands of the valley bottoms, those that included hillside expressed concerns about erosion or actively fought it. Fourth, seven of the eight farmers reported access to active springs. This suggests the continued importance of springs in the North Vaca Plateau and the targeting of surrounding areas for agricultural fields. Similar to both the ancient Maya settlement pattern and relic terraced fields investigated in the Contreras Valley Finally, all interviewees understood the values of the relic terraces in their fields, and preferentially used them to counteract problems with erosion and drying, but none could afford to invest the time or labor to build or maintain them. The restricted ability to invest labor in the construction and maintenance of agricultural terraces by the informants provides insight into the requirements that the inhabitants of Waybil would have need to invest in their own terraced field systems. Results suggest that it would have required the collaboration of more than one household to generate dedicate the labor required to construct or even maintain a terraced field. This has important ramification when considering the social organization behind the construction and maintenance of the relic terraced field systems found prolifically in the North Vaca Plateau.
CHAPTER 7
ESTABLISHING EVIDENCE FOR LOCAL PRECIPITATION VARIATION AS A SOURCE
OF PRESSURE ON THE WAYBIL AGRICULTURAL SYSTEM

Regional and Local Climatic Sequence

As described, reconstructing past climates is a developing field with a multitude of data
and methods applied over a broad area. The benefit in this diversity is the availability of local,
refined, small-scale reconstructions and an ability to draw on the multiple datasets to describe
larger, general, paleoclimatic trends experienced across the Maya area. Within the past decade
there have been a number of studies to compare the datasets (Akers et al. 2016; Beach et al.
Wahl et al. 2016). The majority of these studies draw on the datasets from the Macal Chasm
(Akers et al. 2016; Webster et al. 2007), Tzabnab Cave (Medina-Elizalde et al. 2010), Rio
Secreto (Medina-Elizalde et al. 2016), Yok Balum Cave (Kennett et al. 2012), Laguna Puerto
Arturo (Wahl et al. 2014), and Lake Chichancanab (Hodell et al. 1995; Hodell et al. 2012; Hodell
et al. 2005). Less frequently used sites include Lake Salpeten (Beach et al. 2015), Laguna Yaloch
(Wahl et al. 2013), as well as Lago Paixban and Lake Peten-Itza (Wahl et al. 2016). Difficulties
that are encountered when conducting comparative research are found in the varying levels of
precision of climatic data, chronological sequences, variation in level of resolution reported for
the various proxies, and the distance between study areas.

As work continues in the Maya area there is an increasing emphasis on local paleoclimate
reconstructions because of the evidence of regional climatic variability and non-uniformity
(Figure 7-1 (Akers et al. 2016:285; Douglas et al. 2016b:18; Iannone, ed. 2014). Over the last
decade collaborative studies in the North Vaca Plateau have focused on geologic, geomorphic,
and speleologic data to reconstruct past local weather conditions linked to regional climate trends
(Brook and Akers 2010; Iannone, ed. 2014; Polk 2010; Reeder 2010; Webster 2000). James
Webster collected the MCO1-E stalagmite from the Macal Chasm in 1996 as part of the Northern Vaca Plateau Geoarchaeology Project (NVPGP (Brook and Akers 2010; Reeder et al. 1996; Webster 2000; Webster et al. 2007). Recently the MCO1-E stalagmite was resampled targeting the period of ancient Maya occupation (MC01 stalagmite: Akers et al. 2016; Akers 2011). This analysis was conducted in order to combine earlier analysis of the same stalagmite by Webster (2007) and refine multi-proxy identification of annual wet and dry periods in the North Vaca Plateau during the occupation of Waybil. The Macal Chasm is located 9 km southwest from Waybil.

![Mean Timing (cal yr BP)](image)

<table>
<thead>
<tr>
<th>Regional MDE</th>
<th>MCO1-E MDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1175 – 950 B.C. (±120)</td>
<td>1100 – 900 B.C.</td>
</tr>
<tr>
<td>N/A*</td>
<td>600 – 550 B.C.</td>
</tr>
<tr>
<td>N/A*</td>
<td>200 – 100 B.C.</td>
</tr>
<tr>
<td>150 – 300 A.D. (±140)</td>
<td>250 – 350 A.D.</td>
</tr>
<tr>
<td>750 – 875 A.D. (±80)</td>
<td>750 – 900 A.D.</td>
</tr>
<tr>
<td>1000 – 1175 A.D. (±110)</td>
<td>1050 – 1200 A.D.</td>
</tr>
</tbody>
</table>

*MDE only identified in the MCO1-E

Figure 7-1 Major Dry Events (MDE) identified in paleoclimatic data drawn from Macal Chasm and compared to data from Tzabnab Cave, Rio Secreto, Yok Balum Cave, and Lake Chichancanab, calculated for both beginning and end mean ages [Modified from Akers et al. (2016:Table 4)].

Since I will draw on this data to model Waybil hydrology, susceptibility to erosion, and crop suitability and productivity potential under conditions of differing precipitation, I will first address the specific limitations of the MCO1-E stalagmite for precipitation data. The MCO1-E stalagmite lacked the $\delta^{18}$O equilibrium necessary to pass the Hendy tests (Webster et al. 2007), a likely effect of the close proximity of the stalagmite to the cave entrance shaft and the
subsequent effect of kinetic factors on the speleothem growth. The resampling of MCO1-E was done to reassess the utility of this speleothem as a predictor for precipitation. The authors argue that the correlation between isotope types does not indicate a lack of interpretive power for the speleothem, and they argue that these environmental variabilities acted to amplify, rather than negate, proxy variation of wet and dry periods (Akers et al. 2016:269). While this failure of the $\delta^{18}O$ data to accurately track moisture limits our ability to draw direct correlations between isotope levels and precipitation, as was attempted in the Yucatan by Medina-Elizalde et al. (2010; 2012; 2016), the corroboration of other proxies of the wet and dry trends shown by the oxygen isotopes indicates that this speleothem is a useful source of precipitation information despite the negative Hendy test (Akers et al. 2016; Webster et al. 2007). However, the presentation of the different datasets for the MCO1-E speleothem at varying levels of resolution is also an area of concern (Iannone et al. 2014a:275).

Akers and colleagues use the Macal Chasm speleothem reinterpretation to track major dry events in the history of the Vaca Plateau (Akers et al. 2016:Table 4). They have identified six major dry events (MDE) across the period of Maya occupation that correlate well with interpretations in other areas of the Maya world. MDEs are defined as a multi-decadal period of dryness that maintains levels of $\delta^{18}O$ and $\delta^{13}C$ of 1-3‰ greater than the times before and after the dry period, coinciding with both lower UVL values and petrographic evidence of dryness (Akers et al. 2016:274). It is important to note that MDE are not necessarily singular period of sustained dryness, but rather, an average preponderance of dryer years, often punctuated by brief wet years (Akers et al. 2016:278).
The transition from the Early Preclassic to the end of the Middle Preclassic began as relatively wet. This period started to dry after 1000 BC, ending the last 250 years as a dry period. After which the transition into the Late Preclassic, 400 BC to 100 A.D., returned to wet conditions. Following this wet period, the transition from the Late Preclassic into the Early Classic exhibits a MDE, this continued until the early half of the Early Classic (Akers et al. 2016:282; Iannone et al. 2014a:286-289). This MDE appears younger in the MCOE-1 record when compared to the regional climate model. Akers et al. (2016:281) describes chronological uncertainty in local data at this specific time period and recommends adhering to the regional description of 150 – 250 A.D. This MDE period exhibits two peaks in intensity at the beginning
and end of the event, given the dating difficulties of this period specific dates are problematic. During the latter Early Classic and into the early facet of the Late Classic the climate was in an equilibrium between wet and dry, although subjected to fluctuations (Akers et al. 2016:284; Iannone et al. 2014a:289). The late facet Late Classic exhibited a MDE period that began in 750 A.D. and continued through the Terminal Classic and ending shortly after the onset of the Early Postclassic, 925 A.D. (Akers et al. 2016; Iannone et al. 2014a:290). This 175 yearlong MDE was punctuated by a brief wet period between ~ 800 – 825 CE, with intensity peaks directly before and after (Akers et al. 2016:281). The MCO1-E results confirm the regional datasets for a MDE within this time frame. After a short relatively wet period during the Early Postclassic, a very dry MDE period occurred again (Akers et al. 2016; Iannone et al. 2014a:295). Dating from 1050 – 1175 A.D., this MDE was the most intense recorded by the MCO1-E stalagmite (Akers et al. 2016:280). The ability to draw on the local and high resolution climatic data provides strong chronological connections to the archaeological record and paleoclimatic sequence (Akers et al. 2016; Iannone et al. 2014a). This highlights that the climate was never stable or consistent for very long; even during stretches of MDE there were fluctuations.

**Predicting Precipitation**

Predicting the precipitation level within the North Vaca Plateau will play an important role in this dissertation, as it will be a primary environmental pressure exerted on the agricultural strategy at Waybil. Developing a prediction of precipitation within the North Vaca Plateau raises several concerns, similar to construction regional climatic sequences, issues include resolution, dating, and site-specific characteristics. The predictions used in this dissertation present an annual maximum of 3,000 mm and minimum of 1,700 mm, with the average of 2,500 mm. These values are representative of contemporary precipitation level, based on the TRMM satellite imagery. There are several justifications for using contemporary rainfall levels. With the given
the difficulties quantifying precipitation level in the paleoclimatic data using a robust contemporary levels negates many assumptions that would need to be made. When compared to the paleoclimatic reconstructions the modern annual average falls generally within the reported error range (see discussion below). The specific precipitation levels are only used directly in GIS modeling to identify how agricultural terraces mitigate changes in precipitation, discussion of past climatic changes are automatically reduced to inferences of wetter and dryer periods when considering rainfall due to the resolution and reliance on the MCOE-1 speleothem. For these reasons, the direct correlation to contemporary rainfall is not only justified and an informed approximation of the past, but more importantly, it can be directly applicable to the modern farmers in the Vaca Plateau today. The following section will outline the relation between contemporary and past precipitation regimes.

To date the only quantification of past precipitation estimates constructed on δ^{18}O in the Maya area are based on the Chaac speleothem (Douglas et al. 2016a:626; see Medina-Elizalde et al. 2010). Medina-Elizalde (2010:257) reports a strong correlation (linear regression values: r= -0.62, P= -0.023, root mean square error of the calibration of ±81 mm/year) for modern annual precipitation between the δ^{18}O of the most recent strata of the Chaac speleothem and the recorded δ^{18}O values from the International Atomic Energy Agency (IAEA) meteorological station in the Yucatan Peninsula. Based on the modern correlations, Medina-Elizalde et al (2010: Fig 6) show that during periods of extreme drought in between 800-950 A.D., precipitation was reduced between 36% and 51% of modern annual mean precipitation. Recently, Douglas and colleagues (2016a) have reevaluated these results suggesting that given the difference in variation of the Chaac and modern δ^{18}O, early estimates were too narrow. Rather, upon reanalysis the error rates were expanded to ±160 mm/year during the years between 800 – 950
A.D., equivalent to 14% of modern annual precipitation (Douglas et al. 2016a:627). These new values can be compared to the recorded average annual precipitation level of 1,000 mm in the Yucatan, near the cave where the Chaac speleothem was removed (Figure 7-3).

![Graph](image)

**Figure 7-3.** Correlation between Chaac $\delta^{18}O$ values and precipitation (mm/year) with the contemporary average annual rainfall in central Yucatan (line). [Data from Douglas et al. (2016a: Figure 6); Douglas et al. (2015); Luzzadder-Beach et al. (2016: Figure 1); Medina-Elizalde et al. (2010: Figure 6); Pérez et al. (2011)].

While the data for direct comparison between past and present rainfall is not available, what is clear is that the contemporary levels generally fall within 100 mm past average. Wetter periods recorded in by the Chaac $\delta^{18}O$ range from 1,150 to 1,300 mm (Medina-Elizalde et al. 2010:257), all of which fall above the recorded modern average for the area. Dry periods range from 537.6 to 716.8 mm, which fall below the comparison to the modern averages for the area. A study in the Northwest Yucatan, Ria Lagartos, confirms this trend. Carrillo-Bastos et al. (2013) analyzed fossil pollen as a proxy for past precipitation levels. Results presented an annual average of 850 mm, standard deviation of 66 mm, over the past 3,800 years (2013:6). This study
was conducted in the driest part of the Yucatan with an average annual rainfall of 760 mm (2013:2), suggesting the past reconstruction within 24 mm of average contemporary levels. The results from these studies indicate that estimates of quantified past precipitation values and error ranges encompass the variation of the contemporary record. The question remaining is if these results are transferable to the North Vaca Plateau?

Pollock et al. (2016) analyzed the CHO4-02 speleothem from Chen Ha cave in the Vaca Plateau in order to identify the possible variability between modern and mid-Holocene precipitation levels. A correlation test of δ\textsuperscript{18}O between the CHO4-02 and the IAEA meteorological station in the Yucatan Peninsula, the nearest weather station that recorded δ\textsuperscript{18}O values of rainfall, presented a strong correlation between modern records (r\textsuperscript{2} = 0.723, p= 0.005), similar to that recorded in the Chaac speleothem (Pollock et al. 2016: Supplemental). Based on the correlations with the Chaac study, the authors used the δ\textsuperscript{18}O values recorded in the CHO4-02 speleothem to estimate ancient precipitation. CHO4-02 presents an average δ\textsuperscript{18}O value of -5\%\textsubscript{o} (± 0.6\%\textsubscript{o}) with a range of -3.5\%\textsubscript{o} to -7\%\textsubscript{o} for the mid-Holocene (~4,968 to 2,756 B.C.). This can be compared to the modern average δ\textsuperscript{18}O value at Chen Ha Cave of -3.9\%\textsubscript{o} with a range of -3.6\%\textsubscript{o} to -4.2\%\textsubscript{o} and the nearby Macal Chasm value of -4.38\%\textsubscript{o} (Pollock et al. 2016:108; Webster 2000:190). Results suggest that the mid-Holocene was wetter than early and late Holocene, an interpretation confirmed by other paleoclimatic studies (Hodell et al. 1995). More relevant to this dissertation study, if correlation of δ\textsuperscript{18}O and precipitation levels is accepted, the mid-Holocene presented an increase of ~200 mm of annual precipitation over the early and late periods, or put another way, the late Holocene was, on average 200 mm drier per year than the mid-Holocene. This suggests that the average annual precipitation of the ancient Maya paleoclimate and the modern estimates fall within a 200 mm variance, a range of error consistent
with nearly all the quantitative estimate of paleoclimate precipitation levels. The result of this comparative discussion of precipitation estimates and degrees of error justifies the use of a 2,500 mm annual average precipitation based on the modern TRMM records as interpreted by Akers et al (date). However, a justification of the variance between the wet and dry periods still needs to be addressed.

The range between wet and dry periods used in this dissertation, 3,000 to 1,700 mm, are based on Akers’ derived modern precipitation levels. This suggests that a severe drought (only 1,700mm of rainfall) results in a 30.2% reduction of rainfall from the average 2,400 mm. This value falls within the lower reaches of the range suggested by Medina-Elizalde et al. (2010) during the recorded drought from 800 to 950 A.D. However, the more recent reanalysis of the Chacc data by Douglas et al. (2016a:627) expand the original precipitation variation to 20-65%, placing Akers’ estimated decrease based on modern records almost in the middle of the Douglas re-evaluation of the Medina-Elizalde estimates. When considering above average wet periods Akers’ estimate (3000mm) based on modern data suggests a 20% increase from the average. This is within the ranges identified within the Yucatan, which describe wetter periods as a 15 – 30% (Medina-Elizalde et al. 2010:257) or 20% (Medina-Elizalde et al. 2016:97) increase in precipitation from the modern average. Thus, again, the Akers’ estimate fits well within these other estimates based on the paleorecord. Therefore, the estimated impact of dry and wet years employed in this dissertation are within an acceptable range based on the paleorecord and can be considered reasonable for purposes of modeling local weather variations based on regional climate records.
CHAPTER 8
DEFINING SOCIAL PRESSURE AT WAYBIL

Waybil's association with the Minanha polity provides an opportunity to explore the links between the demands of a growing capital and a nearby minor center. Many years of excavation have shown that the occupation pattern at Waybil and other subsidiary centers were intertwined with the fortunes of the residents of the Minanha polity of which they were part (Figure 8-1).

Figure 8-1. The Major center of Minanha with subsidiary minor centers within a 7 km buffer (Modified from Barry [2014:Figure 3.7]).
After an initial occupation in the Late Preclassic Period (B.C. 400-A.D. 250), the Minanha royal court was established during the Classic Period (A.D. 250-810). During the Classic period, this region was a polity or interacting political unit, with the capital situated at the Minanha royal court with several subsidiary settlements and dispersed populations (exemplified by the Contreras Valley area sampled by the SARP) in the periphery. The immediate political and economic reach of the new royal court encompassed a territorial range of seven kilometers and had a profound effect on this territory. The subsidiary settlements found within the polity, including Martinez, Waybil, and even the small and dispersed settlement of the Contreras Valley generally followed a similar trend of florescence in the Classic period (Barry 2014; Macrae 2010; Schwake et al. 2011). Archaeological research in the polity has shown increased construction during the Classic period in the epicenter and site core of the capital of Minanha, but also in the agricultural regions of the subsidiary sites and dispersed valley settlement. Iannone has proposed this increased construction outside the capital site was a response by the support populations to meet the needs of the developing Minanha bureaucracy (Iannone et al. 2010; Iannone 2005; Schwake and Iannone 2016). During the Late to Terminal Classic, the royal court complex at the capital site underwent three “destruction events” and was abandoned in stages during the Terminal Classic and Early Postclassic (810-1200 A.D. (Iannone 2005; Schwake and Iannone 2016). However, several of the earliest settlement groups of the polity outlasted the capital royal court, surviving these political fluctuations (Lamoureux-St-Hilaire et al. 2015). Armed with the occupation sequence of the North Vaca Plateau (Chapter 4) a discussion of how the changing socio-political and socio-economic influences affected the development and ultimate abandonment of Waybil and its agricultural terraces.
Defining the Waybil Occupation Sequence

Permanent, large-scale, occupation in the North Vaca Plateau during the Late Preclassic period is limited in the archaeological record. The scattering of ceramics at Minanha and Martinez suggests that there were people living within the region in unidentified settlements. However, it is during this period that the larger site Ixchel exhibits the first evidence for kingly trappings. Waybil at this time lacks any evidence for residential settlement units, but does exhibit a significant investment in its ceremonial epicenter. This suggests that the site held a significant ritualistic role within the community of the North Vaca Plateau. A role that may have satisfied needs of a dispersed population in the surrounding region, including Minanha.

Within the North Vaca Plateau, fresh water is a scarcity. This has led to the identification of several of the earliest sites near perennial springs and good agricultural lands (Longstaffe and Iannone 2011; Macrae 2010; Macrae and Iannone 2010). If these natural features were a focal point for occupation, then settling of the North Vaca plateau likely followed a theme of “saltation” (Iannone et al. 2014b). Saltation or leapfrogging refers to a progress of migration wherein locations of particular value, for example fertile soils and springs, are inhabited first, leaving less desirable and ultimately less productive lands vacant as people leapfrogged to new more desirable lands (see Earle et al. 2011; Van Andel and Runnels 1995). When examining agrarian populations who employed low-intensity agricultural strategy they tend to be dependent on the fertile soils found in alluvial valleys (Earle et al. 2011:209). In the North Vaca Plateau, this equates to the accumulated soils found within the interfluvial valleys, with the additional demand for water access. Given the scarce nature of these resources, the settlement pattern during the Terminal and Late Preclassic would have been dispersed. This narrative falls in line with the larger portrayal of Preclassic Maya practicing milpa farming in transient communities. This is supported by evidence of increasing levels of deforestation and agricultural practices.

Waybil does not offer the close proximity to a water source, and thus would not have been targeted as a prime agricultural settlement. However, with the construction of a radial temple, Structure AI, located in the southern side of what would become the principal courtyard, Iannone has suggested that Waybil functioned as a meeting place for both religious and social purposes, as well, potentially, as economic reasons. Structure AI exhibited a Late Preclassic stair-side stucco mask, which depicted the shark aspect of the sun god (Iannone 2017). The placement of masks alongside the temple staircases has been interpreted as being representative of powerful natural forces such as sun, earth, underworld, or sacred mountain (Lucero 2007:412; Marcus 2003:85), or “founders of the community and ... sacred manifestations of the Otherworld” (Freidel et al. 1993:443).

During the Terminal Preclassic Minanha exhibits its first ceremonial activities within the site core. Further, in the nearby Contreras Valley, pioneer settlement units begin to appear. These lineages based groups would have been representative of the dispersed settlements moving into the valleys near Minanha, exploiting the deeper soils and nearby springs, even maximize their lands with agricultural terraces (Macrae and Iannone 2010). The increasing occupation and importance of this region within the North Vaca Plateau may have been reflected at Waybil by the careful entombment of the antepenultimate temple and stucco mask with the larger penultimate structure. This is not a destruction event, but rather the continuation and possible
change in the meaning of the ritual function represented by this isolated shine. The careful interment of the mask may represent an iconographic shift “from the supernatural world to rulership, where gods were conflated with royal lineages” (Lucero 2007:412; see Sharer 1994:125).

The importance of Minanha increased into the Early Classic evident by the expanding epicenter, first settlement groups in the site core, and enlargement of the settlement units in the Contreras Valley. This growth may be related to hiatus and destruction event at Ixchel. It is also possible that during this period we see a slowly emerging new function that Waybil will play within the community of the North Vaca Plateau. With the developing Waybil epicenter there was the addition of a range structure to Group A, structure AV, which exhibited a large open platform on top of the structure (Iannone 2017; Schwake et al. 2013a:140). The interpretation of this structure AV as a storage building, the appearance of the first agricultural terraces, and the prevalence of low numbers of Early Classic ceramics in the terrace walls and planting surfaces indicates that the fields surrounding Waybil may have been in use at this time. Given the close proximity of the growing agrarian population in the nearby Contreras Valley, within 2 km, Waybil may represent that extensification of agricultural strategy employed by the population surrounding the developing Minanha center. Waybil, while lacking direct access to a perennial spring, exhibits significantly less topographic undulation than the Contreras Valley making it attractive for the expansion of milpa farming. The identification of outfields in the North Vaca Plateau and neighboring regions has been difficult given both their ephemeral nature and the fact that Late Classic expansion of agricultural terracing and settlement densities obscures the possibility of identifying these earlier extensification practices (Chase and Chase 1998:61; Drennan 1988:285-287; Wyatt 2008:301). Chase and Chase (1998:61, 71) argue that the
increasing population and labor investments in intensive agricultural practices at Late Classic Caracol replaced the use of outfields. Wyatt (2008:301) suggests that the large tracts of undeveloped land surrounding the Chan site may have been outfields, however, further excavations would be required to make a confident statement. At Waybil the construction of a storage building, appearance of early terraces, and ceramics amongst the fields, makes a stronger argument for the use of the lands surrounding Waybil as an outfield for the agrarian population surrounding Minanha. With the new addition of Structure AV, Waybil appears to have gained a more administrative and economic role in addition to its earlier role as the ceremonial gathering place.

The Contreras Valley is the center of attention during the Middle Classic, while the Minanha epicenter and site core remained fairly stable, the settlement in the Contreras Valley exploded. During this period, the number and size of settlement units expanded. In response, the agricultural terracing expanded and arable lands was maximized as new settlement units targeted hillside and peaks. As populations grew, the earlier settlement were laying claim to lands by investing in the landscape with agricultural terracing. At this time Waybil exhibits the beginning of what will become its first and longest occupied residential unit, Group B. Group B, located adjacent to the central courtyard, experienced two flooring events and an associated simple crypt burial (BIII-B/1) (Schwake et al. 2012:73). In addition, the sealed chultun, Op.W100-1, revealed Middle to Late Classic ceramics (Iannone et al. 2011c:108-111). The lack of any ritual or burial material within this chultun suggests its use to store perishable material, indicating the continued importance of storing agricultural surplus at Waybil.

During the Late Classic, Waybil experienced its most dramatic growth with the construction and expansion of all the settlement units. During this period, structure AI
experienced its terminal construction with the addition of two simple crypt burials within the structure (AI-B/1) and within the new central courtyard (WAP-B/1). Further, evidence suggests that all the agricultural terraces visible at Waybil were constructed and in use during this period. Why did this expansion occur? This is the same period of time the royal court is established at Minanha and the occupation of both the site core and Contreras Valley reached its maximum extent. While Ixchel exhibited a continued expansion, although by the late facet Late Classic all construction projects had been abandoned. Regional studies indicate that Waybil was a target for the centralization of the expanding agrarian landscape of the newly established Minanha royal court.

The apparent transformation of Waybil begs the question of why this location was chosen? The early use and conception of Waybil within the community of the North Vaca Plateau would have instilled a sense of place within people. This idea draws on Heidegger’s (1977) dwelling concept, but more applicable the writings of Basso (1996) and Jojla (2006). Heidegger (1977) describes how dwelling develops a lived experience and consciousness within which people perceive and interact with a place and the related aspects of its surrounding landscape. This is further elaborated by the process of interanimation that is related to fact that familiar places develop an inherent value and meaning within the minds of the people who experience them (Basso 1996:54). Meanings and values that are created by the actions of the people within the landscape, often reinforced by community related activities (Basso 1996:57). In this manner the landscape becomes internalized as a fluid “sense of place”, constantly reconstructed by the actions of the community. Over time, these mentally created places play a greater role in community unity and identity than the actual geographical location, ultimately becoming resilient forgetting (Basso 1996:85). This can act as an anchoring mechanism between
people and the place. Jojla (2006:94) describes how even when a place changes its meaning can still continue or alternatively, meanings can change while the place remains the same (see also Barrett 1999). Thus, even if a place changes people still carry with them their own internal place, either representative of the original creation or something modified over time. From this perspective, even though the physical manifestation of ceremonial activities at Waybil had been transformed, the community still maintained a mental, internal, connection to the place. As time progressed and Waybil changed this sense of place was likely modified, but the connection between the people and landscape remained.

From the perspective of the Minanha royal court, Waybil would have been an attractive place for the incoming and expanding population from Minanha. The site was attractive for its close proximity, administrative capabilities, potential use as an outfield, and inherent historic meaning as an important place. The Late Classic Minanha royal court legitimized their ties and rule over Waybil by tapping into the ancestral heritage and ritual function of the site through the placement of two burials in association with the long-used shrine structure in the epicenter (Hills et al. 2012:42-45; Iannone et al. 2011a:105-108) and potentially also by installing an elite/court administrator. Similar legitimization processes are visible in the Minanha epicenter (Schwake and Iannone 2016:140; Schwake and Iannone 2010). These connections may have been strengthened connections with its administrative minor center in the form of tribute demands or taxes to support the ambitious construction projects in the epicenter. The increasing population at Waybil would have also placed addition stress on this minor center. In response, Waybil inhabitants may have invested in increasing its agricultural production through the construction of agricultural terraces. An agricultural practice that was already in place in select areas around the site but also a technique familiar to incoming agrarian people and potential administrative
elites from Minanha. While originally neglected as a site for intensive agricultural production, likely due to the lack of a reliable water source, the heavy investment in geointensive agricultural features may have also included the construction of several water management features such as the four aguadas evident at Waybil. This was similar to the aguada modification at Minanha (Philpot 2012:90-91). This expanding administrative control from the Minanha royal court is also evident by the construction of the Martinez eastern shrine complex. While this site would not have acted as an authentic E-group due to its placement within the valley bottom, with hills obscuring the actual astronomical observations (Schwake et al. 2011:90), it would have provided a locus for control. Schwake and Iannone (2016) describe how the new ruling elite at Minanha was tapping into the ancestral community power by physically connecting new buildings with ideologically charged locations. Schwake et al. (2011) believes the construction of the Martinez eastern shrine complex could represent the extension of the Minanha rulers control into the countryside by building ideologically charged architecture. This same process would have been utilized at Waybil, evidenced by the interment of burials AI-B/1 and WAP-B/1 (Hills et al. 2012:42-45; Iannone et al. 2011a:105-108).

The abandonment of all settlement units constructed during the Late Classic and continuation of earlier settlement units, suggests that there was a relief of pressure on Waybil. This could be related to the final collapse of the Minanha royal court and its increased social and economic demands or it could be a failure in the agricultural systems that the Waybil farmers invested so heavily in. The ephemeral use of Waybil during the Terminal Classic would suggest a complete abandonment. However, the early addition of a new burial and associated feature during this period does point towards at least a continuation of some sense of place. Evidence suggests that the use and occupation of the Waybil site returned to something similar to the times
before the Late Classic expansion. This Terminal Classic contraction is reflected at both the Minanha epicenter and site core as well as Ixchel. In opposition, the Contreras Valley appears to have reverted to a similar occupation level of the Late Preclassic and Early Classic.

**Section Summary.** The Waybil community, one of the subsidiary sites to the Minanha capital, followed similar trends to the larger Minanha site with Early Preclassic colonization, followed by a low occupation in the Early Classic until a dramatic settlement expansion during the Late Classic (A.D. 675-810), and finally abandonment during the Terminal Classic. Differences between the Minanha capital and Waybil are identified in the longevity of the Classic period expansion. Minanha's site core and the dispersed agricultural settlement of the periphery (exemplified by the Contreras Valley region) experienced an earlier expansion and a protracted abandonment, while Waybil’s expansion and contraction were more compressed. This pattern would be expected if the Waybil community responded to growing pressures from the Minanha polity by increasing and decreasing in size as the demands of the political elite demanded more or less support. Work by other researchers has also shown that Waybil participated in the Minanha exchange network (Schwake et al. 2012) and was intervisible with Minanha (Barry 2014) further supports the model of a close relationship between these two ancient Maya sites. The question that remains is how this Late Classic socio-political and socio-economic relationship with Minanha affected the agricultural decisions made at Waybil.

**Classification of the Agricultural Terrace System at Waybil**

Answering that question requires that we understanding the organization of agricultural production at Waybil and the extent the influence of the expanding Minanha polity had on the agricultural decision-makers of the minor center of Waybil. To reconstruct these two factors, terrace type, standardization, and distribution will be examined in order to determine if they were constructed under a centralized or decentralized organizational scheme, or more specifically, if
they were constructed under control of leadership at the community or polity level, or under family or household control.

Terrace systems that are suggested to have been organized under the direct guidance of the political elites in control of surplus exhibit certain characteristics including large-scale landscape modifications through the vast distribution of high quality terraces (urban fields or extensive rural field systems), a large-scale organization scheme associated with evenly distributed settlement compounds or high density pockets of settlement, and construction sequences indicating short, discrete bursts of labor-intensive expansions (Chase and Chase 1998; Demarest 1992; Doolittle 1984; Dunning 2004; Healy et al. 1983; Healy 1986).

Terrace systems that are small or that exhibit irregular patterns of distribution, loosely associated with clustered or dispersed settlement, and lacking constructional uniformity are proposed to have been created through long-term, small labor investments by individual farming households, lineages, or communities. This piecemeal process is generally associated with gradual investments on agricultural return and a bottom-up, non-hierarchal process locally controlled rather than with the guidance of a state administration (Beach et al. 2002; Chase and Chase 1998; Doolittle 1984; Dunning 2004; see Dunning and Beach 1994; Haviland 1970; Healy et al. 1983; Kunen 2001; McAnany 2000; Netting 1993; Wyatt 2005).

**Agricultural Terrace Construction**

Terrace nomenclature

Terrace structure addresses the uniformity or irregularity of adherence to terrace type definition. Agricultural terraces have been classified into different types based on the various approaches to their study; geomorphic distribution (Donkin 1979; Spencer and Hale 1961; Treacy 1989; Treacy and Denevan 1994), function (Hudson 1992; Moody and Grove 1990; Morgan 1995; Rackham and Moody 1996), and construction (Frederick and Krahtopoulou 2000; Soper 2002; Soper 2006). These different approaches to classification are often intermingled, resulting in numerous variants of terrace types, with no single classification or nomenclatural scheme accepted (Frederick and Krahtopoulou 2000:82). In this dissertation I will use a three-type nomenclature of non-irrigated terraces which is generally accepted in Central and South America and which incorporates aspects of function and morphology from a local perspective (see Ashmore et al. 1994; Brooks 1998; Denevan 2001; Field 1966; Neff 2008; Treacy and Denevan 1994). For discussion on other nomenclatures refer to Rackham and Moody (1996), Moody and Groove (1990), Frederick and Krahtopouou (2000) and Morgan (1995).

Bench terraces, often associated with dry-slope terraces, are one of the most common types and exhibit a number of variants. The stair-like appearance, ascending in serial rows parallel to sloping topography, and level planting surfaces identify these terraces. Variations of bench terraces can include, but are not limited to contour, linear, broad field, and foot slope. Contour terraces conform to the contours of hill slopes (Beach et al. 2002:386; Brooks 1998:132; Donkin 1979:32; Fedick 1994:120; Neff 2008:52; Treacy 1989:81). Linear terraces are independent of the topography and constructed in uniform horizontal lines (Brooks 1998:132; Donkin 1979:32; Fedick 1994:120; Treacy 1989:81). Broad field terraces are located on more gentle slopes exhibiting a much wider planting surface than other bench terraces (Brooks 1998; Denevan 2001:180). Footslope or valley floor terraces, similar to Brooks’ (1998) segmented...
terraces, are located independent of other terrace tiers creating large, flat plots of land at the base of steep slopes (Beach et al. 2002:387; Dunning and Beach 1994:59-60; Kunen 2001:327; Neff 2008:52; Treacy and Denevan 1994:100-101). Box terraces fall outside the traditional description of bench terraces, but are associated with dry-sloped terraces in the Maya area. Located on moderately flat land often in close association with residential complexes, these terraces create rectangular plots considered as seedbeds or intensively cultivated gardens (Beach et al. 2002:386; Dunning and Beach 1994:58; Kunen 2001:326; Neff 2008:52). While traditionally described as square or rectangular in shape, it has been suggested that complex, higher quality, terrace systems in direct association with settlement units may also satisfy the functional qualities of box terraces (Macrae 2010:104).

Cross-channel (weir) terraces are non-contour in placement, functioning to collect and distribute the soil and water resources in a constricted area. They are found running perpendicular to the slope of smaller subsidiary valleys between the residual hills, seasonal drainage channels, between contour terraces, and other locations of constricting topography (Beach et al. 2002:380; Denevan 2001:176; Dunning and Beach 1994:58; Kunen 2001:326; Treacy and Denevan 1994:96; Wyatt 2008:54). As a result, these terraces are usually short in length, crossing the restricted topography, and tall in height, collecting the accumulated sediments (Brooks 1998:130; Donkin 1979:131).

Sloping fields are similar to bench terraces in their positions on valley sides and general conformity to contours. However, the planting surfaces are sloped, as opposed to the flat bench types (Brooks 1998:130). These terraces are noted in higher elevations and have not, to our knowledge, been identified in the Maya area. These terrace perform the same function as bench
terraces, expect the sloped nature of the planting surfaces facilitates the horizontal dispersal of water.

At Waybil there is uniformity in both the types of terraces used and the corresponding topographical locations. The ability to classify terraces into the predefined “types” or nomenclature attests to this uniformity (Figure 8-2). Waybil is dominated by contour terraces and cross-channel terraces. Of the 615 terraces within the terrace systems that surround Waybil there are nine box-terraces, 541 contour terraces, and 65 cross-channel terraces.

Figure 8-2. Distribution of terraces by type nomenclature at Waybil.
When compared to the mapped sample of dispersed agricultural settlements of the neighboring Contreras Valley there is less variability in terrace types at Waybil and an increased emphasis on contour and cross-channel terraces over the more variable types found in the dispersed settlement area (Figure 8-3 [Macrae 2010: Figure 4.1]). These results can be used to argue for a higher level of terrace standardization in the Waybil region. However, it is important to acknowledge that this difference in terrace standardization may also reflect the topographical differences between the two regions, as the definition of terrace typology is heavily dependent on landscape features and placement within them.

<table>
<thead>
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<th>Waybil</th>
<th>Contreras Valley</th>
</tr>
</thead>
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<td>6.99%</td>
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<tr>
<td>Contour</td>
<td>87.97%</td>
<td>65.44%</td>
</tr>
<tr>
<td>Cross-Channel</td>
<td>10.57%</td>
<td>19.67%</td>
</tr>
<tr>
<td>Broad Field</td>
<td>0.00%</td>
<td>6.25%</td>
</tr>
<tr>
<td>Foot-Slope</td>
<td>0.00%</td>
<td>1.65%</td>
</tr>
</tbody>
</table>

Figure 8-3. Percentage of terraces by nomenclature type. A comparison between Waybil and the Contreras Valley.

**Terrace construction**

Construction styles and uniformity can provide insight into the labor investment and timing of the construction and maintenance of terrace systems, and ultimately the social organization behind them. Small levels of labor input over a long time period, which accumulate
into a significant total investment, are suggestive of decentralized organization, while centralized organization requires a high level of investment over a short period of time (Dunning and Beach 1994; Fedick 1994; Wyatt 2005).

Most Maya terraces are composed of several courses of dry-laid, limestone boulders that create a retaining wall, often anchored to the underlying bedrock with larger boulders, and an infilled level planting surface (Beach et al. 2002; Chase and Chase 1998; Dunning and Beach 1994; Healy et al. 1983; Kunen 2001; Neff 2008; Thompson 1939; Turner 1974). Terrace wall height and planting surface width vary based on topography. Within this broad scheme, there are two general construction styles, single or double walled. Single walled terrace facing walls contain a level of cobble sized limestone and/or chert fill (Healy et al. 1983:404; Kunen 2001:327, 339; Turner 1983b:77-84), while double wall terraces also have a buried backing wall of large stacked stones, up to half a meter behind the facing wall (Chase and Chase 1998:69; Dunning and Beach 1994:59; Healy et al. 1983:404) which provides both strength and porosity (Kunen 2001:327). Variations on these construction styles included the placement of additional fill (Healy et al. 1983; Turner 1983b) or use of natural bedrock for construction foundations (Dunning and Beach 1994; Pollock 2007).

Differentiation in terrace walls have been thought to be analogous with specific terrace types: double walled cross-channel terraces and single walled contour terraces (Murtha 2002:161-162, 167-168). However, excavations have demonstrated a level of variability within the construction methods of specific terrace types (Beach et al. 2002:380). The quality of wall construction has also been used to reflect increased investments in areas in close proximity to settlement units as well as areas of higher agricultural potential (Macrae 2010:128). This line of inquiry can be used to suggest a decision in regards to the amount of labor to be invested in the
construction of terraces, regardless of type. This decision reflects the level of labor invested in choosing the more laborious double wall or the less demanding single wall terrace. Given the ambiguity in the purpose of construction styles, its interpretation, as well as the universal requirements of terrace construction and the requirements of specific terrace types, one needs to be cautious drawing interpretations of labor investment to construction methods (Pollock 2006a:186; Wyatt 2008:215). These uncertainties can be untangled by including the consideration of the construction of terrace planting surfaces and site-specific construction dates.

At Waybil, excavations revealed both single wall terraces, Op.W102-1, and double wall terraces, Op.W103-1, Op.W104-1, Op.W105-1 (see Methods and Results). There appears to be no correlation between wall construction and terrace type. Op.W102-1 was a contour terrace while Op.W103-1 and Op.W105-2 were both double wall construction and contour terraces. There is also no correlation between terrace wall type and a temporal evolution from single wall to double walled style, removing the possibility of an evolutionary understanding of terrace wall construction at Waybil. All terraces excavated were also in direct association with settlement units, meaning the differences cannot be attributed to quality differences as a result of increased proximity to settlements (see Macrae 2010:128). There is however, an apparent correlation between terrace planting depth directly behind the retaining wall and terrace wall style. The only single walled terrace excavated was found in association with the shallowest terrace planting surface with an average depth of 18.75 cm in level 3a and 3b. Op.W103-1 exhibited a depth of 24 cm although this terrace wall exhibited the highest degree of slumping, suggesting a taller terrace planting surface in the past. Op.W104-1 exhibited an average depth of 65 cm behind the retaining wall. Finally, Op.W105-1 presented an average depth of 56 cm. These results suggest a functional explanation for terrace wall construction as a product of the planting surface depth.
Double walled terraces appear to have been constructed in areas where a robust terrace wall is required to retain soils. The double walled construction exhibits a degree of investment in the stability of the facing wall by the placement of two courses of stones. While terrace wall type and terrace height are a functional explanation of slope and soil depth, a uniformity that transcends these environmental characteristics is the width of the fill within double walled terraces. The width of this fill is standardized amongst the three terraces exhibiting a variance of only ~20 cm. This was so constant that it was quickly noticed in the field and was then used to dictate the placement of excavation units.

There were two variations used in planting bed construction at Waybil and elsewhere in the Maya world. Incremental surfaces were created by gradual accumulation of eroded soils from above the terrace behind free-standing walls (Beach et al. 2002:380; Dunning and Beach 1994:58; Turner 1974:119). Expedient surfaces were created by stripping soil from above the underlying bedrock to lay the anchoring stones, and refilling with these anthrosols to form the planting surface (Chase and Chase 1998:70; Healy et al. 1983; Kunen 2001:339). The expedient process is identified by a lack of naturally occurring soil horizons, a unique soil classification, and a lack of stones in the planting surface (Chase and Chase 1998:69; Hansen et al. 2002:283; Healy et al. 1983:406; Matheny 1976:643; Turner 1978a:170). All of these identifying characteristics have been noted within the Waybil terrace excavations. Thus, the terrace planting surfaces at Waybil were constructed expediently while the terrace walls were being built. This terrace construction method is a heavy investment in initial labor, suggestive of centralized construction organization.

The final aspect of terrace construction that needs to be addressed is the incorporation of the natural step-like nature of the limestone bedrock into the construction of the terrace walls.
This process was first noted in the Contreras Valley where bedrock steps were used to raise the wall height and bedrock outcrops were used as starting and ending points of the terrace wall (Macrae 2010:127; Pollock 2006:222-223). These two practices reduced the level of labor necessary for the construction and maintenance of the terrace system, indicating an intrinsic knowledge of the underlying topography (Macrae 2010:127; Pollock 2006:222-223). This practice is apparent across the Waybil terrace systems and it was noted during the terrace survey. Further, excavations reveal that all but one of the terrace walls incorporated the underlying bedrock to varying degrees. Op.W103-1 is the only terrace that is not located on top of a bedrock step. This is also the earliest evidence of terracing found at Waybil, dating to the Early Classic. The lack of bedrock use is likely related to the early dates of this terrace. In the Contreras Valley terrace sample, the consolidation of bedrock into terrace construction is a phenomenon dating to the Middle to Late Classic (Pollock 2007:137-153, 196-200). The Early Classic date of the outlier Waybil terrace suggests that this may be evidence of some of the earliest agricultural terracing in the area. This terrace could be evidence of a learning curve during which inhabitants were developing methods of terrace construction. However, the terrace wall construction itself falls within the classification of a double wall which is a technique indicating a degree of prior understanding of the methods and requirements of terrace construction. Since this is a single example, it is difficult to move beyond the hypothesis without further examples dated to earlier periods. Nonetheless, the incorporation of bedrock into the Waybil terrace construction in most terraces is suggestive of a specialized knowledge of terrace construction despite the reduction in labor investment that the use of bedrock provides. This is therefore interpretable as a more centralized organization behind the Waybil terrace construction during the Late Classic period of greatest terrace construction.
Section summary: agricultural terrace construction

The agricultural terrace systems found at the minor center of Waybil exhibit a number of characteristics that suggest that they were constructed in a centralized fashion or under the guidance of individuals who were well versed in the intricacies of terrace construction. This is supported by a number of correlates. First, all terraces fall within the predefined typology and thus do not vary significantly from the typical Maya terraces. Second, there is less variation in the types used in relation to the terraces found in the Contreras Valley, suggesting a higher degree of uniformity in the terraces constructed at Waybil. This is a uniformity that emphasizes contour and cross-channel terraces which are well suited for the topography surrounding Waybil. Third, the construction techniques used to build the terrace walls present a clear understanding of how terraces were constructed from the outset, evident in the uniformity found within the terrace walls. Fourth, there is evidence that builders did not have a specific understanding of the underlying bedrock formations of the Waybil area in comparison to the formations present in the nearby Contreras Valley. This would suggest that early terrace construction was likely conducted by the inhabitants of Waybil or new arrivals who had a previous understanding of terrace construction, but lacked the local knowledge of the specific subsurface landscape at Waybil.

Further evidence to answer the question of labor organization can be found in the distribution of the terraces.

Terrace Distribution

One primary means of classifying terrace system construction and management as centralized or decentralized is by assessing terrace density and interconnectivity as related to natural topography (Chase and Chase 1998:73; Healy et al. 1983:402). The distribution of agricultural terraces, specifically the density of their distribution in relation to agricultural productive lands and settlement units, has been used to make inferences about the social
organization behind their construction and ownership (Macrae 2010:129-131; Macrae and Iannone 2010:186-187). Terrace systems that are uniformly distributed across the landscape, with little grouping among them, are argued to have been created under a centralized organization (Dayton 2008:127, 167). Alternatively, terraces that are pocketed, with varying densities across a landscape, are argued to be more representative of construction at the household/community level organization which is indicative of a decentralized management system (Soper 2002:37; Soper 2006:20, 70). However, when examining terrace frequency one must understand that slope can be a primary dictator of terrace density (Fedick 1994:111; Healy et al. 1983:405; Healy 1986:11).

**Terrace density**

The Waybil agricultural terraces are extensive, covering all conducive lands. The density of distribution was analyzed using the ArcGIS line density tool to create a raster image of the Waybil survey zone depicting terrace density across the landscape (Figure 8-4). Recorded at 1 m intervals, line density describes the summed values of the length of each line within a 10 m radius for each 1 x 1m raster cell, divided by the radius of analysis. The terrace densities were charted by quartiles on a normal Q-Q plot. The results verified that the distribution of terrace density do not conform to a normal distribution curve (Figure 8-5).
Figure 8-4. Density of terrace distribution at Waybil.

Figure 8-5. Q-Q plot of terrace density at Waybil. Results describing non-normality of data.
A comparative analysis of the density of terrace systems in the neighboring Contreras Valley suggests several important divergences (Figure 8-6). Most dramatically there is no 10 m radius area within the Waybil survey zone that does not have at least one terrace. The Contreras Valley exhibits a higher number of areas without terracing. This may represent hill slopes in the Contreras Valley that were too steep to be conducive for agricultural terracing.

Figure 8-6. Density distribution of terrace density at Waybil (Red, Mean 0.098) and the Contreras Valley (Blue, Mean 0.03).

Thus, the gentler landscape in the Waybil region was more conducive to terracing, resulting in more terraces per land area. More informative is a higher terrace density between 0.05 and 0.15m² radius (0.098 mean) at Waybil. This is suggestive of a more standardized terrace distribution across the landscape, due to the more even distribution of terrace density. The terrace system in the Contreras Valley exhibits a few areas of high terrace density and complexity in close association with early settlement units, while terrace distribution and frequency is more sporadic across the majority of the valley (Macrae 2010:128-130; Macrae and Iannone 2010:187). This is suggestive of a piecemeal construction process, which would be more characteristic of a household/community and a decentralized organizational system. Further, prior
testing using combined density and fractal analysis in the Contreras Valley has shown that
terrace density and complexity are not related to terrace type or length, suggesting that neither
the topographical landscape formation nor terrace type dictate density of terraces across the
landscape (Macrae 2010:150).

**Terrace interconnectivity**

The interconnectivity within and amongst terrace systems can also help inform about the
means of their organization (Chase and Chase 1998). Centrally created and managed terrace
systems tend to be large terrace systems that are highly interconnected. Decentralized systems
have terraces that are detached and function independent of each other are less interconnected.
The level of interconnectivity can provide insights into the construction processes of the terrace
systems. Centralized systems would suggest quick, large-scale construction. Decentralized
systems would suggest long-term, small-scale constructions. A study of interconnectivity within
and amongst terrace systems can be conducted by examining terrace placement.

The terraces and terrace systems surrounding Waybil act to complement each other, with
no discernable means of identifying individual terrace systems. This is due to terraces that
change in type classification as they conform to the topography, often creating long terraces. The
length of terraces have been used as a qualification of centralized control at Caracol. At that site,
there are seven larger terraces that extend over 100 m, the largest of which reaches 245 m. Given
that these long terraces include multiple household groups, it is unlikely that they were
constructed by a single family (Chase and Chase 1998:70). In the Contreras Valley, there are 34
terraces over 100 m long, with the largest reaching 309 m and the average length of 39.42 m.
These long terraces in the Contreras Valley have been used to indicate centralized organization
behind their construction (Macrae 2010:167). At Waybil, there are 71 terraces that measure over
100 m, with the longest reaching 325 m, the average length is 51.71 m. These characteristics
indicate a centralized construction process as opposed to a piecemeal approach, as they transcend possible household units (Chase and Chase 1998:70, 72-73).

The Waybil terraces also complement each other and the natural contours of the valley, to best capture and distribute the rain water. The control and distribution of water is a fundamental aspect of agricultural production (Scarborough 2003). In the North Vaca Plateau, the vast majority of agricultural water is derived from rainfall, thus the flow, management, and control of water is of paramount importance within the Waybil agricultural system. Scarborough (1998:136) describes the elite management of water through landscape construction at many sites as an indicator of centralized control. While, on the other hand, Wyatt (2008:216, 298) describes the more localized management of water at sites such as Chan in Belize, specifically the manipulation of natural springs, as a decentralized process, confirming that local farmers also had unrestricted access to water as well as an intimate knowledge of the landscape. Thus, the interconnectivity of the Waybil terrace systems can provide insights to the management and ultimate distribution of water within or between terrace systems, and this can be used to assess the organization behind their construction and use. This relationship has been modeled and mapped in the hydrological analysis of Waybil (See GIS Modeling). Terraces extend beyond the drainage catchment defined around Waybil and collaborate to distribute water beyond an individual system. This reduces the possibility that these were originally constructed as clustered pockets of terraces that might indicate decentralized production. The broader, more effectively distributed drainage networks of Waybil suggest that the terrace systems were constructed as a whole, and were constructed with water distribution and transference across the landscape as a priority. This suggests a more centralized construction process and organization. In contrast, a prior fractal analysis of the Contreras terraces indicates occasional disruption of water flow.
amongst the terraces of the Contreras Valley in areas of high density and close proximity to
settlement units, suggesting a more localized and decentralized construction of terrace systems in
this area as compared to those of Waybil (Macrae 2010:134; see Soper 2002:63, 73). Further,
documentation of direct control of water is so far lacking at Waybil. The four aguadas present at
Waybil have not been investigated and lack the dates or direct excavation data to be addressed in
this dissertation, but this would be an area of future research interest for the site.

Section summary: terrace distribution

The terrace systems surrounding Waybil present several proxies that can be used to
classify the terrace construction and use as either centralized or decentralized. Terrace density
suggests a more uniform distribution of terraces across the landscape at Waybil than the
Contreras Valley and a lack of pockets of increased of terrace density that would be indicative of
household-level organization. This uniformity suggests a centralized organization of creation and
use of the terraces, which is supported by the high level of interconnectivity amongst the
terraces, crossing type definition, and between terrace systems, and transcending drainage
catchment, which supports the idea of centrally organized construction. Overall, the distribution
of terraces further supports a centralizing force behind their construction and placement.

Chapter Summary: Defining Social Pressure at Waybil

This chapter has examined the variability in terrace types, construction qualities,
distribution, and interconnectivity to gain a nuanced understanding of the relationship between
Waybil and Minanha in terms of its agricultural production. This relationship was explored in
order to determine if the agricultural strategy at Waybil was under direct, centralized, authority
of Minanha or an indirect, decentralized, relationship managed by a local, lineage based
households. No single proxy can be relied on to explain the social organization behind the
construction and maintenance of the Waybil terrace systems. However, the combination of
multiple avenues of analysis can develop a strong argument. Results indicate the terrace systems at Waybil were constructed and maintained during the Late Classic under the guidance of a centralized authority. This seems at odds with the few early examples that appear to be differently placed and constructed than the Late Classic ones. The occupation history of the Waybil site suggests that the site was not always a “production enclave” for the Minanha polity, and that it was active well before the establishment of the Minanha royal court. The original role of the site as ritual loci, gathering place, or outfield, may have changed over time to include an increasing agricultural component as the population and use of Waybil, and on a larger scale the North Vaca Plateau, grew. This is evidenced by the dates of the first terraces and the early ceramics throughout the surrounding fields. With the establishment of the Minanha royal court, and direct integration of the Waybil minor center within the Minanha polity, significant changes occurred rapidly at Waybil that ultimately changed the role of terraces in the agricultural strategy. The dominant Late Classic occupation and terrace construction at Waybil as well as the rise and fall of the royal court at the “little kingdom” of Minanha indicate that the Late Classic period was a time of increasing social pressure exerted from Minanha on the minor center of Waybil, resulting in the centralization of the agricultural strategy.
CHAPTER 9
GEOGRAPHICAL INFORMATION SYSTEMS (GIS) MODELING

This chapter is a functional analysis of the Waybil agricultural terraces based on models created in Geographical Information Systems (GIS). The models combine data from mapping, excavation, and soils, with information from the analysis of precipitation and social organization as evidence of external and internal pressures (respectively) on the agricultural system. The models are presented, where possible, to compare the landscape potential with and without terraces. This will allow assessment of how the terraces altered the landscape, and in turn, altered the way their users could interact with their changing environment. The modeling will focus on identifying and quantifying the functional characteristics of relic agricultural terraces, in order to address how beneficial or detrimental qualities of the agricultural terraces liaise with the changing climatic conditions and major drought events (MDE), as well as social pressures from changing political and economic demands experienced by the ancient Maya residents of Waybil.

The modeling analysis is accomplished through three GIS modelling procedures: First, a hydrological analysis exploring water flow accumulation and drainage catchments. Second, an analysis of the landscape soils’ susceptibility to erosion, which quantifies and maps the erosion patterns within the landscape. Third, an assessment of agricultural suitability that evaluates the landscape and soils, ranking their suitability for agriculture. These three analyses function in series, with the results of each model being incorporated into the next. To compare the function of the terraced landscape in these three models, a hypothetical comparative model of the pre-terraced landscape was first developed from the Waybil digital elevation model (DEM) by removing much of the terracing from the landscape (described in detail below). This provides a baseline to contrast with the Waybil terraced landscape. The actual terraced DEM map is representative of the terraced system. The strong temporal connection to a single period of
occupation, the Late Classic, identified in the previous chapter, justifies the assumption for this modeling exercise in that the majority of the terraces were in use within a ca. 150-year span, allowing for holistic analysis of their interaction across the landscape. While this temporally constrains the model, it is important to emphasize that a small proportion of the terraces were likely constructed during the Early Classic although they were likely continuously used into the Late Classic (based on the finding of an Early Classic construction date). The early facet Late Classic exhibited significant variability between wetter and drier conditions. The transition into the late facet Late Classic and into the Terminal Classic is marked by a significant MDE. This is represented in the following models by incorporating the contemporary wet, dry, and average precipitation regimes outlined in Chapter 3.

These models are also considered in terms of climate conditions because these, especially the level of precipitation, have a profound influence on agricultural production (Griffin et al. 2014:80-83). The models incorporate precipitation estimates based on climatic reconstructions of the Waybil region during its Maya occupation (see Chapter 7), to compare erosion and suitability in approximation of wet, dry, and average years. Precipitation changes are incorporated as a fluctuating external variable. Results will inform the discussion of the socio-ecological system formed out of the Waybil agricultural strategy. These results will be considered in terms of the social structure at Waybil by examining the occupation history to understand the construction, maintenance, and eventual abandonment of these terrace systems.

**Creating the Comparative Model**

The following procedure was used to create a terrace-removed DEM (Figure 9-1). The IDW interpolation method, using a weighted value of neighboring cells, created a surface model (see Chapter 5), and then the ArcGIS Focal Statistic tool (ESRI 2014) was used to remove the agricultural terraces from the interpolated raster image.
Focal Statistics operates by calculating the sum elevation value of a specified neighborhood of cells surrounding each interpolated point, as well as adding the value of the processing cells (ESRI 2014). Identified neighborhoods occasionally overlap based on the proximity of the cells being calculated. A circle neighborhood with a radius of 5 m was used to remove most of the agricultural terraces while maintaining accuracy within the topography. Only minimum elevation values from the neighboring cells were calculated. This approach created a smoother surface model from the original interpolated points. It is important to note that while the majority of the terraces (especially walls with smaller elevation changes) were removed, some terrace contours remained. Manipulations of the surface model aimed at removing taller terraces resulted in significant modifications of the natural; therefore, these terraces were
ultimately left in place. Further, survey and excavation of the site clarifies that some aggressive elevation changes represented natural bedrock formations, so these were left unmodified. For example, excavation of the southeastern portion of the survey zone that exhibits cross-channel terraces revealed a relatively small terrace wall built atop naturally step shaped bedrock. Thus, the scale of the focal statistics tool was informed by survey and excavation data as well as caution to avoid over-manipulating the landscape model. As a result, while the terrace-removed DEM has extracted the majority of the terraces, it may not be completely representative of natural topography, which has been obscured by centuries of human occupation and manipulation.

**Hydrological Analysis**

Terraces have long been assumed to play a significant role in the manipulation of water in the creation of an anthropogenic landscape for the benefit of crop production. This section will examine these assumptions for the archaeological past by modeling the hydrological processes at work within the agricultural terrace systems found surrounding Waybil. Combining the topographical information derived from LiDAR and the hydrological mapping tool kit, Arc Hydro (see Maidment et al. 2002), provides a nuanced understanding of the structure of the Waybil agricultural systems in relation to the capture and drainage of water and sediment. Arc Hydro is an ArcGIS (ESRI 2014) based database management system used to map hydrological processes in modern systems, but also has utility for relic landscapes (see Barnhart 2001; Berking et al. 2010; Bolten et al. 2006; Dorshow 2012; Gillings 1995; Harrower 2010; Harrower et al. 2012; Kurashima and Kirch 2011; Ruane 2015; Uysal et al. 2010; Weaver et al. 2015; Wienhold 2013). The hydrological maps of Waybil will be used to address how and to what extent agricultural terraces influenced the hydrological processes at Waybil and how effective they were in compensating for the fluctuations of both internal and external variables.
The Role of Agricultural Terraces and Water


Methods

Arc hydro: drainage, & catchments

Arc Hydro is a geospatial relational database management system (RDBMS) that stores and integrates the data components that create a hydro network, the routes, junctions, and termination points of drainage networks (Maidment et al. 2002). Operating in ArcGIS, it manages a framework designed to present and support models created from geospatial and temporal information for hydrography and hydrology data (Maidment 2002; Shamsi 2008:165). Arc Hydro facilitates geometric network processes using the objects, features, and network
features traditional to ArcGIS, which store spatial coordinates and attributes as well as adds attributes to support hydrological operations by creating a hydro network. In this study, the Waybil drainage networks and catchments are modeled using the ArcHydro Catchment Delineation and Flow Accumulation tools based on the high-resolution LiDAR DEM. Often other primary datasets from water resource studies that collected hydrological information accompany the DEM, usually data of a higher resolution and independent of the DEM. This is not the case in this dissertation, which uses the DEM alone to compute potential hydrological functions.

**Drainage analysis**

Drainage is the flow process of water as it moves from its origin point in the landscape to its final ending location (Olivera et al. 2002:56). This is a function of topography, which directs the flow of water, and an assumption that ridges of higher elevation will have drier soils than the soils of valley bottoms (Olivera et al. 2002:56).

Flow Direction (FDR), the direction water will flow out from one cell to another (Jenson and Domingue 1988:1594) was identified first. In ArcGIS, this is a slope operation, defined by elevation decreased per unit of travel distance. Using an eight-direction pour point model ArcGIS examines every surrounding cell, comprising eight possibilities, and describes water movement from one cell to another contiguous cell based on steepest descent (Jenson 1985:304-305; Olivera et al. 2002:69). The steepest descent is calculated by elevation change between cells divided by distance to cell centers (see Greenlee 1987; Jenson 1985; Jenson and Domingue 1988). The DEM used in this dissertation is created at a 1m resolution, thus each cell is representative of 1m². The simplest model available was used to determine flow direction, only allowing the flow of water from one cell into a single adjacent cell, i.e., not permitting the partitioning of water from one cell into multiple adjacent cells (Olivera et al. 2002:69).
created an integer raster encoding each cell with a single value between 1 and 128, using divisions of two, representative of cardinal directions (Jenson and Domingue 1988:1594; Olivera et al. 2002:69).

<table>
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<tr>
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</table>

Figure 9-2. Eight-direction pour point model.

Flow Accumulation (FAC) was determined next, using the FDR to describe individual cells based on the number of different cells that flow into it in a raster output (Jenson and Domingue 1988:1594-1595; O'Callaghan and Mark 1984:326; Olivera et al. 2002:72). The cells that exhibit a high accumulation of values are interpreted as areas where water may accumulate and may represent stream channels. A thresholds level was set at the recommended 1% of the maximum FAC value, ~2,803, before a cell is defined as a stream. The definition of the threshold value is based on the set standards considering contributing area size (Maidment 2002:73), however aspects of slope, climate, and soils can play a factor (see Tarboton et al. 1991). It is important to note that the term “stream” does not in all cases describe a continuous flow of water but rather areas of higher drainage accumulation. Cells with low accumulation values can be interpreted as areas of high elevation such as ridges (Jenson and Domingue 1988:1596).

**Catchment analysis**

Watersheds or catchments are regions, often basin shaped, in which all the water drains to a common terminus. Arc Hydro defines a catchment as a region with its delineation automatically derived from drainage characteristics while a watershed is a region that has been manually manipulated with a secondary data source of hydrological information (watershed Olivera et al. 2002:60). Without additional hydrological information, this study focused on catchments. Catchments were digitized in Arc Hydro by extracting data from the FDR and FAC
to construct Stream Definition and Stream Segmentation functions. FAC was used to identify cells that meet and supersede a threshold of accumulation as streams, ultimately creating a network of streams. Thresholds were set at the recommended 1% of the maximum value of the FAC, but after initial analysis of resulting catchments, was increased to 2% (see results for discussion of this decision). The constructed stream network was divided into segments/links with junctions separating the segments. Segments were assigned a numeric order starting at one, determined by their location in the stream network, and increasing based on the number of networked tributaries (see Tarboton et al. 1991). With this analysis in hand, the catchments were delimitated using boundaries referred to as drainage divides. The drainage divide begins at a pour point, the loci where all water drains from a specific catchment, and encompasses all the cells that flow in the direction of this point (Olivera et al. 2002:57-58, 74). This places each stream within its own catchment. The resulting model is a series of catchments with associated flow accumulation data.

**Results**

**Drainage analysis**

After the FDR was calculated, the FAC analysis was conducted (Figure 9-3). The FAC values from each 1 x 1m cell were exported from the raster image and examined in terms of their mean and standard deviation. To more succinctly analyse and present the data, zero values were removed. Zero values are representative of erroneous LiDAR returns, similar to previously discussed sinks. Although to a much lesser degree, the summit of hilltops and raised plazas also assigned a value of zero with no cells flowing directly into them. Removing these values assisted in drawing out the data directly affected by the agricultural terraces. Finally, logarithmic scale was utilized to reduce the skewness towards what were previously zero values and standardize the results.
The results from the FAC analysis revealed that the terraced DEM has a mean log FAC value of 2.16 while the terrace-removed DEM has a mean log FAC value of 2.48. The means indicate that the terraced landscape is reducing the number of higher value FAC while increasing the lower level values. To confirm and highlight these trends a smaller area of the survey zone was sampled (see Macrae and Iannone 2016). This area was selected because it was subjected to theodolite survey as well as excavation that revealed a uniform slope to the underlying bedrock. This smaller sample area produced mean FAC value for the terraced DEM of 288 and terrace-removed DEM of 232. To further examine the variation between the FAC means of the terraced and terrace-removed DEM a density distribution of the FAC was examined (Figure 9-4).
This density distribution presents the number of results per value across the range of values. Results indicated that the terraced DEM included a high percentage of lower FAC valued cells and a few of the highest FAC cells while the terrace-removed DEM presented a more even distribution of mid-level FAC, with a decreasing density of higher value FAC cells. This same trend is present in the sampled area, although several of the extreme values, likely outliers, were removed (Figure 9-5). This verifies descriptive qualities of using the FAC density rather than relying solely on mean FAC. In order to test the significance of this distribution, the skewness of the FAC for both the terraced and terrace-removed DEM were subjected to a permutation function (see Good 1994; Good 2005). The test statistic of skewness was used as a means to define the pattern density distribution. This analysis function combines all the FAC values and randomly selects values to test for significance. In order to overcome any discrepancies, this analysis was conducted 14,000 times, five percent of the total values to produce a p-value (Dr.
Pampush personal communication [Table 9-1]). The results of the permutation analysis rejected the null hypothesis and states that there is statistically significant difference between the terraced and terrace-removed FAC values. Examining the density distribution of the FAC of both the terraced DEM and terrace-removed DEM suggests an important divergence. The higher percentage of low level of FAC in the terraced DEM indicates that the agricultural terraces are decreasing the medium level FAC across the landscape, resulting in a more even distribution of lower FAC across the field systems. This trend was highlighted and confirmed in the analysis of the smaller sample area. The wider collection of FAC attests to the infrequent, yet highest FAC values in the terraced DEM.

![Density distribution of Flow Accumulation (FAC)](image)

Figure 9-5. Density distribution depicting flow accumulation (FAC) of terraced and terrace removed.

Table 9-1. Mean, Skewness, and P-values of the Flow accumulation of the terraced and terrace-removed DEM.

<table>
<thead>
<tr>
<th>Flow Accumulation (FAC)</th>
<th>Mean</th>
<th>Standard Dev.</th>
<th>Skewness</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terraced</td>
<td>2.16</td>
<td>2.11</td>
<td>1.19</td>
<td>0.00</td>
</tr>
<tr>
<td>Non-Terraced</td>
<td>2.48</td>
<td>2.11</td>
<td>0.82</td>
<td></td>
</tr>
</tbody>
</table>
Catchment analysis

Catchments are products of the resolution available in both FDR and FAC, and ultimately the LiDAR resolution. LiDAR has been proven to provide more information than required, or even useful, for some hydrological analyses (Jones et al. 2008:4149). The high-resolution LiDAR available of Waybil presented such a situation, where the data resolution outruns the level of analysis. Using the recommended FAC threshold of 1% there were 98 catchments created across Waybil. While this minutia has important implications for analyzing the hydrological process, a less detailed analysis was ultimately more beneficial for understanding agricultural terrace systems. A FAC threshold of 2% created more generalized catchments, grouping many of the smaller ones, and ultimately creating 52 catchments basins (Figure 9-6).

Figure 9-6. Catchment delineation, terraced DEM (A), terrace-removed DEM (B)

These are more useful for visualizing broader hydrological processes at our scale of analysis at Waybil. This level of threshold still maintains an accurate analysis, especially in
rugged terrain (Maidment 2002:73). Adjusting the threshold is one approach to solving this problem. An alternative is to reduce the number of LiDAR point-returns used in creating the DEM by adjusting their classification. This approach was avoided because of the unevenness of point-return distribution and a desire to maintain all the subtle impacts that agricultural terraces have on the elevation and slope modeling.

The results of the catchment analysis delineated 45 catchments across the terraced DEM with a mean surface area of the log value of 8.03 equivalent to 6,205 m². The terrace-removed DEM exhibited 44 catchments with a mean surface area of the log value of 8.07 equivalent to 6,346 m² (Table 9-2). A similarity in the means and standard deviations of both DEMs indicates a similarity between the terraced and terrace-removed DEMs. To further illuminate this relationship the distribution of the data is analyzed.

Table 9-2. Surface area of terraced and terraced removed DEM.

<table>
<thead>
<tr>
<th>Terraced Removed (m²)</th>
<th>Terraced (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 4375 7537</td>
<td>13 3183 7459</td>
</tr>
<tr>
<td>34 4426 7691</td>
<td>40 4154 7470</td>
</tr>
<tr>
<td>59 4432 8044</td>
<td>172 4253 9033</td>
</tr>
<tr>
<td>247 4577 8681</td>
<td>189 4708 9207</td>
</tr>
<tr>
<td>262 4906 10577</td>
<td>359 4754 10216</td>
</tr>
<tr>
<td>507 6141 11291</td>
<td>372 4927 10865</td>
</tr>
<tr>
<td>529 6640 11815</td>
<td>492 4965 11886</td>
</tr>
<tr>
<td>694 6812 12034</td>
<td>606 5335 12364</td>
</tr>
<tr>
<td>829 6835 12809</td>
<td>939 5392 12560</td>
</tr>
<tr>
<td>836 6843 13705</td>
<td>949 6298 12869</td>
</tr>
<tr>
<td>872 7043 14178</td>
<td>1176 6362 14380</td>
</tr>
<tr>
<td>2276 7272 15100</td>
<td>1275 6720 14620</td>
</tr>
<tr>
<td>3709 7289 15382</td>
<td>1323 6823 14937</td>
</tr>
<tr>
<td>4180 7320 18620</td>
<td>2113 6926 15467</td>
</tr>
<tr>
<td>4351 7457</td>
<td>2654 7429 21006</td>
</tr>
</tbody>
</table>

The density distribution of the catchments surface area was plotted and subjected to a similar permutations test of skewness (Figure 9-7; Table 9-3). Given the relatively small number of samples, a higher sample size was chosen to increase the robustness of the results. The sample size was changed to 23 equating to fifty percent of the observations. The resultant P-value was
0.004. This rejects the null hypothesis, and accepts the alternative hypothesis that that the catchments created by the terraced and terrace-removed DEMs are significantly different.

![Figure 9-7. Density distribution of the catchment surface area (1m²) using a 2% FAC threshold.](image)

**Table 9-3. Skewness of the density distribution of the catchment surface area (1m²).**

<table>
<thead>
<tr>
<th>Surface Area (m²)</th>
<th>Mean</th>
<th>Standard Dev.</th>
<th>Skewness</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terraced</td>
<td>6,205.33</td>
<td>5221.85</td>
<td>0.73</td>
<td>0.004</td>
</tr>
<tr>
<td>Non-Terraced</td>
<td>6,346.32</td>
<td>4871.56</td>
<td>0.52</td>
<td></td>
</tr>
</tbody>
</table>

Generally, differences are observed by more gradual variation in values of the terraced DEM compared to the terrace-removed DEM. Further, the terrace DEM has a higher density of catchments with a surface area between 200-5,000 m², 11,000-17,500 m², and 20,000-25,000 m² while the terrace-removed DEM has a higher density between 5,000-11,000 m² and between 17,500-20,000 m². The terraced DEM presents much broader accumulation, and more evenly dispersed networks, while the terrace-removed DEM exhibits narrower, less dispersed accumulation networks. This is especially clear in the broad sloping hillsides found in the north of the survey zone. This relates to the creation of broader catchments in the terraced DEM.
Section summary: hydrological analysis

Critical in interpreting the functional relationship between the agricultural terraces and
the hydrological processes is to assess the role of terraces in modifying drainage catchments and
flow accumulation. The study for correlation between the distribution density of the FAC and
surface areas of the catchment between the terraced and terrace-removed DEM proves to be
statistically significant. In terms of catchments, this suggests that the Waybil terraces did
significantly affect the distribution of the surface area of the Waybil catchments. Further, the
addition of terraces appears to have changed the Waybil catchment shapes. Catchments in the
ranges of 200-5,000 m², 11,000-17,500 m², and 20,000-25,000 m² were more common in the
terraced landscape indicating that the terraced landscape created wider, shorter catchments in
comparison to the terrace-removed topography, which is dominated by narrower, elongated
catchments. In the future geometrical statistics may help in statistically validating this
observation, but it would need to be conducted at a much larger scale then facilitated in this
study (Macrae and Iannone 2016).

The analysis of the FAC in terms of skewedness of the density distribution returns a
result of significance. Thus, describing a high degree of dissimilarity between the two
distributions. Similar to the catchment analysis, valuable insights can be drawn from the visual
assessment of both the stream networks within the landscape and the density distribution. There
is a clear broader distribution of lower value FAC within the terraced DEM. The terrace-
removed DEM exhibited les distribution and higher density of middle level FAC values. This is
reflected in the narrower and elongated catchments.

The majority of agricultural terraces are found perpendicular to the stream networks
created by areas of higher FAC. The terraces functioning in two different manners based on their
type. Cross-channel terraces bisect paths of higher FAC, functioning to slow the movement of
sediment in those areas prone to erosion, while maximizing the size of the planting surfaces with acquired sediments. These terraces are also capitalizing on the capture and dispersal of water. Contour terraces, while bisecting paths of higher FAC, are also functioning to disperse these values, increasing the number of stream segments in the network and lowering the FAC. This process diffuses the sediment and water flow associated with a high FAC laterally across the landscape.

The analysis of the drainage catchment and FAC in both the terraced DEM and non-terrace DEM indicates that the agricultural terraces of Waybil affected the hydrological processes of the landscape. Combined, the drainage catchments and FAC suggest that the agricultural terraces found so prolifically across the Waybil survey area support a model of large-scale manipulation of the local hydrological process that would result in pronounced catchment changes. Although the terraces do appear to have created these changes by acting in a nuanced fashion to compliment the natural topography while broadening the distribution of water flow. These results will be incorporated in the analysis that examines the terrace systems in terms of its functional uses in reducing soil erosion.

**Susceptibility to Erosion**

Agricultural terraces have been described as playing a significant role in the prevention of soil erosion. In this section, the terraced DEM and terrace-removed DEM will be analyzed based on the potential that agricultural terraces hold in terms of the retention and distribution of sediments. Erosion is a process of two phases, the detachment of individual soil particles from the surface and the transportation of these sediments by erosive agents. These phases are primarily controlled by several erosive agents; rainfall and overland flow, wind, animals, and humans (Bevan and Conolly 2011:1310; Morgan 1995:7; Renard et al. 1997:68). This analysis will focus on the erosive agent of rainfall and overland flow, describing the different factors that
influence the susceptibility to erosion. These qualities will be quantified and combined to describe the potential erosion rates of the field systems surrounding the site of Waybil. This will assist in understanding the functional capabilities of terraced field systems within the fluctuating climate that occurred during the occupation of Waybil. It will also provide insight into the production suitability and potential of the terraced field systems, to be analyzed in the next section.

As mentioned, erosion is a product of rainfall, but its degree of erosive power is a product of a number of different factors. When rain falls to the ground it holds the potential to detach soil particles from the greater soil mass, throwing the particles in to the air and up to several centimeters away (Morgan 1995:7; Renard et al. 1997:68). This is referred to as rainsplash, and its effects are controlled by the intensity of rainfall and the size of the droplets. The breath of time soils are subjected to rainfall, intensity of rainfall, as well as the velocity and diameter of raindrops is an expression of the erosivity of rainfall (Morgan 1995:27). The erositivity of rainfall defines the degree that soils are moved and soil structure is weakened (Morgan 1995:7). The composition of soil texture and structure play a role in the erosivity of rainfall. Finer particles such as clay are resistant to detachment due to their high cohesiveness, yet once disturbed they are easily moved, the opposite is true for larger sediments (Farhan and Nawaiseh 2015:4654)

Vegetation cover is another factor in the erosive power of rainfall, acting as a buffer between the atmosphere and the soils below (Morgan 1995:36). During a storm, rain can either land directly on the bare soil or have its fall interrupted by vegetation cover. If raindrops fall directly on the surface or pass through the gaps within the plant cover they exert their full erosive powers on the soils and is referred to as direct fall through. However, if the plant cover interrupts
raindrops two processes can occur. First, if raindrops are not evaporated they drip from vegetation to the ground with less velocity, referred to as leaf drainage. However, if these droplets fall from a canopy of seven meters or higher they can regain over 90 percent of their terminal velocity (Morgan 1995:8, 36). Further, plant cover also offers a location for convergence, where rain can accumulate in size, increasing their erosive power when they fall to the ground. Second, if raindrops find themselves entangled in the vegetation cover they can flow down the stems and trunk, dissipating their immediate erosive power. This is referred to as stemflow (Morgan 1995:8). Thus, the role of vegetation cover in the erosive powers of rainfall is a factor of height, continuity, and density (Farhan and Nawaiseh 2015:4655; Morgan 1995:36).

The underground component of vegetation cover assists in the retention of soils against erosive powers.

When raindrops reach the ground, the water can be stored in surface depressions, infiltrate into the soil, or percolate into the groundwater (Morgan 1995:8). When it encounters the earth’s surface several other factors, soil texture and structure, come into play that deal directly with soil erodability (Discussed Below). These soils characteristics possess inherent properties that relate to infiltration rates and capillary storage. Infiltration rates measure the speed that water enters the soil matrix (Brady and Weil 2007:197-198). Rates of infiltration are a property of gravity and capillary forces, which draw in the water and hold it as a thin molecular film surrounding soil particles (Brady and Weil 2007:221). While gravity stays a constant, capillary pull is reduced as soils become nearly saturated. Thus, as the durations of a storm extends, the infiltration rate will decline until saturation, at which point water can pass through the soils creating surface runoff (Morgan 1995:8). From this perspective, soils with higher infiltration rates will be able to resist the erosive power of rainfall longer than those soils with
lower infiltration rates. However, the level of moisture content that a soil can hold within its pores, capillary storage, adds another dimension to erosive pattern identified with infiltration rates. Soils with a lower capillary storage, despite a high infiltration rate, will become saturated faster than a soil with a higher capillary storage capacity, thus a higher potential to succumb to the erosive powers of the rainfall quicker (Morgan 1995:9). Therefore, when the soil is at its full saturation or rainfall exceeds infiltration rates the excess water travels downslope as subsurface drainage (interflow) or across the surface (overland flow).

Overland flow occurs when water has exceeded the retention qualities of the soils and storage capabilities of surface depressions. This is a downslope surface movement of water and sediments that have achieved a velocity that has surpassed the inherent resistant quality of soils to keep both water and soil particles in place (Morgan 1995:13), and is referred to as sheet erosion. When water is moving across the surface, slope plays an important role in defining velocity and ultimately the erodability of the landscape. This is a function of steepness and length (Morgan 1995:34). Generally, the steeper and longer a slope is the higher the potential velocity surface water can achieve (Farhan and Nawaiseh 2015:4654; Morgan 1995:34). Overland flow begins downhill from the crest of a slope when the surface water has accumulated to a point that flow begins. This movement downslope accelerates as the depth of the flow increases (Morgan 1995:8, 16). Sheet erosion is rarely uniform as it moves downslope, rather different landscape features, surface irregularities, and plant cover, tend to concentrate flow into certain channels, increasing its momentum and focusing its erosive power (Morgan 1995:8, 16). This can result in several different types of erosion, two of which will be examined, rill and gullies.
Rill erosion refers to the formation of shallow channels through the downward movement of water and sediment (Farhan and Nawaiseh 2015:4654; Morgan 1995:17). Once these channels are formed, they migrate upslope, managed by the soils erodability, slope, and velocity of overland flow. Downslope migration is controlled by the stress of the entire flow and soil cohesiveness. Further, rill erosion can develop secondary and tertiary flow paths as the channels progressively climb upslope (Morgan 1995:17-18). As these subsidiary channels converge downslope, they result in increasing erosive power and discharge in the primary channel. Rill erosion has been attributed to the bulk of sediment removal from hillsides (Morgan 1995:18).

Gully erosion creates more aggressive steep sided downslope channels. These deep channels exhibit a step like nature. This is caused by a nearly vertical headcut, starting point, which migrates into a gentler, slightly convex, downhill gradient (Morgan 1995:19). Gully erosion begins with a weak point in the soil surface, weak soil characteristics or breaks in vegetation cover, or depressions where water concentrates and overland flow scours out sediments. The majority of eroded sediments come from behind the headcut but occasionally will be undercut and migrate upslope (Morgan 1995:19). Gullies are often associated with accelerated erosion and landscape instability. However, given the erratic formation behavior the relationship between overland flow and sediment discharge are frequently poor (Morgan 1995:19).

The Role of Agricultural Terraces and Erosion

Agricultural terraces are found predominantly in sloped topography and are constructed to satisfy several interrelated functions necessary for cultivating well-drained, fertile, but shallow soils (Kunen 2001:326). Terraces, in the most basic sense, are a retaining wall that function to ameliorate erosion by retaining, trapping, and accumulating sediment to maintain and/or increase soil depth (Brooks 1998:125; Donkin 1979:34; Dunning and Beach 1994:58; Field 1966:11, 510; Hudson 1992:150-163; Kunen 2001:326; Rackham and Moody 1996:142; Spencer and Hale 2001:326).
Creating a level planting surface upslope of the wall also increases the total area available for cultivation on a hillside (Fischbeck 2001; Neff 2008:51-52; Pollock 2007:58; Wyatt 2008:56).

Methods

As discussed, several factors contribute to the susceptibility of landscape to erosion. These factors can exhibit both beneficial and detrimental qualities. These qualities can be quantified and combined to produce measurements of susceptibility and potential quantity of eroded material in study areas. A number of different approaches have been developed over the years. Two of the most popular approaches are Revised Universal Soil Loss Equation (RULSE, Renard et al. 1997; Wischmeier and Smith 1965; 1978) and Unit Stream Power-based Erosion Deposition (Mitas and Mitasova 1998; Mitasova et al. 1996; Mitasova and Mitas 2001). Both these models are based on long established equations that have been field-tested and provide comparative erosion values (Mitasova and Mitas 2001:321). In this section, the susceptibility and erosion potential of the agrarian landscape at Waybil will be tested. This analysis will use the RUSLE approach because of the easy of which values can be adjusted to correlate with available archaeological data and the plethora of tested and recorded data to fill in the missing information not present in the archaeological record. The RUSLE equation is based on the equation 

\[ A = R \times K \times LS \times C \times P \]

This produces annual soil loss (A) representative of potential sheet and rill erosion. This equation is based on several factors: Rainfall Erosivity (R), Soil Erodibility (K), Slope Length and Steepness (LS), Land Cover Management (C), and Soil Conservation Practice (P). Annual soil loss (A) is measured in tons per hectare per year (ton ha\(^{-1}\) year\(^{-1}\)). The RUSLE equation has been modified from the original USLE methods (Wischmeier and Smith 1965; 1978) which was developed for application with very little consideration given to topographic variance. RUSLE advanced this original equation by reconstructing the slope length and
steepness equation. This analysis is computed and presented in GIS for the terraced and terrace-removed landscapes exploring varying levels of precipitation. The application of RUSLE within the GIS framework is a common affair, especially amongst contemporary resource management, while its application within an archaeological context is less prevalent. Particularly important to this study is the application of RUSLE within contemporary studies in Belize (Burke and Sugg 2006; Chicas and Omene 2015; Chicas et al. 2016; Thattai et al. 2003), the examination of the influences of agricultural terraces (Hussein et al. 2016; Morgan 1995; Renard et al. 1997), and its application to relic terraced landscapes (Bevan and Conolly 2011; Dunning and Beach 1994). The values attributed by the different factors to agrarian landscape surrounding Waybil were calculated and RUSLE equation applied (Table 9-4).

Table 9-4. RUSLE factors and values assigned to terrace and terrace-removed DEM with the three precipitation regimes, wet, average, and dry.

<table>
<thead>
<tr>
<th>RUSLE</th>
<th>Climate</th>
<th>R</th>
<th>K</th>
<th>LS (Mean)</th>
<th>C</th>
<th>P</th>
<th>A (Mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terraced</td>
<td>Wet</td>
<td>1028.106</td>
<td>0.01581</td>
<td>2.333901</td>
<td>0.2</td>
<td>0.5</td>
<td>7.262194</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>1371.015</td>
<td>0.01581</td>
<td>2.333901</td>
<td>0.2</td>
<td>0.5</td>
<td>5.058905</td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>1968.129</td>
<td>0.01581</td>
<td>2.333901</td>
<td>0.2</td>
<td>0.5</td>
<td>3.793607</td>
</tr>
<tr>
<td>Terrace-removed</td>
<td>Wet</td>
<td>1028.106</td>
<td>0.01581</td>
<td>3.187612</td>
<td>0.2</td>
<td>1</td>
<td>19.83722</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>1371.015</td>
<td>0.01581</td>
<td>3.187612</td>
<td>0.2</td>
<td>1</td>
<td>13.81877</td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>1968.129</td>
<td>0.01581</td>
<td>3.187612</td>
<td>0.2</td>
<td>1</td>
<td>10.36252</td>
</tr>
</tbody>
</table>

**R factor**

Rainfall erosivity assesses the effect of raindrop impact as well as the amount and rate of runoff. This is a measure of total storm energy times the maximum 30 min intensity and summed over a year (Chicas and Omene 2015:355-356; Renard et al. 1997:19; Thattai et al. 2003:989). In this manner the equation accounts not only for the duration of rainfall, but also its intensity and pattern (Farhan and Nawaiseh 2015:4653). This relationship between the R factor and soil erosion is linear. Increase in the R factor is directly additive to soil loss (Renard et al. 1997:23).

Calculating the R factor within the Waybil case study presented several difficulties based on the lack of local weather stations to produce the fine grain data necessary for traditional
calculations. This situation is not unique to the North Vaca Plateau with several studies having encountered these complications in Central America (Burke and Sugg 2006; Chicas and Omíne 2015; Chicas et al. 2016; Mikhailova et al. 1997; Thattai et al. 2003). A work around suggested for these situations is to rely on a tested relationship between elevation and rainfall intensity (Mikhailova et al. 1997). However, results from these suggested calculations were extremely high. Therefore, in this study a more general approach was used to approximate the R factor based on the annual precipitation and its monthly distribution, which produced more consistent results. The R factor calculation used is.

\[
R = \sum_{i=1}^{12} 1.735 \times 10^{1.5 \log_{10}(P_i/P) - 0.08188}
\]

Where R is measured in Mj mm ha\(^{-1}\) h\(^{-1}\) per year; P\(_i\) is the proportional monthly rainfall (mm); P is the annual rainfall (mm) (Ganasri and Ramesh 2015). These results were higher than the values reported in northern Belize that exhibited an intense, yet, lower annual rainfall, 2,000 mm (Dunning and Beach 1994:56). Results were also lower than the values reported for southern and coastal parts of Belize, which exhibited a higher annual rainfall, 4,000 mm (Thattai et al. 2003:990). The R factor was calculated for a wet and dry year as well as an average.

K factor

Soil erodibility is a function of the rate soils are susceptible to detachment from the soil mass and transportation of these particles by an amount of overland flow created by a specific storm within an explicit area (Farhan and Nawaiseh 2015:4654). This is related to the soil texture, percentage of organic matter, soil structure, and permeability.

The calculation for the K factor is;
\[ K = 27.66 \, m^{1.14} \times 10^{-8} \times (12 - a) + 0.0043 \times (b - 2) + 0.0033 \times (c - 3) \]

Where \( K \) is measured in ton ha h ha\(^{-1}\) MJ\(^{-1}\) mm\(^{-1}\); \( m \) is particles size; \( a \) is percentage of organic matter; \( b \) is soil structures code used in classification; \( c \) is soil permeability (Farhan and Nawaiseh 2015:4654). The \( K \) factor is scaled from 0 to 1, with values of 1 indicating soils that are highly susceptible to erosion. Results from the soil analysis at Waybil were entered into the Global Erodbitly Database Query (see Borselli et al. 2009). This database estimates the \( K \) factor based on soil texture, organic matter, stone content, and climate (Alberico et al. 2014:122-123).

When conducting this analysis, the average textual values from all four planting surfaces sampled were used. Concerns about inaccuracies when estimating the \( K \) factor have been addressed in other studies (Bevan and Conolly 2011:1311), although having results for several of the contributing factors does make these estimations stronger.

**LS factor**

The LS factor measures the effect that landscapes, slope morphology, have on erosion. It is a combination of slope length (L), and slope steepness (S) (Farhan and Nawaiseh 2015:4654; Zhang et al. 2013:177). The slope length and steepness factors are ratios calculated from the comparison to the standardized soil loss of a 22.13 m long slope at a nine percent slope (Farhan and Nawaiseh 2015:4654-4655; Renard et al. 1997; Wischmeier and Smith 1978; Zhang et al. 2013). The length of slope is calculated based on its termination either when the slope decreases to a point that a deposition occurs or to a point when the flow enters a well-defined drainage network, channel or upslope (Zhang et al. 2013:177-178).

Calculating LS factor is greatly assisted by the implementation of GIS software and generally guided by a DEM. Due to the high resolution LiDAR imagery available for Waybil this factor is probably our best represented and conducted a scale of 1 x 1 m. This calculation draws
on both the slope analysis in ArcGIS as well as the Flow Accumulation (FAC) conducted in the previous hydrological analysis (Farhan and Nawaiseh 2015:4655). The calculation is;

\[ LS = \text{Pow}\left(\frac{\text{flow Acc} \times \text{Res.}}{0.22; 0.6}\right) \times \text{Pow}\left(\frac{\sin [\text{slope gradient}] \times 0.01745}{0.09}, 1.3\right) \]

**C factor**

Cover management is a dimensionless value attributed to affects that vegetation cover, or lack of, have on soil erosion. This is related to the dispersal of kinetic energy behind raindrops and the surface disruption of overland flow (Farhan and Nawaiseh 2015:4655). This calculation is not just limited to the vegetation cover, but also has a temporal component that addresses issues such as duration of cropping, fallow periods, and prior use. There are numerous categories of land use that have been created to simplify and make the application of this category easier (Alberico et al. 2014; Farhan and Nawaiseh 2015; Renard et al. 1997; Wischmeier and Smith 1978). In the case of Waybil, a value of 0.2 was applied to be representative of complex cropping systems. This values falls in line with previous archaeological research in Belize that defined agricultural production as the *milpa* farming of maize and beans with the preservation of some canopy (Dunning and Beach 1994:56).

**P factor**

The conservation practice factor is another dimensionless value that is related to the ratio of soil loss using support practices to the soil loss after “up and down” cultivation (Farhan and Nawaiseh 2015; Renard et al. 1997). In this manner it measures the effect different support practices have on the amount and rate of water overland flow (Farhan and Nawaiseh 2015:4655). The values used in this factor range from 0 to 1, with lower numbers reflecting more effective conservation practices.
The agricultural terraces that surround Waybil form the P factor in this calculation. There have been several studies that assign a ranging value to the agricultural terracing (Bevan and Conolly 2011; Foster and Highfill 1983; Hussein et al. 2016; Renard et al. 1997). The P values of terraces are governed first by the distance between terrace walls, with the maximum benefit, a value of 0.5, being assigned to terraces less than 33.5 m (Foster and Highfill 1983; Renard et al. 1997:237; Wischmeier and Smith 1978). As the spacing between the terrace walls increase, their efficiency in reducing overland flow and erosion decrease. This value is further manipulated based on the slope of the terraced field systems. Slope percentages less than nine receive a lower value. This is computed by multiplying the initial value by $1 - 0.1^{2.4e}$, where e is the percent of slope grade (Renard et al. 1997:214). Terraced fields exhibiting an average slope, 9.6%, steeper than this gradient remain at the same value. Values are further defined by the presence of outlets, drainage point both above and below ground, spaced within the terrace walls (Foster and Highfill 1983; Hussein et al. 2016). While there is evidence for below ground drainage systems within the terrace system at Waybil, there frequency and distribution is unknown. However, given the relatively close interspacing of terracing, even with the presence of below ground outlets, the P value remains at 0.5. This value is within the range suggested for other archaeological terraces within and outside the Maya area (Bevan and Conolly 2011; Dunning and Beach 1994).

**Results**

Analysis of the role agricultural terraces played in the susceptibility to erosion at Waybil was conducted in several fashions. First, three R values were computed which represent extreme wet and dry years as well as an average year. Second, these three scenarios were analyzed on the terraced DEM and terrace-removed DEM. This resulted in six sets of A values for the three scenarios, each calculated for a 1 x 1 m resolution across the agrarian landscape at Waybil (Figure 9-8).
To explore patterns within the data, the A values were converted into a log distribution with the removal all the zeros (Figure 9-9, 9-10, 9-11; Table 9-5, 9-6, 9-7). This was conducted for the distribution analysis, but also to remove erroneous LiDAR data (see previous discussion). It needs to be noted that a small portion of these zero values are representative of highest point of structures or peaks of hilltops where no other surrounding cells exhibit higher elevations. Removing these values narrowed the focus of analysis to the landscape more directly influenced by agricultural terraces. The resultant A values were plotted in a density distribution for the wet, dry and average season, pairing the terraced and terrace-removed datasets. Similar to the hydrological analysis a permutation test was conducted to assess the significance of these distributions. This test sampled 14,000 values independently from each of the scenarios to produce a P-values. The resultant P-value of 0.003 was presented for both the wet and average scenarios and a P-value of 0.001 presented for the dry scenario. This rejects the null hypothesis.
that there is no significant difference between the terraced and terrace-removed DEM in all three scenarios.

Figure 9-9. Density distribution of RUSLE susceptibility to erosion, values derived from the wet precipitation regime.

Table 9-5. RUSLE and skewness analysis derived from the wet precipitation regime.

<table>
<thead>
<tr>
<th>RUSLE</th>
<th>Climate</th>
<th>Mean</th>
<th>Standard Dev.</th>
<th>Skewness</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terraced</td>
<td>Wet</td>
<td>1.74</td>
<td>1.05</td>
<td>-0.45</td>
<td>0.003</td>
</tr>
<tr>
<td>Non-Terraced</td>
<td>Wet</td>
<td>2.59</td>
<td>1.19</td>
<td>-0.69</td>
<td></td>
</tr>
</tbody>
</table>

Figure 9-10. Density distribution of RUSLE susceptibility to erosion, values derived from the average precipitation regime.
Table 9-6. RUSLE and skewness analysis derived from the average precipitation regime.

<table>
<thead>
<tr>
<th>RUSLE</th>
<th>Climate</th>
<th>Mean</th>
<th>Standard Dev.</th>
<th>Skewness</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terraced</td>
<td>Average</td>
<td>1.38</td>
<td>1.19</td>
<td>-0.45</td>
<td>0.003</td>
</tr>
<tr>
<td>Non-Terraced</td>
<td>Average</td>
<td>2.22</td>
<td>1.05</td>
<td>-0.69</td>
<td></td>
</tr>
</tbody>
</table>

Figure 9-11. Density distribution of RUSLE susceptibility to erosion, values derived from the dry precipitation regime.

Table 9-7. RUSLE and skewness analysis derived from the dry precipitation regime.

<table>
<thead>
<tr>
<th>RUSLE</th>
<th>Climate</th>
<th>Mean</th>
<th>Standard Dev.</th>
<th>Skewness</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terraced</td>
<td>Dry</td>
<td>1.09</td>
<td>1.19</td>
<td>-0.45</td>
<td>0.001</td>
</tr>
<tr>
<td>Non-Terraced</td>
<td>Dry</td>
<td>1.94</td>
<td>1.05</td>
<td>-0.69</td>
<td></td>
</tr>
</tbody>
</table>

Section Summary: Susceptibility to Erosion

In this section, the level of erosion has been calculated across the agrarian landscape surrounding Waybil. Results describe a significant difference between the terraced DEM and the terrace-removed DEM, declaring that terraces are reducing the effects of both sheet and rill erosion. When examining the skewness of the distribution of annual soil loss (A), similarities are immediately apparent, as the same values are shared in every circumstance. This suggests that the level of rainfall, while a linear additive to erosion rates, is not changing the overall pattern of erosion across the landscape. The linear nature of this equation is supported by both the raising mean A value from the dry, average, to wet scenarios as well as the percentage difference in the mean A values between terraced and terrace-removed, equally 46% in all climatic conditions.
There is a 31% increase in erosion from a dry season to wet season, which equates to an additional 3.47 tons’ ha⁻¹ year⁻¹ in a terraced landscape and 9.47 tons’ ha⁻¹ year⁻¹ when there are no terraces. This significant increase in erosion suggests that severe rains could cause serious erosion problems, especially if there are no terraces.

Examining the distribution of these values across the landscape suggests similar trends to those identified in the hydrological analysis, although at a much larger extent. The terraces are distributing erosion values across the landscape, by increasing the prevalence of low values and decreasing mid-level values. In terms of erosion, this would equate to less rill and potentially more of a sheet erosion mechanism. This makes sense when considering how a terrace wall would break up the momentum of channelized overland flow. Further, the increased sheet erosion could work in a beneficial manner by evenly distributing sediments along terrace planting surfaces and behind terrace walls. The distribution of these erosion values describe how the long contour terraces are reducing broad sheet erosion found along the hill slope while cross-channel terraces are reducing rill erosion within the constricted valleys.

These results fall in line with the erosion analysis of the Greek terrace systems on the island of Antikythera. Bevan and Conolly suggested that terraces are not always constructed to manage catastrophic soil loss, but rather for “controlling patterns of local soil redistribution rather than soil loss” (2011:1313). This appears to mirror the erosion management that the agricultural terraces are providing at Waybil. However, in the process of managing soils and working with the natural erosional processes these terraces have sculpted the landscape into series of leveled planting surfaces.

**Agricultural Suitability**

Agricultural suitability models are based on the prediction of production capacity through quantification of landscape qualities that adequately support agrarian production. This falls
within the scope of land evaluation for land use planning which generally includes surveys of climate, soils, vegetation and other land use requirements (FAO 1976:1). These are combined to create an index of suitability that evaluates the limitations and benefits of the properties of the land resources (Akinci et al. 2013; Bandyopadhyay et al. 2009; Beek 1978; IIASA/FAO 2012; Malczewski 2004; McRae and Burnham 1981; Mokarram and Aminzadeh 2010) and an assessment of the land’s performance under differing kinds of agriculture practices, predicting the potential and limitations of crop production (Elsheikh et al. 2013:98). For this study, I combine the results from the hydrological and erosion analysis with slope and available sunlight to map the suitability of the Waybil landscape under agrarian production. Similar to previous GIS modeling this analysis will focus on the effects of agricultural terraces in creating more agriculturally suitable lands. This suitability measure will be compared among dry, wet, and average rainfall years using the precipitation data to approximate rainfall quantities.

The use of agricultural suitability models for resource management and conservation has a long history. The most widely used model is the Global Agro-ecological Zones (GAEZ 3.0) created by Food and Agriculture Organization of the United Nations (FAO) and International Institute for Applied Systems Analysis (IIASA (IIASA/FAO 2012). GAEZ 3.0 is based on the upper limits of crop production potential described by matching crop requirements with climate, terrain, soils, and agricultural management practices and is global in scope, using broad resource assessments (IIASA/FAO 2012). Relatively few archaeological projects have used an agricultural suitability model. However, in the nearby Upper Belize River Area Fedick (1988; 1994) conducted an early land resource evaluation that he correlated to ancient Maya settlement distributions across various landscapes. Neither the scale nor analytical level of these projects match well with the local analysis conducted at Waybil. However, they do provide supporting
evidence that will inform the Waybil study. More in line with the analysis conducted at Waybil are the numerous case studies that focus on contemporary land suitability by applying modified classifications based on local datasets (Akinci et al. 2013; Bandyopadhyay et al. 2009; Elsheikh et al. 2013; Feizizadeh and Blaschke 2013; Ghebremeskel 2003; Kalogirou 2002; Pereira and Duckstein 1993; Tiruneh and Ayalew 2016; Wang 1994). These modifications include different classification processes (Akinci et al. 2013; Elsheikh et al. 2013; Feizizadeh and Blaschke 2013) and analysis platforms (Pereira and Duckstein 1993), emphasizing varying landscape features (Bandyopadhyay et al. 2009), as well as different crop management and production techniques (Ghebremeskel 2003; Kalogirou 2002). These studies are part of a trend toward the use of more specific assessments rather than the broader based analyses (Elsheikh et al. 2013:98). This finer scale approach will be used at Waybil, using the data results presented throughout this dissertation and drawing on and modifying the methodology of several of these modern case studies.

Land evaluations have been classified into several dichotomist categories; general and specific, physical and integral, and qualitative and quantitative (Beek 1978; Ghebremeskel 2003). The Waybil analysis will take on the role of a general, physical, quantitative approach. It will assess only the general characteristics of the lands suitability for crop production through the quantitative application of physical datasets. The datasets will be combined within the GIS platform to produce maps describing the varying suitability of the Waybil landscape areas.

The evaluation of agricultural suitability has two limitations: variability in the scale of analysis and data availability/generalization. Land evaluations are primarily conducted at a regional level incorporating diverse datasets at different scales. Several of the datasets, such as climate or elevation, exhibit little or no variation across the site, while other data, such as
drainage or soil characters, provide fine-grained detail. Data availability and generalization also create a limiting factor. Larger analysis programs, often conducted by, or sponsored by, governmental sectors have the ability to draw on large and comprehensive datasets of focused research (IIASA/FAO 2012). At Waybil, analysis is limited to the research available in this dissertation, as no comprehensive land evaluation has been conducted within the North Vaca Plateau. This limiting factor leads into an issue of generalization. Often the data collected at Waybil has been accumulated into a single dataset. An example of this is soil depth, data on soil depth is available from the terrace excavations, however to extrapolate this data across the entire Waybil landscape would be a large and inaccurate assessment. If kept as unique values, they cannot be representative of Waybil and ultimately bias the analysis. This generalization occurs at a level that nullifies the potential of identifying correlates between suitability and specific crop requirements, often the second step after this sort of analysis. Nonetheless, the Waybil data provides a preliminary, localized, agricultural suitability analysis and develops a foundation that future research can add too.

Methods

As discussed, agricultural suitability is calculated based on the quality of several different characteristics of the landscape. In this analysis, these will include slope, RUSLE, sunlight, soil depth, and elevation. Each factor needs to be quantified and calculated across the Waybil landscape. This results in an accumulation of numerous datasets of independent values that must be classified into a standardized scheme of value. Once all the data is standardized, each factor is assigned a specific weight, representative of its role in influencing the agricultural production and calculated by a pairwise comparison and an analytical hierarchy process (see Factor Weighting). The datasets are combined in the GIS platform and their weighted sums, classified as suitability indices, are mapped across the landscape with each 1 m² assigned a value of
suitability. Throughout the process, there are a number of subdivisions and weights assigned to
the different factors and results. These are derived from the databases of several case studies
(Akinci et al. 2013; Bandyopadhyay et al. 2009; Tiruneh and Ayalew 2016) and FAO/IIASA
publications (1976; 1984; 2012). The following is a description of each factor and value assigned
as well as the calculated weights.

**Slope**

The degree of slope is one of the most powerful factors when considering agricultural
suitability. As slopes increase they play a factor in limiting the diversity of crops available for
production, increasing the erosion rates, which ultimately decreases soil depth and fertility
(Akinci et al. 2013:71; IIASA/FAO 2012:77). This can be amplified amongst rain-fed annual
crops (IIASA/FAO 2012:77). The degree of slope was divided into six categories and each
assigned a value (Table 9-8). Values were drawn from Akinci et al. (2013:78) which generally
follow dimensionless values prescribed by GAEZ (IIASA/FAO 2012:77-78) and
Bandyopadhyay et al. (2009:889). It is generally accepted that slopes with a greater incline
percentage of over 30 to 35 are not well suited for agriculture due to the sloping topography and
high overland flow (Akinci et al. 2013:75; Bandyopadhyay et al. 2009:889).

Table 9-8. Agricultural Suitability score values assigned to slope.

<table>
<thead>
<tr>
<th>Slope Percentage (%)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 2</td>
<td>10</td>
</tr>
<tr>
<td>2 to 6</td>
<td>8</td>
</tr>
<tr>
<td>6 to 12</td>
<td>6</td>
</tr>
<tr>
<td>12 to 20</td>
<td>4</td>
</tr>
<tr>
<td>20 to 30</td>
<td>3</td>
</tr>
<tr>
<td>&gt;30</td>
<td>1</td>
</tr>
</tbody>
</table>
Sunlight

Sunlight is a measure of aspect. All plants need a degree of sun exposure to be successful, although this level varies between species (Akinci et al. 2013:74). During analysis each 1 m² points is assigned a value equivalent to a cardinal direction. These values are reclassified based on the score ranking (Table 9-9). The scores were assigned based on the level of incoming sunlight received, grouping several directions together. Because plant growth is typically at an optimum with more sun on the southern facing surfaces, which receive the most sunlight despite the tropical environment, were assigned a higher score (Akinci et al. 2013:75). Similar slope score ratings were acquired from Akinci et al. (2013:78).

Table 9-9. Agricultural Suitability score values assigned to aspect.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Degree</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>157.5 to 202.5</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>202.5 to 247.5</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>112.5 to 157.5</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>67.5 to 112.5</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>247.5 to 292.5</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>22.5 to 67.5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>292.5 to 337.5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0 to 22.5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>337.5 to 360</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>-1</td>
<td>8</td>
</tr>
</tbody>
</table>

RUSLE

The RUSLE equation is rarely incorporated in the agricultural suitability models. However, most models do contain erosion levels and other classifications for soil characteristics which provide a basis for the incorporation of RUSLE data into the suitability model. RUSLE values were categorized using the soil loss rating provided by Tiruneh and Ayalaw (2016:28), who also used the RUSLE method, and scores for the categories were drawn from Akinci et al. (2013:78). However, the scores were increased as the RUSLE equation also contained values for
flow accumulation, soil texture, and precipitation (Table 9-10). In this manner they incorporated
the soil characteristics and moisture retention detailed in Akinci et al. (2013:78) Land Use
Capability Class and scores were increased to reflect this.

Table 9-10. Agricultural Suitability score values assigned to soil loss tolerance.

<table>
<thead>
<tr>
<th>Soil Loss Tolerance</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 5</td>
<td>10</td>
</tr>
<tr>
<td>5 to 15</td>
<td>9</td>
</tr>
<tr>
<td>15 to 30</td>
<td>8</td>
</tr>
<tr>
<td>30 to 50</td>
<td>7</td>
</tr>
<tr>
<td>50 to 100</td>
<td>6</td>
</tr>
<tr>
<td>100 to 200</td>
<td>5</td>
</tr>
<tr>
<td>&gt;200</td>
<td>4</td>
</tr>
</tbody>
</table>

**Factor weighting**

Once all the factors have been calculated and categorized the next step is to assign a
weight to each factor which reflects its importance within the overall suitability equation and to
each other (Mokarram and Aminzadeh 2010:509). Factor weighting will be conducted by
following the methodology outlined by Akinci (2013:76). Akinci et al. (2013) applied analytic
hierarchy process (AHP) to prescribe weights via a pairwise comparison matrix. A pairwise
comparison matrix (see Thurstone 1927) is a process of comparing paired entities to see which is
more dominant or identical (Saaty 1977:235). The level of this dominance is given a numeric
value, higher values prescribed to the more dominant factors. This is an important consideration
as suitability is not dependent on factors individually, but rather the interaction between the
differentially weighted contributing factors (Akinci et al. 2013:72; Ghebremeskel 2003:6). When
conducting an AHP analysis the pairwise comparison establishes the necessary discrete
relationships between entities (Saaty 1987:161). The AHP method gathers these entries and
discrete relationships to conduct a multi-criteria decision-making procedure based on the entities
assigned weights (Saaty 1977; 1990; Saaty 1987). This is accomplished by normalizing the
pairwise rankings by dividing each individual pairwise rank by the sum of the column. These sums are then computed along the rows for every pairwise ranking and the average of the entire row is calculated. This average value, ranging from 0 – 1, is the prescribed AHP value for the specific entity. By including the qualitative data in the pairwise comparison, the AHP is susceptible to a level of inconsistency. These inconsistencies can be tested for by calculating a consistency ratio (CR) (see Ho 2008; Saaty 1987; Saaty 1977; 1990).

The pairwise comparison and AHP method were implemented to determine the differing weights assigned to the factors of agricultural suitability analysis at Waybil (Table 9-11). The values prescribed to these pairwise rankings were derived from Akinci et al. (2013) who worked with a consortium of agricultural experts. This focused only on the factors of Slope, Aspect, and RUSLE. Soil depth and elevation were not included as they only provided a uniform score. This also acted to simplify the AHP method reducing the level of subjectivity, keeping the CR values to an acceptable level of 0.02.

Table 9-11. Pairwise comparison and AHP weights.

<table>
<thead>
<tr>
<th></th>
<th>Slope</th>
<th>Aspect</th>
<th>Erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>1</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Aspect</td>
<td>0.333333</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>RUSLE</td>
<td>0.111111</td>
<td>0.5</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>0.7029915</td>
</tr>
<tr>
<td>Aspect</td>
<td>0.2065527</td>
</tr>
<tr>
<td>RUSLE</td>
<td>0.0904558</td>
</tr>
</tbody>
</table>

Suitability classification

With all the datasets collected, scored individually, and collectively weighted, the next step is the combination of these results into a suitability index. This was accomplished by taking the weighted sum of each value with the GIS platform. The equation is:

\[
\text{Suitability} = (\text{Slope} \times 0.7029915) + (\text{Aspect} \times 0.2065527) + (\text{RUSLE} \times 0.0904558)
\]
This resulted in the assignment of a SI value to every 1 m², with higher values reflecting increasing suitability (Bandyopadhyay et al. 2009:884). This process was conducted six times using the RUSLE values of wet, dry, and average precipitation and slope values from both the terraced DEM and terrace-removed DEM. The final stage of this analysis was to classify the suitability in an index. This final classification is dependent on the purpose and goal of one’s analysis and no specific standard currently exists for the land suitability for agricultural purposes (Akinci et al. 2013:72; Ghebremeskel 2003:13). The FAO (1976) recommends an even division into 4 to 5 classes, ranked from highly suitable to not suitable. Other smaller projects have created capability rankings based on specific production limitations (Bandyopadhyay et al. 2009; Sys and Verheye 1972). This analysis will follow the guidelines set forth by the FAO and divide the suitability values evenly into 4 class. However, it will differ in how these groups are defined. Instead of a ranking from not suitable to suitable, these are simply defined as suitability classes, ranked in suitability from 1 the lowest through to 4 highest. While this may seem a moot differentiation, the decision is based on the reality that these values are ranked against each other, with no explicit connection to specific crop requirements. In this manner, a zero suitability can never be identified, and rather it is a representation of a range of suitability unique to this analysis and the Waybil agricultural field systems.

Results

This section has defined the agricultural suitability across the Waybil agrarian landscape. Results present the changes in suitability in both the terraced and terrace-removed DEMs as well as the results of differing precipitation regimes (Figure 9-12, 9-13, 9-14). Examining the varying levels of suitability assigned to the surface area it is clear that there is a higher amount of areas classified as highly suitable in the terraced landscape versus the terrace-removed landscape (Figure 9-13). This trend is continued amongst the surface area of lowest suitability, except
during the highest rainfall when the trend is reversed. Results suggest that terraces are creating ~10,000 m$^2$ (4%) more surface area which is highly suitable for agricultural production at the cost of creating ~685 m$^2$ (0.24%) of land classified as lowest suitability. A certain degree of this may be attributed to a function of slope. Unmaintained terrace walls exhibit a degree of slump in front of their facing wall creating a strip high slope, lower suitable, surface area in front of the walls.

In terms of the marginal and moderately suitable lands, there is ~1 - 3% more lands classified in these categories attributed to the terrace-removed lands. This represents the reduced amount of highly suitable and lowest suitable lands.

Figure 9-12. Agricultural suitability during a year of high precipitation. Top: non-terrace DEM, Bottom: terraced DEM.
Figure 9-13. Agricultural suitability during a year of average precipitation. Top: non-terrace DEM, Bottom: terraced DEM.

Figure 9-14. Agricultural suitability during a year of low precipitation. Top: non-terrace DEM, Bottom: terraced DEM.
The most interesting results can be found in the variance of change within the amount of suitability as precipitation level changes, especially in the comparison of the terraced and terrace-removed landscape. To highlight this, a coefficient of variation was produced for each suitability index encompassing all precipitation regimes (Table 9-12). This coefficient is used to compare the terraced and terrace-removed landscape (Figure 9-15).

Table 9-12. Percentage of coefficient of variation, Terrace-removed and Terraced.

<table>
<thead>
<tr>
<th>Suitability Index</th>
<th>Wet (m²)</th>
<th>Avg. (m²)</th>
<th>Dry (m²)</th>
<th>Std. (m²)</th>
<th>Mean</th>
<th>Coefficient of Variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrace-removed</td>
<td>Lowest Suitable</td>
<td>17599</td>
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<td>9948</td>
<td>3917.83</td>
<td>10943.46</td>
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<td></td>
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<td>118526</td>
<td>114175</td>
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<td>130059</td>
<td>7701.43</td>
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<td>12066</td>
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<td>35731</td>
<td>35884</td>
<td>197.57</td>
<td>26826.14</td>
</tr>
</tbody>
</table>
Figure 9-16. Percentage of coefficient of variation, Terrace-removed and Terraced.

The coefficient of variation is determined by taking the ratio of standard deviations from the mean. While the results are dimensionless, and unable to be statistically tested for significance they provide important insight into the function of agricultural terraces in terms of maintaining suitability in the face of varying climatic changes. The percentage of variance of change in the terrace-removed DEM is more than double that of the terraced DEM. While not evenly distributed within the suitability index, each category exhibits over double the amount of variation from the terraced to terrace-removed DEM. This suggests that the agricultural terraces are relatively maintaining the same distribution of the suitability index across the landscape despite climatic shifts. The highest percentage of change in both the terraced and terrace-removed landscape occurs within the lowest suitability class. This is likely the result of areas of
high slope and erosion being compounded by changing precipitation levels. This is most drastically felt in the terrace-removed DEM.

**Section Summary: Agricultural Suitability**

The analysis of agricultural suitability incorporated both the hydrological and susceptibility to erosion analysis, combining results from both of the models as well as integrating data on slope and sunlight. The resultant suitability index of the terrace-removed DEM revealed a higher fluctuation with climatic change than the terraced landscape. Despite the relative simplicity of this suitability analysis, it has been able to verify the functional properties of agricultural terraces as they interact with a fluctuating environment. Describing how the inhabitants of the Waybil constructed a unique agroecosystem to maintain consistency in land suitability despite fluctuating environmental variables.

**Chapter Summary: Geographical Information Systems (GIS) Modeling**

In this chapter, three interrelated models have been presented in order to quantify and describe how agricultural terraces function within the agrarian landscape that surrounds Waybil. The hydrological analysis described the effects of the terraces in redistributing the flow accumulation while modifying drainage catchments into broader, truncated shapes. This suggests that terrace construction was not organized around catchments, at our scale of analysis, and that terraces represent a degree of manipulation to ensure that water could be more laterally shared between catchments, or accumulated in larger catchments. These interpretations are supported by the stream networks created by higher density of low FAC values and a lower density of high FAC values in the terraced DEM. This presents a pattern of wider horizontal accumulation and a directed lateral dispersal of water and sediment. These changes presented a significant statistical difference, which can also be visually identified. In modeling the susceptibility to erosion of the terrace systems surrounding Waybil these hydrological results were incorporated. This erosion
analysis presented how the agricultural terraces decrease both sheet along the hill slopes and rill erosion within the constricted valleys. The relationship between the terraced and non-terraces RUSLE values provided that their difference was also significant. Further, the percentage differences in the mean values of the erosion analysis is larger than those of the hydrological and catchment analysis. However, when I examine the factors included within the erosion calculations, they include the FAC results within the LS factor. This suggests that the functionality of terraces is an emergent property, becoming increasingly significant when both hydrological and erosion benefits of the agricultural terraces are considered together. This is supported by the percentage difference between the erosion, hydrological, and catchment analysis.

The analysis of agricultural suitability described how the agricultural terraces created larger areas classified as highly suitable while reducing lands that exhibited the lowest suitability. The most striking results were identified by the coefficient of variation. These results describe how the terraced landscape was able to minimize variation in the suitability index as the landscape was subjected to changing precipitation regimes.

Combining these three GIS models facilitates a quantifiable description of terrace function. The association between FAC (areas of excess water), areas of high erosion potential (rill and sheet), and the placement of agricultural terraces supports the argument that terraces combat overland flow erosion, while accumulating sediment as well as conserving and evenly dispersing sediments and water. The majority of agricultural terraces are found perpendicular to the stream networks in areas of higher FAC and erosion values. These terraces function in two different manners. First, the cross-channel terraces bisect paths of higher FAC, functioning to slow the movement of sediment in those areas prone to erosion, while maximizing the size of the
planting surfaces with acquired sediments. These terraces are also capitalizing on the capture and dispersal of water. Second, the contour terraces, while bisecting paths of higher FAC, are also functioning to disperse these values, increasing the number of stream segments in the network, lowering the FAC and erosion values. This process diffuses the sediment and water flow associated with a high FAC laterally across the landscape, rather than directing it to specific field systems or away from the fields. As a result, the agricultural terraces have increased agricultural suitability while creating a more stable landscape that can withstand the climatic fluctuations identified to have occurred during the Classic period. These results will be incorporated in the discussion chapter in order to evaluate the functional qualities of the terraces within the adaptive decision to incorporate them within the agricultural strategy of the Waybil community in order to deal with fluctuating social and environmental fluctuations.
CHAPTER 10
DISCUSSION

In this discussion chapter all the dataset outlined in my dissertation will be brought together in order to discuss the minor center of Waybil from the perspective of its agricultural strategy, addressing how environmental, climatic, and social factors influenced the decisions made by the Waybil community. These data will also be used to evaluate the original question of whether terrace use at the site were adaptive in the face of pressures created by environmental, climate, demographic, and political changes in the region.

In order to address how the choices of agricultural strategy changed as the Waybil inhabitants reacted to the internal fluctuations of the larger socio-political and socio-economic sphere of the North Vaca Plateau and the external fluctuations of the changing climatic conditions, I first present a chronological history of the Waybil agricultural landscape. To further explore the decisions and motivations behind the development, extensification, and eventual abandonment of the agricultural terrace systems at Waybil, I next draw on several concepts from resilience theory, including niche construction, risk spirals, sunk-costs effect, and rigidity traps. These are applied to the Waybil data to conceptualize and explain significant transitional periods. In doing so, a better understanding emerges of how agricultural terraces fit within the history of Waybil and the greater socio-political and socio-economic sphere of the North Vaca Plateau.

Historical Chronology of the Waybil Agricultural Strategy

As discussed in Chapter 2, the socio-ecological systems framework incorporates shared qualities of both complex systems and the research program of historical ecology (see Balée and Erickson 2006:6). From one perspective, the socio-ecological systems framework operationalizes historical ecology by applying methods used to study complex system. At the same time, it humanizes the ecological perspective of complex systems through adherence to the postulates
outlined in the research program of historical ecology. In the following discussion, these characteristics will be used to describe the changes in the Waybil agricultural strategy. Conducting this study of agricultural strategies, beginning before the construction of terraces through to their abandonment, provides a temporal scale that stretches from the specific to the long term (Crumley 1993:378), addressing both short term and long-term fluctuations amongst the variables over time (Gunderson and Folke 2003:15; Redman et al. 2007:117). Further, by expanding the spatial scale of analysis from the Waybil agricultural strategy to the implications within the larger socio-political and socio-economic sphere of the North Vaca Plateau and its neighboring Maya polities, facilitates a more comprehensive understanding of the dynamics of the human-nature relationship, the degree of interaction, and consequences (Crumley 1993:378).

**Late Preclassic (400 B.C. – 100 A.D.)**

A scattering of ceramics at the sites of Minanha and Martinez, and the first evidence for kingly trappings at the site of Ixchel suggest to Iannone that there was limited permanent occupation at many sites in the North Vaca Plateau during the Late Preclassic (Iannone et al. 2014a:288). Survey by myself and others at Waybil revealed that, at this early time, Waybil lacked any evidence for permanent residential settlement units, but did exhibit a significant investment in its ceremonial epicenter (Hills et al. 2012:47-52; Iannone et al. 2011c:101-107). Iannone has suggested that the site held a significant ritualistic role as a ceremonial center that served dispersed populations in the surrounding regions, including the rural population surrounding the site of Minanha (Iannone 2017). This development of Waybil is analogous with a similar minor center of Zubin associated with Cahal Pech in the Belize River Valley (Iannone 2017).

While the Late Preclassic was a relatively wet time, it exhibited significant climactic fluctuations. (Akers et al. 2016:282; Iannone et al. 2014a:286-287). If the settlement of the
North Vaca Plateau followed the hypothesized saltation dispersal process (Iannone et al. 2014b:160), then populations would have focused on the rich soils found in the valley floors near perennial springs (Longstaffe and Iannone 2011; Macrae 2010; Macrae and Iannone 2010). This narrative falls in line with the larger portrayal of Preclassic Maya practicing milpa farming in transient communities. This is supported by evidence of increasing levels of deforestation and agricultural practices throughout the tropical lowlands, especially around swamp edges, taking advantage of the fertile soils in these areas (Beach et al. 2002:376; Creamer and Haas 1985:740; Dunning et al. 1999:652; Hammond 1978:33-34; Hansen 1998:88; Leyden et al. 1996:44; Matheny 1976:639-642; 1978:199, 207; Pohl and Bloom 1996:153; Pohl et al. 1996:358-365, 369; Pope et al. 1996:172; Rice 1976b:427, 445; Rice 1996:203). The process of saltation is supported by my ethnographic research of the contemporary farming practices targeting the low-lying valley bottoms, often in association with an active spring (see Contemporary Farming in the North Vaca Plateau). These areas are reported to offset the effects of extended seasonal dry periods. However, they are also noted to be more susceptible to the periods of increased precipitation.

The restricted settlement outside of Ixchel would indicate limited political pressure on these scattered populations of the North Vaca Plateau. While Waybil at this time held a degree of importance in terms of civic-ceremonial functions in what will become the sites epicenter, evident by the large plastered shrine structure, Structure AI, with associated stucco mask (Hills et al. 2012:47-52; Iannone et al. 2011c:101-107). Overall, relatively low socio-economic and socio-political pressures and a gentle climate in the North Vaca Plateau was satisfied within the milpa agricultural strategy.
**Section Summary: Late Preclassic.** The Waybil site is in its infancy during this period, developing its identity around a ritual function within the landscape. At this time, there are few external pressures exerted from the wet climate. However, there does appear to be a low, yet developing, internal (social) pressure from a growing population in the North Vaca Plateau. This internal pressure within the systems regime is likely the impetus for developing this initial identity at Waybil within the larger socio-ecological system of the North Vaca Plateau.

**Terminal Preclassic (100 – 250 A.D.)**

Following this wet period, the transition from the Late Preclassic into the Terminal Preclassic exhibited a major dry event (MDE) which continued until the early facet of the Early Classic, lasting from ~200 – 350 A.D. (Akers et al. 2016:282; Iannone et al. 2014a:286-289). Despite growing stress asserted from the increasingly dry conditions, there were significant developments in the North Vaca Plateau. Minanha and Ixchel both presented an increase in civic-ceremonial construction, albeit sporadic at Ixchel (Akers et al. 2016:282; Hills et al. 2013:42-43; Iannone et al. 2011b:63; Iannone et al. 2012:12; Iannone et al. 2014a:287; Schwake et al. 2013b:26). Meanwhile the support population, previously scattered across the North Vaca Plateau, leaving only ephemeral evidence of occupation, began to coalesce leaving more enduring evidence (Macrae and Iannone 2010:189-190; Macrae 2010:112-113). This was evident in the more permanent settlement units found in ideal agricultural locations, as stipulated by the saltation process.

With the increasing pressures, both socially and climatically, there was a shift within agricultural strategy. It was during this period, within the Contreras Valley, that the first evidence for agricultural terracing occurred in the North Vaca Plateau (Macrae and Iannone 2010:189-190; Macrae 2010:112-113). As presented in the previous suitability models (Geographical Information Systems (GIS) Modeling), these early geointensive agricultural
projects would have functioned to maintain suitable lands for agricultural production in the drying climate. As a result, small isolated pockets of denser, more complex, higher quality terraces were produced in a piecemeal fashion within prime agricultural lands amongst the interfluvial valleys (Macrae and Iannone 2010:189-190; Macrae 2010:112-113). The close proximity of these terrace systems to early settlement units and in targeted areas, as well as low population estimates, suggest that they were not necessarily constructed to maximize production in a fully exploited location, but rather to maintain the suitability of the croplands. This drive to maintain production may reflect a mix of decreasing productivity due to climatic shifts, soil degradation from slash-and-burn techniques, and stronger obligations to an increasing social hierarchy. However, this must be caveated by the potential bias that a limited number of terraces are prescribed with robust early dates and that they may not be representative of the all the terraces found prolifically within the anthropogenic landscape.

The increasing presence of Minanha as a focal community and investments in the ceremonial importance at Waybil, evident by the careful entombment of the antepenultimate temple and stucco mask beneath the penultimate structure, suggests a growing community in this micro-region of the North Vaca Plateau (Hills et al. 2012:47-52; Iannone et al. 2011c:101-107). What is clear is that during this dry period these early investments in the terraced landscape were able to maintain production at a level necessary to support a slowly growing socio-political presence in the North Vaca Plateau.

**Section Summary: Terminal Preclassic.** During the Terminal Preclassic, the identity of Waybil as a ritual/ceremonial site within a socio-ecological system remains constant. However, within the larger systems of the North Vaca Plateau there are both increasing external and internal pressures on the site. With the increasing sedentary population in the nearby Contreras
Valley and the construction within both Minanha and Ixchel, the community in the North Vaca Plateau was growing. This growth could have placed increasing pressure on the Waybil community to fulfill its obligation as a focal point in this micro community; as a result, this may have spurred the investment in structure A shrine. Despite the external pressure exerted by the MDE during this period, which may have been an impetus for the more sedentary population and early investment in agricultural terraces, it does not appear to have effected Waybil.

**Early Classic (250 – 550 A.D.)**

The early facet Early Classic continued to experience the Terminal Preclassic MDE, punctuated by two peak dry periods and separated by ~25 – 50 years’ of high level precipitation. During the latter Early Classic there was a period of relative stability in the climate, neither too wet nor too dry. (Akers et al. 2016:285; Dahlin and Chase 2014; Iannone et al. 2014a:289). During this period, the importance of Minanha as a focal community in its micro-region of the North Vaca Plateau escalated, evident by the expanding epicenter, first settlement groups in the site core, and then enlargement of the settlement units in the Contreras Valley (Macrae 2010:112; Macrae and Iannone 2010:190). Iannone (Personal Communication) hypothesizes that this growth may have been related to a hiatus and destruction event at Ixchel, although direct archaeological evidence is still missing.

It is during this period that the first evidence for agricultural terraces appears at Waybil. The excavated terrace wall and planting surface revealed in Op. W103-1 is dated to the Early Classic. This first terrace construction at Waybil presents two important features that need to be considered. First, the terrace wall exhibits the standardized two wall construction style exhibited in the later terraces. Second, the terrace wall does not take advantage of the underlying bedrock, a construction principle that is used in the later periods of construction at Waybil and the nearby Contreras Valley (Macrae 2010:127; Pollock 2007:222-223). Combined, these factors suggest
that the people who built this terrace had a well-founded understanding of how to construct a terrace walls that can withstand the pressures exerted by retained soils and water. However, they appear to have lacked the localized knowledge of the Waybil land formations.

Several additional inferences can be drawn from the Early Classic terrace constructions. While not dominating the landscape yet, the construction quality of the earliest terrace at Waybil suggests a connection with the resident terrace farmers’ surrounding Minanha in earlier periods. The construction of a storage building, structure AV, the first agricultural terraces, and Early Classic ceramics amongst the fields surrounding Waybil together indicate the agricultural use of the lands surrounding Waybil. I hypothesize that at this time Waybil may represent an extensification of the agricultural strategy utilized by the growing agrarian population in the nearby Contreras Valley and use of these lands as a milpa outfield. Waybil's changing relationship with the increasingly centralized power at Minanha in the Early Classic, may have resulted in the migration of a non-local population of terrace-farmers or the transmission of their expertise to the local Waybil residents who aimed to, if not increase production, at least stabilize it during the extreme dry and wet phases of the associated MDE.

While terraces were experimented with at Waybil, they were likely only one of several techniques used during this period of low-level, household production. For example, Ford and colleagues suggest that polycultivation plots including arboriculture or “forest gardens” were adopted at least by the Early Classic in the neighboring region of El Pilar Belize (Ford 2008; Ford and Nigh 2014; Ford and Nigh 2015). I identified a similar approach amongst the contemporary farmers in the North Vaca Plateau with nearly every interviewee in my ethnographic study reporting both a dedicated milpa, vegetable garden, and forest stand. This finding is supported by other ethnographic research on multi-cropping practices in the Maya area.
(Atran 1993; Nigh and Diemont 2013). This may have been the case at Waybil. The ubiquity of small numbers of Late Preclassic to Early Classic ceramics in all but one of the terrace excavations suggest that there were people active in the surrounding landscape of Waybil, potentially practicing a less archaeologically impactful agricultural practice such as milpa.

Iannone and Akers have both hypothesized that the extended MDE period from the Terminal Classic to the beginning of the Early Classic may have acted as an instigator for terrace construction (Akers et al. 2016:282). My archaeopedological data revealed a high clay content amongst the Waybil soils, which would have been beneficial in both moisture and nutrient retention for early farmers. However, these qualities would have been diminished once the soils were subjected to unmanaged intensive milpa farming and the associated vegetation removal (Nigh and Diemont 2013:45). The removal of cover vegetation decreases the organic matter entering the soils and increases the impact of direct sunlight. When these soils are subjected to direct sunlight, soil temperature and evaporation rise, which further decreases soil moisture and encourages expedient mineralization of the already decreased organic matter. This process results in the accumulation of the limited nutrient in the upper soil horizons and increased susceptibility to sheet erosion during the fluctuating, intense, rainfalls of the Waybil region. These processes would have been exacerbated during the dry phases of the Early Classic MDE, resulting in a quick reduction of soil potential for agriculture and increased degradation during sporadic, yet heavy, rainfall. The construction of agricultural terraces would combat these erosive problems. It is during the break between the peaks of the MDE that the North Vaca Plateau experience one of the highest levels of rainfall. The GIS models constructed within this dissertation describe the effectiveness of terraces in reducing the level of erosion and dispersal of water during wetter periods. The terraced erosion model presents 36.64% decrease in the amount
of eroded sediment during an extreme wet period. It has suggests that the earlier construction of terraces during the first peak of the Terminal Preclassic to Early Classic MDE in the Contreras Valley may be related to the earlier occupation and more extensive farming of this area (Akers et al. 2016:282; Macrae 2010:134-137; Macrae and Iannone 2010:193). Waybil, with a lower population in these early periods, may not have experienced these issues until ~100 years later, explaining the delayed incorporation of terraces into their agricultural strategy.

As discussed my ethnographic research revealed the common practice of using intensive infields (gardens) and extensive outfields (milpa). Further, research noted a desire to construct these terraces is often expressed by modern farmers as a need to increase planting surfaces, reduce erosion, and increase moisture retention, all of which facilitate a stable crop climate and possibly extend the growing season in tropical areas, like the Maya world, where seasonal droughts prevail. My excavation data shows that these early terrace systems differed from the larger systems that were constructed in later periods. I hypothesize that this early process would have been locally occurring in a piece-meal fashion with long-term, small labor investments conducted by lineage or family based social units such as is described elsewhere in the Maya region (see Beach et al. 2002; Doolittle 1984; Dunning 2004; Dunning and Beach 1994; Haviland 1970; Healy et al. 1983; Kunen 2001; McAnany 2000; Netting 1993; Wyatt 2005). These constant field modifications were a familiar process with household based production world-wide. Furer-Haimendorf (1962:26), for example, notes that the traditional householders amongst the Apa Tani rice farmers of Northern India knew the precise annual yield of each field system. These farmers were constantly modifying their terraced padi systems in order to maintain normality and maximize yields. My research reveals this same local knowledge among the contemporary family farms around Waybil. Discussions indicated that farmers have a well-
founded knowledge of where to plant each year in order to maximize production and reduce risk. Yield estimates amongst these farmers were relatively good, yet conditional upon annual climatic variations.

**Section Summary: Early Classic.** At the start of the Early Classic, both climatic (external) and social pressures (internal) are increasing their influence on the Minanha rural population, which caused the first utilization of the Waybil for intensive agricultural purposes. Thus, this period shows a shift in the identity of the Waybil site within the socio-ecological system. While previously the identity of Waybil was to satisfy the ritual and ceremonial needs of the growing community in this micro-region of the North Vaca Plateau, during this period, it has shifted to an agricultural focus supplying the food-security for the surrounding community. As Waybil takes on this new identity, our analysis needs to reevaluate the variables that compose the regime and ultimately the system itself. While the larger external (climate) and internal (social) variables remain constant in the system, new considerations of the variables directly relevant to agricultural production at Waybil need to be included, i.e. soils and production techniques. From this perspective, variability in the climatic component of the system has caused stress on the newly established Waybil identity, which spurred the initial use of terracing to disperse and capture the limited precipitation. Further, the use of milpa fields in both the nearby Contreras Valley and potentially Waybil likely increased the susceptibility to erosion amongst the fields, a factor escalated by sporadic wet periods, which would also have increased the demand for agricultural terracing. The lack of permanent settlement at Waybil, suggests that the agricultural systems were strongly interconnected with remote farming populations.

**Middle Classic (550 – 675 A.D.)**

The Middle Classic represents a period of relative climatic stability (Akers et al. 2016:285; Dahlin and Chase 2014; Iannone et al. 2014a:289). At this time, Waybil residents
constructed the site's first and longest occupied residential unit indicating that the site housed a permanent resident population. This population had sufficient resources to construct an anti-penultimate cobble ballast foundation for a plaster floor and an associated simple crypt burial (BIII-B/1). Immediately atop this earlier level was another level of cobble ballast and subsequent flooring, dating to the Middle Classic period (Schwake et al. 2012:72). It is at this time that the chultunob within the Waybil site are used (Iannone et al. 2011c:108-111). The lack of ritual or burial material found in the Op.W100-1 excavations of a sealed chulun suggest that they were used to store perishable materials (Iannone et al. 2011c:108-111).

At the same time, while the populations of the Minanha epicenter and site core remained fairly stable, the number and size of settlement units in the Contreras Valley expanded. In earlier work, Pollock (2007:158, 197-200) found that many of the Contreras terraces contained Middle Classic ceramics, indicating that terrace construction was also rapid in this period. I have argued in my earlier work that, in response to this growing population in the periphery of the Minanha polity, farmers expanded agricultural terracing to maximize the arable lands, potentially using these to lay claim to a shrinking land resource (Macrae 2010:139; Macrae and Iannone 2010:191). This is supported by evidence that the Contreras farmers targeted the least suitable lands for settlement and that there were increasingly close associations between settlement units and terraces (Macrae 2010:142; Macrae and Iannone 2010:191). It is possible that with the increased occupation of the Contreras Valley, there was enough labor available to facilitate the construction of terraces throughout their landscape. As discussed, this was the most limiting factor amongst the contemporary farmers I interviewed when asked about the possibility of constructing and maintaining terraces, despite recognizing their potential value.
The persistent and increasing investment in agricultural terraces since their experimentation during the MDE of the Terminal Preclassic raises the question of why continue this investment. It is not surprising that over the centuries of farming within the mountainous landscape of the North Vaca Plateau the inhabitants recognized the benefits of these geointensive agricultural features. The expanding systems of agricultural terraces can be characterized by agricultural “colonization”, creating an agroecosystem by altering the natural process in order to produce favorable conditions for increased benefits (see Bleed 2006:9; Iannone and Schwake 2013:6; Smith 2007:195-196; Weisz et al. 2001:124-127). Further, GIS modeling of agricultural suitability describes how terraces function to maintain land suitability despite fluctuation in precipitation. While the Early to Middle Classic period is described as a relatively stable period, with no MDE or exceedingly wet conditions, this does not mean that smaller precipitation fluctuations were not a concern. This is supported by the higher degree of concern expressed about the seasonal timing and level of rainfall, over the larger scale of droughts by the contemporary local farmers, even though long term trends are identified and noted. This variability is escalated by the high degree of precipitation variability occurring between the different valleys. The knowledge that agricultural terraces reduce the variation in erosion and water distribution had centuries to develop. With production being conducted at a household level, variations between terraced and none-terraced landscapes would have been quickly identified. Further, the increased population in these support populations would provide a sufficient labor pool to invest heavily in creating these agroecosystems. In the Contreras Valley, this would have been encouraged by the increasing demands from the higher population levels as well as the developing Minanha epicenter.
Section Summary: Middle Classic. The Middle Classic socio-ecological system in place at Waybil exhibits a decrease in pressure from the external (climatic) variable, likely prompting an increase in the production potential at Waybil. However, the internal (social) pressure appears to have increased at this time. This increase is evident by both the permanent residences at Waybil and the developing agrarian population in the Contreras Valley. The use of the chultunob for storage during this period at Waybil is a potential a reaction to these increased pressures for surplus and heightened production levels.

Late Classic (675 – 810 A.D.)

Early facet Late Classic (675 – 775 A.D.)

During the latter Early Classic and into the early facet of the Late Classic Akers and colleagues indicate that the climate was in fluctuation between wet and dry, although generally trending towards a MDE (Akers et al. 2016:284; Iannone et al. 2014a:289). During this period of favorable climate conditions, survey and excavation data shows that Waybil experienced its most dramatic growth with construction and expansion in all the settlement units. This evidence suggests that all the agricultural terraces visible at Waybil were constructed and/or in use during this period, including those constructed during the earlier period. The continued use of chultunob indicates the importance of food storage at this time. At the same time the royal court was established at Minanha (Iannone and Longstaffe 2010:72; Iannone and Schwake 2010; Iannone 2005:30; Schwake and Iannone 2016:139-140), and the occupation of the Minanha site core and the surrounding Contreras Valley including the subordinate site of Martinez reached maximum extent (Macrae 2010:114; Macrae and Iannone 2010:192-193; Schwake et al. 2011:90). The construction of the Martinez eastern shrine complex suggests to Iannone and colleagues an increasing governance of the Minanha elite of the surrounding countryside (Iannone et al. 2016; Schwake et al. 2011). My survey and excavation data indicates an increasing administrative and
economic function for the site of Waybil which supports Iannone’s model of shifting importance to Minanha, and suggests that Waybil had become a subsidiary minor center in the developing Minanha polity at this time.

I hypothesize that Waybil would have been an attractive place for the incoming populations from the Minanha polity because of its administrative capabilities, previous use as an outfield, and centuries of importance as a ceremonial place. The production of the expanding agricultural terraces would have become an extremely valuable resource. The GIS models indicate that at Waybil, the construction of agricultural terraces not only created ~10,000 m² of more suitable lands, based on the decrease in erosion and dispersal of surface water, but also decreased the variation of land suitability due to precipitation variations by 30.98%. This transformation was rapid as seen in the dates of both the agricultural terraces and settlement units at Waybil. By transforming the Waybil landscape into an agroecosystem and enhancing its agricultural suitability to buffer against fluctuating precipitation, Waybil would provide dependable agricultural production. With terracing practices already in place in select areas around Waybil, an expanding agrarian population throughout the Minanha polity, and an increasing hierarchy of administrative elites at the Minanha capital, I hypothesize that Waybil was an ideal target for the royal court of Minanha. I propose that the Late Classic Minanha royal court would likely have strengthened connections with its administrative minor center in the form of increasing tribute demands or taxes to support the ambitious construction projects in the capital site epicenter. This correlation between the newly established royal court and agricultural expansion was also experienced in the Contreras Valley with the more centralized construction and increased interconnection of terrace systems appearing there at the same time as they do at Waybil (Macrae 2010; Macrae and Iannone 2010; McCane et al. 2009).
The role Waybil played in the larger socio-political and socio-economic sphere explains the importance of a stable agricultural base for the Minanha polity. During the Middle to early facet Late Classic was characterized by an uneasiness amongst the surrounding polities, evident in the increased prevalence of warfare and political alliances between Caracol, Tikal, Naranjo, and Calakmul (Akers et al. 2016:283; Martin and Grube 2008:63-99; see also Cioffi-Revilla and Landman 1999; Kennett et al. 2012; Marcus 1993; Martin 1995). These aggressive interactions have been described as a byproduct of increased social stratification with its associated artisans, administrative roles, and general labors, all of which added to a general population growth and placed additional stress on the agricultural production (Kennett and Beach 2013; Stuart 1993; Webster 1985). This pressure placed a premium on areas with agricultural infrastructure, especially intensive practices such as terracing that maintained land suitability in a fluctuating climate. With Minanha located in the frontiers between two competing states, Naranjo and Caracol, but not allied with either, Iannone has argued that it would have been a target for expansionist polities (Iannone 2005; Schwake and Iannone 2016). Minanha's isolation within the rugged North Vaca Plateau, the independence of its unaligned king, and the volatile nature of the socio-political structure in the Maya lowlands, further increased the risk to the Minanha polity. However, Minanha with its growing population and stable agrarian support had the means to negotiate its relationship with other polities. This is where the importance of the subsidiary minor center of Waybil during the early Late Classic can be found. With a rising value of stable agricultural production in the Maya lowlands and an understanding of the beneficial qualities of agricultural terracing, the rulers of Minanha may have decided to increase their negotiating capital by dramatically expanding their agricultural field system through terracing at the subsidiary sites and surrounding countryside. I argue that a centralized investment at Waybil is
evident in the uniformity of terrace construction styles and distribution amongst the Late Classic terraces and larger interconnected terrace systems that transcend the catchments and household sizes. I argue further that the fast expansion of occupation at Waybil suggests some incentive and/or translocation of people into the area. The production of vast terracing system surrounding Waybil would have bolstered Minanha’s autonomous nature through the resultant economic capital, but also its ability to converse with its neighboring polities on a more equal level. From this agricultural perspective, the stable agrarian landscape would have assisted in the rapid development of the Minanha royal court during the early facet of the Late Classic.

**Late facet Late Classic (775 – 810 A.D.)**

The late facet Late Classic exhibited a MDE period that began in 750 A.D. and continued through to the Terminal Classic and beyond, ending around 925 A.D. (Akers et al. 2016; Iannone et al. 2014a:290). This MDE was punctuated by a brief wet period between ~ 800 – 825 A.D. at the end of the late facet Late Classic, with intensity peaks directly before and after (Akers et al. 2016:281). This drought period is often associated with the “collapse” of the lowland Maya.

During this period, the occupation and terracing evident at Waybil and within the Contreras Valley were maintained at their highest level. Although Minanha also continued to expand to its highest occupation levels, the epicenter went through two distinctly different termination events (Schwake and Iannone 2016). The first destruction event in the Minanha epicenter occurred briefly after 775 A.D. and resulted in the demolition of parts of the royal residence and associated shrine, a burning event in the plaza, and looting of caches and burials in the central shrine structure of the E-Group (Iannone and Longstaffe 2010:72; Schwake 2001:19; Schwake and Iannone 2016:142-144). Schwake and Iannone (2016:144-145) describe this event as a “desecratory termination” act that likely coincided with a shift in rulership (see Freidel 1998; Stanton et al. 2008). Iannone and colleagues (Iannone and Longstaffe 2010:69; Schwake
and Iannone 2016:146, 155) argue that this shift in rulership brought Minanha under the rule of one of the Great kingdom as evidenced by the construction of a two level throne representing the great king/agent (upper) and a vassal ruler (lower). It is possible that this overthrow resulted from the interrelated circumstances of the onset of a MDE, and the buildup of enough pressure for agricultural surplus and suitable lands amongst the neighboring polities that they could no longer afford to negotiate with the Minanha ruler and needed to assert a more direct control. I hypothesize that this may have also been spurred on by the increasing terrace infrastructure at communities such as Waybil and in the Contreras Valley, which became too attractive for foreign powers to ignore. This is supported by the continuation of terracing at Waybil suggesting that the new ruler in the Minanha royal court would have continued to encourage the construction and maintenance of the prolific terrace systems found in the periphery surrounding Minanha and particularly at the subsidiary center of Waybil.

After a short period, approximately 25 years, Minanha experienced a second destruction event between 800 and 810 A.D. (Schwake and Iannone 2016:146-152). This destruction event targeted both the royal residence and E-Group Complex, as well as the stucco frieze(s), stela monuments, and administrative structures which Iannone argues contained key politically charged references (Schwake and Iannone 2016:146-149), suggesting the removal of the encroaching vassal ruler and external authority. These actions may have been on behalf of the long-standing lineage of the larger community and/or another polity striving to gain another resource base (Schwake and Iannone 2016:153-54). Iannone and colleagues (Akers et al. 2016:284; Iannone et al. 2014a:293-294; Iannone 2005:40) posits that the final abandonment of the Minanha royal court was likely due to the combined stress of local inefficiencies of the rulers to combat climatic change and declining productivity and on a regional scale the maneuvering of
the surrounding polities attempting to secure resources. Again, there was no discernable impact of this political upset on the Waybil community.

Nearing the end of the Late Classic period the MDE had been in effect for approximately 35 years. While the functional analysis of the agricultural terraces describe how they maintained land suitability during fluctuant climates, qualities that first supported the autonomous nature of Minanha and drew the attention of neighboring polities, I argue that it was during this period of extended drought that the threshold of these beneficial qualities was surpassed. This suggestion is based on the evidence from the soils analysis, which suggests a decreased phosphorus level that can be attributed to intensive use and declining productivity of the agricultural soils. The possibility of mulching or adding organic matter to the terraced planting surfaces, evident in the elevated organic matters, hints at the detection of declining production and attempts to mitigate these problems. It is also likely that Waybil, which lacked a perennial spring and was dependent on rainfed-terraced agriculture, would have suffered during the extended drought periods of the late facet MDE. The increased level of production demanded by the various rulers of Minanha was a social demand that would have been amplified by the persistent lack of rain which would eventually reduce production levels despite several characteristics of the North Vaca Plateau and its occupation that may have minimized the effects of the MDE (see Schwake and Iannone 2016:155-156). These problems may have been causal to the abandonment of nearly all the settlement units and the termination of all terrace constructions at Waybil by the end of the Late Classic.

**Section Summary: Late Classic.** It is clear that the Late Classic period exhibited significant changes amongst the variables that compose the Waybil socio-ecological system. While the climatic conditions (external) pressures are favorable during the early facet Late
Classic, there is a significant increase in social (internal) pressures evidenced by the expansion of all settlement units. This trend is also evident in the larger socio-ecological system of the North Vaca Plateau. This is correlated with the establishment of the Minanha royal court and subsequent increase in political mandate. The agricultural strategy in place at Waybil adapted to these pressures and took advantage of the favorable climate by increasing their land suitability and dependability of production through the extensification of agricultural terracing. Evidence suggests that these developments at Waybil were constructed under the guidance of the centralizing authority of the Minanha royal court.

During the late facet Late Classic, the favorable climate had transitioned into a MDE increasing the pressure exerted on the Waybil agricultural strategy. It is possible that the continuous farming of the Waybil field systems was denuding soil nutrients, escalating the environmental pressure on the Waybil socio-ecological system. The social pressure exerted on Waybil and its agricultural production was maintained during this period, although it may have been elevated given the ambitious construction projects that continued throughout the Late Classic in the Minanha epicenter. Both the escalating internal (social and agricultural) and external (climatic) pressures were mitigated by the continued maintenance and construction of agricultural terraces in order to both maintain land suitability and mitigate the developing MDE.

Particularly important to note are the significant changes in the larger socio-ecological system of the North Vaca Plateau and Minanha polity, within which the agricultural strategy at Waybil was nested. With the onset of the late facet Late Classic, 775 A.D., and shortly after by 810 A.D. the Minanha royal court underwent substantial social fluctuations as evidenced by the several destruction events of the royal courts. While significant in the larger socio-ecological systems, there are no indications that these effects cascaded into the smaller, nested, socio-
ecological system of Waybil. As suggested, this may be attributed to the mirrored desires, and potential motivations, of both the rulers in power at the Minanha royal court.

**Terminal Classic (810 – 900 A.D.)**

The MDE that took hold during the late facet Late Classic continued throughout the entire Terminal Classic period (Akers et al. 2016; Iannone et al. 2014a:290). During this period, only ephemeral use of Waybil is evident, with one residential unit, the earliest occupied, and two terrace walls or planting surfaces exhibiting ceramics from this period, but in only half the quantity of Late Classic ceramics. However, the presence of these Terminal Classic ceramics suggests that at least some of the terraces surrounding Waybil were being maintained. Archaeopedological results suggest that the soils maintained a degree of productivity and were not completely degraded of all soil nutrients, indicating that, although production may have declined, the terraces were still capable of supporting agriculture. A similar reduction in occupation has been identified in the Contreras Valley with only the founding lineages maintaining a presence amongst the terraced field systems (Macrae and Iannone 2015:6-7; Macrae 2010:114; Macrae and Iannone 2010:193). This Terminal Classic contraction and abrupt construction halts are reflected at both the Minanha epicenter and its site core as well as in the site core of Ixchel. This period in the North Vaca Plateau is characterized by conclusion of all sociopolitical systems (Akers et al. 2016:284). Ixchel had been reduced to a small, non-royal occupation while Minanha suffered from social compression (see Iannone et al. 2014a:293-294).

The persistence of the founding groups and lower populations within both the Contreras Valley and to a lesser degree at Waybil during the peak of MDE may be attributable to both the continued function of the agricultural terraces and to the strength of local ecological knowledge. These two one-time support populations for the Minanha polity and the neighboring
communities appear to have reverted levels of occupation and agricultural strategies similar to those from prior to their engagement with the larger socio-political and socio-economic sphere.

Section Summary: Terminal Classic. The persistence of the MDE (external variable) exerted continuous pressure on the socio-ecological system that encompassed Waybil. At the same time, there was a clear reduction of social and political (internal) pressures exerted on the Waybil agricultural strategy. In reaction to these changes in the variables, there was another shift in the identity of the Waybil socio-ecological system, a regime change, and Waybil transitioned into a new system by the end of the Terminal Classic period. I argue that there were two substantial fluctuations that ultimately resulted in the reorganization of the system. First, the social compression of the Minanha polity resulted in the subsequent loss of its status and attractiveness as a full-service center. This created a reduction in the investments and connections that Minanha had to the surrounding administrative minor centers and production enclaves. The decline of social pressures exerted from the Minanha royal court and dense occupation of Waybil occurred early in the Terminal Classic or possibly the very end of the Late Classic. In reaction to the reduced social pressures, the agricultural strategy of Waybil changed, no longer including the aggressive extensification of terraced fields and apparently only including the maintenance of select terrace walls by a limited population. This was followed by a substantial reorganization of the Waybil socio-ecological system by the end of the Terminal Classic period. The extended MDE and developing soil exhaustion forced the agricultural system at Waybil to cross a threshold, as the system was no longer able to support the necessary food-security for the inhabitants of Waybil, as well as any remaining social obligations to the community of this micro region of the North Vaca Plateau.
Early Postclassic (900 – 1200 A.D.)

There was a short, relatively, wet period during the Early Postclassic before the initiation of yet another a very dry MDE (Akers et al. 2016; Iannone et al. 2014a:295). By the Early Postclassic, there is no evidence for occupation at Waybil, and it is here that the story of this subsidiary minor center ends. However, there is still a persistent population found in the Contreras Valley amongst the longstanding settlement groups. The longevity of these early groups can be contrasted with what remained of Waybil during its last occupation in the Terminal Classic. The inhabitants of the Contreras Valley were some of the earliest settlements in the Vaca Plateau, developing into a lineage-based unit, while the occupation of Waybil, outside of its early ceremonial and administrative functions were primarily initiated by the centralizing forces of the Minanha royal court. In a sense, Waybil lacked the foundation within the landscape that the Contreras Valley settlements enjoyed.

Section Summary: Early Postclassic. With the complete abandonment of the Waybil minor center and dissolution of its agricultural strategy the socio-ecological system that has been the focus of this dissertation no longer persisted. Further, given the complete lack of any Early Postclassic ceramics, cultural features previously used to identify agricultural practices (i.e. storage facilities), or activities in the epicenter, Waybil’s function within the larger socio-ecological system of the North Vaca Plateau, as an outfield or ceremonial/administrative center also appears to have concluded.

In the next section, I will explore some of the beneficial and detrimental qualities of the agricultural strategy utilized at Waybil and its role as a minor center within the Minanha polity. This will be framed within the concept associated with socio-ecological systems and resilience theory.
Contextualizing the Waybil Agricultural Strategy with Resilience Theory

In this section, the resilience of the Waybil agricultural strategy will be examined within the framework of socio-ecological systems using concepts drawn from resilience theory. To add depth to this discussion, Waybil will be compared to the Contreras Valley that formed the basis for my earlier research (see Macrae and Iannone 2016; Macrae 2010; Macrae and Iannone 2010). Comparing the nearby Contreras Valley to the Waybil minor center highlights both differences and similarities in their agricultural strategies and historical trajectories, describing the importance of historical dependency and uncertainty within systems (see Ellner and Turchin 1995; Hastings et al. 1993; May 1989; 1990).

As archaeologists have incorporated the socio-ecological systems framework to investigate the dynamic nature of the interconnection between humanity and nature, they have turned to several concepts that govern these relationships (see Costanza et al., ed. 2007; Faulseit, ed. 2016; Iannone, ed. 2014). These concepts are often drawn from ecosystem and resilience theory, and are governed by the ideas of societal metabolism, diminishing returns, and path dependency (Iannone 2014:5-8). Societal metabolism refers to the procurement and movement of material and energy that supports a population or is under the direct control/guidance of a society (Fischer- Kowalski and Haberl 1997:62-66; Weisz et al. 2001:123). The materials and energy in question are used to “build up or maintain the functioning of society’s biophysical structure, that is, human bodies, domesticated animals, and artefacts” (Weisz et al. 2001:123). Diminishing returns (declining marginal resources) refers to harnessing a level of energy necessary to maintain human society, more specifically the increasing input of energy required to support developing societal complexity (Tainter 1988:91-92). This concept is based on the premise that as complexity and energy demands escalate, energy production must also increase in tandem (Tainter 1988:91). Despite the capacity of problem-solving amongst societies, at some point the
investment in energy production will outweigh the returns (Tainter 2000:5-10; Tainter and Crumley 2007:70-72). Path dependency refers to the difficulty/inability of a society to apply new innovation in order to break free of their current progressing trajectory (Berkhout 2002:3; Chase and Chase 2014:143-144; van der Leeuw 2007:215). A trajectory is developed over time as people continually invest energy in modifying their environment, social and political structure, and/or economic system (Berkhout 2002:2; van der Leeuw 2007:215).

Choosing from the plethora of concepts associated with these studies, this discussion addresses four that encapsulate the changing agricultural strategy implemented at Waybil; niche construction, risk spirals, sunk-costs effect, and rigidity traps. Presenting the Waybil case study will be an important contribution to the study and application of resilience theory. Taking this small scale, data driven, approach will not only help understand the processes within the socio-ecological system at Waybil, but add to the larger discussion of resilience theory, addressing important concerns raised in its archaeological application. The recent interest and application of resilience theory in archaeology has left room for theoretical and methodological development, as many of the concepts remain abstractions within our field (Iannone 2016b:4). In order to explore the potential of a coupled socio-ecological approach to understanding the resilience and vulnerabilities found in past societies, there is a need for strong case studies to link the material record to these concepts (Iannone 2016b:4). This dissertation is helping to fill this void by presenting the Waybil case study. Drawing on multiple high-resolution datasets within defined temporal brackets, facilitates the correlation between changes identified in the archaeological record and the intangible processes of the concepts defined within resilience theory.

Before discussing our four concepts, a brief review of resilience needs to be presented to frame these processes. Resiliency relates to the robusticity of a system to withstand perturbation
amongst the variables, and when necessary being flexible enough to change structural components in order to maintain system integrity. Evidence for a lack of flexibility in decision making and/or an inelasticity in certain structure components, brought on by increasing rigidity, indicates vulnerability (Berkes et al. 2003:22; Davidson-Hunt and Berkes 2003:60; Lamson 1986:272; McCay 1981:371; Vayda and McCay 1975:299; Walker and Salt 2006:84, 121, 138).

In terms of agricultural strategies, resiliency equates to the ability to continue agricultural production using a select suite of techniques (strategy) to meet subsistence and social demands, despite changing natural and cultural variables. Identifying and testing resilience and vulnerability, beyond that of a theoretical realm, requires one to identify the “resilience (and vulnerability) of what, to what” (Carpenter et al. 2001:767; Redman et al. 2007:119). Thus, this dissertation examines the resiliency of ancient Maya agricultural strategy at Waybil to the changing food security brought on by changing climatic conditions and demands of Minanha royal court.

Niche Construction, similar to the theme “colonization of nature” in social ecology (see Fischer-Kowalski and Haberl 1997), refers to the human manipulation of the natural environment in order to produce favorable conditions for development (Bleed 2006:9; Smith 2007:195-196). In terms of agricultural practices, this includes the modification of the landscape and ecosystem through subtle processes such as weeding to more aggressive manipulations of geointensive features, both of which develop an agroecosystem which is beneficial for production. The terrace construction within Contreras Valley by 100 – 250 A.D. and at Waybil by 250 – 550 A.D. both of which had peaked by 810 A.D., indicating the “colonization” of the landscape and its natural processes. These first exploratory manipulations of the surrounding ecosystem appear, from the various analyses of terracing (Macrae MA and this dissertation), to
have occurred in two different fashions. The longer process in the Contreras Valley developed over time in an accretional fashion with lower levels of investment, evident by the pocketed, denser, terrace systems in prime agricultural lands (Macrae 2010:139-140; Macrae and Iannone 2010:190-191). The more rapid transformation of the Waybil landscape, despite early experiments, would have been involved a significant labor investment and commitment to agricultural terracing. Evidence for this expedient terrace construction is highlighted by the restricted, Late Classic, dates prescribed to the majority of terrace (see Results of the Survey and Excavations) as well as their standardization of construction techniques and interconnectivity (see Defining Social Pressures at Waybil and Geographical Information Systems (GIS) Modeling). The process of niche construction has resilient qualities, although these qualities can bring with them a degree of vulnerability. Hydrological modeling of the Waybil terraces suggests that, in general, the construction of agricultural terraces in the North Vaca Plateau would have reduced erosion while dispersing the water across broader catchments. Further, the terraces would have maintained land suitability despite local precipitation fluctuation as well as larger climatic fluctuation, at least for a time, as presented in the hydrological and agricultural suitability modeling. All of these are innovative approaches brought a degree of resilience to the Waybil agricultural production. Yet, there is a vulnerability that would come with these investments. This vulnerability, which results in reduced flexibility, is described in the concept of risk spirals, sunk-cost effect, and rigidity traps.

Risk spirals, refers to the decisions to minimize immediate risks through increased investment and the dependence on permanent, although often times riskier, innovations which ultimately lead to new unforeseen risks (Dearing et al. 2007:266; Muller-Herold 2000:27-28; Pimentel et al. 1990; Sieferle and Müller-Herold 1997). This results in maintained pressure for
innovations to address the continually arising new risks (Muller-Herold 2000; Sieferle and Müller-Herold 1997). As discussed, the initial risks felt by the North Vaca Plateau farmers would have been the susceptibility to erosion caused by the hilly topography of the region. This rugged landscape was formed by combined solutional dissolution and mechanical erosion dictated by the karst limestone bedrock (Brady and Weil 2007:39; Ford and Williams 1989:39-65; Jennings 1985; Reeder et al. 1996:127-128). These topographic features would have led to loss of soil depth and the poor dispersal of surface water, as well as the seasonally fluctuating local and regional precipitation regimes. These risks can compound agricultural failure when conducting unmanaged milpa, or slash and burn, agricultural practices. The innovation that first minimized these risks was agricultural terracing. Drawing on our comparison, the Contreras Valley was first to utilize this innovation, followed later by Waybil. While environmental risks were likely the impetus for the development of terracing in the Contreras Valley and perhaps across the entire North Vaca Plateau (as evidenced by the early use of terraces at Waybil), this may not have been the same impetus that caused the intensification of terrace agriculture at Waybil, which was more likely the fear of not being able to support a growing population and simultaneously maintain negotiations with Minanha’s capital. The evidence supporting the argument of new innovations to meet this later need may be found in the better terrace wall construction, utilization of underlying bedrock features, incorporation of subtle drainage features, and the addition of organic material to terrace beds that this study has revealed. An unforeseen consequence of developing an intensive agricultural strategy such as terracing is the increasing labor requirement to maintain and continually expand these geo-intensive agricultural field systems. The clearance of increasing expanses of land, as would be necessary to agriculturally support the growing and required labor force, would have caused micro-climatic droughts (Griffin et al. 2014:75-76, 80-
83, 85). These local droughts created additional concerns such as water management, which were met by the increasing interconnectivity amongst the elements of the Late Classic terrace system in order to distribute water (see Geographical Information Systems (GIS) Modeling) and also by the construction of Late Classic aguadas at Minanha (Philpot 2012:90-91). A second consequence of intensive agriculture may have been the increasing food supply and need for storage, as indicated in the Middle and Late Classic use of chultunob (Iannone et al. 2011c:108-111) and terminal construction of Structure AV (Schwake et al. 2013a:130-141).

Another concept that can explain the lack of more dramatic innovation expected in a risk spiral is sunk-cost effects. Sunk-cost effects are the maladaptive decision to continue on ones course of action once an investment has been made, despite the potential detriment or other beneficial alternative avenues (Arkes and Ayton 1999; Janssen and Scheffer 2004). An alternative perspective, is a period of time when a community has invested so heavily in one agricultural technique that the cost or desire to consider and invest in different techniques, one that’s potentially more beneficial or innovative, are undermined. When applied to our cases studies this can relate to the decision to continue investing in the expansion of agricultural terraces. This decision occurred differently between the two support populations, the Contreras Valley took ~425 years to reach the peak of terrace use while this occurred within ~125 years at Waybil. This difference may have been related to a delayed consequence of changing the entire landscape into an agroecosystem dominated by agricultural terracing, resulting in increased labor requirements to maintain large terrace systems. Other possible consequences, although lacking direct archaeological correlates, may have included decreased biodiversity and declining soil productivity due to intensive use and decisions that reduce fallow periods. The slower encroachment of the agricultural terraces in the Contreras Valley would have delayed these
consequences. As discussed the long-term local farmers in the Contreras Valley would be well attuned to expected production levels and aware if any issues arose. After nearly half a millennia of farming with agricultural terraces as well as the earlier centralized expansion, these farmers would have identified any potential issues that develop. The social pressures exerted by the Minanha royal court may have demanded the continuation of this practice, despite understanding these emergent consequences. The later decision to invest heavily in the terracing at Waybil would also have been done despite these identified consequences.

Associated with these unforeseen consequences is rigidity traps. Rigidity traps are defined as maladaptive systems that have developed significant connections and rigidity that they suppress both innovations and consequences, at least for a time. However, when the unavoidable change does come, the lack of flexibility in the system means the result of change more catastrophic (Hegmon et al. 2008; Holling 2001:400). The development of these systems maybe reflected, “as an outgrowth of unintentional actions or of the specific strategies of agents (or agents acting as a group) seeking to maintain or expand adaptive benefits” (Kidder et al. 2016:75). In terms of agricultural systems, a rigidity and high interconnectivity develops within an agroecosystem over time, which exhibits a higher threshold of resistance to both internal and external fluctuations, at the cost of amplifying the harshness of eventual change in the agricultural strategy. There are two scales this can be examined at, the local level of Waybil and the regional level of Minanha. At the local level, the terraced agroecosystem covers the vast majority of the surrounding landscape, discouraging other agricultural techniques. The terrace systems are constructed in a highly interconnected fashion, erasing earlier smaller systems, while construction techniques are standardized in both wall construction and placement. These characteristics increased predictability and production capacity, providing the ability to
withstand environmental fluctuations and for a time, increasing social demands. However, with both the extended MDE from 750 – 900 A.D. (Akers et al. 2016:284; Iannone et al. 2014a:289), and external surplus demands from costly construction programs and rapid population growth associated with the establishment of Minanha royal court between 693 – 775 A.D. until its collapse between 800 – 810 A.D. (Iannone 2005:29; Schwake and Iannone 2016:139, 146-152), these systems surpassed their threshold and rather abrupt collapse occurred. On a regional scale of the Minanha polity, the drive to construct vast terrace systems reduced variability in production techniques, and differentiation between production enclaves. During the Middle and early Late Classic this supported the growing community and autonomy of Minanha. However, due to the rigidity and uniformity in the agricultural strategy that when a catalyst(s), social and/or environmental, exerted too much pressure, beyond the capability of the system to withstand, there was a dramatic and fast collapse in the late facet Late Classic of the Minanha royal court.

The final aspect to be discussed is the differential collapse that was experienced throughout the Minanha agrarian landscape. To clarify when “collapse” is discussed it refers to the definition provided by Tainter (1988:4) “A society has collapsed when it displays a rapid, significant loss of an established level of sociopolitical complexity”. When taken from an agricultural perspective, collapse is related to the abandonment of a particular agricultural strategy, often defined by a singular technique, resulting in the release of interconnections and decline of standardization. It also need to be mentioned that the conception of whether collapse was a beneficial or a detrimental process is a matter of perspective. For example, the collapse of the Minanha royal court would have been detrimental for the Kings of Minanha for obvious reasons but may have been a beneficial for the long-standing lineage households who experienced a release of social pressure and production demand. When considered in terms of
ecosystem theory and resilience “collapse” is often associated reorganization (Holling and Gunderson 2002: 34, 45). The goal of this dissertation is not to redefine collapse, but rather explore the reasoning behind the differential collapse in the Minanha support community. As discussed previously, the Contreras Valley experienced a protracted abandonment, which is in opposition to the more punctuated abandonment of Waybil. These collapse sequences can be classified as a “remembrance” and “poverty trap”.

Remembrance represents the continuity of accumulated resources and ideas across critical transitions (Aimers and Iannone 2014:26-27; see also Nelson et al. 2006). In the Contreras Valley there was the continuance of the founding lineage household attesting to the longevity of this primary settlement locus within improved terrace lands and proximity to a spring, both crucial given the erratic climatic conditions (Macrae 2010:141). The connections between fields systems are broken, with no evidence for terrace construction, suggesting minimal use of agricultural terraces, potentially the use of encroaching natural resources, and with the large tracts of land available, a return to milpa or a mixed production strategy.

A poverty-trap is defined as the degradation of the system, after collapse, into an “impoverished” or “degraded” state of low potential, low connectedness, and low resilience (Aimers and Iannone 2014:26-27; Holling 2001:400). In terms of our agricultural perspective, this would represent an agricultural strategy that has collapsed to a state of bare subsistence, with techniques no longer able to produce enough to match the food security demands, potentially a result of land over use or misuse (Holling 2001:400). In opposition to our case of remembrance, these communities are no longer able to persist, despite changes in the agricultural strategies. This concept analogous with the collapse of the Waybil agricultural strategy. The fast and nearly total abandonment of Waybil suggests that the agricultural strategy of terracing not only could no
longer maintain the high occupation level of the Late Classic and the social demands of the
greater socio-political and socio-economic sphere, but had also degraded to a point that it could
no longer support the immediate populace. At this point, it is possible that the population
contracted to the earlier areas of high agricultural potential targeted during the immigration (i.e.
saltation). Alternatively, or in addition to the previous explanation, with the collapse of the
Minanha royal court the polity lost its attractive qualities that attracted an abundant support
population as well as the ability to organize and coordinate labor. Labor that would have been
necessary to maintain the agricultural terrace systems at the subsidiary minor center of Waybil.
However, these interpretation needs to be caveated by the fact I am only discussing this from a
subsistence perspective. There are other social and political powers at work during this period
that may have drawn the occupants of Waybil away. Despite these yet to be identified variables
it is clear that the larger socio-ecological system that framed Waybil had become impoverished
to a point that occupation was no longer a viable option.

Chapter Summary: Discussion

Waybil presents a complex history that is intertwined in the fluctuating social and
environmental climates of the North Vaca Plateau. Describing this history in the socio-ecological
framework facilitates a vibrant portrait of the changes and reactions within the Waybil
agricultural strategy as it endeavors to mitigate the fluctuating internal and external pressures.
The terracing within the Waybil agricultural strategy developed from humble beginnings to
maintain agricultural suitability in a fluctuating environment. This terraced agroecosystem
dramatically expanded to satisfy the needs of a negotiating Little Kingdom. Despite identified
consequences, intensive use of the terrace systems was maintained to sate the needs of a Great
Kingdom. Finally, the agricultural strategy and associated terrace systems are abandoned in the
face of depleted resources and social change. Drawing on concepts developed in ecosystem and
resilience theory the changes and consequences that occur throughout the different stages identified within the agricultural strategy are illuminated. Ultimately, the functional qualities of agricultural terracing at Waybil were able to maintain and absorb the climatic fluctuations and local demands. However, over time, with increased extensification and uniformity of the agricultural terrace systems the resilience of this strategy was reduced. With reduced resilience and flexibility, growing social and protracted environmental pressures caused the agricultural strategy to cross the threshold of sustainability. After this “collapse” of the Waybil agricultural strategy, the inhabitants lacked the resources and social desire to reorganize their production strategy, ultimately leading to the abandonment of the Waybil minor center.
CHAPTER 11
CONCLUSION

The premise of this dissertation rested upon answering five questions. These questions are designed to address; How terraces functioned in terms of soil and water management? How agricultural terraces were integrated into the agricultural strategy and community of Waybil? Why were the agricultural terraces adopted into the agricultural strategy, did the relationship change over time, and was it a beneficial or detrimental decision? What larger inferences can be drawn from this case study to the North Vaca Plateau and the ancient Maya as a whole? In answering these questions, the dissertation addresses the research question; Were agricultural terraces a successful adaptive mechanism within the subsistence strategy of Maya communities to a buffer against internal (social) and external (environmental) stress?

Question and Answer

1. How did the Waybil terraces function in terms of soil and water management? Did the Waybil terraces increase the agricultural resilience of the community?

Terraces have been known to have a series of functional qualities that increase moisture content in terrace planting surfaces while reducing the erosion of these agricultural soils. Throughout the long history of research, the functional qualities of agricultural terraces have mostly been taken as a given. Occasionally, references are connected to modern terrace farming and assessments or the effects on larger natural processes are examined. What is lacking is the direct assessment and quantification of these characteristics from a context drawn from the archaeological record.

Two analyses, surface water dispersal and erosion susceptibility, were undertaken utilizing the LiDAR data and analysis functions in ArcGIS. The hydrological analysis identified drainage catchments and flow accumulation (FAC). This model described the subtle effects that terraces had in redistributing the FAC while modifying drainage catchments into broader,
truncated shapes. This described terraces as altering the natural drainage to a degree of manipulation to ensure that water moved laterally, shared between catchments, or accumulated in larger catchments. This was supported by the FAC, which presented patterns of wider horizontal accumulation and a directed lateral dispersal of water and sediment. Results present a significant statistical difference between the terraced and terraced-removed landscape. To assess the susceptibility to erosion, the flow accumulation data, slope, precipitation estimates, and soil characteristics were combined in the RUSLE equation to define potential erosion loss across the anthropogenic landscape. Erosion analysis presented how the agricultural terraces decrease both sheet along the hill slopes and rill erosion within the constricted valleys. The relationship between the terraced and terrace-removed DEM was proved statistically different and identified the emergent properties of the agricultural terrace systems, becoming more significant when both hydrological and erosion benefits of the agricultural terraces are considered together. These tests clearly identified how the terraces function within the Waybil agricultural strategy. They also suggest an increased resilience to both fluctuating climatic changes but also demands of food security and social obligations.

To learn from these results and elaborate on whether terraces increased the resilience of the Waybil agricultural strategy, a third test of agricultural suitability was conducted. This model assessed the role terraces played in maintaining land suitability within the fluctuating climate experienced by the ancient Maya. The test combined weighted sum of the varying effects of slope, RUSLE, flow accumulation, as well as sunlight to produce suitability values. Results describe how agricultural terraces increased the highly suitability areas of the agricultural landscape around Waybil by ~10,000 m². Further, the terraces reduced the variation of land suitability by 30.98% overall in relation to the climatic change from wet to dry. This consistency
and ability to mitigate climatic and social fluctuations attests to the increased resiliency that agricultural terraces brought to community of Waybil and their agricultural strategy.

2. How did the Waybil terraces function in terms of community activities (regardless of whether they did or did not increase resilience)? By whom and in what manner were they organized, constructed, and maintained?

Waybil presents a complex history that is intertwined in the fluctuating social and environmental climates of the North Vaca Plateau. In order to address how terracing was integrated into the Waybil community a study of the variability in terrace types, construction qualities, distribution, and interconnectivity was required. This approach facilitated an assessment of how terrace construction and maintenance was organized within the Waybil community and also how social pressures manifested themselves in the agricultural strategy.

The original role of Waybil as ritual loci or gathering place changed over time to include an increasing agricultural component as both the population and use of Waybil and on a larger scale, the North Vaca Plateau grew. Early agricultural exploitation is evident by the first terraces and ceramics throughout the surrounding fields during the Early Classic, and potentially the use of the surrounding lands as an outfield in the Terminal Preclassic. The substantial expansion of Waybil and its agricultural terrace systems during the Late Classic suggests that by this point that the vast majority of the Waybil population was dedicated to the agrarian landscape, not just for subsistence production but also to satisfy the increasing demands of the growing Minanha polity. It is argued in this dissertation that the overall organization behind the terrace construction and maintenance was under the guidance of a centralized authority either at the community or polity level. Supporting evidence is found within the standardization of terrace construction, all of which fall within the predefined nomenclature, which exhibited less variation then the Contreras Valley, construction techniques that produced similarities found within the terrace walls, and an even distribution of terrace density across the agrarian landscape which exhibited terrace that
transcended both types and watersheds. The clear transition of the role Waybil and its community played in the North Vaca Plateau coincides with the incorporation of Waybil as subsidiary minor center in the larger Minanha polity.

3. What initiated the adoption of terraced agriculture and their increased use over time? As a response to perceived risk or demand (increasing resilience)? As a reaction to continued or episodic stress (required resilience)? As a gradual, accretive, improvement in farming (not as part of risk management)?

There is a significant difference in what initiated the incorporation of terracing within the agricultural strategy at Waybil and what perpetuated the continuation and intensification of this tradition throughout the Waybil occupation.

The terraces were initially incorporated into the Waybil agricultural strategy during the Early Classic. These terraces were built to maintain the suitability of the agricultural fields when subjected to local environmental variation. These variations included small, localized, precipitation regimes and erosion patterns. It can be suggested that the local farmers around Waybil had a well-founded knowledge about annual production levels, suggesting that terrace construction was directed to at least maintain these levels, if not to maximize production. These early farming strategies are evident by the low numbers of Terminal Preclassic and Early Classic ceramics in the later terrace walls, likely incorporated during the collection of building materials and re-distribution of terrace planting soils. This is similar to the continued investment in agricultural terracing after the Late Preclassic MDE in the Contreras Valley. In this stage of the Waybil agricultural strategy this was a gradual, accretive, improvement in farming.

There was however a drastic change in the agricultural strategy at Waybil with the onset of the Late Classic. This change included a heavy investment in terrace construction. The centralized coordination of these extensive terrace field systems is described a valuable resource to counteract the fluctuant climate conditions and the increasing pressure from the growing
Minanha polity. This process is a reaction to the sustained, possibly increasing, pressure exerted by of the royal court and being incorporated into the larger socio-political and socio-economic sphere as well as the fluctuating stress of wet and dry climatic conditions. Within the Waybil agricultural systems, this can be perceived as a response to episodic stress, and the required resilience necessary to mitigate these fluctuations.

4. Were the Waybil terraces useful only in the face of pressures, or once adopted did they create a permanent dependence within and between the agricultural and social systems at Waybil? Were the Waybil terraces ultimately “resilient”, or in other words, did the Waybil community continue through periods of pressure they would otherwise not have survived?

It is clear that with the initial investment in agricultural terracing at Waybil they were a successful adaptive mechanism to combat both the fluctuating external (climate) and internal (social) pressures. The proficiency of the agricultural terraces to mitigate these demands continued into the early facet Late Classic. However, by the end of the late facet Late Classic these qualities of the agricultural strategy were surpassed. Drawing on the descriptive concepts in resiliency theory an interpretation of why this system surpassed its threshold can be made. Ultimately, the decision to engage in agricultural terracing was a resilient choice. Terracing, when mixed with other agricultural techniques, increased the diversity within production strategies. However, over time as the beneficial qualities of terraced agriculture were identified and further exploited within the agricultural strategy of the Waybil community, and at a larger scale the Minanha polity, there was increasing dependency on terraced agriculture and the resultant production capacity and economic/social capital. This process developed into what is referred to as “sunk-cost effect” and “rigidity trap” where the decision to invest in a different production technique in order to avoid developing consequences were ignored in order to maintain and grow the social and economic capital that the Minanha polity achieved through terraced agriculture. The inability to maintain this level of production due to unforeseen or
ignore environmental issues, protracted MDE, and/or a social turmoil, resulted in the “collapse” of the agricultural strategy. In order to address the question in a more succinct fashion. On one hand, the agricultural terraces were a resilient strategy to combat fluctuating social and environmental demands. However, like in all systems there was a threshold. A threshold that was ultimately surpassed by the continually increasing demand of the social pressures and maintained climatic instabilities.

5. What does this interpretation of the Waybil agricultural strategy mean for the extensive anthropogenic landscape of the North Vaca Plateau? What extrapolations can be made from understanding the Waybil agricultural strategy to the resiliency of the ancient Maya agriculture?

The North Vaca Plateau exhibits one of the most modified agrarian landscape in the Maya area. By studying the Waybil agricultural strategy, its development and changes, a much stronger case can be proposed in terms of how the North Vaca Plateau developed into the anthropogenic landscape it is today. Waybil provides one, of potentially several, case studies of how the periphery communities reacted to the rise and fall of the Minanha polity. More specifically, Waybil describes the centralizing force that developed in the North Vaca Plateau during the Late Classic period and how it ultimately came to its crescendo by the Terminal Classic. The large-scale construction of agricultural terraces at Waybil and throughout the region during this period describes both the increasing demand of a growing population but also the greater demands of the Minanha polity engaging in a larger socio-political and socio-economic sphere. On a more basic level, the terraced agricultural strategy of Waybil can describe how a region that people once described as unproductive can, if properly managed, can become an importance production enclave.

The ramifications or insights that the Waybil case study provides for understanding the resiliency of ancient Maya agriculture can be perceived in two fashions.
First, the decision to invest and rely heavily on intensive agricultural practices can prove to be detrimental. The Maya area has been described as a heterogenic mosaic of environmental niches and landscape formations (Fedick 1996b). A diversity that the ancient Maya exploited to give rise to a great and complex civilization. However, over time with the homogenization of their agricultural strategies and landscape they lost the resilience that comes with diversity. A resilience that throughout the Preclassic and Classic period allowed communities to not just survive climatic fluctuations but support the ever increasing demands of a growing socio-political and socio-economic sphere. Similar to the Waybil case study, whether it was the continued climatic pressure or the social demand, ultimately homogenization of the agricultural techniques and dependence on intensive practices could no longer supply these demands. While this interpretation comes from the agrarian perspective and the “collapse” of the ancient Maya was multifaceted, Waybil can provide a glimpse into one of the larger factors that contributed to the social and political reorganization of the ancient Maya.

Second, the construction and use of intensive practices has frequently been viewed as a means to increase production, often in relation to a growing population. The Waybil case study and functional analysis of the agricultural terrace system suggests a different perspective. While the geointensive modification of the agricultural landscape did results in an increase of land suitability, this came second in importance to the capacity these intensive agricultural features have in maintaining suitability and mitigating climatic fluctuations. From this perspective, intensive agricultural features were not designed or constructed to necessarily increase production but rather to maintain a level of consistency in returns.
Future Work and Direction

To conclude my dissertation, I would like to address how the current state of resiliency theory can be advanced in archaeological research to avoid several potential pitfalls. Further, several avenues of future archaeological research will be presented that can improve the interpretation of past agricultural studies not only within the case study of Waybil and the North Vaca Plateau, but more broadly in terms of the study of past agricultural strategies.

Complexity and Problem-Solving

As presented in this dissertation, resiliency theory and associated heuristic models provide a powerful tool for interpreting the trajectory of socio-ecological systems. This has proven to be especially useful when investigating past agricultural strategies. However, there are trepidations that deserve acknowledgement. These concerns gravitate around the tendencies that interpretations based on resiliency theory and complex adaptive systems have become deterministic and evolutionary, i.e. a system is only resilient until it is not. This would essentially recreate the tautological arguments of earlier evolutionary and systems models used in archaeology (Boserup 1965; Flannery 1968; Flannery 1972; Malthus 1798; Steward 1949; Wittfogel 1957). In order to avoid this, I suggest a reevaluation of the use of “complexity” and integration of “problem-solving” into resiliency studies.

Complexity has been a topic of discussion in archaeological discourse for a long time, often associated with variation and evolution in human organization (e.g. Crumley 2005; Plog 1974; Service 1971; Tainter 1988) and more recently in terms of resilience and complex systems (Redman et al. 2007; Tainter and Crumley 2007; Walker and Salt 2006; 2012). Complexity plays a fundamental role within resiliency studies as it is heavily based on modeling the trajectory of
complex adaptive systems and understanding both their resilient and vulnerable qualities (see Carpenter et al. 2001; Cumming and Collier 2005; Holling 1973; Redman et al. 2007; Schoon et al. 2011; Walker and Salt 2006; 2012). However, the application of resiliency models and ultimately the definition of complex adaptive system draws heavily on biological and ecological studies. Thus, their definitions both lack the flexibility required to reflect the variability of human society, and also make correlation with the archaeological record difficult.

I would argue that a reevaluation of how complexity is defined in socio-ecological systems would assist in overcoming these potential pitfalls. Over the years, anthropologists and academics have defined complexity in a number of different ways. I prefer the definition presented by Marquardt (1985:63) “Complexity refers generally to a condition or quality of being composed of many elaborately interrelated or interconnected parts”. Marquart (1985:63) further refines this definition, drawing on work by Service (1978:3), describing three characteristics of increasing complexity; 1) increasing the subcomponents of the whole; 2) greater differentiation or specialization within the subcomponents; 3) stronger interconnectivity amongst the subcomponents and the whole. Returning to such an anthropological definition of complexity not only incorporates the characteristics commonly prescribed in biological and ecological fields, but also exhibits a history of anthropological use (Crumley 1995; Crumley 2005; Marquardt 1985; Sassaman 2004; Scarborough and Burnside 2010). This definition also provides an index of characteristics that can be easily correlated to archaeological signatures (Macrae 2017).

A fruitful approach to understanding the development of complexity within past societies, and ultimately agricultural strategies, is to view the varying levels of society, from the individual to state levels, as problem-solving systems (Tainter 2000:5, 7-9). From this perspective, societies
are consistently entangled in a process of solving a problem. These problems can range from the mundane to vital, the simple to complex, and the inexpensive to expensive (Redman et al. 2007:120). Following this line of thinking, academics have often suggested that the solutions to problems are achieved through increasing or decreasing complexity (Macrae 2017; Redman et al. 2007:120; Tainter 2000:8; Tainter and Crumley 2007:70).

Drawing archaeological correlates for complexity and interpreting these processes from the perspective of problem-solving allows us to define human society on a continuum of varying degrees of complexity that progresses in a non-linear, non-incremental, fashion (Scarborough and Burnside 2010:327; Tainter 1988:4). In reference to the study of agricultural strategies, the variation involved in problems associated with agricultural production, and the diversity of human decision-making strategies, provides for the capacity for complexity to increase or decrease simultaneously amongst the various components, suggesting that the resiliency found in a system is also just as fluid. Using this approach, progressing from archaeological signatures of complexity to how complexity influences system resilience, not only forces archaeologists to take a materially grounded interpretation of resilience, but also provides an avenue to break free from the often ensnaring linear and deterministic use of resiliency theory. Knowledge of the decisions involved in problem-solving requires a stronger understanding of the ramifications that various decisions have on agricultural strategy and how alterations in the different structural components interact to change the resilience of the whole system. A more in-depth understanding of problem-solving and the archaeological signatures characteristic of changing complexity will provide a stronger foundation for testing the heuristic models such as rigidity traps, sunk-cost, path dependency, and niche construction, that have been presented in this dissertation.
This approach offers an interesting avenue for considering resiliency, but also outlines several areas in need of expansion. We now need research which focuses on investigations that not only are conducted under the premise that increasing or decreasing complexity does not exhibit a direct correlation to system resilience, but also that appreciate the varying complexities between different variables/components of the system and their interactions. It quickly becomes apparent that to accomplish this task will require a holistic approach that takes into consideration the nature-human relationship, historical circumstances, and the political powers entwined in these relationships. While this dissertation has addressed many of these relationships, the future work of incorporating these results into a larger scale study that addresses the political and symbolic ecology of Minanha will produce important insights on this polity and have larger ramification for understanding the southern Maya Lowlands.

**Methodological Advances**

In the remainder of this chapter, I will address the future direction of agricultural studies at the Minanha polity as well as more generally in the Maya area. I believe the methods discussed below will assist in understanding the variables that compose the agricultural strategy, which can ultimately assist in describing changing complexity and resiliency. These advances are not just applicable to the ancient Maya, but can resonate in any agricultural study.

First, with the arrival of LiDAR within the Mayanist toolkit the vast dispersal of geointensive agricultural features across the Maya area are being identified. However, this spatial data is only one-dimensional and lacks the necessary chronological correlates. Despite the challenges associated with dating agricultural features, this dissertation revealed that robust dates can be reported using a strong chronological sequence of associated settlement units and strategic terrace excavations. However, in the future, increased systematic excavations of
agricultural terraces, preferably within a confined survey zone, will be able to provide valuable and robust information on the development of terracing as an agricultural practice as well as changes in the practice of terrace construction over the course of their use. Given the complications of dating geointensive features, the relatively unreliable nature of AMS dating of SOM, alternative methods need to be explored. Recent advances in luminescence may be an innovative method to tackle these dating questions (see Liritzis et al. 2013). Optically stimulated luminescence (OSL) can provide a date for the most recent exposure of a mineral grain to daylight. If applied in the appropriate contexts, OSL may be able to date the sequence of soil deposition within terrace planting bed as well as the construction of terrace walls.

Further, with these recent advances in remote sensing, a concentrated effort needs to be dedicated to moving beyond the identification of archaeological traces in the landscape to utilizing this robust data to conduct more investigator analysis. As presented in this dissertation, understanding the spatial and temporal distribution of these features provides an intriguing avenue for understanding the environmental process and patterns of investment within the anthropogenic landscape. Specific to the GIS analysis and modeling conducted in this dissertation, future work could focus on advanced statistical tests. Incorporating geometrical statistics holds the potential to expand the analysis of the effects terraces had on the surface areas and shapes of drainage catchments beyond the visual identification used in the dissertation. In addition, employing a function of spatial autocorrelation, identification of the degree an object is similar to neighboring values, within the permutation tests used here to assess the significance of terracing on drainage and erosion susceptibility, may assist in illuminating greater differences within the dataset.
Second, the archaeopedological analysis of terrace planting surfaces and other geointensive agricultural fields is incredibly useful for modeling and understanding production capabilities. However, there is a lack of systematic soil testing within sites and public reporting of results, which severely limits the potential for both intrasite analysis and intersite comparison. This level of detailed investigation is building in the Maya area. Research in Northern Belize, the Petén region of Guatemala, the Sierra regions and Usumacinta plains of western Guatemala, and eastern Mexico holds the greatest potential for such investigations (Beach 1998a; 1998b; Beach et al. 2006; Beach et al. 2008; Beach et al. 2009; Dunning and Beach 1994; Fernández et al. 2005; Foias and Emery 2012; Johnson et al. 2007; Lentz et al. 2015; Liendo Stuardo, Rodrigo Ruben Gregorio et al. 2014; Luzzadder-Beach et al. 2012). Increasing the systematic survey and standardization of research methods in exploring these questions holds the potential for both beneficial collaborations between archaeologists and a much better understanding of the impact agricultural practices had on the landscape.

Third, while macrobotanical recovery has faltered in numerous areas, especially in the North Vaca Plateau, advances in microbotanical analysis are being made as this type of research is becoming more prevalent and sophisticated in terms of recovery and identification. This has resulted in a wide variety of applications and interpretations (Bozarth and Guderjan 2004; Hammond and Miksicek 1981; Hansen et al. 2002; Leyden et al. 1996; Sheets et al. 2012; Wyatt et al. 2012; Cortella and Pochettino 1994; Haslam 2004; Jones and Handreck 1967; Messner et al. 2008; Pearsall 1982; 2000; Pearsall et al. 2003; Piperno 1998; 2006; 2009). This method of analysis should become an accepted practice for any agricultural study. Results can be incorporated in suitability models to produce accurate production estimates, an element missing in this dissertation.
Fourth, while geointensive agricultural features have received a steadily growing appreciation within the excavation strategy of archaeological projects, their inclusion is often very targeted and limited to small-scale excavations, including my own research. Investigation needs to be focused on larger systems. This may include moving beyond the excavation of a single unit or series of independent units, towards more numerous horizontal excavations or trenches through multiple features. This approach would assist in identifying changes and standardization in construction techniques as well as the more elusive subsurface water management features. In the North Vaca Plateau, this may also include standardized terrace excavations over much larger study areas, beyond that of the immediate support populations or site survey zones. Larger terrace excavations, potentially including reconstructions, will help refine labor estimates and identify benefits beyond those in my models.

With advances in these four avenues of archaeological research, the potential of investigations into ancient agricultural strategies can be tremendously advanced. The current atmosphere in agricultural studies is leading in many of these directions, increasing the appreciation for the often less glamorous archaeological research. Ultimately, the study of relic agricultural strategies is, in many ways, a ripening field with numerous low- and high-hanging fruit waiting to be picked.
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Willey, Gordon R., William R. Bullard, John B. Glass, and James C. Gifford

Wingard, John D., and Sue E. Hayes

Wischmeier, Walter H., and Dwight D. Smith
Wischmeier, Walter H., and Dwight D. Smith  

Wittfogel, Karl A.  

Woods, William I.  

Wright, A. C. S., D. H. Rommey, R. H. Arbuckle, and E. Vial  

Wyatt, Andrew R.  

Wyatt, Andrew R., David M. Jarzen, Lizzy Hare, and Kitty F. Emery  

Wyatt, Andrew R.  

Wyatt, Andrew R.  

Yaeger, Jason, and Marcello A. Canuto  

Yan, Yuk Y.  
Yocom, Larissa L., Peter Z. Fulé, Peter M. Brown, Julián Cerano, José Villanueva-Díaz, Donald A. Falk, and Eladio Cornejo-Oviedo

Young, Anthony

Zehrt, Claudia, and Gyles Iannone

Zhang, Hongming, Qinke Yang, Rui Li, Qingrui Liu, Demie Moore, Peng He, Coen J. Ritsema, and Violette Geissen
BIOGRAPHICAL SKETCH

Scott Macrae started his archaeological career with a Bachelor of Science with honors in Anthropology with an emphasis in Archaeology at Trent University in 2007. Scott’s Honors Thesis focused on remote sensing, drawing on a case study from the Greek island of Antikythera. Dr. Macrae followed this degree with a Master of Arts in Anthropology from Trent University in 2010. His Master’s thesis focused on the ancient Maya agricultural terracing amongst the support population of the Contreras Valley associated with the major center of Minanha. Shortly after completion, he joined the doctoral program in anthropology at the University of Florida. His dissertation work expanded on his Master’s research with his dissertation also focusing on understanding ancient Maya agricultural terraces. Dr. Macrae received his Ph.D from the University of Florida in the spring of 2017.

While pursuing his degree Dr. Macrae has worked as teaching assistant and lecturer for the University of Florida, instructing students in World Archaeology and the Principals of Archaeology. His research has appeared in archaeological journals including Latin American Antiquity, Advances in Archaeological Practices, as well as others. He has also presented research at both national and regional meetings.

Dr. Macrae’s dissertation, Terracing, Agricultural Strategies, and Resilience at the Ancient Maya Minor Center of Waybil, was supervised by Dr. Kitty Emery.