



Ancient Maya wood selection and forest exploitation: a view from the Paynes Creek salt works, Belize



Mark E. Robinson*, Heather I. McKillop

Louisiana State University, Department of Geography and Anthropology, 227 Howe-Russell-Kniffen Geoscience Complex, Baton Rouge, LA 70803, USA

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ABSTRACT

Ancient building construction wood preserved in a peat bog below the seafloor in a shallow mangrove lagoon in Paynes Creek National Park, Belize, provides an exceptional record of Classic Maya wood use. Identifications of construction wood at Early Classic Chan B'i, and Late Classic Atz'aam Na, are reported and discussed to assess forest exploitation and species selection over time. Black mangrove (*Avicennia germinans*) dominates the Early Classic assemblage. The Late Classic assemblage is characterized by greater variability and an absence of mangrove species. When considered in the environmental context, identified species conform to principles of optimal foraging. The change in the wood assemblage over time suggests overexploitation of forest resources, resulting in deforestation of the local landscape and subsequent adaptation of foraging behavior. Deforestation is linked to the wider social context in which growing inland populations created demand for salt, putting greater pressure on the forest resources exploited by the Paynes Creek salt works for fuel and timber.

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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 (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 (Dunning and Beach, 1994; 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).

Intensive and successful management of forest resources has been suggested for the ancient Copán society, Honduras, based on

* Corresponding author. Tel.: +1 225 578 5942.

E-mail addresses: mrobi15@lsu.edu, markrobinson.uk@gmail.com (M.E. Robinson).

palynological data from a sediment core (McNeil et al., 2010). The pollen profile of a core from Petapilla pond, 5 km from the Copán site core, 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, indicating a high degree of resource management at the time of greatest population pressure. Perhaps learning from the earlier overexploitation of forest resources (resulting in reduced forests in the Early Classic), managers were able to promote forest growth and preservation in Late Classic Copán.

The contrasting findings in forest management practices and their ecological impacts confirm the need for localized studies of the use of forest resources, and the adaptations of the ancient Maya. The heterogeneous socio-environmental landscape of the Maya area includes distinct localized ecological and social forces with distinct socio-environmental 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, paleoethnobotanical research cannot only reveal environmental data, but also assess human knowledge, 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 (Fig. 1), provides an opportunity to directly study wood exploitation and assess resource management and issues of anthropogenic environmental impacts, including 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. The taxonomic identification of archaeological samples is compared to foraging expectations under principles of optimal foraging to assess the factors driving resource exploitation. Species identifications from an Early Classic (A.D. 250–600) and Late Classic (A.D. 600–900) salt workshop suggest overexploitation of forests patches with a resulting change in forest composition and adaptation of selection behavior.

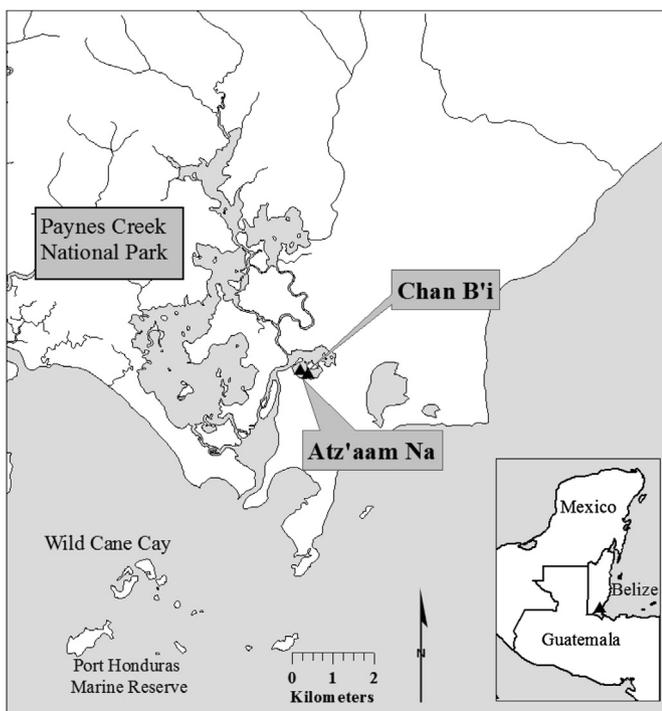


Fig. 1. Map of study area.

2. Optimal foraging and behavioral ecology

Optimal foraging models derive from evolutionary studies to explain and predict foraging behavior in terms of maximizing net returns per unit of foraging time within a particular environmental context, as a natural response to guarantee survival and reproductive success (Smith, 1983). Traditionally, optimal foraging has been applied to subsistence strategies in biology to model foraging behavior using encounter rates, processing time and gained energy (calories), to model diet choices; however, the principles can be applied to the procurement of other resources (Marston, 2009).

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). Principles of patch choice and prey choice are used here to evaluate wood selection strategies at the Paynes Creek salt works. 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, cultural considerations, and alternative strategies (Jochim, 1988; Marston, 2009; Stephens and Krebs, 1986). The forager searches for all resources simultaneously. Upon encounter with a potential resource, the forager is faced with the decision of whether to extract that resource or continue the search for alternatives. Highly ranked resources will always be selected when encountered. Lower ranked resources are only taken when the perceived costs of continuing the search outweigh the potential benefits of finding a higher ranked resource. As higher ranked resources become scarce, a forager will add a wider range of resources of descending rank to their search/diet (Bird and O'Connell, 2006).

Imposing a ranking of resources is complicated by the high diversity of tropical forests, an unknown past forest composition, and the difficulty in accurately including all socio-environmental variables in a model (Marston, 2009); however, archaeological data can be tested against the assumptions derived from principals of optimal foraging to inductively reconstruct selection behavior, resource preferences, and the factors influencing selection. Applied to wood selection for construction timbers, the following expectations can be made under optimal foraging:

- 1) High frequency taxa reflect high preference. Although availability will impact the presence of taxa. A high ranked resource with low availability may have a low frequency in the archaeological record despite the preference for the species.

- 2) Low frequency taxa reflect low preference.
- 3) A low variability in taxa reflects the availability of higher ranked resources, allowing more specific selection for the few preferred species.
- 4) A high variability in taxa reflects a lack of high ranked resources, with foragers exploiting a wider resource base that include lower ranked resources.
- 5) Foragers will select resources with functional properties suited to the demand. For construction wood, strength, durability, length, and straightness are likely to be desirable physical properties.
- 6) Overexploitation of resources will result in the utilization of resources of lower functional suitability.
- 7) Patch choice will be made on the perceived chance of successful and efficient return. An efficient forager will exploit the closest resource patches to avoid the time and labor costs associated with increasing distance. The closest habitat to the sites is mangrove forest, therefore a high presence of mangrove taxa in the archaeological assemblage would fit the basic assumptions of efficiency.
- 8) Deforestation and exhaustion of resources within a foraging patch will result in a change in patch choice.
- 9) Species diversity, richness, and the growth habits of broadleaf forest provides a high proportion of viable resources, delivering a good chance of foraging success with low search times. A high proportion of broadleaf species may reflect patch choice decisions to increase chances of success, and/or the exhaustion of the closer mangrove resources.
- 10) A high frequency of taxa that do not fit within optimal foraging criteria likely reflect the importance of cultural value associated with specific species and resource selection.

These expectations assess elements of optimization in relation to distance to resource, patch assessment (i.e. species richness and diversity within a patch and therefore the number of potential resources), the functional properties of selected resources, and socio-environmental change over time. Archaeological samples are tested against the expectations relating to these features to assess whether foraging behavior was guided by these criteria.

The assumptions should be considered within the active social and environmental context. Environmental systems are not static entities upon which humans act, but rather dynamic interconnected systems subject to periods of stability, fluctuation and change. Natural and anthropogenic processes and changes in forest composition impact foraging decisions in a dynamic feedback mechanism. In a coastal environment, changes in hydrology, including fresh water inputs and sea-level rise can impact forest patches through localized changes in nutrient balance, salinity, sedimentation, and inundation (Feller, 1995; McCloskey and Liu, 2013; Monacci et al., 2009, 2011). Broader climatic affects, such as droughts, can cause considerable disruption to ecosystems, and has been linked to social change (Haug et al., 2003; Hodell et al., 1995; Kennett et al., 2012). While these environmental conditions can place strain on ecological systems and flora, the effects are exacerbated and often overwhelmed by human action during these fragile periods. Understanding of human–environment interaction has increased in complexity over the years, with greater comprehension of the change, resilience and adaptation of communities and ecological systems in the face of natural and anthropogenic environmental impacts and change (Redman, 2005; Walker et al., 2006). The diachronic nature of this study enables the documentation of selection behavior through time, allowing assessment of the socio-environmental processes that effect changes in resource selection and resource availability.

A benefit of employing an optimal foraging framework is that it provides a method for testing assumptions of foraging behavior without requiring a certain outcome to validate or negate the theoretical framework. Rather than being a rigid model to which data is applied to provide support for the theory, the patterns of the archaeological data are tested against the framework of expectations to determine whether or not there was specific species selection for construction timber based in principles of efficiency. If the archaeological data do not match the assumptions then principles other than optimization guided foraging behavior.

Maya ethnobotany and paleoethnobotany has typically utilized, and benefited from, a cultural approach to understanding flora, developing understanding of folk taxonomy, cosmological beliefs, plant use, floral markers of fertile land, and processes of succession (Barrera-Bassols and Toledo, 2005). Ethnographic research has provided great insight into folk taxonomy, and plant use, revealing indigenous conceptions and uses of flora (Alcorn, 1984; Amiguet et al., 2005; Arvigo and Balick, 1993; Barrera-Bassols and Toledo, 2005; Atran and Ucan Ek', 1999; Breedlove and Laughlin, 2000; Metzger and Williams, 1966; Taube, 2003). Contextual discussion of archaeological botanical samples has provided insight into the use and conception of select, culturally valued species, such as pine (*Pinus* sp.) in various contexts, from elite to er, and agricultural to ceremonial (Lentz et al., 2005; Morehart, 2011; Morehart and Helmke, 2008; Morehart et al., 2005; Wyatt, 2008).

Breedlove and Laughlin (2000) document the classification of flora into three groups by the Zinacanteco of Chiapas, Mexico. Vines are classified *ak'*, tree plants with woody stems are assigned to *te'*, and other non-woody plants are classified *tz'i'lel* (Breedlove and Laughlin, 2000). Within these groups flora are assigned to sets according to similarities and shared attributes including morphology, silhouette, use, or a single feature such as toxicity (Breedlove and Laughlin, 2000). Similarly, Metzger and Williams (1966) employ a linguistic approach to analyzing resource classification for the modern Tzeltal Maya, documenting the terminology used to classify and evaluate woody resources as firewood. All firewood comes from the *te'* "tree" set of flora. Within this group, trees are evaluated for use and may be further qualified as either good or bad at that function, with appropriate terms used to characterize each potential resource (Metzger and Williams, 1966). In a study of modern Maya houses, Wauchope (1938) documents the form and materials used for building construction. Informants revealed the utilization of different resources for the various functional demands within a structure, such as the strength and durability needs for upright posts, with the preferred species termed "earth wood" in relation to their ability to avoid rot while in the ground (Wauchope, 1938: 32). While these studies are invaluable, Metzger and Williams (1966) do note that there is not a uniform conception, knowledge, and classification of flora amongst people, and they note, "the occurrence of "charcoal" *ak'al* in this classificatory array is not paralleled by actual use or manufacture of charcoal..." (p395), demonstrating that the classification scheme does not necessarily reflect actual behavior.

A framework derived from principles of optimal foraging offers a number of benefits that cultural approaches to ethnobotany alone cannot address. The framework facilitates the assessment of an archaeological sample for which there may be limited or non-existent cultural data, especially as the low presence of modern Maya populations in coastal environments has resulted in a lack of analogous ethnobotanical data addressing human–environment interaction and wood resource exploitation within coastal habitats.

The presence of the identified taxa confirms the actual use of these species in construction against the changing ecological context. The issues of disparities among individuals' evaluations and classifications of resources and the actual use of flora are

removed when assessing the record of actual wood use. Working from an archaeological sample where all identified taxa were selected for use as upright posts in construction, applying the folk taxonomy as documented by Breedlove and Laughlin (2000) and Metzger and Williams common (1966) would likely place all identified taxa in the *te'* "tree" group, and possibly within the same or similar set based on use. All the identified taxa were determined to be acceptable materials as standing construction posts, although some of the species may be assigned primacy and preference as a construction material in folk classification. Although the study incorporates all wooden posts discovered at the two sites, future research, incorporating samples from more workshops will refine selection preferences. Testing the archaeological record against the assumptions of optimal foraging inductively reconstructs resource selection and preference, and if the data do not meet the foraging expectations, a level of cultural value attached to species and employed in resource selection can still be determined.

3. Archaeological and ecological context

In this diachronic study, wood assemblages are compared 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 (A.D. 440–490, A.D. 520–640, 2σ) and a Late Classic date at Atz'aam Na (A.D. 660–890, 2σ). The sites share a geographic resource base, located just 300 m apart in the eastern arm of Punta Ycaos lagoon, a micro-tidal coastal lagoon system within Paynes Creek National Park (Fig. 1). Chan B'i is located in the middle of the open water of the lagoon in deeper water than Atz'aam Na, which is closer to the shore, possibly suggesting that the Early Classic location was abandoned due to rising sea-level. Archaeological survey has located over 100 inundated salt works in the Paynes Creek lagoon system, indicating the presence of an extensive salt production industry (McKillop, 1995, 2002, 2008). Systematic survey of the sites resulted in the discovery of wooden posts preserved in the anaerobic mangrove peat below the seafloor (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, with demand for salt likely expanding beyond the household level. The regional population reached its peak in the Late Classic, with an increasing number of inland centers spread across the landscape (Braswell and Prufer, 2009). Salt production expanded in line with the increasing regional population and rising demand for salt during the Late Classic with the establishment of more salt works in the lagoon system. 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 300 cm in the south, compared to 150 cm 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; Fig. 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 (*Acoelorrhaphe wrightii*), oak (*Quercus oleoides*), and extensive monotypic stands of pine (*Pinus caribaea*). 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,

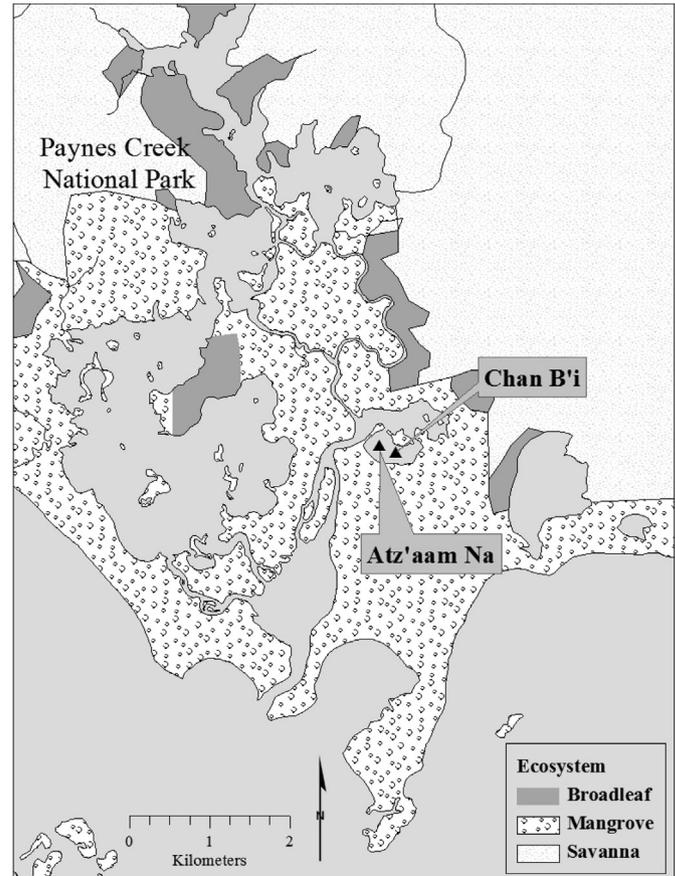


Fig. 2. Map of Broad Ecosystem Classifications in Paynes Creek National Park.

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.

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 heavy 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.

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 seafloor. Exposed wood above the seafloor has decomposed, whereas wood in the anaerobic matrix is preserved. All posts discovered at the two 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 desalinate them.

Wood samples were sectioned along the transverse, tangential and radial planes using a backed razor. The thin sections were mounted on a glass slide for observation of anatomical features using a 10×–100× transmitted light microscope. Gross anatomical features were intact in the waterlogged wood, with some decomposition present. 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,

2004; Barajas-Morales et al., 1997; Detienne and Jacquet, 1983; Kribs, 1968). Identifications were made to the lowest taxonomic unit, with anatomical structure generally allowing separation to the genus level.

The assessed value and ranking of wood resources depends on the function to which the wood is put. In a combustion context, the amount of heat, speed of burn, spitting, and smoke generation are important, whereas for construction wood, length, straightness, strength and durability are typically of paramount concern. To assess whether the functional characteristics of the timber used was a factor in selection choice Specific Gravity (SG) was used as a proxy measurement of wood strength. 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 (strength and durability) of the wood was an important factor in wood selection for construction wood. 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.

5. Results

5.1. Wood species identification

Table 1 documents the wood taxa identified for wood posts at Chan B'i. Thirty-three samples were analyzed, with seven identified taxa represented. Four samples could not be identified due to structural degradation. *A. germinans* (black mangrove; Fig. 3A), easily recognizable by concentric bands of phloem, dominates the assemblage representing 34% of the total sample (Fig. 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. (Fig. 3D) and *Ficus* sp. (Fig. 3I) both occur twice. Only *C. brasiliense* (Santa Maria; Fig. 3G and H) appears a single time.

Of the 25 identified wood samples from Atz'aam Na, ten taxa were identified (plus two unidentified samples; Table 2). Atz'aam Na also shows a single dominant species, *Symplocos martinicensis*, identifiable by the presence of scalariform plates (Fig. 3B) and multiseriate rays, representing 44% of the total assemblage (Fig. 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 (Fig. 3C). The remaining seven genera appear only once each. Out of 17 total identified taxa from the two sites, four occur at both sites.

Table 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	<i>Avicennia germinans</i>	Black mangrove	11	34	0.9
Chrysobalanaceae		Pigeon plum	3	9	0.9
Clusiaceae	<i>Calophyllum brasiliense</i>	Santa Maria	1	3	0.47
Euphorbiaceae	<i>Hieronyma</i> sp.	Redwood	4	12	0.63
Flacourtiaceae	<i>Casearia</i> sp.	Billy hop	2	6	0.66
Moraceae	<i>Ficus</i> sp.	Fig	2	6	0.4
Myrtaceae	<i>Eugenia</i> sp.	–	6	18	0.7
–	Unknown hardwood	–	4	12	
	Total		33	100	

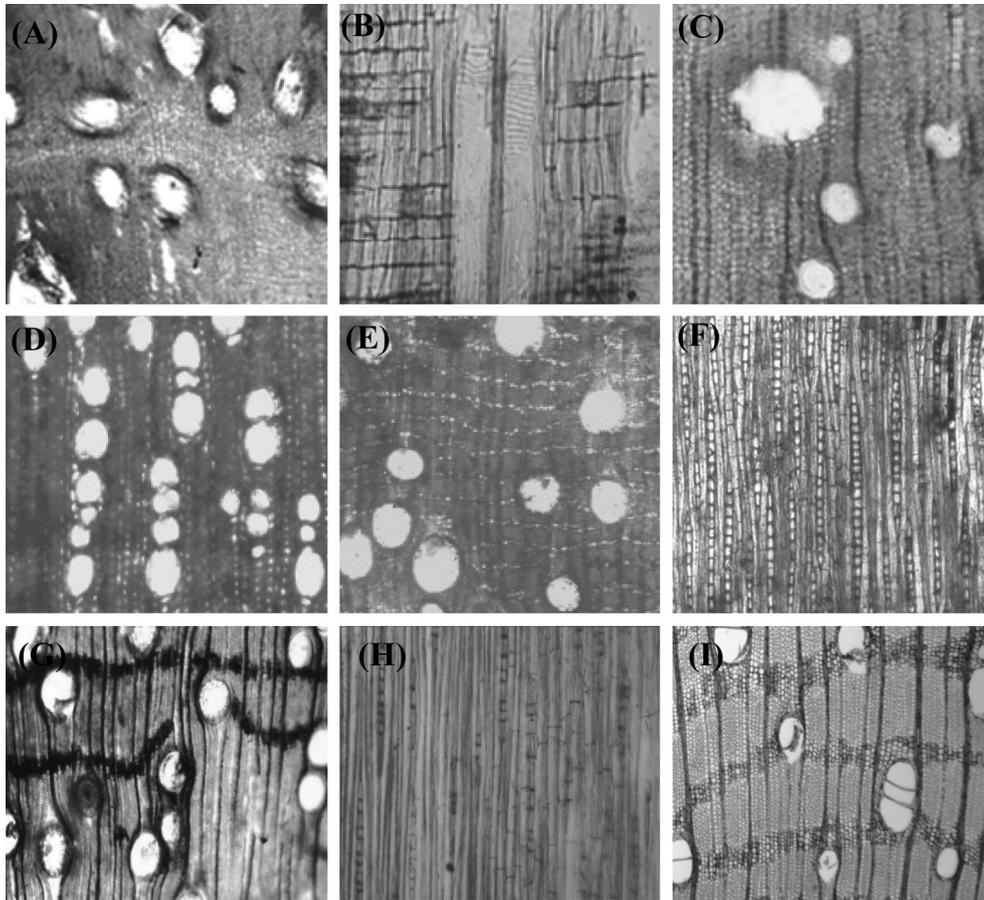


Fig. 3. Microphotographs of archaeological wood from Paynes Creek National Park: (A) *Avicennia germinans*, transverse section; (B) *Symplocos martinicensis*, radial section; (C) *Mouriri* sp., transverse section; (D) *Casearia* sp., transverse section; (E) Chrysobalanaceae, transverse section; (F) Chrysobalanaceae, 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.

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 (50–100 µm), suggests the species *H. oblonga*; however, overlap in anatomical variability negates classification beyond the genus level.

Samples identified to Chrysobalanaceae display solitary vessels, uniseriate rays and banded axial parenchyma one cell wide (Fig. 3E and F). 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.

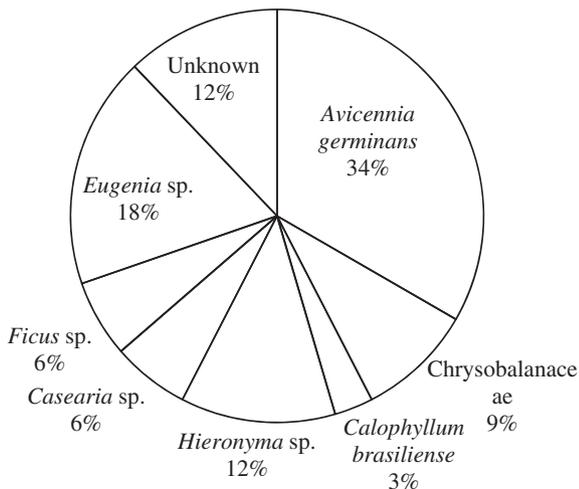


Fig. 4. Pie chart showing relative proportion of taxa at Chan B'i.

Table 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	<i>Alchornea</i> sp.	Fiddlewood	1	4	0.4
Euphorbiaceae	<i>Hieronyma</i> sp.	Redwood	1	4	0.63
Flacourtiaceae	<i>Casearia</i> sp.	Billy hop	1	4	0.66
Leguminosae	<i>Dalbergia</i> sp.	Rosewood	1	4	0.82
Melastomataceae	<i>Mouriri</i> sp.	Cacho de venado hembra	2	8	0.9
Moraceae	<i>Ficus</i> sp.	Fig	1	4	0.4
Myrtaceae	<i>Eugenia</i> sp.	—	3	12	0.7
Myrtaceae	<i>Myrciaria floribunda</i>	Walk naked	1	4	0.73
Sapindaceae	<i>Matayba</i> sp.	Bastard willow	1	4	0.82
Symplocaceae	<i>Symplocos martinicensis</i>	—	11	44	0.8
—	Unknown hardwood	—	2	8	—
Total			25	100	

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).

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

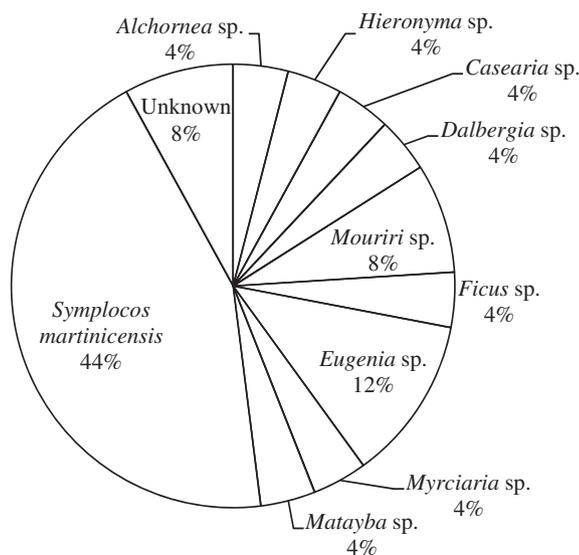


Fig. 5. Pie chart showing relative proportion of taxa at Atz'aam Na.

available for *S. martinicensis*. In Nepal, *Symplocos 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 (Standley 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.

5.4. Specific Gravity

Tables 1 and 2 record SG values for identified taxa as a proxy for strength. Fig. 6 charts SG values compared to the frequency of

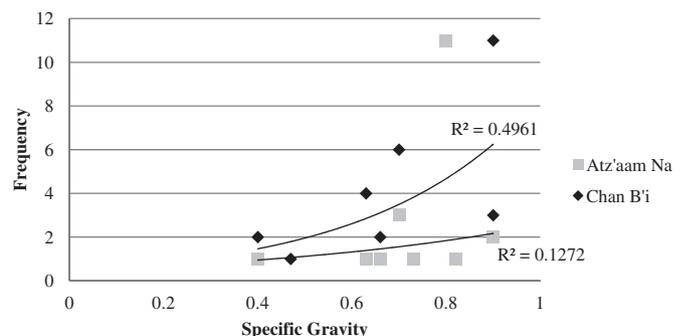


Fig. 6. Relationship between specific gravity values and the frequency of taxa at Chan B'i and Atz'aam Na.

identified species from Chan B'i and Atz'aam Na to assess the possible role of wood strength in wood selection. Chan B'i shows a higher correlation between SG and frequency ($R^2 = 0.4961$) than Atz'aam Na ($R^2 = 0.1272$). 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.

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. The extensive salt production industry in Paynes Creek (McKillop, 2008) required large quantities of wood for construction timbers, and in particular as fuel to maintain the fires needed in the production process. The extraction of wood resources results in a complex feedback mechanism of socio-environmental adaptation as foragers adjust to natural and anthropogenically driven environmental change and succession.

Principles of behavioral ecology and optimal foraging are useful for interpreting wood selection strategies at the Paynes Creek sites by providing a set of expectations against which to test archaeological data. 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 over-exploitation of the environment resulting in a change in resource availability, including the exhaustion of suitable mangrove trees for construction wood. Foragers adapted to the changing conditions, changing selection behavior and preferences to the altered forest composition and resource availability.

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. In a lagoon system dominated by mangrove habitats, *A. germinans* is one of the few functionally viable species available for construction wood, and would have therefore likely 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, requiring a change in patch choice to an alternative habitat with a greater chance of successful return, rather than suffering the increased costs of continuing the search within the depleted mangrove habitats. The presence of multiple tree species with long, straight trunks of acceptable strength and durability within the broadleaf forest patches meant a wide resource inventory could be utilized and little time needed to be spent foraging for select functionally suitable species.

The frequency of *S. martinicensis* at Atz'aam Na implies a change in environmental availability. The absence of the species at Chan B'i indicates the lack of availability of *S. martinicensis* within the exploited forest patches during the Early Classic. The preference for

S. martinicensis in the Late Classic would suggest that had the species been available within the foraging locations during the Early Classic, the species would have been selected. 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 typically 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.

Changes in forest composition due to anthropogenic disturbances through the extraction of resources can be lessened or heightened through natural environmental processes. Climate proxies have documented high rainfall during the Early Classic followed by a drying trend during the Late Classic (Kennett et al., 2012). Increasing aridity and droughts likely created water shortages and agricultural failure, which has been linked to socio-political disturbance and collapse (Hodell et al., 1995; Kennett et al., 2012). The fragility of forest patches, and in particular the broadleaf patches surrounded by saline water, increases with the decrease in fresh water inputs. Resource extraction during this period would increase evapotranspiration and negatively impact seedling recruitment, tree growth, and tree survival. The adaptations of *A. germinans*, however, especially in relation to salt and toxin tolerance, increase the species' competitive advantage during arid periods (Ellison and Farnsworth, 1996). Furthermore, Toscano and Macintyre (2003) present a model of decreased sea-level rise during the Classic period. A slowing in the rate of sea-level rise has been linked with decreased sedimentation and increased salinity, creating conditions that favor the adaptations of *A. germinans* (Ellison and Farnsworth, 1996; Monacci et al., 2011; Wooller et al., 2007). As such, the exhaustion of *A. germinans*, as suggested by the archaeological record, further supports the overexploitation of the mangrove resource by foragers.

Extensive research on the environmental impacts on mangrove communities has recorded a variety of localized responses, including changes in forest composition, stature, and survival, although unfortunately there is limited high-resolution data for the time period associated with ancient Maya occupation (Ellison and Farnsworth, 1996; McCloskey and Liu, 2013; Monacci et al., 2009, 2011). Ellison and Farnsworth (1996) note that, "direct and indirect anthropogenic impacts on mangal (mangrove communities) dwarf natural disturbances in their spatial scale and severity, and their temporal persistence, and are now considered to be major determinants of mangrove community composition and extent world-wide."

The coast of Belize has been characterized by the response of mangrove communities to sea-level rise. Sediment cores along the coast reveal a Holocene history of mangrove peat formation keeping pace with sea-level rise (MacIntyre et al., 2004; McKee and Faulkner, 2000). Localized disturbances and changes in the rate of net sea-level rise create periods of disrupted vegetation and sedimentation (McCloskey and Liu, 2013; McKee and Faulkner, 2000; Monacci et al., 2011). The abandonment of the Early Classic site, Chan B'i, and later inundation of the salt works in Paynes Creek, may be related to mangrove disturbance. The felling of mangroves to establish the workshops, alongside the impacts of trampling,

halted the production of mangrove peat at the workshop locations, with the rising waters subsequently covering the sites. Although human impacts likely overwhelmed natural processes of forest succession, targeted paleoenvironmental reconstruction within the sheltered lagoon system at Paynes Creek will provide greater understanding of the environmental conditions and forest composition during occupation of the salt works.

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 400 m² 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 (Murca 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 19 m² and 24,000 m², 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 variability at the two sites is relatively low in comparison to the richness of a typical tropical forest. The low variability likely reflects the specific selection of construction woods, in which the full range of trees in the forest patches were not exploited.

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.

6.3. Functional demands and selection

Strength and durability appear to have been important considerations in the selection and ranking of potential construction wood resources. The most dominant taxa, *A. germinans* and *S. martinicensis*, are two of the highest 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 for timbers 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. Alongside the relatively low variability of taxa in the archaeological record, the relatively high SG of the selected species suggests that the functional characteristics (i.e. strength) was a principle concern in determining what trees were available as potential construction posts.

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 demand for resources overburdens the environment's carrying capacity. Natural environmental forces also exert influence over forest health and resilience and can intensify human impacts. 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 at large population centers 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, 2011; McNeil et al., 2010) 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 for construction wood in elite temples. The low resource demands and adaptability 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 paleoethnobotanical 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. The overexploitation of the forest can be linked to the pressures exerted by the salt demands of the regional population and the subsequent impacts on the forest patches close to the salt works in order to provide construction wood and fuel wood to maintain the fires required to produce salt. Despite the evidence for deforestation, the abandonment of the salt works is not directly linked to resource exhaustion as foragers were able to adequately adapt. Salt production ceased with the decline in demand associated with the socio-political collapse of the interior centers.

Forest resource management at Paynes Creek provides a case study of low intensity management practices, but adaptive foraging. The higher variability and reduced frequency of taxa that characterize the difference between the Early and Late Classic sites, alludes to the use of a widening 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 in the Late Classic, its presence suggests the exploitation of different patches, where *S. martinicensis* was available in numbers to allow preferential selection, than those utilized in the Early Classic as foragers adapted to the changing resource base. Future research, incorporating more intensive dating and high resolution ecological studies may refine the characteristics, processes, and chronology of socio-environmental change.

7. Conclusions

New paleoethnobotanical data are challenging traditional views of ancient Maya land stewardship and forest management. Pressures were not the same across ancient Maya society. Understanding the paleoethnobotanical record requires a broader comprehension of the local environment, the pressures placed upon the environment, and the response of communities to societal demands. 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 among the various communities. 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 to maintain environmental composition. 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 lower resource demand 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 new inland centers established and populations increased, demand for salt increased resulting in greater activity at the salt works, with more demand for wood for new construction and to provide for the constant need for wood to fuel the salt production process. The archaeological record of Paynes Creek shows a wood exploitation strategy that follows principles of optimal foraging in which a functionally suitable resource was selected with the least costs in terms of the searching and processing time. Mangroves, as the closed resources, were initially exploited, keeping costs associated with distance to a minimum. Viable mangrove species for use as construction posts were exhausted over time. The result was a change in patch choice and a widening of the resource base to include a greater number of lower ranked species. Although limited on the landscape, broadleaf patches provided a species richness and diversity that provided a high chance of successful return for viable resources that meet the functional demands of construction posts. The case study demonstrates the importance of localized studies of human–environment interaction and the intricate relationship between the Maya, their local environment, and broader social trends.

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