Seeing the Forest and the Trees: Ancient Maya Wood Selection and Forest Exploitation at the Paynes Creek Salt Works, Belize

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SEEING THE FOREST AND THE TREES: ANCIENT MAYA WOOD SELECTION AND FOREST EXPLOITATION AT THE PAYNES CREEK SALT WORKS, BELIZE

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ABSTRACT

The discovery of ancient wood, preserved below the seafloor in a shallow mangrove lagoon in Paynes Creek National Park, Belize, provides the opportunity to study human-environment interaction for an aspect of society that can rarely be glimpsed. Taxonomic identification of construction wood and charcoal at Early Classic (A.D. 300-600) Chan B'i, and Late Classic (A.D. 600-900) Atz'aam Na, are reported and discussed to assess forest exploitation strategies and species selection over time. Principles of optimal foraging are applied to interpret the specific contexts of human behavior in wood selection. Insights from the Annales School of French Structural History and the temporal framework of Fernand Braudel are employed to discuss the particulars of wood selection at Paynes Creek in relation to broader socio-environmental processes and structures.

Black mangrove (*Avicennia germinans*) dominates the Early Classic construction wood assemblage. Charcoal at Chan' Bi demonstrates a preference for four species, two mangrove and two broadleaf. The Late Classic construction wood is characterized by greater variability than the Early Classic, and an absence of mangrove species. When considered in the environmental context, identified species conform to principles of optimal foraging, with efficiency a primary concern in foraging behavior. The change in the wood assemblage over time suggests overexploitation of forest resources, resulting in deforestation of the local landscape. Land use and deforestation are linked to the wider social context in which growing inland populations created increased demand for salt, putting greater pressure on the forest resources exploited by the Paynes Creek salt works for fuel and timber.

CHAPTER 1. INTRODUCTION

1.1 Introduction

The 2004 discovery of preserved ancient wood in the lagoons of Paynes Creek National Park, Belize, provides a unique opportunity to study a facet of ancient Maya culture largely unavailable to archaeology (Figure 1.1). The excitement of the day of discovery is vividly remembered when the first wooden post was excavated from the mangrove peat; those of us present immediately recognizing the significance of the discovery in a region where the tropical climate is devastating to the preservation of organic material (McKillop 2005a). Despite the reliance on wood and its importance to the ancient Maya, outside of a limited number of specific contexts, wood is all but absent from the archaeological record of the region. This dissertation takes advantage of the unique collection of preserved wood to document, analyze, and interpret the wooden record in terms of human-environment interaction at two workshops, Early Classic (A.D. 300-600) Chan B'i, and Late Classic (A.D. 600-900) Atz'aam Na.

Figure 1.1 Excavated wooden post (photo courtesy of Heather McKillop)

The research that comprises this dissertation is a part of the Underwater Maya project directed by Dr. Heather McKillop, of which I have been a part since 2004. The multifaceted project examines the salt production workshops of Paynes Creek, with multiple research goals exploring the ancient culture and environment. The salt works are located in a shallow micro-tidal mangrove lagoon system. Sea-level rise has inundated the workshops, creating the favorable preservation conditions, in which the mangrove peat protects ancient wood from decay. The landscape is dominated by mangrove habitats, and in particular *Rhizophora mangle* (red mangrove). Broadleaf patches are also present close by, as well as a large savanna ecosystem within 3km (Figure 1.2). The heterogeneous landscape and the unparalleled preservation of ancient wood provide the opportunity to combine geography, anthropology, and ecology to address human-environment interaction in relation to wood selection and forest resource exploitation.

Figure 1.2 Ecosystems of Paynes Creek. A) mangrove, B) broadleaf, C) savanna (Photo A courtesy of Heather McKillop; Photo B and C by author)

1.2 Background

The benefits of paleoethnobotanical research to archaeological inquiry has long been known and utilized, the study of plants proving valuable to reconstructing and understanding the past environment and lifeways (Pearsall 2000). Theoretical and methodological development and refinement within paleoethnobotany, and in conjunction with ecology, geography and anthropology, have continued to offer new insights into ancient cultures, paleoenvironment, and climate reconstructions (Asouti and Austin 2005; Jones and Cloke 2002; Kennett et al. n.d.; McNeil 2012; Toledo 2002). Paleoethnobotany covers the whole gamut of relationships among past people and plants. Although much paleoethnobotanical research has focused on subsistence, this discussion concentrates on the area of paleoethnobotany concerned with the analysis of ancient wood use.

Despite the benefits of paleoethnobotanical research, the discipline often is neglected in archaeological investigations, either through exclusion or through the lack of integration within the research design, project goals, and synthesis. To date just a handful of researchers have been actively involved in identifying and discussing wood remains from ancient Maya sites (Lentz 1999; Lentz and Hockaday 2009: Lentz et al. 1996, 2005; McKillop 1994; Miksicek 1983; Morehart 2011; Morehart and Helmke 2008; Morehart et al. 2005; Wyatt 2008). The marginal role of paleoethnobotanical studies concerning wood remains within Maya archaeological research design is largely due to three factors:

1. Poor preservation
2. Specialized skills
3. Institutional bias

These non-exclusive factors are interrelated with multiple components that are discussed briefly below.

Poor preservation

Wood rots quickly in the humid tropics. Typically, the only remnant of a house post is the stain the decomposed post leaves in the soil. Rarely, wooden architectural elements have been discovered. Miksicek (1990) reports identifiable fragments of wooden posts from San Antonio Rio Hondo, northern Belize, including fig (*Ficus* sp.), pole wood (*Xylopia* sp.), and turtlebone (*Pithecellobium* sp.) posts. Charred remains of architecture were preserved by volcanic ash and tephra at El Cerén, providing evidence of thatch (*Tithonia rotundifolia*), fence posts (*Casearia* sp.), wattle and daub walls, and roofing poles (*Ficus* sp., *Aspidosperma* sp., *Nectandra* sp., and *Cupania dentate*; Lentz and Ramirez-Sosa 2002; Sheets 2002). Limited wooden architectural elements also have been discovered at Tzibanche (Hammond 1982), Nohmul (Hammond et al. 1987), El Zotz (Schuster 1999), Chichén Itzá (Coggins and Shane 1984), Tikal, Edzna, Bonampak, Palenque and Uxmal (Henderson 1997; Jones and Satterwhwaite 1982; Lentz and Hockaday 2009; Maler 1911; Thompson 1954).

In addition to building construction, the ancient Maya also used wood in the construction of material objects ranging from tools to elaborate ceremonial objects. Certain contexts provide favorable environmental conditions for wood preservation, such as dry caves and anaerobic sediments in cenotes. Wooden artifacts recovered include atlatls, scepters, earflares, spindle whorls, pendants (Coggins and Shane 1984), effigies (Coggins and Shane 1984; Martin and Grube 2000), figurines (Prufer 2002; Prufer et al. 2003; Stuart and Houseley 1999), bowls, mirror backs, litters, biers (Welsh 1988), thrones (Martin and Grube 2000), masks (Coe 1999), plain boxes (Coe 1974; Prufer 2002), carved boxes (Anaya et al. 2001; Coe 1974), torches (Morehart et al. 2005; Moyes 2007), a paddle (McKillop 2005a), benches (Morehart et al. 2005: Prufer and Dunham 2009) and a possible canoe (Moyes 2007).

Charcoal, on the other hand, is more abundant than wood, the carbonized structure of charred wood proving more resistant to decay. Charcoal is often the most abundant ecofact within a site's assemblage and is often the only access to ancient wood use. However, charcoal is often primarily collected for radiometric dating, rather than paleoethnobotanical studies. Also, charcoal fragments are commonly recovered from secondary contexts, clouding potential interpretation.

Specialized skills

Archaeologists develop skills in the classification of patterns within material culture as a way to answer questions regarding the similarities and connections within and amongst contexts and to isolate temporally sensitive markers. Although the concept is similar for identifying wood species, the skill set is highly specialized and labor intensive. The interdisciplinary nature of archaeological investigation means an individual archaeologist cannot specialize in every possible research direction. Archaeologists have tended to concentrate on other elements and materials for investigation, such as ceramics, lithics, architecture, survey, or osteology, relying on outside specialists or neglecting plant remains, which often represent more abundant artifact classes and more directly related to human input. Multidisciplinary research and the use of outside specialists, who are not necessarily trained in anthropology, has often lacked the internal coherence and synthesis of true interdisciplinary inquiry. The lack of synthesis can also result in the taxonomic identification of wood and charcoal, with little interpretation of the deeper socio-environmental context. Furthermore, the need for specialists, and the use of specialized equipment such as Scanning Electron Microscopes, can be prohibitive to archaeological projects that are often run on limited budgets.

Institutional bias

Academic research is driven and facilitated by granting agencies and publication houses; institutions that demand high impact results and dictate what is "hot" at the moment. Although commoner contexts, households, settlement and low level theory has gained considerable attention, elite contexts, spectacular discoveries and high level theory (e.g. ancient Maya collapse) is more likely to gain international attention, be reported in mass media outlets, and be published in high impact journals. Sadly, paleoethnobotanical investigations do not often have the draw for high impact publication. Unless the work relates to the collapse of cities and civilizations (Kennett et al. n.d.; Lentz and Hockaday 2009), provides museum quality showpieces (McKillop 2005a; Prufer et al. 2003), or can be attached to a superlative (i.e. first, largest, or oldest), paleoethnobotanical data are more often consigned to chapters in site monographs, edited volumes, research reports, or unpublished theses and dissertations (e.g. Lentz 1999; Lentz et al. 2012; Miksicek 1983, 1990, 1991; Morehart 2011).

Furthermore, the basic methods of wood identification have been successfully established for some time, and although organic material, such as wood, is often required to apply new scientific methods (such as in isotopic or elemental studies), the material itself and anthropological questions regarding the wood's entanglement with society is not the focus of study, but rather acts as a material to develop proxies for other inquiries, such as climate reconstruction (Kennett et al. n.d.).

A combination of poor preservation, the need for specialists, and an institutional bias have resulted in a marginalization of wood-centric paleoethnobotanical research within archaeological investigations. Despite these issues, paleoethnobotanical work endures and researchers continue to show the value of anthropological studies of ancient wood in archaeological investigations (e.g. Lentz and Hockaday 2009; Morehart et al. 2005; Wyatt 2008). Theoretical developments in particular have provided an avenue for paleoethnobotanical development, with increasing consideration of the complexity of the nature of human-environment interaction, non-human agency, and the synthesis of paleoethnobotanical data into interdisciplinary research.

Recent theoretical movements have attempted broader synthesis with anthropology, human ecology, political ecology, and behavioral ecology (Jones and Cloke 2002; Marston 2009; Maxwell 2011; Rubiales et al. 2011; Toledo 2002). Toledo (2002:514) forwarded a framework that focuses on *kosmos* (beliefs and cosmology), *corpus* (knowledge), and *praxis* (set of practices), to explore how nature is viewed by social groups "through a screen of beliefs and knowledge". Drawing attention to the important role nature plays in developing human response, Jones and Cloke (2002) highlight human-environment interaction in terms of non-human agency, paying detailed attention to the multivocality of trees across time and space. The concept of fuelscape, as applied by Maxwell (2011), provides an integrative analysis of fuel consumption that considers the complexities of the legacies of human behavior and the environment in guiding fuel procurement and use. Using an approach that focuses on the distribution of resources on the landscape and the rational choices of foragers, principles of optimal foraging applied to archaeological wood and charcoal remains has provided a method for testing assumptions of human behavior (Marston 2009; Rubiales et al. 2011).

1.3 Dissertation Objectives

The objectives of this dissertation are to address the above highlighted issues. 1) The research benefits from the unparalleled preservation of archaeological wood in Paynes Creek. 2) During my dissertation research I apprenticed under Dr. Michael Wiemann at the USDA Forest Products Laboratory, Madison, Wisconsin, learning wood structure and identification. Taxonomic identifications form the primary data of this dissertation, which are interpreted using theoretical frameworks to consider socio-environmental relationships focused on behavioral and environmental adaptations. 3) This dissertation is in the form of three principle chapters acting as self-contained publishable manuscripts. Each manuscript is tailored for journal publication, using primary data to answer anthropological questions of human-environment interaction.

The objectives of the research are as follows:

- Document construction wood species.

- Document charcoal species.
- Explore forest exploitation and management.
- Understand changes in wood selection practice through time.
- Explore the principles guiding resource selection.
- Assess anthropogenic impacts on the environment.
- Understand the local wood selection practices within the context of the broader region.
- Explore the complexities of human-environment interaction.

Chapter 2, *Ancient Maya wood selection and forest exploitation: A view from the Paynes Creek salt works, Belize,* employs principles of optimal foraging, in particular drawing from prey choice and patch choice models, to assess the selection of construction wood within the local environmental context. Wood identifications from Chan B'i, an Early Classic site (A.D. 300-600), and Atz'aam Na, a Late Classic site (A.D. 600-900), provide a diachronic dataset to assess wood selection and anthropogenic impacts on the environment and resource availability through time.

Chapter 3, *Fuelling Ancient Maya Salt Works at Paynes Creek, Belize*, documents and analyses excavated charcoal from Chan B'i, providing a record of wood fuel selection from a workshop context with high fuel demands. Patterns in the data reveal species preference and suggest foraging strategies and the importance of efficiency in resource acquisition.

Chapter 4, *Temporal Wavelengths of Ancient Maya Forest Exploitation: The General and the Particular of Wood Foraging at the Paynes Creek Salt Works*, draws from the temporal framework of Fernand Braudel (1972) of the Annales School of French Structural History to understand the specific context of wood selection for fuel and construction within the lagoon, as well as the socio-environmental forces that guide wood selection in terms of the structures, institutions, and processes of the broader region. The variability of culture and the environment are discussed in terms of fluctuations around an equilibrium state at three timescales; short-term, medium-term, and long-term.

Together, the body of work represents an in-depth analysis of wood selection and forest exploitation at the Paynes Creek salt works, addressing the interrelationships and adaptations of human behavior and the heterogeneous environment.

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CHAPTER 2. ANCIENT MAYA WOOD SELECTION AND FOREST EXPLOITATION: A VIEW FROM THE PAYNES CREEK SALT WORKS, BELIZE

Mark E. Robinson and Heather I. McKillop

2.1 Introduction

Ancient settlements in the southern Maya Lowlands reached their apogee in the Late Classic period (A.D. 600-900) with populations at their greatest and a heightened era of monumental site expansion. The burgeoning populations drove an increased demand on land and forest resources used for settlement, agriculture, construction and fuel (Diamond, 2005; Hansen et al., 2002; Shimkin, 1973; Wiseman, 1983). Cooke discussed deforestation and its impacts as early as 1931, suggesting that the agricultural production needed to feed the ancient population required clearance of the surrounding forests. The fuel demands for lime plaster production alone have been suggested as the cause of mass deforestation and environmental collapse at the Preclassic site of El Mirador, Guatemala (Hansen et al., 2002). Further theoretical support for deforestation and its impacts on vegetation and soils was discussed by Sanders (1962, 1973), which was later corroborated by paleoenvironmental data (Abrams and Rue, 1988; Anselmetti et al., 2007; Binford et al., 1987; Brenner et al., 2001, 2002; Curtis et al., 1998; Deevey et al., 1979; Dunning et al., 1998; Dunning and Beach, 2000; Hodell et al., 1995, 2000, 2005; Islebe et al., 1996; Lentz and Hockaday, 2009; Leyden, 1987; Rice, 1996; Rosenmeier et al., 2002; Shaw, 2003; Wahl et al., 2006, 2007; Wiseman, 1978, 1983).

Despite the championing of deforestation as a major feature of the ancient Maya landscape and its impacts on society, the last forty years of research has uncovered a multitude of environmental management practices in agriculture and landscape modification that portray the ancient Maya as skilled managers and conservators of the environment (Lentz et al., 2012; McNeil, 2011). Two recent studies (Lentz and Hockaday, 2009; McNeil et al., 2010) weigh in on the deforestation debate, providing contrasting evidence of forest management. Lentz and Hockaday (2009) present wood species data from the lintels and beams of Tikal's temples documenting a temporally sensitive change in selection of wood from the exclusive selection of the large, primary upland forest species, sapodilla (*Manilkara zapota)*, to the seasonal wetland species, logwood (*Haematoxylon campechianum),* after A.D. 750. A later return to sapodilla of a much smaller size confirms the preference for the species in elite constructions, but indicates the use of wood from secondary forests. They argue for the careful management of resources that included conserved stands of important primary forests and their resources up to the Late Classic; however, toward the end of the Classic Period when ancient Maya populations were at their highest, these stands were exhausted and alternatives sought (Lentz and Hockaday, 2009).

Mismanagement of the Maya forest has been suggested for the ancient Copán society, Honduras, based on palynological data from a sediment core in the Petapilla pond, 5km from the site core. Abrams and Rue (1988) argue that successful forest management practices broke down to the point that the Terminal Classic Maya were unable to adequately and sustainably, manage the forest. Pollen trapped in the deposited sediments in the pond form a stratigraphic record of vegetation that indicates a greater proportion of non-arboreal vegetation in the region during the

Terminal Classic compared to subsequent time periods after the abandonment of the urban center, indicating deforestation of the forest (Abrams and Rue, 1988). McNeil and colleagues (2010) analysis of a much longer core from Petapilla gives greater time depth and refutes the earlier findings of resource mismanagement at the end of the Classic period. The pollen profile from the core extracted by McNeil provides a 3000 year environmental history that records two peak periods of reduced arboreal vegetation dating to 900 B.C. and A.D. 400, with increasing forest cover during the Late Classic when populations were at their greatest, indicating a high degree of resource management.

The contrasting findings in forest management practices and their ecological impacts confirm the need for localized studies of use of forest resources by the ancient Maya. The heterogeneous socio-environmental landscape of the Maya area includes distinct localized ecological and social conditions with different human responses. The archaeological record can be assessed against principles of optimal foraging to test general patterns of behavior and address selection practices against a dynamic ecological context. Thus, paleobotanical research can not only reveal environmental data, but also assess human knowledge and behavior and the pressures and demands of society that guide human-environment interaction. The spectacular discovery of preserved archaeological wood from a coastal mangrove lagoon system in Paynes Creek National Park, southern Belize (Figure 2.1), provides an opportunity to directly study wood exploitation and assess resource management and issues of deforestation. In this paper, preserved wooden posts are taxonomically identified to generate a record of species selection, which is considered in relation to the local environmental context. Species identifications from Early Classic (A.D. 250-600) and Late Classic (A.D. 600-900) salt works suggest a lack of resource management and the overexploitation of forests patches.

2.2 Optimal Foraging and Behavioral Ecology

Principles of patch choice and prey choice employed in optimal foraging models in behavioral ecology are used to evaluate wood selection strategies at the Paynes Creek salt works. Behavioral ecology and optimal foraging models have been widely used to interpret the archaeological record (Bird and O'Connell, 2006; Brown, 1988; Cannon, 2003; Charnov, 1976; Jochim, 1988; Kennet and Winterhalder, 2006; MacArthur and Pianka, 1966; Marston, 2009; Rubiales et al., 2011; Smith, 1983; Stephens and Krebs, 1986; Winterhalder and Goland, 1997; Winterhalder and Smith, 2000). Concepts of patch choice address decision-making across a heterogeneous landscape with an uneven distribution of resources over time and space (Brown, 1988; MacArthur and Pianka, 1966; Marston, 2009; Stephens and Krebs, 1986). A forager will actively select a location on the landscape that will give the greatest opportunity for satisfying the resource need with the least costs (travel and processing time). A forager will move to another patch once a perceived threshold is reached in which the time and energy spent looking for a viable resource outweighs the benefits of changing patch and continuing the forage elsewhere with a greater chance of return.

Prey choice, also known as diet breadth, predicts which resources a decision-maker will pursue while foraging (Bird and O'Connell, 2006; Cannon, 2003; Charnov, 1976; Marston, 2009; Rubiales et al., 2011; Smith, 1983; Stephens and Krebs, 1986; Winterhalder and Goland, 1997; Winterhalder and Smith, 2000). The model implies that a forager ranks resources based on a cost-benefit analysis that takes into account the desired goal for the resource, a currency with which to assess value (a combination of factors including functional suitability and handling time), the environmental context of available resources, and alternative strategies (Jochim, 1988; Marston, 2009; Stephens and Krebs, 1986). Highly ranked resources will be selected when encountered; a forager will add a wider range of resources of descending rank to their search/diet as higher ranked resources become scarce (Bird and O'Connell, 2006).

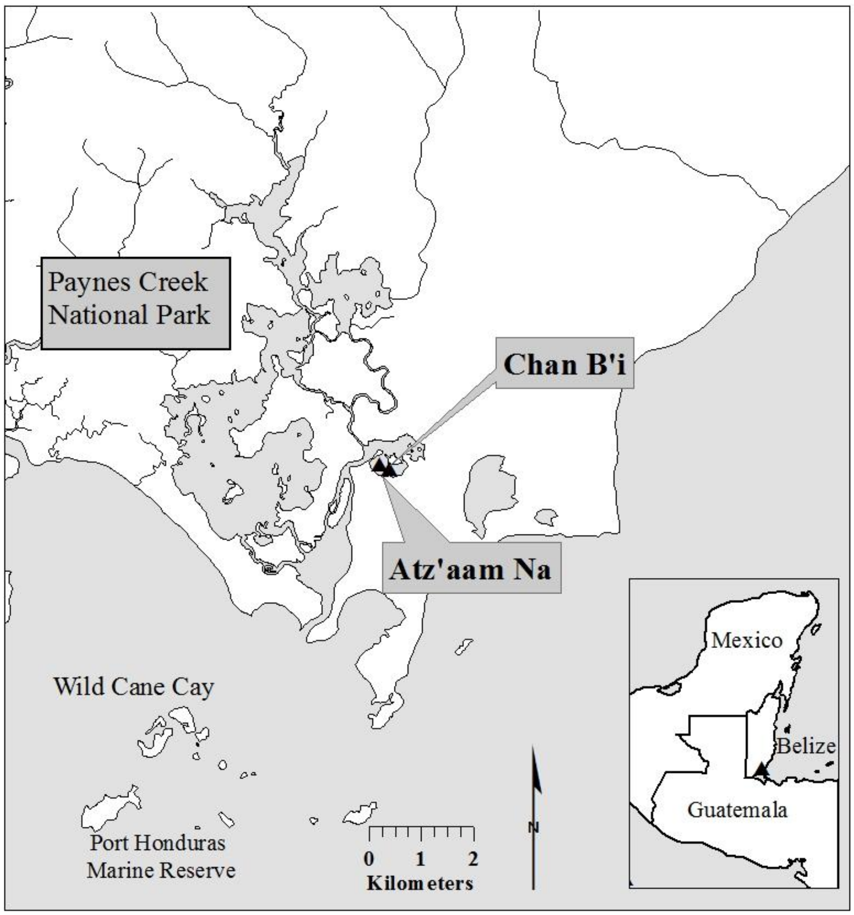

Figure 2.1 Map of study area

2.3 Archaeological and Ecological Context

In this diachronic study, we compare wood assemblages from two salt production workshops in southern Belize, Chan B'i and Atz'aam Na (Designated Site 24 and Site 35 respectively at the time of discovery). Radiocarbon dating of preserved wooden posts yields an Early Classic date at Chan B'i and a Late Classic date at Atz'aam Na. The sites share a geographic resource base, located just 300m apart in the eastern arm of Punta Ycacos lagoon, a micro-tidal coastal lagoon system within Paynes Creek National Park (Figure 2.1). Archaeological survey located inundated sites in the lagoon (McKillop, 1995, 2002). Systematic survey of the sites resulted in the discovery of wooden posts preserved in the anaerobic mangrove peat below the sea floor (McKillop, 2005a). Relative sea-level rise inundated the workshops since abandonment creating favorable preservation conditions. The ceramic assemblage characterizes the sites as non-domestic salt production workshops, where brine is evaporated in ceramic vessels over fires to produce salt (McKillop, 2002, 2005a).

Archaeological evidence points toward a limited number of small farming and fishing communities occupying southern Belize on the coast and inland up until the Late Preclassic (400 B.C. – A.D. 250), with the first monumental public spaces constructed at the start of the Early Classic (Braswell and Prufer, 2009; McKillop, 1996; Prufer et al., 2008). The expansion of Early Classic coastal settlement at Wild Cane Cay, and at inland centers including Ek Xux and Uxbenka, saw an increase in regional population and associated increase in demand for resources. The rise of the Paynes Creek salt works in the Early Classic mirrors the growing inland population. The regional population reached its peak in the Late Classic, likely centered around the developing sites of Lubaantun and Nim Li Punit (Braswell and Prufer, 2009). Salt production expanded in line with the increasing regional population and rising demand for salt during the Late Classic. The inland centers of southern Belize were abandoned by the Terminal Classic, with an associated decline in demand for salt and the subsequent abandonment of the salt works (McKillop, 2002, 2005a). However, coastal settlement continued into the Post Classic at Wild Cane Cay, tied into the circum-Yucatán canoe trade (McKillop, 2005b).

Belize's climate is defined by a wet and dry season, the dry season running from February to May. Annual rainfall varies greatly over the country, with over 300cm in the south, compared to 150cm in the north. Paynes Creek National Park encompasses a number of distinct ecosystems with supporting flora and fauna (Meerman and Clabaugh, 2010; Wright et al., 1959; Figure 2.2). Ecosystem composition and structure is characterized by the adaptation of flora to the particular geomorphologic setting and biotic and abiotic stresses. The western portion of the park is dominated by lowland savanna, with leached soils, acidic topsoil and low fertility, incorporating savanna grasses, sedges, palmetto palm (*Acoelorraphe wrightii*), oak (*Quercus oleoides*), and extensive monotypic stands of pine (*Pinus caribea).* The eastern part of the park comprises a series of storm ridges formed by the reworking of fluvial deposits, lacking woody vegetation. The southern portion of the park, encompassing the salt works, is dominated by mangrove and littoral forest, limited in composition to the salt tolerant species: red mangrove (*Rhizophora mangle)*,black mangrove *(Avicennia germinans)*,white mangrove (*Laguncularia racemosa),* and button wood (*Conocarpus erecta)*.

Mangrove ecosystems dominate tropical and sub-tropical intertidal landscapes across the world (Chen and Twilley, 1998; McKee, 1995). A spatial zonation characterizes mangrove forest structure in Belize (McKee, 1995), including Paynes Creek National Park. Red mangrove dominates the local landscape and is the sole species found proximal to the water's edge. The stunted growth typical of local red mangrove prevents the development of tall straight trunks, limiting the functional suitability of this species. Black mangrove is adapted to hyper-saline conditions and is typically found in small numbers behind the red mangrove fringe, where hydrology limits the flushing of soils and transport of toxins and nutrients (McKee, 1995). White mangrove is shade intolerant and appears in limited numbers where light regime and soil conditions are favorable.

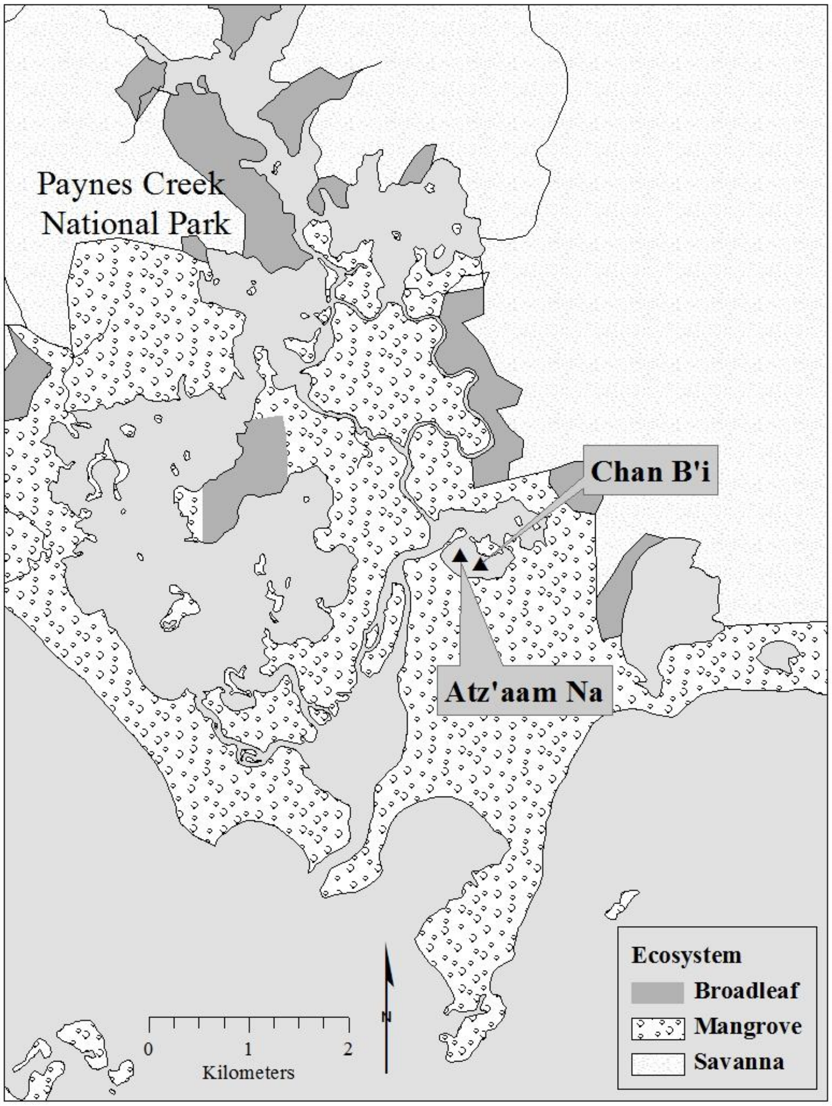

Figure 2.2 Map of broad ecosystem classifications in Paynes Creek National Park

Local broadleaf patches in and around the lagoon system in the modern environment are small and scattered with dense undergrowth. Strips of broadleaf forest are found on higher elevations and follow alluvial deposits along river courses, including the Deep River to the south and Monkey River to the north (Wright et al., 1959). Forest composition is rich, although Standley and Record (1936) note a characteristic Terminalia-Calophyllum-Symphonia-Vochysia association of primary flora, which accords well with the modern dominant emergent species of nargusta (*Terminalia amazonia*), Santa Maria (*Calophyllum brasiliense*), waika chewstick (*Symphonia globulifera*) and yemeri (*Vochysia hondurensis*). The remaining forest composition includes a wide range of lowland broadleaf species.

Unlike the environmental issues faced by inland communities, demands on the landscape in the immediate area of the Paynes Creek salt works were limited. Although coastal settlement increased along the southern coast in the Classic Period, no large centers, with increasing demands on fuel and agricultural land, are evident (McKillop, 1996, 2005b). Beyond clearance of mangroves to establish the salt works, forests were not cleared to accommodate expanding communities or converted into agricultural plots. The demands on forest patches were focused on extraction of wood resources for construction and fuel.

2.4 Materials and Methods

Chan B'i and Atz'aam Na were discovered and surveyed between 2005 and 2010, using a pedestrian survey technique adapted to the inundated conditions. Posts were identified on the sea surface, protruding through the sea floor. Exposed wood above the seafloor has decomposed, whereas wood in the anaerobic matrix is preserved. All posts discovered at the workshops were sampled and included in this study. A small sample of wood from each post was collected and exported for species identification. Sampled wood was kept in fresh water to maintain wood structure. The samples were periodically rinsed with fresh water to desalinize them.

The rarity of preserved wood in archaeological contexts in the neo-tropics has resulted in the growth of skills in the identification of charred wood and the development of comparative charcoal collections. In some cases archaeological wood samples are first charred before identification is attempted (e.g. Lentz and Hockaday 2009). The condition of wood from submerged conditions at Paynes Creek preserved gross anatomical features, with minor amounts of decomposition and degradation of anatomical structure present.

Wood samples were sectioned along the transverse, tangential and radial planes using a backed razor. The saturated nature of the wood samples made thin-sectioning relatively easy through the softened wood without further pretreatment. The samples were mounted on a glass slide for observation of anatomical features using a 10x-100x transmitted light microscope. For identification, sections were compared to the modern reference collection at the USDA Forest Products Laboratory, Madison, Wisconsin, the authors' reference collection from Belize, and published wood atlases and databases (Insidewood; Detienne and Jacquet 1983; Uribe 1988). The presence, form and arrangement of anatomical features, including vessels, parenchyma, rays, and perforation plates are compared to known samples to make an identification. Identifications were made to the lowest taxonomic unit, with anatomical structure generally allowing separation to the genus level.

Specific Gravity (SG) was used as a measure of wood strength to compare the suitability of the identified trees for building construction. Measured as green weight/oven dry weight divided by fresh volume (Muller-Landau, 2004; Williamson and Wiemann, 2010), SG is a measure of the structural material allocated to support and strength (Williamson and Wiemann, 2010) and therefore can be used as a quantitative proxy for wood strength. SG values for wood species were compared to frequency of occurrence of a species to assess whether the functional characteristics of the wood was an important factor in wood selection. Degradation prohibits direct SG measurement of the archaeological samples. As such, SG measurements were compiled from published sources based on a representation of the genus/species for the region.

2.5 Results

2.5.1 Wood Species identification

Table 1 documents the wood taxa identified for wood posts at Chan B'i. Thirty-three samples were analysed, with seven identified taxa represented. Four samples could not be identified due to structural degradation. *Avicennia germinans* (black mangrove; Figure 2.3A), easily recognizable by concentric bands of phloem, dominates the assemblage representing 34% of the total sample (Figure 2.4). *Eugenia* sp. represents 18% and *Hieronyma* sp. 12%. Three samples were identified from the family Chrysobalanaceae, although likely representing the same species. *Casearia* sp. (Figure 2.3D) and *Ficus* sp. (fig; Figure 2.3I) both occur twice. Only *Calophyllum brasiliense* (Santa Maria; Figure 2.3G and 2.3H) appears a single time.

Table 2.1 Wood identifications from Chan B'i
(Specific gravity values from, Little and Wadesworth 1964; Malavassi 1992; Reyes et al. 1992).

Family	**Taxa**	**Common name**	**Count**	**% of Site Total**	**Specific Gravity**
Acanthaceae	*Avicennia germinans*	black mangrove	11	34	0.9
Chrysobalanaceae		pigeon plum	3	9	0.9
Clusiaceae	*Calophyllum brasiliense*	Santa Maria	1	3	0.47
Euphorbiaceae	*Hieronyma sp.*	Redwood	4	12	0.63
Flacourtaceae	*Casearia sp.*	billy hop	2	6	0.66
Moraceae	*Ficus sp.*	Fig	2	6	0.4
Myrtaceae	*Eugenia sp.*	-	6	18	0.7
-	Unknown hardwood	-	4	12	
		Total	**33**	**100**	

Of the 25 identified wood samples from Atz'aam Na, ten taxa were identified (plus two unidentified samples; Table 2.2). Atz'aam Na also shows a single dominant species, *Symplocos martinicensis*, identifiable by the presence of scalariform plates (Figure 2.3B) and multiseriate rays, representing 44% of the total assemblage (Figure 2.5). As with Chan B'i, *Eugenia* sp. was the second most represented genus (12%). *Mouriri* sp., clearly distinguished by the presence of diffuse included phloem, appears twice (Figure 2.3C). The remaining seven genera appear only once each. Out of 17 total identified taxa from the two sites, four occur at both sites.

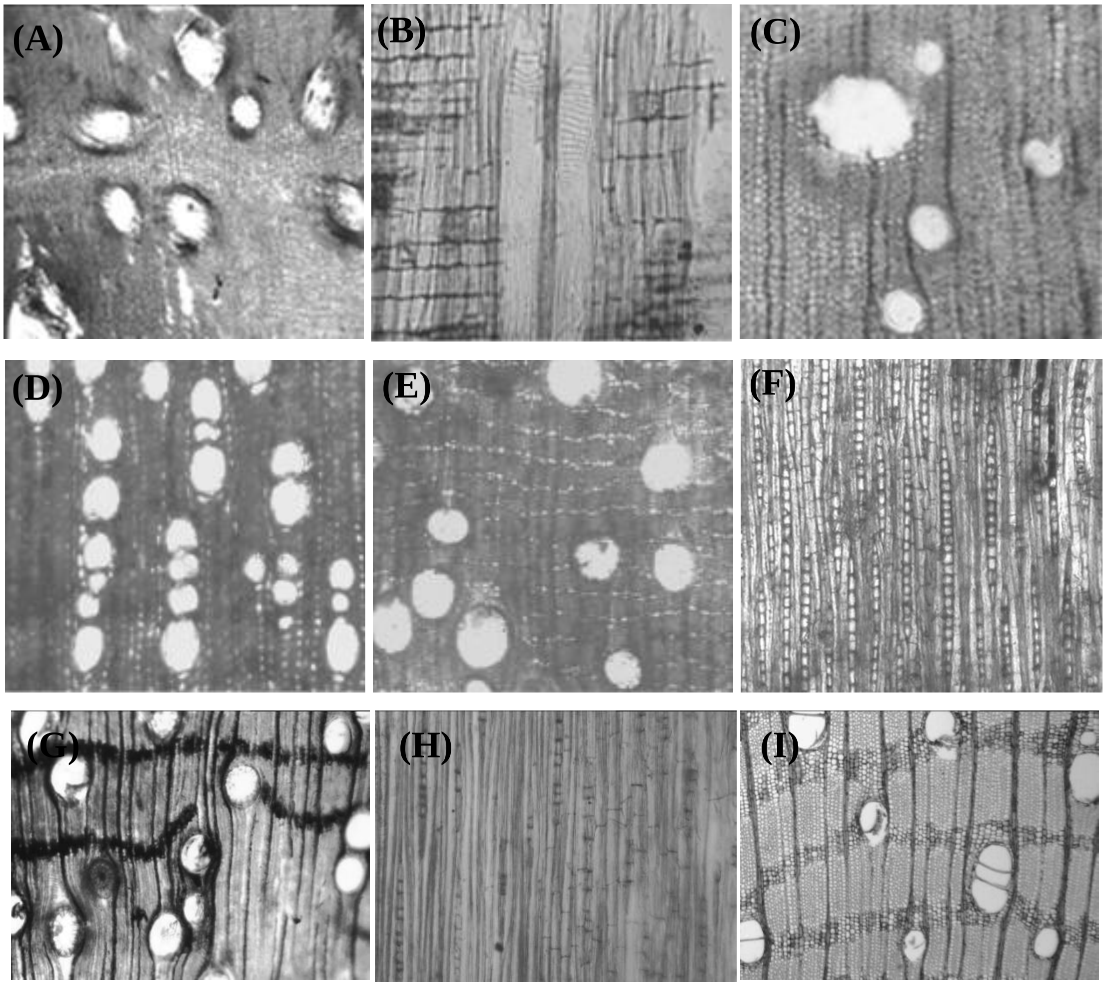

Figure 2.3 Microphotographs of archaeological wood from Paynes Creek National Park: (A) *Avicennia germinans*, transverse section; (B) *Symplocos martinicensis*, radial section; (C) *Mouriri* sp., transverse section; (D) *Casearia* sp., transverse section; (E) Chrysobalanaceae, transverse section; (F) Chrysobalanaceae, tangential section; (G) *Calophyllum brasiliense*, transverse section; (H) *Calophyllum brasiliense*, tangential section; (I) *Ficus* sp., transverse section.

Eugenia and *Ficus* are large genera that are well represented in Belize. The identification of wood samples to *Eugenia* or *Ficus* at the genus level could incorporate multiple individual species. *Eugenia* is variable anatomically with over thirty species listed within Belize (Balick et al., 2000). The identified *Eugenia* samples incorporate solitary vessels, multiseriate ray forms, typically two or three cells wide, and a distinctive diffuse-in-aggregate axial parenchyma arrangement. *Eugenia axillaris* is a likely candidate and is used in construction (Balick et al., 2000), although the species cannot be confirmed. Similar to *Eugenia* and in the same family (Myrtaceae), *Myrciaria floribunda* is distinguished by the diagonal alignment of vessels. *Ficus* is easily recognizable from the wide banded axial parenchyma, but with over 20 species present in Belize, identification beyond the genus level cannot be confirmed.

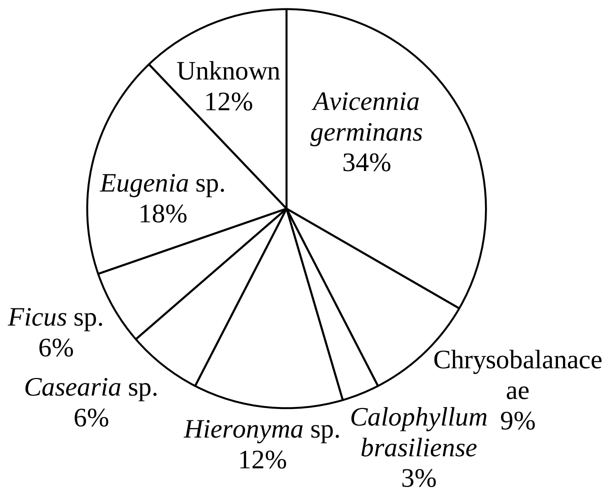

Figure 2.4 Pie Chart showing relative proportion of taxa at Chan B'i

Two species of *Hieronyma* (or *Hyeronima*) from the Euphorbiaceae family are present in modern Belize: *H. alchorneoides* and *H. oblonga*. Distinguishing anatomical features of the genus are its tall multiseriate rays, solitary vessels, and lack of distinctive parenchyma. The frequent presence of scalariform plates and a small vessel size (50-100µm), suggests the species *H. oblonga*; however, overlap in anatomical variability negates classification beyond the genus level.

Table 2.2 Wood identifications from Atz'aam Na
(Specific gravity values from, Little and Wadesworth 1964; Malavassi 1992; Reyes et al. 1992).

Family	**Taxa**	**Common name**	**Count**	**% of Site Total**	**Specific Gravity**
Euphorbiaceae	*Alchornea sp.*	fiddlewood	1	4	0.4
Euphorbiaceae	*Hieronyma sp.*	redwood	1	**4**	0.63
Flacourtaceae	*Casearia sp.*	billy hop	1	4	0.66
Leguminosae	*Dalbergia sp.*	rosewood	1	4	0.82
Melastomataceae	*Mouriri sp.*	cacho de venado hembra	2	8	0.9
Moraceae	*Ficus sp.*	fig	1	4	0.4
Myrtaceae	*Eugenia sp.*	-	3	12	0.7
Myrtaceae	*Myrciaria floribunda*	walk naked	1	4	0.73
Sapindaceae	*Matayba sp.*	bastard willow	1	4	0.82
Symplocaceae	*Symplocos martinicensis*	-	11	44	0.8
-	Unknown hardwood	-	2	8	-
		Total	**25**	**100**	

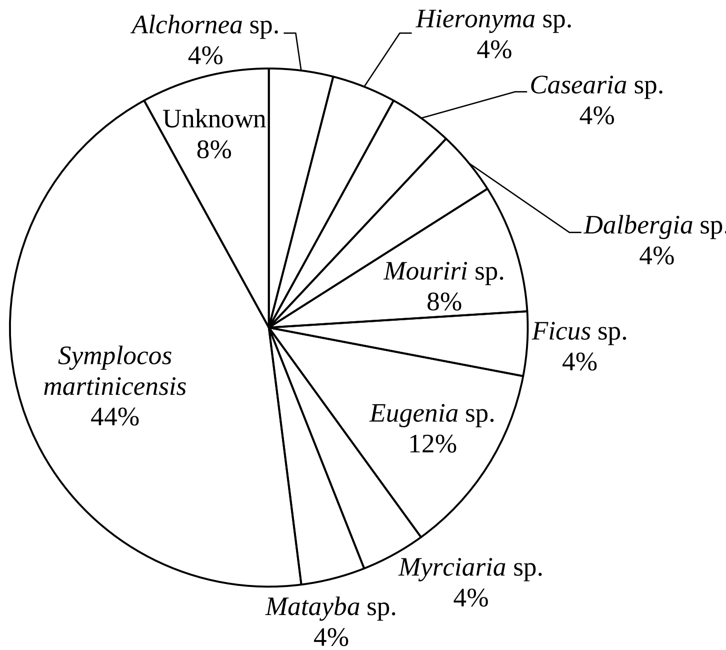

Figure 2.5 Pie Chart showing relative proportion of taxa at Atz'aam Na

Samples identified to Chrysobalanaceae display solitary vessels, uniseriate rays and banded axial parenchyma one cell wide (Figure 2.3E and 2.3F). The Chrysobalanaceae samples can be identified to either *Licania* or *Hirtella* at the genus level; however, the two genera are too similar in anatomy to differentiate based on the visible structure in the archaeological samples. Species within both genera are commonly called pigeon plum (Balick et al., 2000), suggesting that in folk classification systems the trees were not separated; therefore, the Western Linnaean system's taxonomic distinction may not be applicable.

2.5.2 Habitats Exploited

A. germinans is the only non-broadleaf species identified for the wood at Chan B'i and Atz'aam Na. Despite limited distribution close to the salt works, broadleaf habitats were an important source of wood resources. No distinctive savanna species are present at either site, although two taxa identified can adapt to a savanna habitat. *S. martinicensis* has been documented in low numbers in a coastal savanna in Stann Creek district to the north (Farruggia et al., 2008); however, the species is absent in other savanna systems in Belize (Laughlin, 2002). *Mouriri* sp., although predominately found in submontane and lowland broad-leaved forests, also has been documented in savanna and coastal habitats in Belize (Meerman and Clabaugh, 2010). Standley and Record (1936) note that *Casearia* sp. is one of the most common shrubs in thickets. The tree has a hard, heavy trunk. Of the taxa identified, a single sample (*C. brasiliense* "Santa Maria") matches the Terminalia-Calophyllum-Symphonia-Vochysia association of flora that characterizes the undisturbed broadleaf stands in the area (Standley and Record, 1936).

2.5.3 Ethnographic Uses

All identified woods have documented uses in modern construction and miscellaneous products in modern Belize, except for *Myrciaria* and *Symplocos* (Balick et al., 2000). Little local use data are available for *S. martinicensis*. In Nepal, *S. ramosissima* is employed in the construction of herders' huts (Bolton and McClaran, 2008). Although *Hieronyma* sp. is not listed as being utilized in construction in Belize (Balick et al., 2000), elsewhere the species is valued for its quick growth and functional suitability for construction, and as such has been forwarded as a sustainable timber (Carnevale and Montagnini, 2002; Montagnini and Mendelsohn, 1997). *Mouriri* sp. is hard and durable although documented modern uses are limited due to an irregular grain that makes the wood difficult to work (Stanley and Record, 1936).

C. brasiliense is a commercially important species with an attractive grain. The species is used in construction, and is preferred for boat building, including dugout canoes, due to its durability (Standley and Record, 1936). *Ficus* is a light, perishable wood that has many uses. *Ficus* sp. has been documented in various contexts archaeologically, including as food, firewood and construction (Lentz, 1991; Lentz et al., 1996; McKillop, 1994; Miksicek, 1983, 1990, 1991; Standley and Record, 1936), including a post from San Antonio Rio Hondo in northern Belize (Miksicek, 1990). *Casearia* sp. has been documented archaeologically as firewood and in construction contexts at El Cerén, Cobá, and caves in the Belize Valley (Lentz, 1991; Morehart, 2011). In Yucatán, *Casearia nitida* is known as *ixim che* "maize tree" as it bears a fruit like maize, and is used medicinally (Roys, 1931). In Chiapas, Mexico, *Casearia* sp. is known as "coffee tree" due to the fruit's resemblance to a coffee plant (Breedlove and Laughlin, 2000). An Early Classic wooden stool found in a cave, associated with a possible shaman's burial, is made of *Dalbergia* sp. (Prufer and Dunham, 2009). *Dalbergia* sp. is a species favored in the construction of modern xylophones.

2.5.4 Specific Gravity

Tables 2.1 and 2.2 record SG values for identified taxa. Figure 2.6 charts SG values compared to the frequency of identified species from Chan B'i and Atz'aam Na to assess the role of functional characteristics in wood selection. Chan B'i has a higher correlation between SG and frequency (R2 = 0.4961) than Atz'aam Na (R2 = 0.1272). The range of SG values for species from Chan B'i is 0.4 – 0.9, with a mean of 0.67. The range of SG for Atz'aam Na is 0.4 – 0.9, with a mean of 0.69. The two most frequent species, *A. germinans* and *S. martinicensis*, with SG values of 0.9 and 0.8 respectively, are at the high end of SG values, both within the identified sample and within a typical tropical forest.

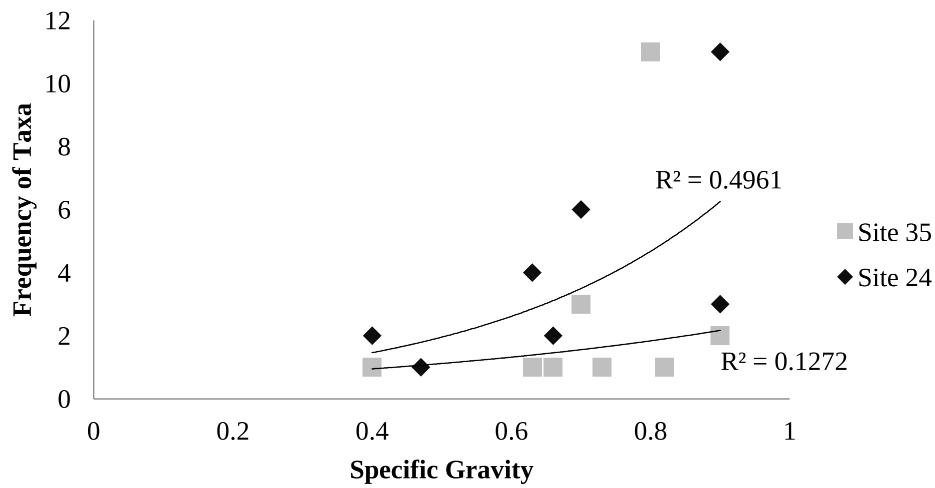

Figure 2.6 Relationship between specific gravity values and the frequency of taxa at Chan B'i and Atz'aam Na

2.6 Discussion

What factors were important in the selection of trees for building construction by the Paynes Creek Maya? Can selection practices reveal aspects of the ancient environment? Selection of all available nearby species would reveal an array of taxa reflecting the forest cover; by way of contrast, selection based on functional demands on construction wood could include desirable factors of strength, durability, size, and length that narrow the range of utilized species. Although the driving forces behind selection may not represent total availability of all species, and therefore obscure environmental reconstruction, changing selection over time can reveal environmental factors that guide selection. Principles of behavioral ecology and optimal foraging are useful for interpreting wood selection strategies at the Paynes Creek sites. Comparison of wood from Early Classic Chan B'i and Late Classic Atz'aam Na conform to principles of optimization as understood by patch choice and prey choice, and suggest an overexploitation of the environment and a lack of sustainable resource management practices.

2.6.1 Patch Choice

The closest tree species to Chan B'i and Atz'aam Na are mangroves, but they were not the only tree resources utilized and are absent altogether at the Late Classic site. The frequency of use of *A. germinans* in the Early Classic at Chan B'i is consistent with principles of optimal foraging within an undisturbed environment. In a lagoon system dominated by mangrove habitats, *A. germinans* is one of the few functionally viable species available, and would have therefore been a top ranked resource based on functional suitability and the low costs involved in procurement. The absence of any mangrove or salt tolerant species in the Late Classic at Atz'aam Na documents the exhaustion of the immediate resources and a change in patch choice to an alternative habitat with greater species richness and chance of successful returns, rather than suffering the increased costs of continuing the search within the mangrove habitats.

The frequency of *S. martinicensis* at Atz'aam Na implies a change in environmental availability. The absence of the species at Chan B'i, despite a number of taxa appearing in low frequencies (signifying low selection preference and the use of lower ranked resources), indicates the lack of availability of *S. martinicensis* within the exploited forest patches during the Early Classic. The change in availability of *S. martinicensis* implies a change in forest structure, or a change in forest patches exploited. Forest structure undergoes change as a result of resource exploitation, with natural and anthropogenic factors influencing subsequent succession. Natural processes of seed recruitment and competition begin processes of secondary succession, with fast growing species dominating. Pioneer secondary species are typically of low wood density as the speed of growth prohibits a dense structural development. Although the growth habits of *S. martinicensis* in the region are not well documented, its high SG value (0.8) suggests a slower growth and does not characterize the species as a pioneer species. The frequency of *S. martinicensis* at Atz'aam Na points toward either anthropogenic management of forest patches, or, more likely, increased foraging distance to forest patches where the species was established.

2.6.2 Prey Choice

The exhaustion of the mangrove resources put increased strain on alternative options. As preferred species are extracted from each patch, search times increase to capture higher ranked species. As such, to maintain efficiency, the resource base widened to include lower ranked species. The increased number of taxa and less repetition of taxa at the Late Classic site agree with this principle; despite a 24% decrease in samples from Atz'aam Na, there was a 43% increase in taxa represented, with 70% of identified taxa appearing only once at Atz'aam Na (compared to 14% at Chan B'i).

Although the composition of the ancient resource base is unknown, the generally high species richness of tropical forests suggests that a wide range of species would have been available in broadleaf stands. Species richness in a tropical forest can be highly variable, dependent on many factors and therefore difficult to quantify. Ross (2011) documents an average species richness of 31.7 species per 400m2 plots in western Belize, associated with the ancient Maya site of El Pilar. The total species richness for the forest across all plots was over 120. Black et al. (1950) found that more than a third of all species found were represented by a single individual in an Amazonian forest, with three one-hectare plots yielding 60, 87, and 79 species respectively. Species richness is affected by plot size and the distribution of included plots. The accumulation of new species with each subsequent sampled plot follows a saturation curve with a diminishing amount of new species recorded until the total forest composition is largely accounted for in the sample (Murça Pires et al., 1953; Ross, 2011).

In Puerto Rico, Thompson et al. (2002) found an average of 44.3 ± 5.7 woody species per hectare, with a total of 89 species identified in the forest. Data from the upper Amazon document some of the most species-rich plots in the world with approximately 300 species in hectare plots (Gentry, 1988), although Gentry notes that African and neotropical forests typically contain 60-120 species. Areas of forest bounded by a small ring of stones in Yucatán, called *petkot* (plural: *petkotoob*), are ancient delimited areas of managed vegetation for the protection and promotion of growth of economic species (Gomez-Pompa et al., 1987). A remnant signal of ancient management practices has been identified in the *petkotoob* through the low species richness and high presence of economic species. Of five *petkotoob* of varying sizes between 19m2 and 24000m2, only 29 tree species were identified, many of which are important fruit trees. With thirteen identified taxa in the archaeological record of the two Paynes Creek salt works, species richness at the two sites is relatively low in comparison to the richness of a typical tropical forest.

The high frequency of *A. germinans* and *S. martinicensis* in the archaeological sample provides evidence of specific selection, whereas the repetition of taxa, both at a site and between sites, also suggests a preference in resource exploitation. Taxa that appear only once in the archaeological record may reflect a low level of selection and/or a low frequency in forest composition. A highly variable identified archaeological sample with low frequencies of each taxa may reflect the exploitation of multiple patches, in which the number of available species is much higher, but the frequency of many of the taxa are low (Black et al., 1950). *A. germinans* and *S. martinicensis* are top ranked resources that were collected whenever encountered. The higher frequency of *Eugenia* sp. and *Hieronyma* sp. suggest these taxa also were ranked highly. In contrast, the taxa with only one occurrence were of low rank and extracted opportunistically in the absence of higher ranked resources.

With only seven taxa identified at Chan B'i and only one of those appearing a single time, a level of specific selection can be surmised. With ten taxa represented at Atz'aam Na and seven of those appearing only once, the data support a model of reduced specific selection and access to greater diversity in the resource base over time. When considered alongside the dominance of *S. martinicensis* and in comparison to the wood record from Chan B'i, over time, wood exploitation practices adapted to a changing environment, resulting in the use of different patches, with less discriminating behavior in timber selection.

2.6.3 Functional Demands and Selection

The most dominant species, *A. germinans* and *S. martinicensis*, are two of the highest SG woods at 0.9 and 0.8 respectively. Wiemann and Williamson (2002) report a mean SG of 0.548, with a minimum SG of 0.24 and a maximum SG of 0.87 for tree species from forests in the central Petén, Guatemala. Two locations in Costa Rica, Santa Rosa National Park and La Selva Biological Station, display a greater range with a minimum SG of 0.14 and 0.16, a maximum SG of 0.96, and a mean of 0.565 and 0.523 respectively. Similarly, the Los Tuxtlas Biological Station, Mexico, displays a mean of 0.547, a minimum SG of 0.16 and a maximum SG of 0.94. With a mean SG of 0.666 at Chan B'i, 0.686 at Atz'aam Na, and a combined total mean of 0.676, the woods selected by the ancient Maya are stronger and denser than the average wood reported by Wiemann and Williamson (2002) for other Central American forests, suggesting that functional properties of wood in relation to strength was a factor in selection by the Paynes Creek Maya. Furthermore, the lower range of SG values reported elsewhere for tropical forests are absent at Chan B'i and Atz'aam Na in Paynes Creek. The SG range in the archaeological samples is from 0.4 to 0.9, with only four samples, representing three species with a SG lower than 0.5.

The relatively low richness of species in the archaeological record, and recurrence of four of the Early Classic taxa at the Late Classic site, when considering the typical richness of a broadleaf forest is indicative of a ranked preference for species in which higher ranked resources are selected; however, if search costs are raised, a lower ranked resource will suffice. Distance appears to be the fundamental factor guiding resource selection. Although a resource must fulfill the desired role, prime physical characteristics or cultural values were not of major concern. The presence of multiple tree species with long, straight trunks of acceptable strength and durability within the broadleaf forest patches meant a large resource inventory could be utilized and little time was spent foraging for select species or in forest management to promote specific species growth.

2.6.4 Forest Management

Population pressure is typically cited as the driving force behind deforestation and the need for developed forest management practices, as the increased demands on resources overburdens the environment's carrying capacity. However, social responses are not uniform. As mentioned previously, a recent review of deforestation by McNeil (2011) highlights the abilities of the ancient Maya in resource management and refutes many of the earlier assumptions regarding forest mismanagement and deforestation that had guided discussions of the Late Classic Maya. McNeil's research at Copán (McNeil et al., 2010; McNeil, 2011) demonstrates increased forest cover during the height of the site's settlement history. At Tikal, Lentz and Hockaday (2009) discuss developed management and conservation strategies, including elite control of forest resources, although ultimately overburden on forest resources resulted from unsustainable practices that required a change in prey choice and patch choice. The low resource demands typically associated with small settlements facilitate sustainable management. The small farming community of Chan, western Belize, provides an example of effective forest management at a time of socio-political disruption at the end of the Classic period (Lentz et al., 2012). The paleobotanical record implies the landscape was carefully managed to provide for agricultural and arboricultural needs, including terracing, orchards, and timber management (Lentz et al., 2012).

While the resource needs for smaller populations may not put excessive pressure on environmental resources, the socio-political landscape can create localized pressures related to the demands of the large population centers. Forest resource management at Paynes Creek provides a case study of unsustainable practices, with evidence of a degree of specific selection, yet little evidence of resource management. The over exploitation of the forest can be linked to the pressures exerted by the demands of the growing regional population. The higher variability and reduced frequency of taxa that characterize the difference between the Early and Late Classic sites, alludes to an increasing resource base in which higher ranked resources were becoming scarcer over time. A strong management practice that selectively promoted the growth of specific, favored species, should demonstrate low variability and high frequency of those preferred species. As such, although the frequency of *S. martinicensis* shows a clear preference, its presence suggests the exploitation of different patches than those utilized in the Early Classic in Paynes Creek. The identification of overexploitation in the mangrove patches and the apparent expansion of the resource base into lower ranked taxa indicate that these patches were at a greater distance from the site, where *S. martinicensis* was available in numbers to allow preferential selection. The negative impact on the environment coincides with the growth of the regional population. Increased demand for salt required an intensification of activity at the salt works, which increased demand on forest resources for construction and fuel beyond the carrying capacity of the local environment.

2.7 Conclusions

New paleobotanical data are challenging traditional views of ancient Maya land stewardship and forest management. Understanding the paleobotanical record requires a broader comprehension of the local environment, the pressures placed upon the environment, and the response of communities to societal demands. Pressures were not the same across ancient Maya society. How did human-environment interaction differ among large population centers, such as Tikal and Copán, small farming communities, such as Chan, and coastal workshops, such as those at Paynes Creek? Population pressure certainly placed increased demand on resources; however, management responses were not uniform even at population centers. Although some communities may have shown a level of autonomy and resilience against environmental and social pressures, other communities, despite being geographically removed, were intricately tied into the broader social trends.

Growing populations at the large cities in the Late Classic and the subsequent demand on land and resources required strong management practices, from the individual household to the level of the state. The necessity for strong resource management was at times successful, as at Copán (McNeil et al., 2010). Other times resource management was not adequate in the face of ever increasing demand, and the landscape was exploited beyond its capacity, such as at Tikal (Lentz and Hockaday, 2009). Smaller communities perhaps escaped some of the social and environmental pressures due to low populations and adaptive land management practices.

The Maya of Paynes Creek were subject to a host of socio-environmental forces, with strong influence from the pressures associated with the inland centers despite their geographical distance. Inland populations drove demand for salt. As populations increased, demand for salt increased resulting in greater activity at the salt works, with more demand for wood for new construction and to fuel the salt production industry. The archaeological record of Paynes Creek shows a wood exploitation strategy that follows principles of optimal foraging in which a resource was selected with the least costs in terms of the searching and processing time. During the Early Classic at Chan B'i, the mangrove species *Avicennia germinans* comprised 34% of the wood assemblage. In the Late Classic at Atz'aam Na, when regional populations reached their highest, no mangrove species are present, with *Symplocos martinicensis* (44%) the principle species selected. A change in dominant taxa from the surrounding mangrove ecosystems to the more distant broadleaf patches confirms the importance of shorter distance for optimal foraging and implies the exhaustion of the mangrove ecosystems through overexploitation. The result was a change in patch choice and a widening of the resource base to include a greater number of lower ranked species as higher ranked taxa and successive patches were exhausted over time. The data support a local model of overexploitation and inadequate management of forest resources, leading to deforestation. The change in wood species coincides with the apogee of the large centers in the southern Belize, pointing to the intricate relationship between the Maya, their local environment, and broader social trends.

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CHAPTER 3. FUELLING ANCIENT MAYA SALT WORKS AT PAYNES CREEK, BELIZE

Mark E. Robinson and Heather I. McKillop

3.1 Introduction

The selection of wood for fuel reveals much about a society's ability to manage their social and environmental landscape. Seventy years of research, debate, and methodological refinement have explored the possibilities and limitations of charcoal analysis in reconstructing paleoenvironment, paleoclimate, and cultural behavior (e.g. Asouti and Austin 2005; Asouti and Hather 2001; Figueiral and Mosbrugger 2000; Lancelotti et al. 2010; Marston 2009; Smart and Hoffman 1988; Théry-Parisot et al. 2010). Even in the face of the positive results of charcoal analysis and the repeated highlighting of the dearth of paleobotanical analysis in archaeological research design, anthracological studies are still marginal to most archaeological research. Despite the often poor preservation of organic wood in the humid climate of Mesoamerica, paleobotanical work has revealed insights into ancient Maya diet, agriculture, forest management, use of economic species, and fuel wood selection (Gomez-Pompa et al. 1987, 1990; Lentz 1991, 1999; Lentz and Hockaday 2009; Lentz et al. 1996, 2005; McKillop 1994; Miksicek 1983, 1990, 1991; Morehart 2011; Morehart et al. 2005; Morehart and Helmke 2008; Peters 2000; Prufer and Dunham 2009; Wyatt 2008). In this study charcoal identifications from Chan B'i, an ancient Maya salt workshop in Paynes Creek National Park, Belize (Figure 3.1), explore wood fuel selection for an industry with a high fuel demand.

Many archaeological studies of charcoal focus on reconstructing the paleoenvironment through the principle of least effort; wood resources are collected from the closest source and the frequency of taxa within an archaeological assemblage is a direct reflection of the proportion of taxa in the past local landscape (Shakleton and Prins 1992). Although the principle of least effort is a useful concept, researchers acknowledge the limitations of this assumption and recognize the various processes and filters that affect the archaeological record, including environmental and cultural factors, as well as archaeological sampling techniques (Asouti and Austin 2005; Rubiales et al. 2011; Shakleton and Prins 1992; Théry-Parisot et al. 2010). These factors include, availability, succession, combustion properties, size of wood, the type of fire needed, smoke generation, dead wood versus green wood, water content, and cultural concepts of preference, the sacred and the taboo (Picornell et al. 2011; Tabuti et al. 2003; Théry-Parisot et al. 2010). For the modern day, Huastec of Mexico, Alcorn (1984) found an indiscriminate selection of fuel wood species driven by availability rather than combustion qualities. In an ethnographic study in Bulamogi, Uganda, the abundance of deadwood, rather than species' properties drives firewood collection (Tabuti et al. 2003). For the Fang of Equatorial Guinea, Picornell et al. (2011) note a firewood selection strategy that is based on the availability of dead wood; however, the strategy incorporates a cognitive ranking of wood based on combustion qualities as well as a rigid avoidance of certain species due to attached beliefs. Charcoal remains from Central Anatolia reveal a pattern of wood acquisition in which fuel wood was collected based on local availability. Specific demands for construction wood incorporated long distance procurement strategies (Marston 2009).

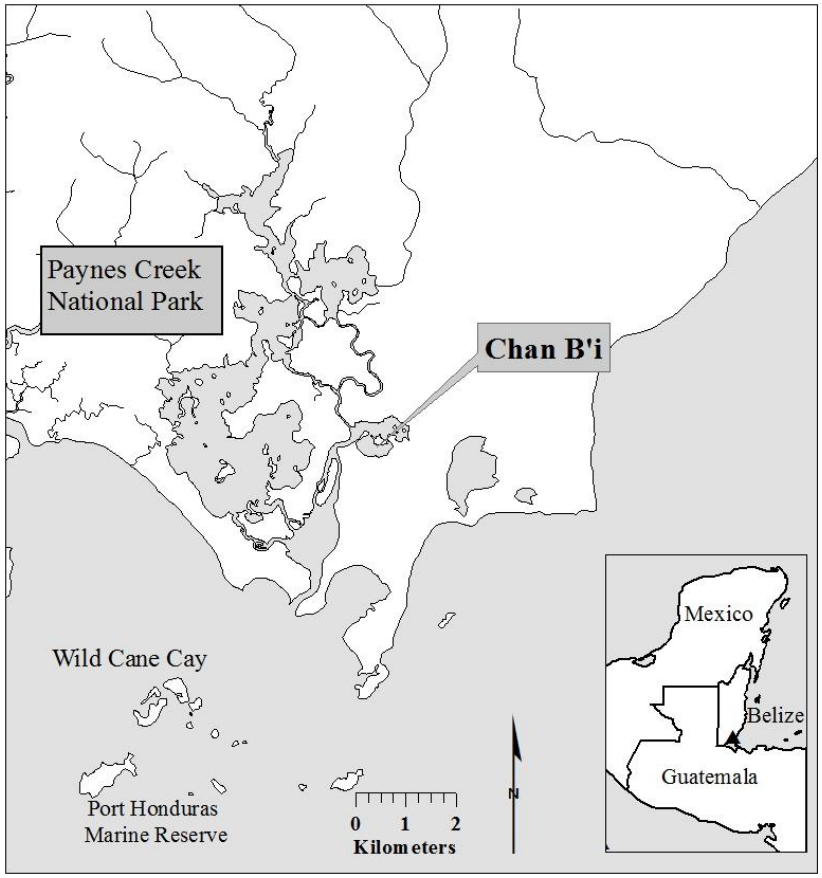

Figure 3.1 Map of the study area

Charred wood remains have been documented by archaeological investigations across the Maya lowlands (See Lentz 1999, Table 1 for a review, and Lentz et al. 2012 for a recent inventory of plant remains from a single site). Lentz (1999) compiled the documented occurrences of taxonomically identified wood and charcoal remains at Maya sites, noting proposed usage, including combustion. Morehart (2011) notes two potential problems with classifying charred plant remains as wood fuel: First, charcoal fragments often are recovered from secondary contexts, such as construction fill, so the charcoal lacks data on primary use. Secondly, wood charcoal from economic species may reflect dietary use rather than combustion. Paleobotanical studies in the Maya area have concentrated on documenting the presence of economic and subsistence species, rather than understanding ancient fuel.

Paleobotanical work on wood fuel use in the Maya area has focused primarily on the use of pine (*Pinus* sp.) in combustion. The ubiquitous distribution of pine in caves throughout Belize has demonstrated the importance of pine for combustion in ritual contexts (Morehart 2011; Morehart et al. 2005). The presence of pine charcoal in domestic contexts has revealed social divisions and differential access to resources. Morehart and Helmke (2008) note differential access to pine resources between Pook's Hill and Chan Nóohol in the upper Belize Valley, arguing for socially contingent consumption patterns based on the socio-economic landscape. Pine is a non-local resource in the ecosystems around both sites, yet 96% of total charcoal weight from Pook's Hill can be attributed to pine, whereas less than one percent of the assemblage is identified as pine at Chan Nóohol. As a medium sized center, Pook's Hill had access to exchange networks for exotic goods including pine. Chan Nóohol, a small self-sustaining community with limited access to exchange networks, was reliant on local wood collection. The heterogeneity in assemblages is further interpreted to give insight into the organization of household labor, including questioning traditional views of the gendered division of labor (Morehart and Helmke 2008).

3.2 Ecological Context

Chan B'i is one of the salt works located in a shallow, micro-tidal lagoon, in Paynes Creek National Park, in coastal southern Belize (McKillop 2005a; Figure 3.1). The climate is defined by a wet and dry season with an average rainfall of over 300cm. Sea-level rise and subsidence have inundated the salt works under 40-80cm of water. Inundation and a mangrove peat substrate protect the site from disturbance and create an anaerobic environment that is favorable to the preservation of buried organic artifacts.

High salinity and coastal geomorphologic processes dictate ecosystem distribution (Figure 3.2). Salt tolerant mangroves comprise the majority of the vegetative environment. Analysis of sediment cores from the lagoon confirms the dominance of the mangrove ecosystem throughout the Holocene (McKillop et al. 2010a, 2010b). *Rhizophora mangle* (red mangrove) is the principle species present, often forming a homogenous monotypic landscape. Small numbers of *Avicennia germinans* (black mangrove) and *Laguncularia racemosa* (white mangrove) grow behind the *R. mangle* fringe where environmental conditions favor the adaptations of these species.

Where edaphic conditions allow, monotypic stands of palmetto palm (*Acoelorrhaphe wrightii*), and patches of broadleaf forest occur. Savanna environments are present on the coastal plain within 3km of the salt workshop. The savanna is composed of large open grasslands and stands of *Pinus caribaea*. Other tree species on the savanna include oak (*Quercus olioedes*), crabboe (*Byrsonima crassifolia*), and sandpaper tree (*Curtella americana*), although the presence of these taxa is limited and in a scattered distribution. Broadleaf patches in the region are geographically limited. When present, they are characterised by an association dominated by nargusta (*Terminalia amazonia*), Santa Maria (*Calophyllum brasiliense*), yemeri (*Vochysia hondurensis*), and waika chewstick (*Symphonia globulifera*; Standley and Record 1936). Other tropical tree species are also present in the broadleaf patches (see Standley and Record 1936; Wright et al. 1959).

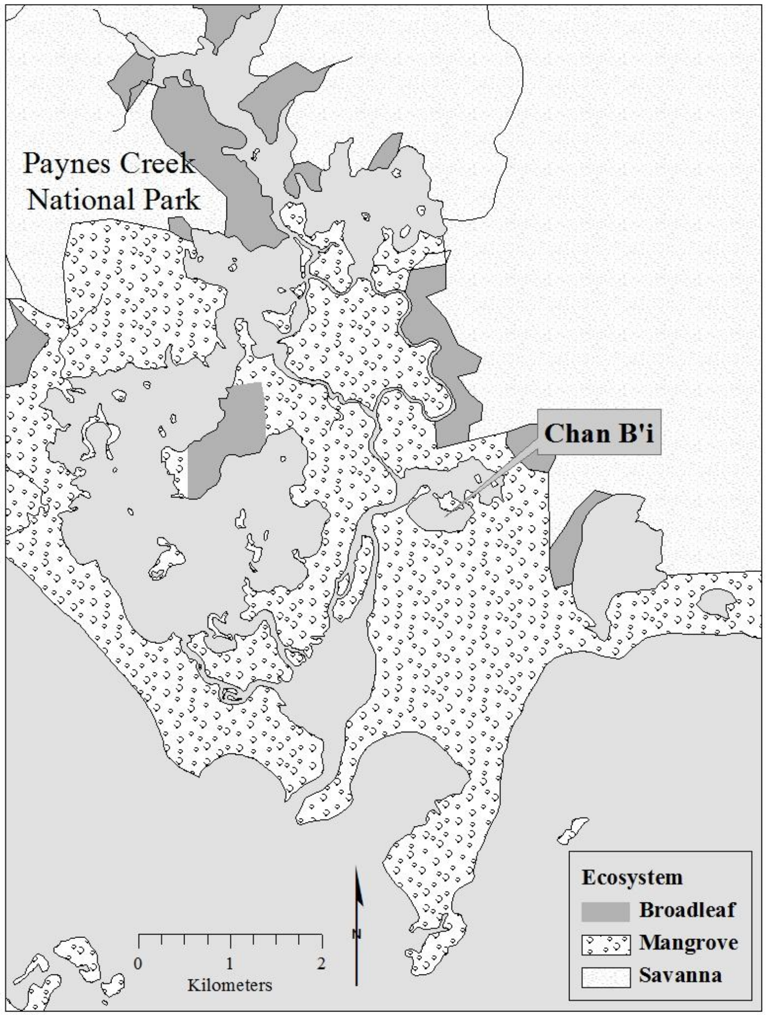

Figure 3.2 Map of broad ecosystem classifications in Paynes Creek National Park

3.4 Archaeological Context

Current archaeological evidence suggests southern Belize was occupied by small inland farming and coastal fishing communities until the end of the Late Preclassic when larger centers were established inland (Prufer et al. 2011), and coastal trade developed (McKillop 2005b). Expanding populations created a demand for resources beyond the level of household production. As a basic dietary need, the rising demand for salt provided the impetus for the establishment of the Paynes Creek salt works. Archaeological research in the lagoon system has identified salt works radiocarbon dated from the Early Classic (A.D. 300 – 600) to the Late Classic (A.D. 600 – 900; McKillop 2002, 2005a, 2007), mirroring the regional population dynamics. The abandonment of the inland urban centers resulted in a decline in demand for salt, leading to the abandonment of the salt works in the Terminal Classic. Chan B’i, a salt production workshop radiocarbon dated to the Early Classic, defined by a discreet distribution of artifacts, is located in the eastern arm of Punta Ycacos lagoon in Paynes Creek National Park (Figure 3.1). The immediate landscape is dominated by *R. mangle*. Occasional *L. racemosa* and *A. germinans* are present behind the *R. mangle* fringe. Inland from the open lagoon, patches of *A. wrightii* are visible. Emergent *C. brasiliense* and *T. amazonia* are evident in distant broadleaf patches, behind dense mangrove and palmetto stands.

3.5 Salt Production

Analysis of the artifacts from the Payne Creek salt works identifies high standardization and low variability in the ceramic assemblage, suggesting the sites were solely workshops and did not serve a domestic function (McKillop 2002). Workshops are characterized by a distinct artifact assemblage representing the tools of the trade and debitage from the production process. Pottery cylinders, spacers, and sockets, in abundance at the site, are distinctive apparatuses used in salt production (collectively known as briquetage). Ceramic vessels filled with brine are supported on solid clay cylinders above a fire, with the heat evaporating the fluid component and leaving the salt behind for collection. The process requires a constant supply of fuel to maintain the fires.

Salt production by evaporation in vessels over fire has been documented across the globe, with fuel an important factor in the management and successful functioning of the industry (Ewald 1985). In sixteenth century China, Adshead (1992) documents an energy crisis associated with salt production, with a scarcity of wood for fuel. Wood became a trade good that the salt industry had to procure to maintain production. The industrial production of salt in England was dependent upon coal, requiring mechanisms for access and exchange. The salt industry in Bengal was located close to large woodlands to ensure a supply of fuel (Barui 1985). Despite the importance and reliance on fuel, little attention has been paid to the fuel resources themselves. As such, there is a lack of information on specific woods utilized, forest management, and ecological adaptations in fuel procurement.

3.6 Methods

Charcoal was recovered from underwater excavations at Chan B'i associated with briquetage. Charcoal was separated from other excavated materials in the excavation screen and exported under permit from the Belize government, for identification at Louisiana State University. All encountered charcoal was collected. Charcoal samples were identified through the analysis of anatomical features along three planes of view (transverse, tangential, and radial), using standard methods (Figueiral and Mosbrugger 2000). All three planes were analyzed to increase identification accuracy. Features identified include the presence, form, and arrangement of vessels, rays, and parenchyma. The archaeological samples were compared to the modern reference collection at the USDA Forest Products Laboratory, Madison, Wisconsin, the authors' region specific comparative collection, and published wood atlases and databases (Insidewood; Detienne and Jacquet 1983; Uribe 1988). Each charcoal sample was fractured along the three planes and viewed under a reflected light microscope at various magnifications (50x to 200x). For higher resolution, samples were imaged using a Scanning Electron Microscope (SEM). All samples were weighed individually to provide both fragment count and weight for each identified taxon. Growth habitats for identified taxa were identified.

Specific gravity (SG) measurements compiled from published literature for each identified taxon were employed as a quantitative value of wood density to assess whether the functional characteristics of the wood was an important factor in wood selection. SG is unitless, measured as green weight/oven dry weight divided by fresh volume (Muller-Landau 2004; Williamson and Wiemann 2010). SG is a measure of the structural material allocated to support and strength (Williamson and Wiemann 2010).

3.7 Results

Taxonomic identification was attempted on all charcoal fragments >1mm collected during excavation. A total of 310 charcoal fragments, weighing 120.85g was recovered from the excavations at Chan B'i (Figure 3.3; Table 3.1). One hundred ninety-one fragments, representing 21 taxa were identified. Taxonomic counts represent Number of Identified Specimens. An additional indeterminate category in the Chan B'i sample represents samples that could not be identified (n=119, 22.12g weight). A directly proportional relationship exists between fragment count and weight for the identified taxa (Figure 3.4; $R^2 = 0.7169$). Researchers have demonstrated that there is little difference in fragmentation and mass reduction among species (Asouti and Austin 2005). As such, the proportions of each taxa in the charcoal assemblage can be assumed to reflect the proportions of each taxa used as fuel. A single sample of pine weighing 10.42g provides an anomalous result; however, the pine fragment is large and not fully combusted and may not have been fuel. The 119 indeterminate samples are mostly <2mm in size and either too small to identify, or too degraded to analyze wood structure. Based on the sample size and sampling strategy (all fragments collected and analyzed), the indeterminate samples are expected to match the proportions of identified samples. Of course, certain types of wood functions may be underrepresented, such as wood used as kindling, which is unlikely to leave any remains due to complete combustion.

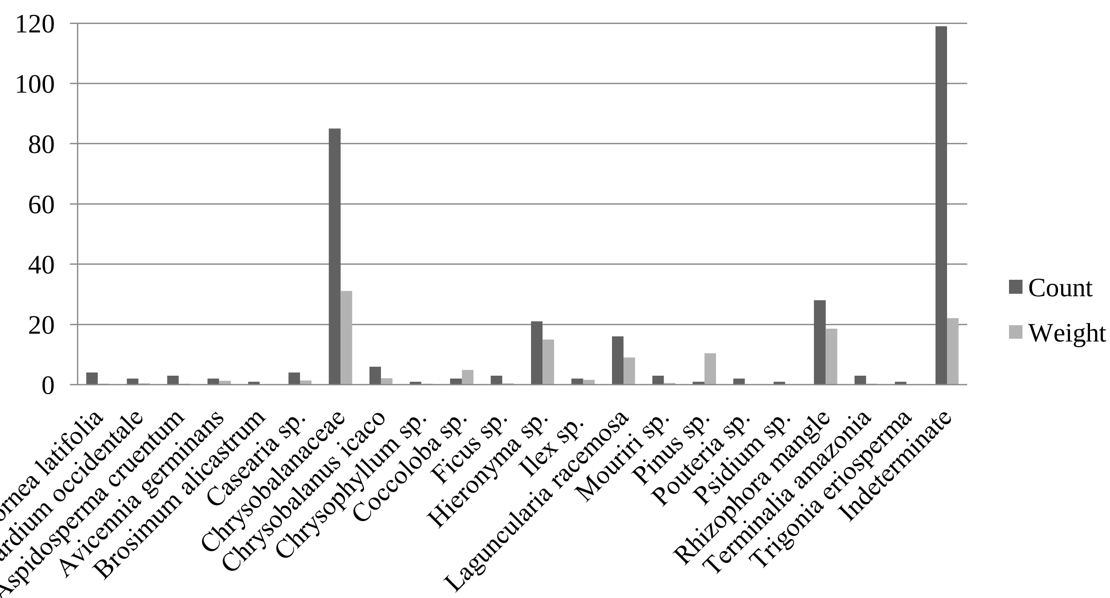

Figure 3.3 Charcoal Identifications from Chan B'i

Table 3.1 Charcoal identifications from Chan B'i
(Specific gravity values from, Little and Wadesworth 1964; Malavassi 1992; Reyes et al. 1992).

Family	Taxa	Common Name	Count	Weight (g)	SG
Mangrove Habitat					
Verbenaceae	*Avicennia germinans*	black mangrove	2	1.28	0.90
Chrysobalanaceae	*Chrysobalanus icaco*	coco plum	6	2.18	0.80
Combretaceae	*Laguncularia racemosa*	white mangrove	16	8.99	0.60
Polygonaceae	*Coccoloba* sp.	sea grape	2	4.90	0.80
Rhizophoraceae	*Rhizophora mangle*	red mangrove	28	18.55	0.84
Broadleaf Habitat					
Euphorbiaceae	*Alchornea latifolia*	fiddlewood	4	0.37	0.40
Anacardiaceae	*Anacardium occidentale*	cashew	2	0.41	0.50
Apocynaceae	*Aspidosperma cruentum*	mylady	3	0.28	0.75
Moraceae	*Brosimum alicastrum*	breadnut	1	0.12	0.44
Flacourtiaceae	*Casearia* sp.	billy hop	4	1.44	0.66
Chrysobalanaceae	-	pigeon plum	85	31.13	0.90
Sapotaceae	*Chrysophyllum* sp.	chike	1	0.30	0.90
Moraceae	*Ficus* sp.	fig	3	0.48	0.40
Euphorbiaceae	*Hieronyma* sp.	red wood	21	15.00	0.63
Aquifoliaceae	*Ilex* sp.	birdberry	2	1.60	0.77
Melastomataceae	*Mouriri* sp.	cacho de venado	3	0.59	0.90
Sapotaceae	*Pouteria* sp.	mamee	2	0.17	0.81
Combretaceae	*Terminalia amazonia*	nargusta	3	0.33	0.68
Trigoniaceae	*Trigonia eriosperma*	-	1	0.02	0.64
Savanna Habitat					
Pinaceae	*Pinus* sp.	pine	1	10.42	0.63
Myrtaceae	*Psidium* sp.	guava	1	0.17	0.63
	Indeterminate		119	22.12	
		Total	310	120.85	

3.7.1 Exploited Ecosystems

Three broad ecosystems can be identified in the area with distinct flora composition: mangrove, broadleaf, and savanna. Table 3.1 and Figure 3.5 show the proportion of taxa by habitat of growth. There is an overlap in growth habitats for some species which are adapted to multiple ecological conditions. Ecosystems are also rarely defined by rigid boundaries, with transition zones between ecosystems and isolated pockets containing a mixture of species. For this discussion, species are assigned to an ecosystem of growth based on growth habits, field observations, documented voucher specimens, and optimal foraging, in which the closest ecosystem is assigned as the most efficient option. Although the savanna covers an extensive geographic area and is easily accessible by waterways, the savanna is the farthest habitat from the study site (see Figure 3.2). As such, species that grow in both mangrove and savanna ecosystems (*Chrysobalanus icaco* and *Coccoloba* sp., both of which have been identified in the local mangrove communities) are assigned to the mangrove ecosystem. Likewise, although broadleaf patches are scattered, they are in closer proximity to Chan B'i than the savanna and are complex systems, densely packed with a multitude of vegetative species, making them an important resource location.

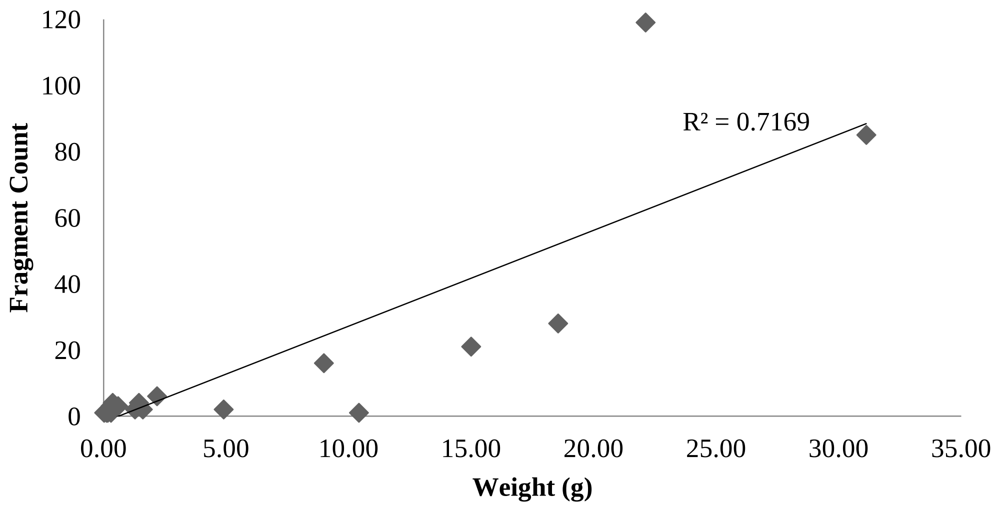

Figure 3.4 Relationship between charcoal weight and fragment count

Of the 191 samples identified, 24% (5 taxa) are from mangrove habitats, 67% (14 taxa) are from broadleaf habitats, and 9% (2 taxa) are from the savanna (Table 3.2). Of the identified samples, mangrove habitats account for 28% of the count and 36% of the weight. Broadleaf species represent 71% of the total identified count and 53% of the weight. Savanna taxa account for 1% of the count and 11% of the weight. The single large piece of partly burned pine skews the results to overemphasize the weight of savanna species.

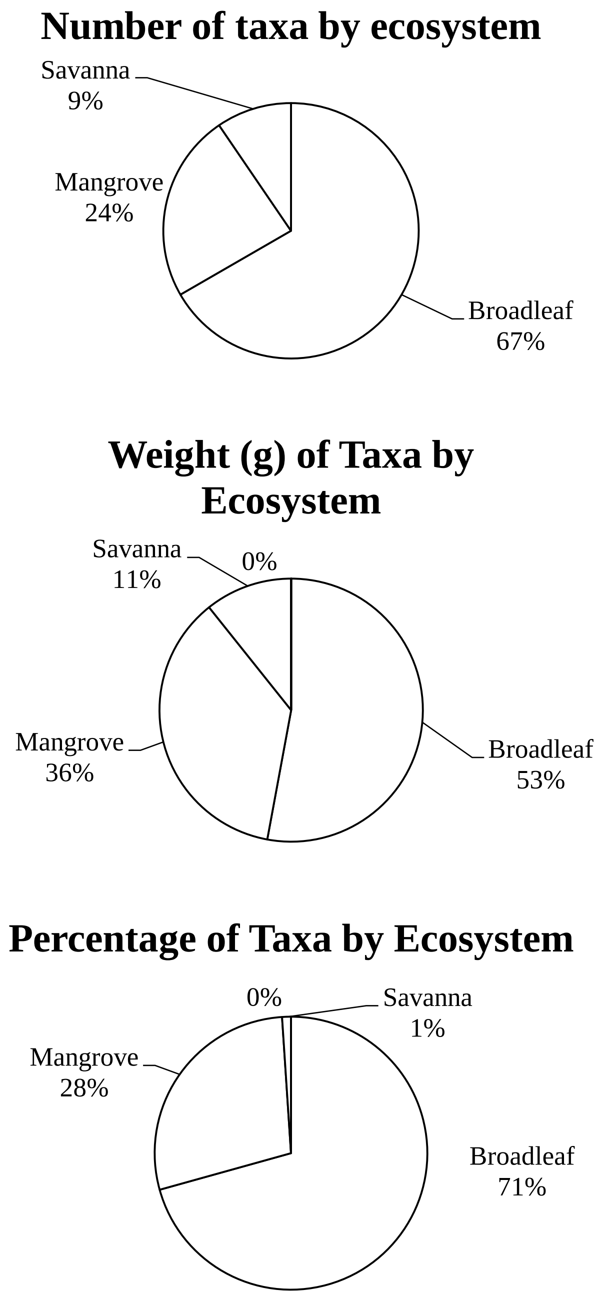

Figure 3.5 Species distribution by habitat of growth

3.7.2 Exploited Taxa

Four taxa stand out in the assemblage for both counts and weights, namely, *L. racemosa* (n=16, 8.99g; Figure 3.6e,f), *Hieronyma* sp. (n=21, 15g; Figure 3.6g,h,i), *R. mangle* (n=28, 18.55g; Figure 3.6c,d), and the dominant Chrysobalanaceae (n=85, 31.13g; Figure 3.6a,b). Fourteen of the identified taxa have three instances or less. *Alchornea latifolia* and *Casearia* sp. appear four times, whereas *Chrysobalanus icaco* has six occurrences.

R. mangle, *L. racemosa*, and *A. germinans* (n=1) are the three New World mangrove species, adapted to saline conditions and present throughout brackish water in Belize. *R. mangle* dominates the landscape, but suffers from stunted growth locally, reducing its usefulness for other functions, such as in architecture. *L. racemosa* and *A. germinans* are less common than *R. mangle*, but grow with straight trunks and produce hard, strong wood (Standley and Record 1936).

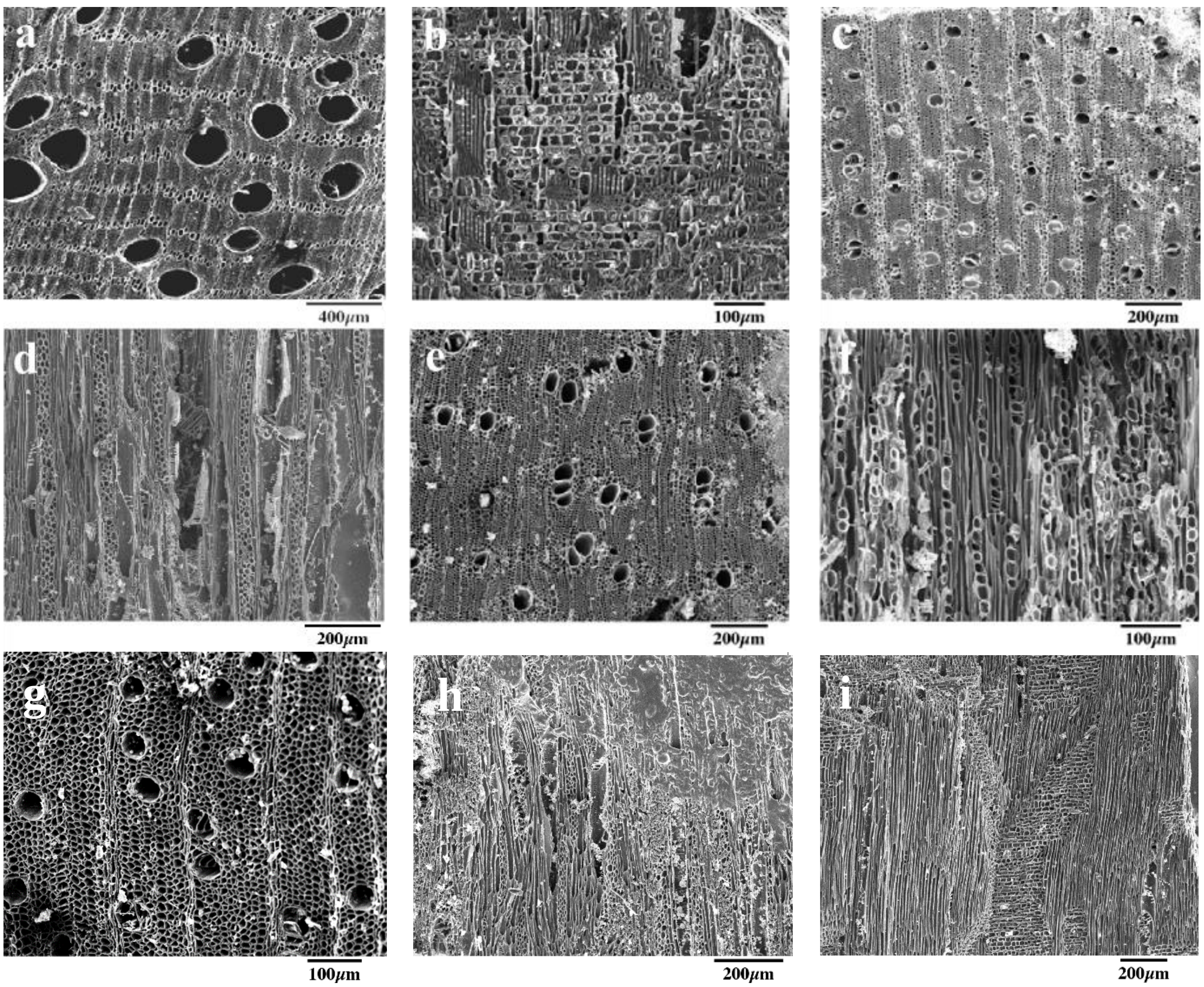

Figure 3.6 Scanning Electron Micrographs of archaeological charcoal: (a) Chrysobalanaceae, transverse section; (b) Chrysobalanaceae, radial section; (c) *Rhizophora mangle*, transverse section; (d) *R. mangle*, tangential section; (e) *Laguncularia racemosa*, transverse section; (f) *L. racemosa*, tangential section; (g) *Hieronyma* sp., transverse section; (h) *Hieronyma* sp., tangential section; (i) *Hieronyma* sp., radial section;

The samples identified as Chrysobalanaceae (Figure 3.6a,b) have a wood structure that has thin banded parenchyma and uniseriate rays, and are either *Licania* sp. or *Hirtella* sp. Worldwide, Chrysobalanaceae consists of seventeen genera and over 450 species, with four genera and nine species identified in modern Belize (Balick et al. 2000). Four species of *Hirtella* and three species of *Licania* are present in modern Belize (Balick et al. 2000). The anatomical structure in the samples does not allow differentiation among the genera. Species within both genera are commonly called pigeon plum (Balick et al. 2000), suggesting they may not have been separated in folk classification systems and therefore when assessing selection behavior a Linnaean taxonomic distinction may not be applicable. *Chrysobalanus icaco* (coco plum) is an evergreen shrub or bushy tree that is adapted to saline conditions and found close to coastal waters. *C. icaco,* a member of the Chrysobalanaceae family, shares anatomical traits with other species in the family; however, the parenchyma formation distinguishes *C. icaco* from other members of the family.

Two species of *Hieronyma* are present in modern Belize: *Hieronyma alchorneoides* and *Hieronyma oblonga*. The wood structure of trees in the genus is distinctive for its tall multiseriate rays, solitary vessels, and lack of axial parenchyma. The frequent presence of scalariform plates and small vessel size (50-100µm), suggests the samples may be predominately *H. oblonga*. Overlap in anatomical variability between the two species and in the archaeological samples negates classification beyond the genus level. *Hieronyma* sp. is hard and durable, although the species is not widely utilized in Belize (Balick et al. 2000; Standley and Record 1936). Elsewhere, the genus is valued for its quick growth in secondary forests and functional suitability for construction, and as such has been forwarded as a sustainable timber (Carnevale and Montagnini 2002; Montagnini and Mendelsohn 1997).

Casearia sp. is one of the most common shrubs in Central America, especially in thickets and secondary growth forests. With a hard and heavy trunk, *Casearia* sp. is commonly used across Mesoamerica for functions including fuel, timber, and medicine (Breedlove and Laughlin 2000; Roys 1931; Standley and Record 1936). *Alchornea latifolia* is a common tree growing to 15m with a hard, heavy wood. The three fragments of *Terminalia amazonia* are the only samples that match the flora association that characterizes the primary local broadleaf stands (Standley and Record 1936). The savanna is not well represented in the charcoal record. Aside from the single, large piece of partly burned pine, a single sample of *Psidium* sp. is the only other species designated as from the savanna ecosystem.

Specific gravity values for the identified taxa produce a range of 0.4 to 0.9 (the higher the value the denser the wood), with a mean SG and median SG of 0.69. The mean SG of the four most represented taxa (Chrysobalanaceae, *R. mangle*, *Hieronyma* sp., and *L. racemosa*) is 0.74, whereas the average SG of the taxa with only one occurrence is 0.65.

3.8 Discussion

What guided wood fuel selection at the salt works? Were specific trees sought for their physical properties, or was distance to the resource and procurement costs the guiding factor? Resource acquisition entails a choice, which results in the rejection of alternative options. The low representation of savanna species is a telling feature of the fuel charcoal assemblage. The exclusion of one habitat as a source for resources in a heterogeneous landscape highlights the role of choice by foragers and alludes to aspects of environmental knowledge, to knowledge of the properties of different woods, as well as to principles guiding resource exploitation and the economic demands of craft production.

The savanna constitutes a large area of the regional landscape, and although incorporating open grasslands, the savanna includes a number of woody species, including oak (*Quercus olioides*) and extensive stands of pine. At less than three kilometers from Chan B'i, the savanna is within range as a resource location. In fact, the distances travelled overland to obtain pine for use in combustion at inland ritual and domestic contexts put the salt works in an ideal location to access the highly valued resource. The resinous heartwood of pine makes it a prominent choice for combustion and ideal for torches and as kindling among the Maya (Atran and Ucan Ek' 1999; Breedlove and Laughlin 2000; Vogt 1969). Pine charcoal is found at ancient Maya sites tens of kilometers away from pine sources, in both domestic, prestige and ceremonial contexts (Lentz 1991; Lentz and Ramirez-Sosa 2002; Lentz et al. 2005; Morehart 2011; Morehart and Helmke 2008; Morehart et al. 2005; Wyatt 2008). Prufer and Dunham (2009) document pine remains in Bats'ub cave, Belize, and note the closest pine sources are some 30km distant. Likewise, the closest pine stands to Chan and Xunantunich in western Belize, where pine is documented archaeologically, are 17km away (Lentz et al. 2005; Wyatt 2008). Ethnographic reports also document the long distance procurement and exchange of pine for combustion in Mesoamerica; Maya *carboneros* from Cajola, Guatemala, transport pine charcoal 16km to the Quetzaltenango market (Lentz et al. 2005).

Pine is the dominant woody species growing on the savanna, with extensive monotypic stands. As such, a foraging venture can guarantee the successful acquisition of pine. Despite its rapid growth and production of a large mass of wood, pine also burns quickly, producing copious amounts of smoke and generating a pungent aroma. For the salt production industry, which required continued heating of vessels for evaporating saline solution, a slower burning wood that produced a steady heat was preferable (although pine would have been an ideal wood as kindling). The aromatic aspect of pine may have been undesirable when producing salt for ingestion, and smoke generation, a desirable trait in ritual, was disagreeable in a workshop, especially if the production occurred under a roofed structure as the evidence currently suggests for the salt works of Paynes Creek (McKillop 2005a).

Due to the sparse distribution of non-pine resources, successful expeditions to forage for other woody resources on the savanna were less guaranteed and may have required extended periods of searching and excursions farther inland. Principles of optimal foraging state that resources should be sought that exhibit the least costs for the greatest benefits. Two key costs are search time and distance of transport. When comparing resource choices, a resource that fulfills the desired function and incorporates fewer costs in processing should be selected. Foragers also maximize efficiency by selecting a patch with a greater chance of success (Brown 1988; Kennett and Winterhalder 2006; MacArthur and Pianka 1966; Marston 2009; Stephens and Krebs 1986). The greater distance to the savanna than to mangrove or broadleaf patches, alongside the sparsely distributed non-pine vegetation on the savanna made the savanna a less efficient foraging patch than alternative options.

The relative proportion of mangrove species (*R. mangle* and *L. racemosa*) in the charcoal assemblage demonstrates the utilization of flora in the immediate environment of Chan B'i and adheres to principles of optimal foraging. The ecological and economic benefits of mangroves have been discussed globally, although ethnographic documentation of mangrove utilization in

Central America is limited (see Kovacs 1999). Balick et al. (2000) note the use of *R. mangle* and *L. racemosa* in modern Belize for fuel wood, construction, medicine and dyes. Kovacs' (1999) study of mangrove use in Nayarit, Mexico, documents the importance of mangrove species in fulfilling fuel needs. *L. racemosa* is preferable for fuel wood, and although utilized for fuel, *R. mangle* is not favored due to the difficulty in cutting the dense wood. The straight trunk of *L. racemosa* and a resistance to rot when wet, makes the species the popular local choice for construction (Kovacs 1999). In Sulawesi, Indonesia, *Rhizophora* spp. is an important source of fuel wood, favored over other forest resources due to its high, even burning temperature and low smoke generation (Weinstock 1994). Sin (1990) documents the popularity of mangrove species, and in particular, *Rhizophora*, for use as firewood due to its combustion properties, and also notes the use of mangrove charcoal as a fuel source in Kampuchea. Both functional properties and accessibility make mangrove species ideal as fuel resources. The dominance of *R. mangle* in proximity to Chan B'i guarantees successful foraging opportunities for fuel wood in the surrounding mangrove habitat until all mangroves are exploited and the landscape is deforested. However, the limited use of *R. mangle* for construction, due to its stunted growth, required foraging outside of the mangrove ecosystem for suitable wood to fulfill all wood needs.

As foraging distance increases from the site, broadleaf patches become available which encompass an abundance of viable forest resources for construction and fuel. Broadleaf patches provide a number of benefits as a resource location. The abundance of woody stems, fast regrowth, and a greater amount of deadwood generation provides a large quantity of potential fuel wood. Perhaps more importantly, the branches and leftover wood after processing a tree for use in construction can serve as fuel. The low frequency and weight of many of the taxa identified in the charcoal assemblage from Chan B'i (including twelve from broadleaf ecosystems) suggest that the low frequency taxa were not specifically sought, but taken opportunistically, perhaps as dead wood or as off cuts from construction posts. As a patch choice, broadleaf habitats are an efficient option in which foraging efforts can be maximized as part of an integrated resource exploitation strategy.

Importantly, most of the broadleaf species are characteristic of secondary forests (including Chrysobalanaceae and *Hieronyma* sp.), with only *Pouteria* sp. and *Terminalia amazonia* distinctive of primary forest. Three principle factors could explain the high presence of secondary species and low frequency of primary species in the charcoal record. The small broadleaf stands are subject to edge effects in which light regime, access to pollen, and weather impacts are different from those of a closed forest (Laurance 1991; Murcia 1995). These conditions favor fast growing secondary and pioneer species. Modern forest composition confirms the establishment of primary species within the small broadleaf stands, implying that if natural processes of succession were not interrupted, these species would have been available in antiquity. Alternatively, overexploitation of the forest resources may have decimated the primary species making them unavailable and starting processes of secondary succession, in which case, anthropogenic impacts on forest composition dictated resource availability. One further possibility is that foragers may have targeted secondary species, even selectively managing the forest to promote growth of certain taxa (such as Chrysobalanaceae) and perhaps reserving the primary species for more appropriate functions, such as construction. A combination of factors is likely to be in effect in which selection preference and management practices determined wood selection and influenced succession in the small broadleaf patches.

Even though 21 taxa are represented in the charcoal record, the uneven distribution of taxa imply a strong selection preference within the assemblage, suggesting a cognitive framework was applied to foraging and wood selection in which distance to resource was not the only factor considered. SG values correlate with a preference for denser woods. Reported SG measurements from tropical forests show a greater range of SG than the archaeological charcoal from Paynes Creek. For example, the research of Wiemann and Williamson (2002) report a range of 0.24 to 0.87, with a mean SG of 0.55, from a forest in the central Petén, Guatemala. Two forests in Costa Rica, Santa Rosa National Park and La Selva Biological Station, display a minimum SG of ~0.15, a maximum SG of 0.96, and a mean of ~0.55. Similarly, the Los Tuxtlas Biological Station, Mexico, shows a mean SG of 0.55, a minimum SG of 0.16, and a maximum SG of 0.94. The identified wood taxa used as charcoal at the Chan B'i salt workshop show a higher mean SG value (0.69) and a distinct lack of the lowest density trees (i.e. none lower than 0.4). The four preferred taxa are of above average density (mean = 0.74), with Chrysobalanaceae displaying one of the highest SG values (0.9). The taxa that appear only once (suggesting low selection preference) show a mean SG of 0.65. Although there is little correlation between the presence of a species (frequency or weight) and SG ($R^2 = 0.0987$ for weight, and $R^2 = 0.0944$ for frequency), the overall pattern of selection does suggest the utilization of higher density woods, which are likely to produce a high, constant heat over a longer period that would be preferable to maintain fires for the salt production industry.

3.9 Conclusion

The procurement of fuel was integral for salt production in Paynes Creek. The mangrove ecosystem was a key foraging habitat for wood fuel, providing low transport costs. *R. mangle*, dominant on the immediate landscape, was an important fuel source as was the less common *L. racemosa*. However, the lack of straight trunks in the stunted *R. mangle* dominated landscape resulted in a need to also forage in broadleaf stands. The greater abundance of potential resources in broadleaf patches affords an efficient patch choice and was likely exploited as part of an integrated wood management practice that targeted forest products including construction wood and fuel, and likely extending to food and fibers.

Charcoal samples identified to Chrysobalanaceae, representing *Licania* sp. or *Hirtella* sp., were favored for fuel at the salt works, accounting for 46% of the identified assemblage. The preference for Chrysobalanaceae, a broadleaf taxon, was likely due in part to availability and fast regrowth, but also due to its high structural density, which would have created long burning fires with a high, steady heat. The charcoal record also shows specific selection preference for *Hieronyma* sp., another fast growing secondary broadleaf species. Other broadleaf species make up the bulk of the remaining charcoal. However, the low frequency of these species suggests they were collected opportunistically, perhaps when found as deadwood on a foraging expedition.

The broadleaf species identified in the charcoal record are characteristic of secondary growth forest suggesting anthropogenic disturbance to forest composition had occurred by the Classic period or a selection practice that targeted the fast growing pioneer species, perhaps incorporating forest management practices to promote the growth of specific species, and reserved the large primary species for alternative functions.

Despite the closeness of the savanna and the high cultural value attached to pine, the savanna was not foraged for fuel. More efficient options were available and the physical properties of pine, the most abundant species on the savanna, although highly desirable for ritual, are disadvantageous in a workshop. The charcoal assemblage, and in particular the frequency of species from mangrove habitats, indicates that the salt works were self-sufficient in wood acquisition and did not import wood through trade.

Archaeological charred fuel wood remains are the product of purposeful human action and are therefore a record of culturally and environmentally bounded decision-making. The results show a high degree of specific selection for resources with conscious decision-making characterizing fuel procurement, which follows principles of optimal foraging. Availability, low procurement costs, wood properties, species preference, and an integrated collection practice suggest a resource management practice based on optimal foraging for the ancient Maya of Paynes Creek.

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CHAPTER 4. TEMPORAL WAVELENGTHS OF ANCIENT MAYA FOREST EXPLOITATION: THE GENERAL AND THE PARTICULAR OF WOOD FORAGING AT THE PAYNES CREEK SALT WORKS

Mark E. Robinson and Heather I. McKillop

4.1 Introduction

Recent decades of research have begun to address the dynamic interaction of human-environment relationships, dependencies, entanglement, and non-human agency, which are contingent on time and place (Butzer 2012; Hodder 2012; Hodder and Hutson 2003; Jones and Cloke 2002, 2008; Turner and Sabloff 2012). The opening chapter of Jones and Cloke's (2002), *Tree cultures: the place of trees and trees in their place*, provides an apt summary of the complex interrelationships between humans and nature:

> As a living complex of life-forms and processes, natural relations will always be embedded in, and thereby interact with and condition, human social relations to varying extents and in different ways in specific times and space (2002: 1-2).

The complexities of human-environment relationships and the processes and manifestations of these relationships through time and space creates a bewildering area of study in which the heterogeneity of each case study requires increasingly greater particularization to accommodate specific details and provide accurate description and discussion (see Culbert 1973; Turner and Sabloff 2012, for discussion on heterogeneity of ancient Maya collapse, and Maxwell 2011 for the application of the concept of fuelscapes). Archaeologists strive to find a way to derive meaning from the static archaeological record, developing methodologies and theoretical frameworks to test hypotheses that identify patterns of human behavior (Hodder and Hutson 2003). Researching fuel procurement and use in Rayanpata, in contemporary Andean Peru, Maxwell (2011:475) employs the term "fuelscape" to illuminate "the complex and layered dimensions of landscape production". Fuelscapes extend beyond simple aspects of supply, demand, scarcity and abundance, instead drawing from the range of socio-environmental factors reflecting legacies from the past in terms of emic material and symbolic conceptions of the landscape (Maxwell 2011). In particular, anthropogenic boundaries, property rights, wealth, status, gendered and intergenerational division of labor, and individual family histories guide fuel access and use. In the face of increasing attention to the way socio-environmental relationships are addressed, a reliance on individual narrative histories may seem the only way to recognize and accommodate individual expressions of human and non-human identity, adaptation, and resilience.

Although paying heed to the particulars of a specific context is important for developing an accurate picture of past phenomena and debunking simplistic causal explanations, the neglect of broader patterns prohibits comparison and a meaningful understanding of wider socio-environmental phenomena that broader frameworks facilitate. In a recent discussion of human-environment interaction, Turner and Sabloff (2012:13912), state that a "balance between the extremes of generalization and context is required". In this discussion, the insights of the

Annales School of French Structural History, and specifically the temporal framework of Fernand Braudel (1972), are drawn from to discuss the particular and the general in relation to wood selection by the Classic period Maya of Paynes Creek National Park in coastal southern Belize (Figure 4.1). Braudel's scheme addresses history in terms of three temporal wavelengths - *événement, conjoncture,* and the *longue durée* - reflecting short, medium, and long-term socio-environmental, political, and economic, phenomena, structures, and institutions. The short-term allows highly detailed discussion of individual contexts, whereas the medium and long-term allow the identification of repeated patterns and the processes and structures that guide history. The framework in modified form is applied here to taxonomic identifications of construction wood from an Early Classic (A.D. 300-600) salt work, Chan B'i, and a Late Classic (A.D. 600-900) salt work, Atz'aam Na (Figure 4.1), alongside charcoal identifications from Chan B'i. Braudel's temporal framework is utilized as a filter to understand the archaeological record and interpret patterns of human behavior, the scales of socio-environmental processes and structures that influence decision-making for wood resource selection and the formation of the archaeological record. Principles of optimal foraging, and in particular prey choice models, also are employed to aid the interpretation of the archaeological record.

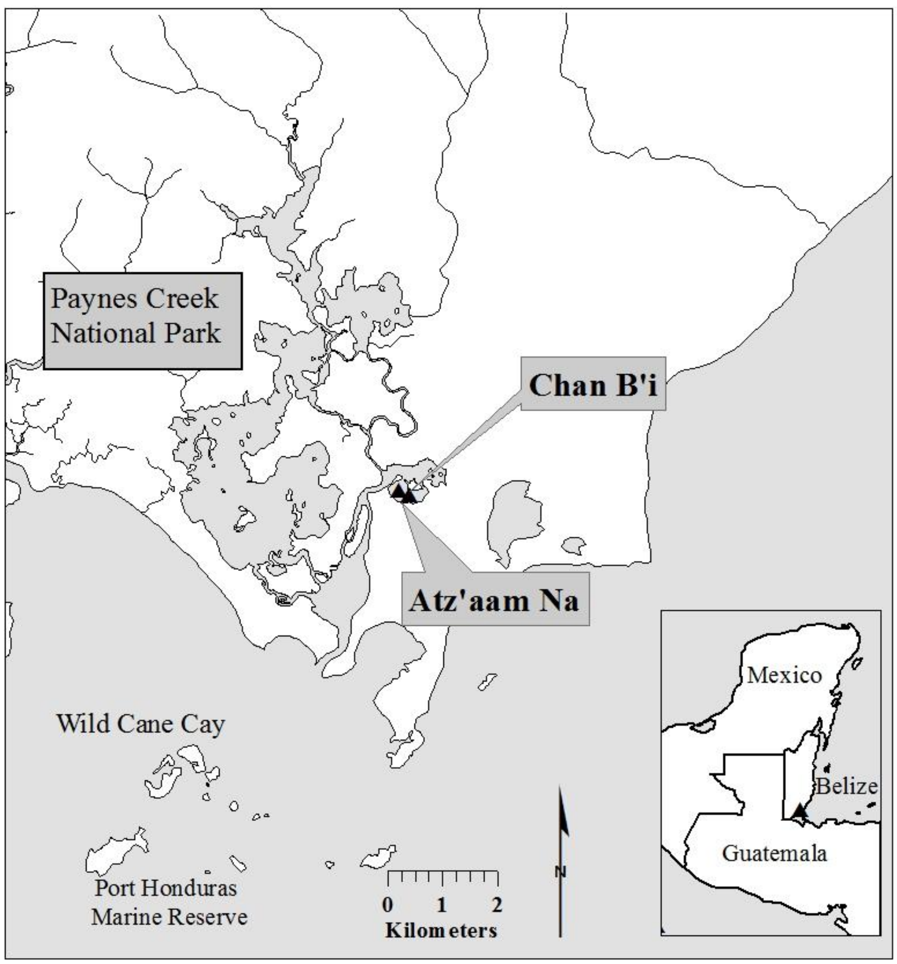

Figure 4.1 Map of study area

4.2 Theoretical Perspectives

Taking its name from the journal Annales d'histoire *économique et sociale*, founded in 1929 by Marc Bloch and Lucien Febvre, scholars of the Annales School of thought championed the idea of total history at a time when traditional histories, documenting specific narrative, politics, and accounts of individuals was the norm (see Bintliff 1991a, and Knapp 1992a for archaeological reviews). Instead, the Annales scholars took an interdisciplinary approach, drawing from history, geography, anthropology, and sociology, emphasizing socio-economic structures that guide and constrain culture to explain both the general and the particulars of cultural manifestation (Braudel 1972, 1980; Hodder 1987; Iannone 2002; Smith 1992). Perhaps the most enduring and influential legacy of the Annales is associated with Fernand Braudel, the leader of the second generation of the Annales school during the 1950s and 1960s, with his often cited, applied and critiqued concept of temporal rhythms that characterize social change (Braudel 1972; Bintliff 1991b; Fletcher 1992; Knapp 1992b).

At the core of Braudel's discussion are three levels of historical processes that operate at different temporal scales: events (*événement*), *conjoncture*, and the *longue durée*, equating with short-term socio-political events, medium-term socio-economic cycles, and long-term environmental structures respectively (Braudel 1972; Knapp 1992b). The three rhythms are causally interrelated, often in conflict, operating simultaneously, albeit at different "wavelengths" (Figure 4.2; Bintliff 1991b; Braudel 1972; Iannone 2002).

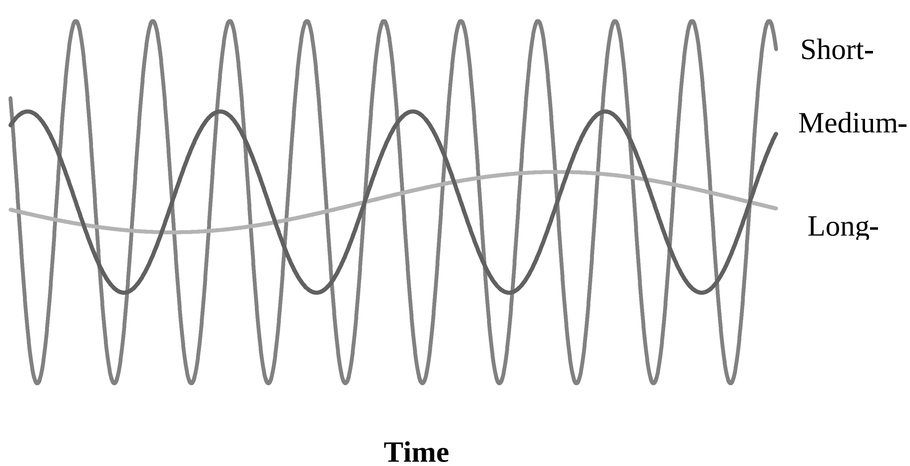

Figure 4.2 Simplified conceptual model of the three wavelengths operating simultaneously. The short-term is marked by high variability, high frequency, and low duration. The medium-term is less variable. The long-term is almost unchanging.

Events focus on "traditional history", dealing with a temporal span that records the actions and events within the life of an individual (Bintliff 1991b; Braudel 1972; Smith 1992).

The short-term events are the realm of politics and people, including battles, alliances, treaties, kings, and so forth (Braudel 1972; Hodder 1987; Smith 1992). Events are typically difficult to isolate in the archaeological record, especially for prehistoric cultures that lack written historic documentation; however, burials, caches, monument erection, hieroglyphic texts, and architectural phases can provide a glimpse of short-term events. Importantly, events break up medium-term patterns and as such are critical to understanding the process of socio-environmental change (Knapp 1992b).

Medium-term conjonctures are dynamic processes that typically operate over generations or the course of decades to centuries, embodied in socio-economic cycles that oscillate around a norm (Bintliff 1991b; Smith 1992). *Conjonctures* particularly focus on demographic and economic trends and cycles, such as price changes, population growth, and manufacturing production. Braudel further divided the medium-term into intermediate-term *conjonctures*, including rates of industrialization, wages, and wars; and long-term *conjonctures*, dealing with demographic movements and broader institutional changes (Braudel 1972; Smith 1992). Aspects of worldview and ideologies are also a feature of the medium-term, collectively known as *mentalities*, which grew in importance to Annales scholars after Braudel (Bintliff 1991b; Knapp 1992b).

The *longue dureé* examines the scale of geologic history and the slow changing, almost permanent structures that constrain society (Iannone 2002). The environment is the basic unit of analysis for the *longue durée*, but long standing cultural ideologies (*mentalities*) also are included (Smith 1992). Braudel and many of the Annales scholars emphasize the *longue durée* over the event, concluding that the long-term cultural and environmental structures ultimately determine the course of history. Importantly, although there is a hierarchical aspect to the temporal framework, the processes at each temporal rhythm are interrelated in a dynamic feedback relationship that drives cultural and environmental continuity and change.

Braudel's framework and in particular his own application of the temporal scheme have come under criticism from archaeologists (for discussion see Fletcher 1992). Arguments focus on Braudel's inability to demonstrate the interconnections between temporal scales, the little attention he paid to events, and an environmentally deterministic approach to the *longue durée* that also fails to account for complex change possible at this level (Fletcher 1992; Iannone 2002; Smith 1992). At a more fundamental level, concerns are raised regarding the lack of definition of the boundaries and processes at each temporal scale, and their appropriateness for archaeological study (Fletcher 1992; Smith 1992).

The criticism of the individual application of a framework should not negate the framework outright, but rather allow for discussion and development. Theoretical developments since Braudel have recognized to a greater extent the complexity of cultural and environmental systems (Butzer 1982), the agency of non-human entities (Gell 1998), and the non-linear relationship between structure and agent (see Hodder 2012 for a recent archaeological discussion on the complexity of culture). The core insights of the Annales School, including interdisciplinary study and the discussion of the particular and the general remain poignant, and despite the criticisms of Braudel's temporal scheme, scales of time and culture change remain key aspects of archaeological inquiry, with archaeologists offering revisions and alternatives to

Braudel's scheme (Bailey 1981, 1983, 2008; Butzer 1982; Hodder 1987; Iannone 2002; Smith 1992).

Butzer (1982) also discusses the dynamics of culture change and continuity in terms of three temporal scales, which he terms adaptations; adaptive adjustments, adaptive modifications, and adaptive transformations, representing short, medium, and long-term cultural and environmental fluctuations around a state of equilibrium. The event is not isolated in the scheme, but incorporated under adaptive adjustments alongside short-term and medium-term oscillations that do not involve permanent or long-term equilibrium shifts. Adaptive modifications mark "discontinuities in equilibrium levels or long-term directional trends" (Butzer 1982:288), equating with Braudel's long-term *conjonctures* and a variable form of the *longue durée* (Smith 1992:25). The phenomena of Butzer's adaptive transformations, which incorporate the development of "radically new adaptive modes" with global repercussions (Butzer 1982:289), are absent from Braudel's scheme.

The processes and manifestations of each temporal scale can be understood in terms of variability and conflict around a state of equilibrium. Social and environmental institutions bind and guide decisions that characterize the equilibrium state; however, the complexities of culture and the environment results in deviations from the norm. Socio-environmental processes and institutions act to maintain balance and stability within a system (Butzer 1982). In a steady-state system, variability has no lasting impact on the structure. In a dynamic system, thresholds can be reached that create fundamental changes to the equilibrium state (Butzer 1982). Change to a system can be slow or rapid. The accumulation of deviations and response can cause gradual change, or alternatively, rapid high-impact events (such as natural disasters) can cause immediate irreversible change. An abstracted visual representation of change and adaption is portrayed in Figure 4.3. In this example, socio-environmental variability oscillates around an equilibrium. Accumulated changes over time result in a shift in socio-environmental variability around a new equilibrium. For example, wood exploitation within a forest patch can result in a change in stand composition. Wood selection behavior adapts to the changing environmental availability. Butzer's (1982) model provides a more intricate understanding of the environment, feedback mechanisms and the nature and types of change than Braudel's initial scheme (Smith 1992).

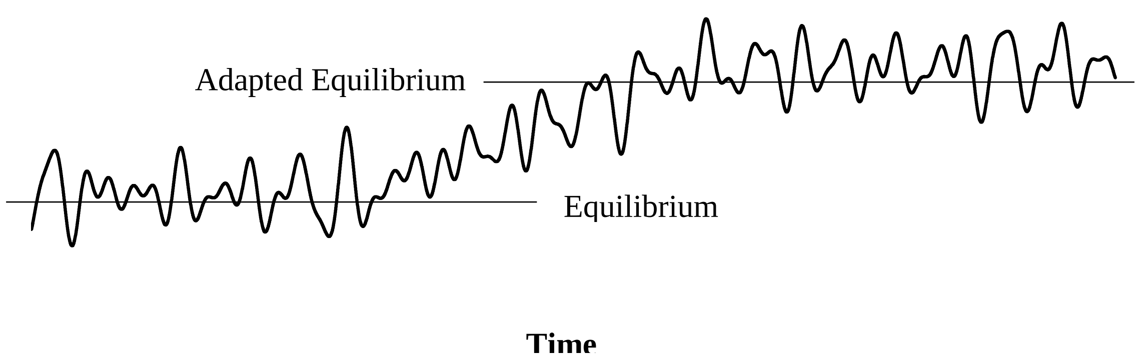

Figure 4.3 Conceptual model showing variability around an equilibrium. Once a threshold is passed, new adaptive strategies characterize the new equilibrium.

A framework flexible enough to be applicable to multiple contexts while providing an analytical tool to answer problem orientated questions and facilitate comparison and discussion can be a powerful device. Individual context, temporal changes in the agency of a phenomena, and complex multi-causal processes make the isolation of the processes and scale of change difficult in a single universal framework. The application of a framework, however, maintains relevance if the framework can represent real divisions between phenomena. In relation to the Annales approach, Bintliff (1991) notes, "the reality observed when we reveal how a particular era or region underwent historical change is the final result of an inner dialect between these different temporalities." Essentially, time must be dealt with in a framework that reflects reality and makes meaningful distinctions that aid interpretation and discussion of the archaeological record.

The framework as applied here preserves events as highly variable short-term actions that can be temporarily isolated. The short-term is considered difficult to isolate archaeologically due to chronological imprecision in prehistoric data (Barker 1991); however, if one considers the processes involved in procuring wood, a conception of the forces acting on the individual event can be assessed from the patterns of the archaeological record. Wood selection is a product of foraging and the socio-environmental factors that guide and restrict choice. Foragers choose a resource based on an assessment of the value of the potential resource (Marston 2009; Rubiales et al. 2011). The currency used to value a resource is dependent upon the resource goal. Availability, combustion properties, size of wood, the type of fire needed, smoke generation, dead wood versus green wood, water content, and cultural concepts of preference, the sacred and the taboo guide fuel selection (Asouti and Austin 2005; Picornell et al. 2011; Tabuti et al. 2003; Théry-Parisot et al. 2010). Selection for construction wood incorporates demands on strength, length, straightness, grain, ease of processing, resistance to rot, and durability, alongside environmental issues of availability, regrowth habits, ideological considerations and alternative options (Alcorn 1984; Marston 2009; Rubiales et al. 2011). The accumulation of foraging events comprises the wood and charcoal assemblage, the patterning of which represents characteristics of human selection behavior and deviations from that norm that can be understood as short-term selection practice and medium or long-term selection preference.

The medium-term reflects accumulated patterns of behavior and the dynamic processes and institutions that influence behavior. The medium-term is the realm of socio-environmental change, adaptation, and resilience. In particular, anthropogenic disturbance to the environment and social and environmental adaptation are important at the medium-term. Consideration of the regional culture history and socio-economic structures are also particularly apt at this scale to understand the external forces acting upon wood foragers. The long-term is the realm of the overriding structures that guide and constrain cultural and environmental expression. Deeply embedded characteristics of cultural identity (see Iannone 2002:75, Table 1) and the almost relentless creative and maintaining forces of the environment define the underlying structures that guide behavior at the long-term.

Further aid in interpretation is drawn from principles of optimal foraging. Prey choice (also known as diet breadth) models are particularly useful in testing the archaeological record against expectations under optimal foraging (Bird and O'Connell 2006; Kennett and

Winterhalder 2006; MacArthur and Pianka 1966; Shackleton and Prinns 1992; Stephens and Krebs 1986; Winterhalder and Goland 1997; Winterhalder and Smith 2000). Optimal foraging implies that a forager will maximize efficiency by seeking resources with the greatest benefit for the least cost, taking into consideration handling and search time (MacArthur and Pianka 1966). Prey choice models propose a ranking of resources in which a top ranked resource will always be taken upon encounter on a foraging expedition (Bird and O'Connell 2006; Kennett and Winterhalder 2006; Martson 2009; Rubiales et al. 2011). In the absence of top ranked resources, a widening array of lower ranked options are considered, whereby the increasing costs of time foraging and transportation distance outweigh the benefits of continuing the search to procure a top ranked resource (Bird and O'Connell 2006). As such, the model implies that an archaeological record will show low variability and high frequency of individual species in a resource rich landscape in which availability of high ranked resources allows discriminating selection. Whereas an archaeological record that shows high variability and low frequency of individual taxa reflects the scarcity of higher ranked resources or low selection preference. The Annales framework and principles of optimal foraging are applied here as filters to interpret the static archaeological record to isolate patterns of behavior and the processes and structures that guide decision-making.

4.3 Maya Paleoethnobotany

The growing body of research on ancient Maya flora and human-environment interaction provides a dataset that facilitates systematic lines of inquiry addressing botanical remains in a specific context while drawing from general conceptions and patterns of ancient Maya socio-environmental interaction. Knowledge of ancient Maya forestry is limited, but increasing (Ford 2008; Gómez-Pompa 1987; Lentz and Hockaday 2009; McNeil 2012; Morehart 2011). Paleobotanical, ecological, archaeological, iconographic, and ethnographic research are beginning to address aspects of ancient Maya forest management, forest gardens, home gardens, ideology, ritual, resource acquisition, medicine, economic species, subsistence, climate, and deforestation (Atran and Ucan Ek' 1999; Breedlove and Laughlin 1993; Ford 2008; Gama-Campillo and Gómez-Pompa 1992; Gómez-Pompa 1987; Gómez-Pompa et al. 1987, 1990; Lentz 1991, 1999; Lentz and Hockaday 2009; Lentz and Ramirez-Sosa 2002; Lentz et al. 1996, 2005; McKillop 1994, 1996; McNeil 2012; McNeil et al. 2010; Miksicek 1983, 1990; Morehart 2011; Morehart et al. 2005; Morehart and Helmke 2008; Peters 1983, 2000; Puleston 1982; Taube 2003; Turner and Miksicek 1984; Vogt 1969; Wyatt 2008). The forest provides food, fiber, timber, fuel, shade, habitat, hunting grounds, medicine, and an interactive landscape. Ethnographic accounts document an extensive indigenous floral knowledge that reveals a practical and spiritual relationship with forest resources in which the boundaries between the physical and ceremonial properties of plants is blurred (Alcorn 1984; Breedlove and Laughlin 1993; Morehart 2011; Vogt 1969).

Beyond the functional properties of forest products, trees frequently take a central role in ancient Maya iconography reflecting long-term cosmological structures that are core aspects of Maya cultural identity (Freidel et al. 1993; Morehart 2011; Morehart et al. 2005; Schele and Freidel 1990; Taube 2003). Unsurprisingly, with Maya culture developing in a tropical forest setting, trees and forests are deeply intertwined with Maya cosmological beliefs and the ordering and functioning of the universe. The ancient Maya conceived of a quincunx cosmological model;

a large tree occupies each cardinal direction, holding up the sky and marking the boundaries of the world (Freidel et al. 1993; Schele and Freidel 1990). At the center of the quincunx is a pivotal world tree, known as the *yax che* "first tree", typically believed to be a grand emergent ceiba tree (*Ceiba pentandra*, Taube 2003). The raising of the world tree was the action at the center of creation, bringing the universe into order out of the primordial waters (Freidel et al. 1993). Furthermore, trees and plants became a symbol of sustenance and abundance, and are incorporated into religious iconography, ceremony, and symbols of kingship and the divine rule of kings and queens as the provider and the pivotal force at the center of the world (Freidel et al. 1993).

Nature has a relational agential role in the production of society and the construction of place (Jones and Cloke 2002, 2008). Even individual trees can take an active role in defining landscape. For example, in forest clearance to establish agricultural plots, the largest trees are often left in place, providing shade for young maize growth (Redfield and Villa Rojas 1934; Taube 2003), and a large ceiba tree will often be present at the center of Yucatec communities, as a symbol of the central axis (Taube 2003). These short-term decisions to selectively cut or leave trees form persistent behaviors that are guided by the medium-term socio-political forces regarding the creation of space and place.

The incorporation of paleobotanical studies into archaeological projects and research design has provided a growing body of data documenting plant material, providing quantitative evidence for site specific reconstructions of floral composition and plant use (Lentz 1991, 1999; Lentz et al. 1996; Miksicek 1983, 1990; Morehart 2011). Furthermore, modern botanical survey has been employed to identify the remnant signature of ancient forest composition, silviculture, and plant utilization (Folan et al. 1979; Ford and Nigh 2009; Gómez-Pompa 1987; Gómez-Pompa et al. 1987; Peters 2000; Puleston 1982; Ross 2011). Ethnographic studies have aided conceptions of ancient forestry, questioning modern Western ideas of what constitutes forest management (Alcorn 1984; Ford 2008; Ford and Nigh 2009; Peters 2000). Peters (2000) groups indigenous practices into three main silvicultural systems: 1) homegardens, 2) managed fallow systems, and 3) managed forest systems. The degree and intensity of management varies in each system, detailing medium and long-term indigenous botanical knowledge and the sophisticated but often subtle forest management practices employed on the modern landscape, and potentially employed in antiquity. The identification of plants around houses at Cerén has documented a rich practice of home gardening (Lentz and Ramirez-Sosa 2002), while McNeil and colleagues (McNeil 2012; McNeil et al. 2010) suggest extensive and intensive management of forest resources at Copán based on data from sediment cores. In particular, McNeil's (McNeil 2012; McNeil et al. 2010) analysis and discussion of Copán reveals the dynamics of socio-environmental adaptation at the medium-term in relation to changing resource management practices and population pressure.

In a well known example, Puleston (1982) proposed the utilization of ramón (Brosium alicastrum) in ancient Maya subsistence, in part based on the high frequency of the tree in the modern forest around ancient ruins. Although the growth habits, adaptations, and seed recruitment of ramón has questioned the reliability of Puleston's hypothesis (Lambert and Arnason 1982) the approach has since been applied across the Maya area, finding patterns of low variability and high frequency of economic species associated with ancient settlement, suggesting that the ancient forest was managed to promote economically important species and that the modern forest composition retains a remnant signal of past flora (Folan et al. 1979; Ford and Nigh 2009; Gómez-Pompa 1987; Gómez-Pompa et al. 1987; Peters 2000; Puleston 1982; Ross 2011).

One noteworthy study of ancient Maya silviculture assessed species composition within ancient stone ringed forest patches called *pet kot* (Gómez-Pompa et al. 1987). A high frequency of economic species is present within these defined ancient patches compared to the surrounding forest. The research indicates that the ancient forest management practices caused an interconnected relationship to ecological processes of succession in which the human manipulated forest favored the growth and continued recruitment of the desired economic species, thereby preserving a signature of ancient forest composition through the following centuries, despite the absence of further human input (Gómez-Pompa et al. 1987).

Targeted paleobotanical research, such as the identification of sapodilla (*Manilkara sapota*) and logwood (*Haematoxylom campechianum*) used in temple construction as lintels and beams at Tikal, Guatemala, has revealed contextually based patterns of specific wood selection (Lentz and Hockaday 2009). The shift in species use from sapodilla to logwood and back to sapodilla in the temples at Tikal is further interpreted to provide evidence of forest management, resource overexploitation, and deforestation (Lentz and Hockaday 2009). The specific short-term selection practices form medium-term patterns of cognitive selection preferences, and, as with the case from Copán, resource management, deforestation and socio-environmental adaptation were characterized by medium-term variability. In the case of Tikal, an environmental threshold was reached during the Late Classic with the over exploitation of sapodilla, resulting in a temporary equilibrium shift in which environmental resource availability was altered, requiring a behavioral change in wood selection practices. The data from Tikal demonstrate the socio-environmental variability present at the medium-term, and the causal inter-relationship in human-environment interaction.

Research by Morehart (2011:1) has documented charcoal assemblages in a number of caves in Belize. Although Morehart documents variation, commonalities amongst assemblages, in particular in relation to the ubiquitous presence of pine (*Pinus* sp.), are interpreted as “shared cosmological understandings of ritual behavior that crosscut social, economic, and political difference”. Further botanical identifications by Morehart (Morehart and Helmke 2008; Morehart et al. 2005), Lentz (Lentz et al. 2005), and Wyatt (2008), document pine remains from cave and terrestrial locations, across domestic, elite, agricultural, and ceremonial contexts revealing the multivocality of pine, the agency of non-human objects, and the importance of context when interpreting materials. The importance and cultural value of pine in antiquity and ethnographically is enhanced by the species’ limited distribution on the tropical landscape in the Maya region. In many of the areas where pine is found archaeologically, the predominant geomorphology favors the growth of broadleaf forest, with pine sources often many kilometers distant (Lentz et al. 2005; Morehart 2011; Morehart and Helmke 2008; Morehart et al. 2005; Prufer and Dunham 2009; Wyatt 2008). The pervading cultural value of pine to this day (Breedlove and Laughlin 1993; Vogt 1969) confirms the long-term social structures of Maya cosmology and belief, while the patterning pine in the archaeological record provides case studies of the medium-term utilization of pine resources, and alludes to mechanisms for pine acquisition, resource management, and trade.

Deforestation has been forwarded as a prime factor leading to the ancient Maya socio-political collapse of the Central Lowlands (Abrams and Rue 1988; Anselmetti et al. 2007; Hansen et al. 2002; Shaw 2003; Shimkin 1973; Wiseman 1983). Increasing populations during the Late Classic period drove demand for land and resources beyond the carrying capacity of the environment, resulting in deforestation, erosion of soil, and crop failure, from which the population was ultimately unable to recover. Although monocausal explanations have long been dispelled (Culbert 1973; Turner and Sabloff 2012), and examples of keen forest management have been forwarded (McNeil 2012; McNeil et al. 2010), human-environment interaction and the pressures and thresholds of environmental systems are closely linked to the socio-political history of the Maya Lowlands (Turner and Sabloff 2012). In particular, research is providing strong evidence for a climatic impact coinciding with the socio-political strife of the Late Classic in the form of sustained droughts (Aimers and Hodell 2011; Brenner et al. 2002; Haug et al. 2003; Hodell et al. 1995, 2005; Kennett et al. 2012; Medina-Elizalde and Rohling 2012). Even in the face of heterogeneous responses and adaptations to climatic stressors, the impacts of drought on Maya subsistence would have caused social and economic problems and conflicts throughout the region (Kennet et al. 2012; Turner and Sabloff 2012), ultimately resulting in the equilibrium shift that marks the collapse.

The short discussion above begins to reveal the complexity of the relationship between the ancient Maya and the forest and the processes at short, medium and long term scales that guide and characterize Maya history. Case studies document and describe the particulars of plant use, interaction, and ideology, while general themes and shared patterns of knowledge, beliefs and impacts are also elucidated. Despite the identification of individual plant remains, researchers have typically focused on general patterns of plant use, with discussion at the short-term largely absent. Although the problem of isolating the short-term has been well discussed (Bintliff 1991b; Fletcher 1992; Smith 1992), for the wood and charcoal archaeological record of Paynes Creek, the short-term is a focus of inquiry. In this paper, the identification of wood and charcoal from the salt production sites in Paynes Creek National Park in coastal southern Belize are used as a case study to address the particular socio-environmental context of wood selection and the wider socio-economic and environmental factors that guide wood selection. Insight is drawn from the Annales School of French Structural History, to provide a framework for the systematic study of ancient Maya human-environment interaction in relation to wood selection.

4.4 Study Area

Belize has a tropical climate with a pronounced wet season from June to November. Rainfall varies across the region, with over 300cm per annum in the south compared to 150cm in the north. Paynes Creek National Park protects a variety of ecosystems along the coast and coastal plain of southern Belize (Figure 4.4). Ecosystem composition and structure is characterized by the adaptation of flora to the geomorphologic setting and biotic and abiotic stresses, including hydrology, nutrient input, salinity, seed recruitment, light regime, competition, and natural and anthropogenic processes of succession (Wright et al. 1959). The western portion of the park is dominated by lowland savanna, with leached soils, acidic topsoil and low fertility, incorporating savanna grasses, sedges, palmetto palm (*Acoelorraphe Wrightii*), oak (*Quercus oleoides*), and extensive monotypic stands of pine (*Pinus caribea*). Storm-built ridges devoid of woody vegetation, created by the reworking of fluvial deposits, characterize the eastern portion of the park. A shallow micro-tidal lagoon comprises the southern portion of the park and hosts the salt works of this study. The brackish lagoon system is dominated by the salt tolerant mangrove species, red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemosa*).

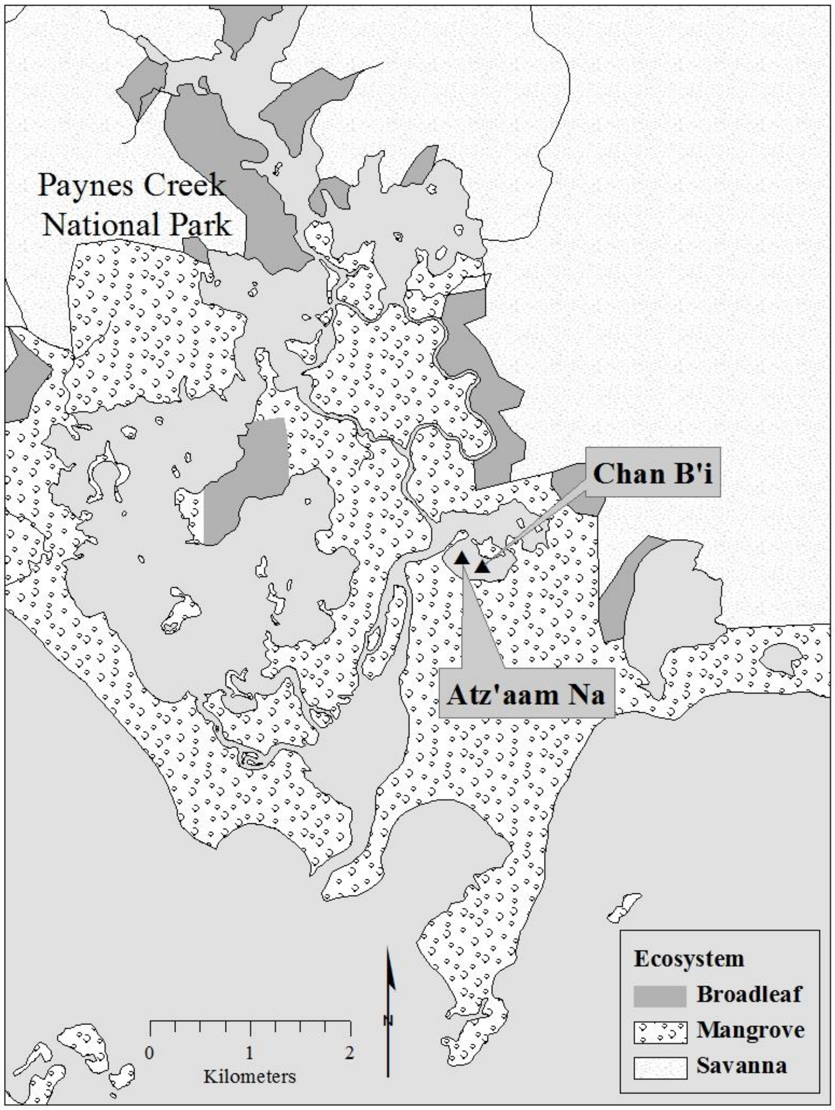

Figure 4.4 Map of broad ecosystem classifications in Paynes Creek National Park

A spatial zonation characterizes mangrove forest structure in Paynes Creek, with hydrology, light regime, seed dispersal, competition and disturbance some of the principle controlling factors in mangrove ecosystem composition and structure (Berger et al. 2006; McKee 1995; Snedaker 1982). *R. mangle* dominates the landscape as the sole species present in the forest fringe and forming extensive monotypic stands across the landscape. The prop roots of *R. mangle* provide a functional adaptation to the forces of wave energy. The stunted growth typical of local *R. mangle*, in part due to lack of nutrient inputs, prevents the development of tall straight trunks, limiting the functional suitability of this species. *A. germinans* is found in small numbers behind the *R. mangle* fringe, where limited flushing creates hypersaline conditions to which the species is adapted (McKee 1995). *L. racemosa* is shade intolerant and appears in limited numbers where light regime and soil conditions are favorable (McKee 1995; Snedaker 1982). A few other salt tolerant species are present in the mangrove ecosystem, though rare, including, *Chrysobalanus icaco*, and *Conocarpus erecta*. Analysis of sediment cores from the lagoon confirms the dominance of the mangrove ecosystem in the local area throughout the Holocene (McKillop et al. 2010a, 2010b).

Small broadleaf patches are present in the lagoon system where higher elevation and river courses provide suitable edaphic conditions to overcome salinity stress (Wright et al. 1959). The broadleaf structure is particularly subject to edge effects and gap dynamics, creating dense undergrowth and favoring fast growing, pioneer and secondary species to fill the ecological niche (Brokaw 1982, 1985; Chazdon 2003; Laurance 1991; Murcia 1995). A characteristic succession toward a Terminalia-Calophyllum-Symphonia-Vochysia association of flora, representing nargusta (*Terminalia amazonia*), Santa Maria (*Calophyllum brasiliense*), waika chewstick (*Symphonia globulifera*) and yemeri (*Vochysia hondurensis*), defines the dominant primary species under natural processes of succession (Standley and Record 1936).

Current archaeological evidence suggests southern Belize was occupied by small subsistence farming and coastal fishing communities until the end of the Late Preclassic (A.D. 100–300), when political centers including Uxbenka and Ek Xux were established (Braswell and Prufer 2009; Prufer et al. 2008; Prufer et al. 2011), and coastal trade increased focused at Wild Cane Cay (McKillop 1996, 2005a). The developments of the Early Classic period saw population growth and the development of marked social differentiation, the construction of public space and monumental architecture, and the adoption of a cosmological worldview and cultural expression shared across the Maya geopolitical landscape. Inland communities increased in number and size, with a regional florescence and population peak in the Late Classic, incorporating centers such as Pusilha, Lubaantun, and Nim Li Punit (Braswell and Prufer 2009) and expansion of the coastal trading port at Wild Cane Cay (McKillop 2005a). The political centers were abandoned in the Terminal Classic period (A.D. 800-1000). Coastal trade at Wild Cane Cay continued into the Postclassic period as part of the circum-Yucatan canoe trade route (McKillop 2005a).

Archaeological research in Paynes Creek National Park discovered an extensive salt production industry dating from the Early Classic to the Terminal Classic, now submerged below rising sea-level (McKillop 1995, 2002, 2005b). To produce salt, brine was heated in ceramic vessels over fire, evaporating the liquid component, leaving salt for trade and consumption. The process requires a constant supply of fuel to maintain the fires. The remnants of wooden structures to support the salt production industry are preserved in the anaerobic mangrove peat that characterizes the substrate of the inundated workshops. Identification of wood taxa used for construction and fuel at the workshops provides a record of forest resource exploitation and selection behavior (Robinson and McKillop n.d. a, Robinson and McKillop n.d. a,). As with the interior centers, the salt works were abandoned in the Terminal Classic period.

4.5 Methods

Taxonomic identifications of wooden posts from Chan B'i and Atz'aam Na provide a diachronic assessment of wood selection within the lagoon. Radiocarbon dating of wooden posts provides an Early Classic date at Chan B'i and a Late Classic date from Atz'aam Na. The two workshops are located 300m apart in the eastern arm of the lagoon system. The proximity of the two sites enables an assessment of environmental and cultural change and adaptation over time in response to natural and anthropogenic processes affecting the geographic resource base. Charcoal collected from excavation at Chan B'i provides a comparison of wood resources for combustion and construction at the site.

All discovered wooden posts and all excavated charcoal fragments larger than 1mm are included in the study to provide a more complete record and reduce sampling bias. Wood was identified through the analysis of wood structure under light microscopy, utilizing the comparative collection at the USDA Forest Products Laboratory, Madison, Wisconsin, the authors' modern reference collection from Belize, and published wood databases (Robinson and McKillop n.d.a). Charcoal was imaged using a Scanning Electron Microscope (SEM) in the Socolofsky Microscope Center, Louisiana State University (Robinson and McKillop n.d. b).

4.6 Results

4.6.1 Wood Species Identification

Thirty-three wood samples, representing all discovered architectural posts, were identified at Chan B'i (Figure 4.5). Seven taxa are represented. *A. germinans* is the most frequent species representing 34% of the assemblage (n=11). *Eugenia* sp. (n=6) represents 18% and *Hieronyma* sp. (n=4) 12%. Three samples are identified to the Chrysobalanaceae family. *Casearia* sp. and *Ficus* sp. both occur twice. Only *Calophyllum brasiliense* (Santa Maria) appears a single time. Aside from the one mangrove species, *A. germinans*, all other taxa are from broadleaf habitats.

Twenty-five samples, representing ten taxa were identified from Atz'aam Na (Figure 4.5). *Symplocos martinicensis* (n=11) dominates, accounting for 44% of the assemblage. *Eugenia* sp. (n=3) represents 12%. *Mouriri* sp. appears twice. The remaining seven genera each occur once. All taxa identified at Atz'aam Na are characteristic of broadleaf habitats. Four taxa out of the seventeen identified appear at both sites.

The results of wood identification from the two sites show a change in species selection over the Classic period from the mangrove species, *A. germinans*, at Early Classic Chan B'i, to the broadleaf *S. martinicensis* at Late Classic Atz'aam Na. The change in species composition is accompanied by a greater amount of diversity in the Late Classic sample; despite fewer total samples, more taxa are represented at the Late Classic site with seven taxa appearing only once.

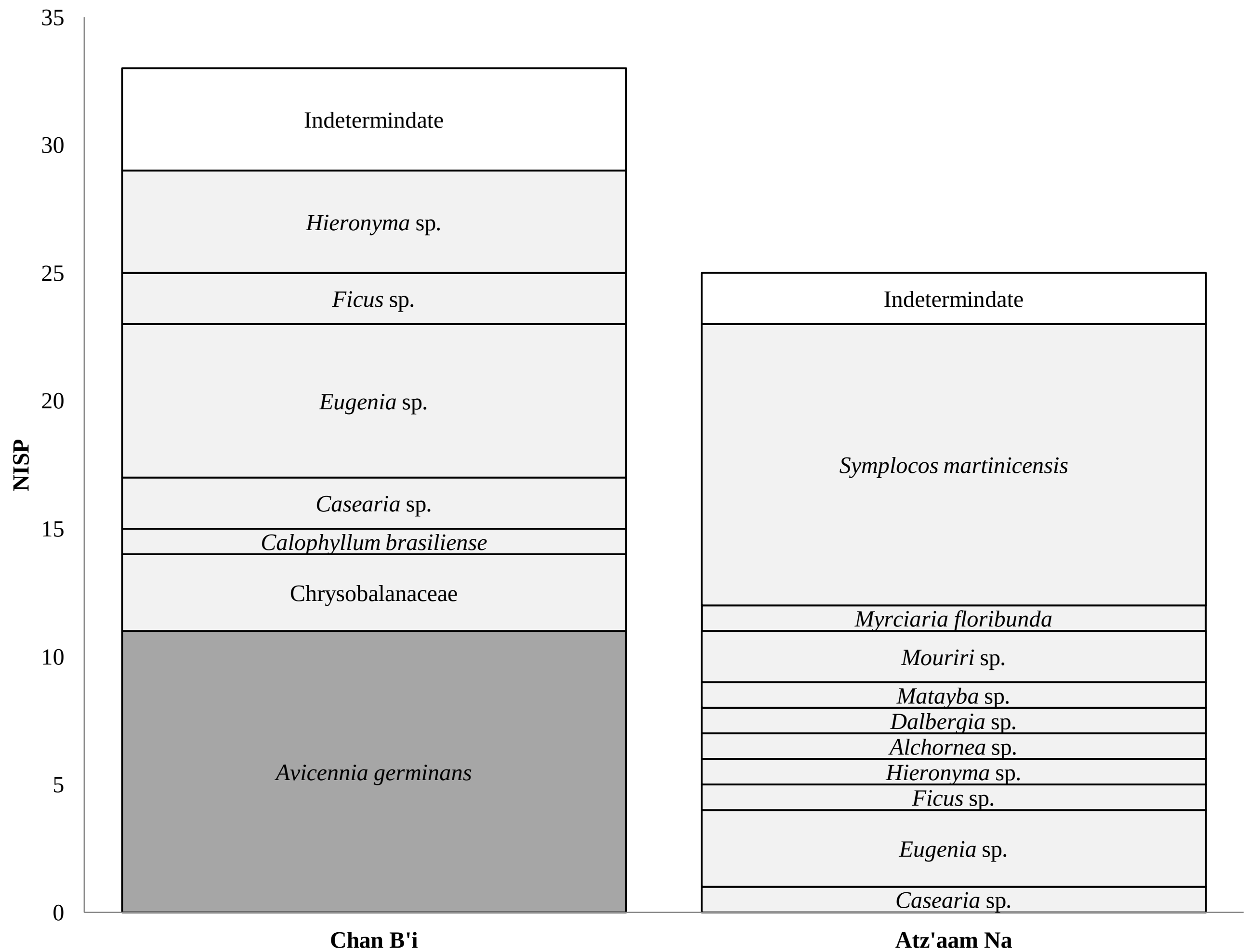

Figure 4.5 Wood identifications at Chan B'i and Atz'aam Na
Color represents ecosystem; dark grey = mangrove, light grey = broadleaf.

4.6.2 Charcoal Identifications

Taxonomic identification was attempted on all (n=310) charcoal samples >1mm recovered during excavation. Taxonomic charcoal counts represent Number of Identified Specimens (NISP). Fragmentation studies (see Asouti and Austin 2005 for review) have demonstrated the positive relationship between number of fragments and proportion of wood; therefore, although the count may represent multiple pieces of charcoal from a single piece of wood, the relative proportions of charcoal reflect the proportional use of each taxon. A total of 191 charcoal fragments, representing 21 taxa were identified from the excavated material at Chan B'i (Figure 4.6). A further 119 fragments could not be identified due to the small size of these samples and degradation of anatomical structure. Four taxa characterize 79% of the identified samples, Chrysobalanaceae (n=85, 31.13g), *R. mangle* (n=28, 18.55g), *Hieronyma* sp. (n=21, 15g), and *L. racemosa* (n=16, 8.99g), with samples identified to the Chrysobalanaceae family dominating the assemblage. *Alchornea latifolia* and *Casearia* sp. appear four times.

Chrysobalanus icaco has six occurrences. Fourteen of the identified taxa have three instances or less. Broadleaf species make up the majority of the assemblage (14 taxa, 71% of the count and 53% of the weight). The mangrove ecosystem was also an important fuel source (5 taxa, 28% of the count, and 36% of the weight). Savanna species are limited to 2 taxa, representing only 1% of the total sample count.

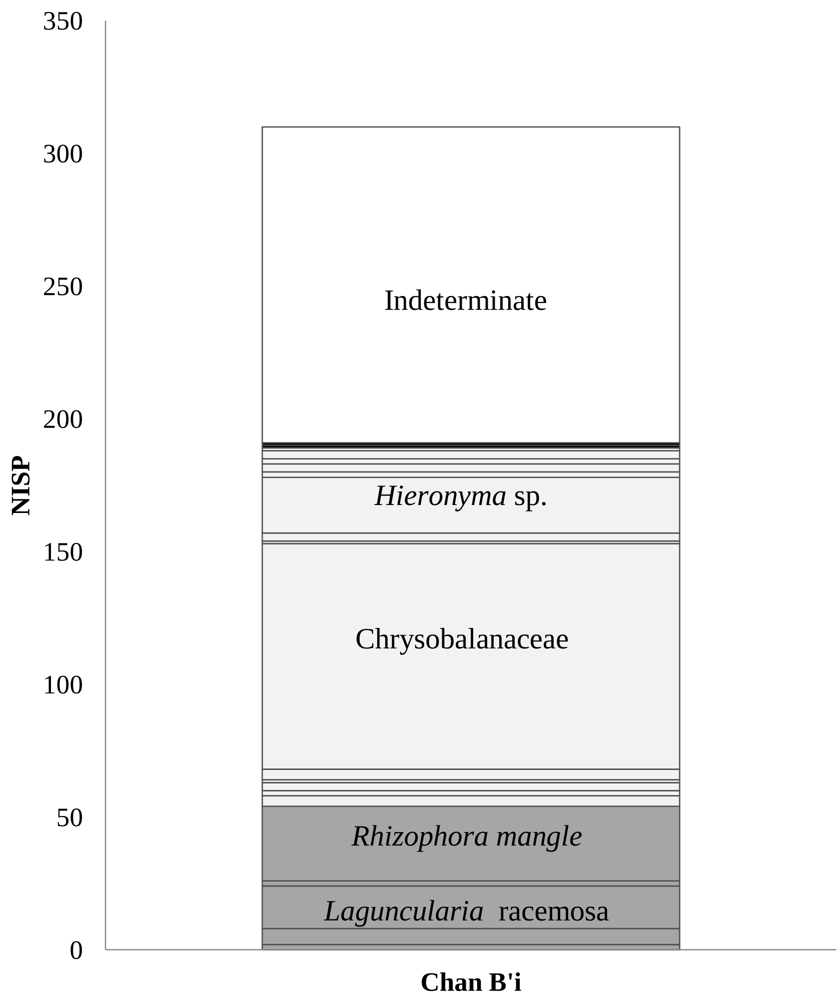

Figure 4.6 Charcoal identifications from Chan B’i
Color represents ecosystem; dark grey = mangrove, light grey = broadleaf, black = savanna.

4.7 Discussion

The wooden archaeological record is a reflection of human behavior and the various cultural and environmental factors that guide and constrain resource exploitation. Archaeological wood and charcoal from Paynes Creek enable a contextual approach to assessing wood selection that can target the particulars of wood selection, comparing construction and combustion wood at a single site, while also enabling a broader discussion of wood selection in relation to the wider socio-economic and environmental context.

4.7.1 Short-Term

Principles of optimal foraging, and in particular prey choice models, are useful in interpreting the archaeological record. The proximity of the two study sites, only 300m apart in the eastern arm of the lagoon, allows the assessment of wood selection against a shared geographic resource base through time. The patterns of wood and charcoal identifications at Paynes Creek show a preference for specific woods for construction and fuel. *A. germinans* was favored for construction at Chan B'i, *S. martinicensis* at Atz'aam Na. Chrysobalanaceae, *R. mangle*, *Hieronyma* sp. and *L. racemosa* were the preferred fuels at Chan B'i. These taxa reflect the repeated patterns of behavior representing a cognitive socio-environmentally bound ranked selection preference, which can be understood as selection preference at the medium-term. The species that appear only once or in low frequencies on the other hand were likely of lower rank and taken opportunistically and collected when the costs of continuing to forage for higher ranked resources were too high to maintain efficiency.

The change in species preference for construction wood over time suggests a level of deforestation. The dominance of A. germinans in the Early Classic at Chan B'i demonstrates the selection of resources from the immediate mangrove ecosystem, conforming to ideas of optimal foraging in which distance to a resource, and therefore time spent in foraging and transport, was a primary consideration. The change to the broadleaf *S. martinicensis* as the dominant taxa, with no mangrove species recorded at Late Classic Atz'aam Na, suggests the mangrove resources were exhausted and alternative, more distant resources had to be exploited, which made *S. martinicensis* available. The greater variability of species at Atz'aam Na, despite fewer recorded samples, further suggests higher ranked resources were becoming scarce over time, resulting in a widening of the resource base to accommodate lower ranked resources.

Charcoal identifications document differences in wood selection for combustion and construction at Chan B'i. The mangrove ecosystem was an important resource location for both construction and fuel, although even within the low diversity habitat, different mangrove species were utilized for each function. As with construction wood, the preference for the mangrove species *R. mangle* and *L. racemosa* as fuel reflects the importance of shortest distance in efficient foraging. The stunted growth of *R. mangle*, with little alternate use value, makes the species ideal for fuel. The near absence of *A. germinans* from the charcoal record may reflect the species' importance as a construction wood, with specific management practices to reserve *A. germinans* stock for construction. Although, the charcoal record may also be temporally distinct from the architectural construction, dating to a time period some time after building construction, and therefore representing resource exploitation after the exhaustion of *A. germinans*. If so, the preference for *L. racemosa* as a fuel source could represent changing forest structure in relation to gap dynamics. *L. racemosa* is light sensitive, requiring high levels of sunlight to establish. The gaps in forest cover created through exploitation of the mangrove resources could favor the establishment of *L. racemosa* where *A. germinans* previously grew.

As with construction wood, the immediate mangrove ecosystem was unable to fulfill all demands for fuel. The high frequency of broadleaf species in the charcoal assemblage confirms the importance of the habitat for fuel resources. Unlike mangrove habitats, broadleaf forest patches provide a wide variety of suitable species, fast regrowth, and high deadwood production, making them a useful potential fuel resource location. Broadleaf species identified in the charcoal record overlap with the construction woods. The favored fuels, Chrysobalanaceae and *Hieronyma* sp., account for 9% and 12% of the construction wood samples respectively. The utilization of the same species for both functions may reflect general preference, the abundance of those species in the environment, or charcoal fragments may result from burning offcuts from the preparation of construction posts. A low selection preference characterizes the remaining charcoal taxa, with less than five charcoal fragments present for most of the identified taxa. These species were potentially collected opportunistically, perhaps as deadwood, or to maintain efficient foraging when high ranked taxa were not available.

Of particular interest, beside a single piece of charcoal, is the absence of pine in the archaeological record from Paynes Creek. The importance of pine to the Maya has been documented archaeologically and ethnographically, revealing long-term ideological structures that transcend the socio-economic oscillations of Maya history (Lentz et al. 2005; Morehart 2011; Morehart et al. 2005; Vogt 1969). Furthermore, pine is transported anciently and historically over long distances to fulfill specific selection demands, and yet despite the accessibility of pine in Paynes Creek, the resource is not present in the archaeological sample. Although mangrove and broadleaf species may be closer to the salt works, and thus incur fewer transport costs, compared to the efforts exerted to obtain pine for use in ceremonial, elite, and domestic contexts elsewhere, transport cost alone cannot be deemed the only reason for the absence of pine. As construction wood pine would seem ideal, with long straight trunks, quick regrowth and an easily workable grain, although smoke generation, aroma, and a fast, hot burn are perhaps less than ideal as a fuel for the salt production industry. Perhaps more importantly is the highly coveted nature of pine to explain its absence. As a status and ceremonial material, pine use at a salt workshop is not socially appropriate. Long-term underlying cultural structures dictate the sacred and profane, guiding acceptable behavior and resource use.

The preferences and principles of wood selection discussed at the short-term reflect socio-environmentally determined decision-making. Patterns in the data act as filters, distinguishing and isolating high ranked taxa from low ranked and opportunistically foraged resources. The low frequency taxa may be cancelled out as noise or oscillations around an equilibrium state (adaptive adjustment in Butzer's temporal framework) to recognize broader socially embedded selection preference over time. Low frequency taxa remain useful for understanding holistic selection practices, assessing resource availability, and reconstructing the environment.

Differences between construction and combustion wood shows the importance of context and the heterogeneity within selection practices for wood resources even at the scale of a small workshop. The ancient Maya of Paynes Creek demonstrate knowledge of tree species and their properties and a selection practice that is based in efficiency which is integrated into a broad forest exploitation strategy to cater for fuel and construction wood needs.

The variability of cultural and environmental systems and the feedback within and amongst each system is reflected in the archaeological record. Construction wood records the socio-environmental impacts of disturbance. Inadequate management of forest resources resulted in a change in forest composition and a necessary adaptation of foraging location and wood selection practices to accommodate the environmental change. The impacts to the landscape mark a discontinuity in the equilibrium state with a shift to a new equilibrium level, representing an adaptive modification in Butzer's scheme (1982). The regional socio-economic dynamics of the Classic period provide the backdrop to understanding the broader processes and pressures that drive resource selection in Paynes Creek, which are better discussed at the medium-term scale.

4.7.2 Medium-Term

Discussion of wood selection at the short-term considered foraging behavior, filtering preferred species from low preference, or opportunistic species. The identification of high ranked species, as discussed above, reflects repeated behavior that reveals a cognitive selection practice, which is a function of learnt practical knowledge, shared cosmological beliefs and applied practice at the medium-scale. *A. germinans* and *S. martinicensis*, in particular, were favored as construction wood. Chrysobalanaceae, *R. mangle*, *L. racemosa* and *Hieronyma* sp., were specifically sought and collected upon encounter for use as fuel.

The patterning of the archaeological record presented in this article documents a change in selection practices for construction wood from mangrove to broadleaf species, accompanied by a broadening of the resource base. Selection behavior was revised as an adaptive modification to the changing resource base. Exhaustion of viable mangrove resources passed a threshold that required a change in selection behavior, with a reliance on the more distant broadleaf patches. The prevalence of secondary species and wider variety of taxa in the Late Classic assemblage is also indicative of a disturbed broadleaf forest and behavioral accommodations. The environmental impacts, and related change in selection, coincide with the regional demographic patterns. Although forest disturbance may have begun in the Early Classic, by the time of the Late Classic population expansion, any forest management practices employed were insufficient to sustainably manage the forest resources and maintain the equilibrium state, whist achieving the required level of salt production to meet demand.

Forest composition, structure, and therefore resource availability is dependent on the complex interaction of biotic and abiotic processes that affect an ecosystem (Butzer 2012; Chazdon 2003; Jones and Cloak 2002; Turner and Sabloff 2012). Both human and natural impacts can cause changes to the ecological system that affects forest health, disturbance and recovery (Chazdon 2003). Mangrove species, although adapted to high salinity, are less resilient to disturbance and low nutrient inputs. The stunted growth characteristic of the local *R. mangle* is primarily a result of low nutrient input. Disturbance to the mangrove resource base, especially the sparse *A. germinans* suitable for architecture, quickly diminishes resource availability. If mangrove resources become scarce, broadleaf patches become the closest and most bountiful resource patch.

Broadleaf patches are also impacted by disturbance (Chazdon 2003). In the small broadleaf patches that characterize the local landscape close to the salt works, edge effects and gap dynamics are major factors influencing forest structure and composition (Brokaw 1982, 1985; Chazdon 2003; Chen and Twilley 1998; Laurance 1991; Murcia 1995). Edge effects, in which the fringe of a forest stand is exposed to biotic and abiotic processes from outside of the stand, are particularly pronounced and can extend throughout small forest stands (Didham and Lawton 1999; Laurance 1991; Murcia 1995). In the landscape surrounding the salt works, forest stands are mostly characterized by open boundaries, increasing exposure to sunlight, wind, and available seed bank, promoting the growth of scrub and pioneer secondary species. Gap dynamics create a similar impact in the small broadleaf patches, with disturbance to the canopy allowing light to penetrate the understory and creating favorable conditions for fast growing, pioneer species (Brokaw 1982, 1985; Feeley et al. 2011). Without direct management practice, anthropogenic impacts from the extraction of forest resources in Paynes Creek favor the adaptations of opportunistic secondary and scrub species. Over time, the extraction of trees passed a threshold in patch resilience and the ability to maintain an equilibrium state, resulting in a change in composition to the fast growing secondary species, with a subsequent need to change foraging strategy to exploit alternate resources and resource patches.

The socio-environmental history of salt production in Paynes Creek closely ties into the configuration of social knowledge, cultural beliefs, political structures, economic mechanisms, demographic trends, resource demands, and environmental systems that operate and fluctuate at the medium-scale, creating the context for events and the structures and processes that guide and restrict choice and behavior. At a fundamental level, salt is a basic dietary requirement, necessary for maintaining the body's water balance, and nerve and muscle function. The ancient Maya diet primarily relied on foods that were low in naturally occurring salt. As such, Maya diet required supplemental salt. The importance of salt production and trade has been documented across the globe and throughout history, with significant impacts on socio-economic, political and environmental organization (Adshead 1992; Andrews 1983; Barui 1985; Ewald 1985; Kurlansky 2003; McKillop 2002). The locating of the salt works in Paynes Creek was likely a well considered decision. The sheltered lagoon system delivers an unlimited supply of brackish water protected from wave and weather, providing an ideal location to develop the salt industry, while the proximity of Wild Cane Cay enabled access to a coastal trade route that could be utilized for distribution.

The history of the Paynes Creek salt works mirrors the demographic patterns of the region. As interior polities expanded, the growing regional population created a demand for salt beyond the level of household production, leading to the establishment of the salt works. Expansion of the salt works met the demand throughout the Classic period as the region flourished. The abandonment of the interior centers and depopulation of the region in the Terminal Classic dried up demand for salt and disrupted the established trade networks, resulting in the cessation of salt production in the lagoon system.

By necessity salt production was tied into the wider socio-economic environment. Structures had to be in place, or developed, to facilitate the redistribution of goods, including transport, a forum for exchange, and a method of compensation or payment for goods. Merchants, marketplaces, and bartering rates are necessary for the salt works to function. The socio-economic environment was created by and influenced demographic trends, which created demands for resources and allowed a portion of the regional population to engage in the salt production industry.

During the Late Classic period, high demands on environmental resources, created ecological stress that was heightened by regional drought and increasing aridity (Turner and Sabloff 2012). Increasing evidence of drought, soil erosion, and deforestation have drawn direct links to socio-political collapse (Aimers and Hodell 2011; Brenner et al. 2002; Haug et al. 2003; Hodell et al. 1995, 2005; Kennett et al. 2012; Medina-Elizalde and Rohling 2012; Wahl et al. 2006). Societal conflict, disrupted trade relations, and eroding political power and alliances intertwined with environmental factors, reaching systemwide thresholds throughout the Central Lowlands (Tuner and Sabloff 2012). Turner and Sabloff's (2012) recent revision of human-environment interaction and the ancient Maya collapse in the Central Lowlands highlights the heterogeneity of individual adaptations across the Maya landscape, with examples of both disintegration and resilience. For example, along the Pasión River, while Seibal and Altar de Sacrificios experienced renewed growth during the 10th Century, Aguateca, Dos Pilas and Cancuen had all suffered decline and abandonment (Turner and Sabloff 2012). The different responses of settlements cannot be explained by monocausal explanations such as drought and water access, especially when polities such as Palenque had abundant access to water resources yet still suffered decline (French et al. 2012; Turner and Sabloff 2012). Turner and Sabloff (2012) conclude that socio-economic factors were at play alongside environmental stressors, especially in relation to macro-economic trade. Disruption to trade mechanisms and political alliances were felt throughout the region with a large impact on a settlement's resilience to the sociopolitical and environmental upheaval of the Terminal Classic period.

Despite the evidence for deforestation in Paynes Creek and regional drought (Kennett et al. 2012), deforestation, climatic, and environmental stress is not considered a direct factor in the abandonment of the salt works. The adaptive strategies of the salt workers demonstrate changing selection practices to cope with environmental stress. Furthermore, Turner and Sabloff (2012) note the importance of access to coastal networks for continuity after the 9th Century when trade routes took a new direction. The Post Classic florescence of Wild Cane Cay at the mouth of the Paynes Creek lagoon as a trading port provides evidence of the adapting mechanism for trade, yet also confirms that this was not a factor in the survival of the salt works. More importantly, the salt demand had dried up in the southern Belize region and the demand created by the expanding population of the Northern Lowlands could be satisfied by the abundant salt flats of the Yucatan Peninsula (Andrews 1983).

Discussions of the collapse show the importance and relevance of the general and particular and the temporal rhythms of history as realms of analysis. Regional climate and system wide impacts are important to understand the pressures, processes and structures active in affecting human behavior. The oscillations of response between polities and sectors of society at the short-term scale emphasize the importance of context in accurate description, and interpretation of the past; however, regional and broader socio-environmental patterns can have direct and indirect impacts of an individual context, with socio-economic and political disruption felt throughout a region, regardless of individual resilience.

Since the abandonment of the salt works, the forest habitats have largely been left to their own processes of succession. Without major anthropogenic disturbance, primary emergent trees have been able to establish in the center of the small broadleaf stands resulting in the Terminalia-Calophyllum-Symphonia-Vochysia association of flora characterized by Standley and Record (1936). Edge effects continue to have an impact, dominating the broadleaf fringe with secondary, pioneer and scrub species. *R. mangle* dominates the mangrove habitats. When considering the frequency of *L. racemosa* and *A. germinans* in the archaeological assemblage, the low numbers of these species in the modern environment suggests they were unable to reestablish after human abandonment, and the mangrove forest composition was permanently altered.

4.7.3 Long-Term

Even in the face of radical culture change, florescence and collapse, ideologies and cosmological beliefs may persist as underlying social structures that can be characterized at the long-term. Archaeological, iconographic, and ethnographic research has explored the intricate relationship between nature, cosmological beliefs, functional knowledge, and praxis throughout Maya history. As previously discussed, knowledge and beliefs regarding the natural world and forest products are integral to Maya *mentalities* and are embedded in long-term structures and institutions that inform processes of decision-making. Despite the apparent unsustainable forest management of the Paynes Creek Maya, the mounting evidence of environmental knowledge, and often subtle management practices of the ancient and modern Maya, provides a long-term cultural structure against which individual context and archaeological data can be assessed.

In an area with a relatively short human occupation, and a history of rapid socio-economic change and anthropogenic environmental impacts, the long-term has less relevance to problem orientated archaeological questions than the shorter wavelengths discussed above. Whilst the identification of deeply embedded *mentalities* pervading Maya history are important as analogs and in understanding socio-environmental structures that guide human-environment interaction (for example the absence of pine in the Paynes Creek record), broad analogy has limited ability to inform the specifics of the archaeological assemblage in the localized context.

Likewise, the dynamism of the environment in response to anthropogenic impacts makes the medium-term a more appropriate realm of attention for this particular archaeological context and questions of resource selection behavior. However, long-term environmental and climatic structures created the landscape onto which the ecological, social and economic systems of the medium and short-term history operated. The complexity and conflict in maintaining equilibrium at the long-term scale is in particular evidence in a fragile coastal environment susceptible to sea-level rise, subsidence, wave action, erosion, and hurricane events. Furthermore, structures and processes at the long-term were instrumental in the formation of the archaeological record, submerging the sites under water and preserving artifacts in the anaerobic mangrove peat.

The Holocene history of Paynes Creek National Park describes a process of land accumulation as mangrove peat developed on top of the underlying limestone shelf, with mangrove growth and peat formation keeping pace with rising sea-level. These transformations have an irreversible impact on long-term environmental structures. The landscape and geomorphology was further created by the distribution of rivers in the drainage system from the Maya Mountains to the west. Reworking of alluvial sediment by coastal processes, prevailing climatic conditions, and weather events further created the geomorphology of the park.

As discussed above, the rivers and their tributaries provide freshwater sources that are key factors in ecosystem distribution and vegetation composition in the area. The absence of fresh water sources led to the formation of the savanna habitats, whereas, broadleaf patches were able to establish along river courses and where salinity stress was minimized. Likewise, the adaptation of mangroves to high salinity and tropical temperatures was instrumental in the creation of the characteristic lagoon vegetation and the peat substrate that was essential in preservation of the wooden archaeological record. The ecological forces and processes involved in the continual creation, maintenance and modification of the landscape continue to act in a feedback mechanism with natural and anthropogenic disturbance that determines vegetation composition and processes of succession.

4.8 Summary

The power of the Annales, and in particular Braudel's temporal rhythms and modifications to his scheme, is in the discussion and reconciliation of the general and the particular and its ability to isolate and integrate social and environmental processes and structures across scales. Recent research on the ancient Maya has highlighted the complexity of the ancient landscape and the heterogeneity of social responses and adaptation. Individual communities, sub-groups and the environment are active participants with interrelated processes of adaptation, conflict, and resilience that define a particular context. Although the specific context is important, the identification of general trends, processes, institutions, and structures and the interrelationships that guide and restrict behavior is essential to understand the individual context and larger anthropological questions of culture and culture change. A framework that addresses the inner dialectic between different temporal wavelengths and various socio-environmental phenomena becomes a powerful tool in deconstructing and reconstructing the past.

An assessment of the different wavelengths of history demonstrates the variability of socio-environmental responses oscillating around an equilibrium state at each temporal scale. Readjustments in the adaptive systems at each scale seek to maintain the equilibrium until a threshold is reached and behavioral accommodations adapt to the new equilibrium. Data from the two study sites record a change in preference for construction wood from *A. germinans* in the Early Classic, to *S. martinicensis* in the Late Classic. Deviations from these preferred species suggest adaptive adjustments of wood foragers to maintain efficiency while the shift in species preference can be attributed to a change in resource availability due to overexploitation of the local landscape. The establishment and abandonment of the salt works and the history of resource exploitation in Paynes Creek is tied into the wider regional demographic patterns of population growth and demand for salt, which in turn are reflective of system-wide responses to socio-environmental disruption and upheaval. Differences between charcoal and construction wood at Chan B'i further demonstrates the importance of context when discussing resource acquisition strategies. Wood selection and the relationship between human and environmental adaptations must be considered in relation to the specific functional demands of the resource. The differences in desired functional properties for fuel wood and construction wood determine the available resource base and the ranking of potential resources, and the consideration of the various contexts of wood selection enables recognition of holistic forest exploitation and management strategies. The Braudelian framework facilitates the isolation of particular contexts, while identifying the underlying socio-environmental processes and structures common to both wood and charcoal data sets, enabling the recognition of the appropriate realm of study for problem orientated research.

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CHAPTER 5. SUMMARY AND CONCLUSIONS

How people conceptualize, interact with, impact, and adapt to their surroundings is integral to reconstructing the past. Archaeologists develop a methodological and theoretical toolkit to analyze the material and environmental signatures of the past, reducing socio-environmental complexity into an understandable and meaningful discussion. The context of wood use at Paynes Creek provides a material record and heterogeneous landscape can be used to test theoretical principles of human behavior and provide insight into the challenges, impacts, and adaptations the ancient Maya faced in relation to the complex socio-environmental interactions.

Beyond the documentation of the wood and charcoal assemblage, this research applies frameworks to allow in-depth interpretation of the specific contexts of wood selection behavior for construction and combustion wood, as well as discussing the broader social, political, economic, and environmental processes and structures that form the archaeological record which are beyond the control of the forager.

The history of ancient Maya presence in Paynes Creek and the salt production industry is rooted in the regional socio-economics and politics. Temporal wavelengths as applied in Chapter 4, contextualize the salt works within the wider regional history, discussing the forces acting upon foragers, the processes that caused change, the structures that guide and bind decision-making and environmental response, and the creation and preservation of the archaeological record. Long and medium-term forces affect short-term choices and vice-versa, in a complex feedback cycle.

Regional demographics drove demand, with increasing population supporting salt production beyond the household level. Socio-political collapse at the end of the Late Classic interrupted salt demand, resulting in the abandonment of the salt works. The impacts of population pressure was felt in the landscape of Paynes Creek as the rising demand for salt required an increasing and continuous supply of wood to support the salt production industry, resulting in overexploitation of forest resources. By the Late Classic, suitable mangrove resources for construction posts were exhausted, requiring a change in foraging location and selection behavior. Although the wood data support a model of deforestation, the adaptations and resilience of foragers and the environment were able to offset the negative impacts of overexploitation, as such deforestation is not considered a causal factor in the cessation of salt production and abandonment of Paynes Creek.

At a finer scale, principles of optimal foraging provide insight into the specific contexts of wood selection for combustion and construction needs as discussed in Chapter 2 and Chapter 3. The application of optimal foraging concepts demonstrates the knowledge of tree resources and a cognitive selection process that was employed in wood foraging for specific wood needs. Decision-making is reflected in the differences in selection preference between construction wood and combustion wood at Chan B'i. The required physical properties of wood for the task at hand created distinct assemblages that reflect a holistic wood resource exploitation strategy. Preferred species were taken when encountered; however, foraging efficiency was a principle concern. When high ranked species were unavailable, a widening resource base of lower ranked species was exploited to fulfill demand.

Transport costs were an important consideration in foraging behavior. The immediate mangrove habitats that characterize the landscape around the salt works provided fuel and construction wood during the Early Classic at Chan B'i. *Avicennia germinans* was the favored construction wood, whereas *Rhizophora mangle* and *Laguncularia racemosa* were valued as wood fuel. The mangrove habitats were unable to fulfill all wood demands, so broadleaf patches were also exploited for construction and combustion needs as part of a holistic forest exploitation strategy.

Wood selection behavior is characterized by the dynamic interrelationships and adaptations of culture and the environment to each other over time. This research demonstrates the importance of the particulars of specific archaeology contexts in time and space, highlighting the value of paleoethnobotanical research in reconstructing the lives of past peoples.

VITA

Mark Robinson was born in southeast England to Kathy and Ken Robinson. While reading for a bachelor's degree in geography at the University of Portsmouth, Hampshire, researching environmental management in Belize, Mark came across the ancient Maya and his path was decided as a Mayanist. Before embarking into graduate research in the art history department at the University of Essex, studying Maya art and writing, he travelled to Mesoamerica to see the remnants of the ancient civilization. In the small, tranquil coastal town of Punta Gorda, Mark met Heather McKillop. One short introduction later and he was off to Paynes Creek to begin what would turn into his Ph.D. research at Louisiana State University.

During a decade long career in Maya archaeology, Mark has participated in archaeological investigations in southern, western, and northern Belize, exploring underwater, terrestrial, and cave contexts. Since 2012 Mark is the field director for the Las Cuevas Archeological Reconnaissance project and the Belize Cave Regional Archaeology Project, under the direction of Holley Moyes.

During his graduate career at Louisiana State University, while holding the Maya Archaeology Assistantship, Mark has taught courses in geography and anthropology. A Board of Regents grant awarded to McKillop enabled Mark to apprentice to Michael Wiemann, learning wood identification at the USDA Forest Products Laboratory, Madison, Wisconsin. His interest and experience transecting geography and anthropology manifested in his dissertation research on human-environment interaction related to ancient Maya wood selection behavior.