Fuelling the Ancient Maya Salt Industry[1]

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Fuelling the Ancient Maya Salt Industry. The ancient Maya of Paynes Creek National Park in coastal southern Belize produced salt by boiling brine in ceramic vessels above fires. The process requires a constant supply of wood to maintain the fires. Charcoal recovered from Chan B'i, an Early Classic (300–600 C.E.) salt work, provides a record of fuel wood selection within a workshop context. Taxonomic identifications reveal a selection preference for species from both mangrove and broadleaf habitats. Wood from the Chrysobalanaceae family dominates the assemblage. *Rhizophora mangle* L., *Laguncularia racemosa* (L.) C.F. Gaertn., and *Hieronyma* sp. were also preferred wood fuel species. A total of 21 species were identified in the assemblage. Charcoal identifications are considered in terms of selection strategies within a heterogeneous landscape to better understand forest exploitation behavior for wood fuel. Selection follows principles of optimal foraging in which transport cost was a principal concern for foragers.

Key Words: Ancient Maya, Paynes Creek, charcoal, wood fuel, salt production.

Introduction

Despite the often poor preservation of organic wood in the humid climate of Mesoamerica, the paleoethnobotanical work that has been undertaken has revealed insights into ancient Maya diet, agriculture, ritual, forest management, use of economic species, cultural beliefs, and social organization (Lentz 1999; Lentz and Hockaday 2009; Morehart 2011; Morehart and Helmke 2008; Wyatt 2008). In this study, charcoal identifications from Chan B'i, an ancient Maya salt workshop in Paynes Creek National Park, Belize, explore wood fuel selection for an industry with a high fuel demand.

Fuel wood selection may be influenced by a range of environmental and cultural factors, including availability, processes of ecosystem succession, combustion properties of the wood, size of wood, the type of fire needed, smoke generation, length of time since cut (green wood versus seasoned or dead wood), water content, available labor, availability of time for procurement and preparation, and cultural concepts of preference, the sacred and the taboo (Picornell et al. 2011; Tabuti et al. 2003; Théry-Parisot et al. 2010). Globally, communities prioritize different factors in fuel wood selection. 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 classificatory 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, whereas specific demands for construction wood incorporated long-distance procurement strategies (Marston 2009).

In the Maya lowlands, where collections allow, archaeobotanists have speculated on fuel use (see Lentz 1999 for a list of taxonomically identified

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wood and charcoal remains at Maya sites, noting proposed usage). In particular, pine (*Pinus* spp.) has been discussed in combustion contexts (Lentz et al. 2005; Morehart et al. 2005; Morehart and Helmke 2008; Wyatt 2008). Pine was an important, culturally valuable commodity, as evidenced by its presence in contexts far from pine sources (Morehart et al. 2005; Wyatt 2008), its use in ceremonial contexts (Lentz et al. 2005; Morehart et al. 2005), and differential, socioeconomically contingent access to the resource (Morehart and Helmke 2008). The cultural preference for pine, especially in ritual settings, such as caves, likely derived from the species' combustion qualities, light production, smoke generation, and fragrant aroma (Morehart et al. 2005).

In this study, identified wood charcoal is associated with apparatus used in the salt production process, providing an ideal context to directly assess wood fuel selection in a workshop setting. Principles of optimal foraging (MacArthur and Pianka 1966; Stephens and Krebs 1986) are employed as a framework for testing the archaeological record to assess wood fuel acquisition. Rooted in environmental composition and distribution, optimal foraging assumes that foragers make decisions based in efficiency, with the closest available resources exploited. Archaeological data are tested against these assumptions to assess whether selection behavior conforms to this principle. Data that do not conform suggests other factors were of importance in fuel wood selection. Results from charcoal identifications at Chan B'i reveal the exploitation of both mangrove and broadleaf ecosystems, and suggest the use of multiple strategies for resource procurement that included considerations of proximity, species preference, opportunistic foraging, and an avoidance of certain species.

Ecological Context

The salt workshop Chan B'i is located in a shallow, micro-tidal lagoon, in Paynes Creek National Park in coastal southern Belize (McKillop 2005a; Fig. 1). The climate is defined by a wet and dry season, with an average rainfall of over 300 cm. Sea-level rise and subsidence have inundated the salt works under 40–80 cm of water.

High salinity and coastal geomorphologic processes dictate ecosystem distribution (Fig. 2). Salt-tolerant mangroves comprise the majority of the vegetative environment. Analysis of peat fibers and pollen from sediment cores from the lagoon confirms the dominance of the mangrove ecosystem throughout the Holocene (McKillop et al. 2010a, b). *Rhizophora mangle* L. (red mangrove) is the principal species present, often forming a homogenous monotypic landscape. Small numbers of *Avicennia germinans* L. (black mangrove) and *Laguncularia racemosa* (L.) C.F. Gaertn. (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* [Griseb. & H. Wendl.] ex Becc.) and patches of broadleaf forest occur. Savanna environments are present on the coastal plain within 3 km of the salt workshop. The savanna is composed of large open grasslands and stands of *Pinus caribaea* Morelet. Other tree species on the savanna include oak (*Quercus oleoides* Schltdl. & Cham.), crabboe (*Byrsonima crassifolia* [L.] Kunth), and sandpaper tree (*Curatella americana* L.), although the presence of these taxa is limited and in a scattered distribution. Broadleaf stands in the immediate area are geographically limited and patchy. When present, they are characterized by an association dominated by nargusta (*Terminalia amazonia* [J.F. Gmel.] Excell), Santa Maria (*Calophyllum brasiliense* var. *Rekoi* Standl.), yemeri (*Vochysia hondurensis* var. *parvifolia* Stafleu.), and waika chewstick (*Symphonia globulifera* L.f.; Standley and Record 1936). A wide array of other tropical tree species are also present in the broadleaf patches (see Standley and Record 1936; Wright et al. 1959).

Archaeological Context

Current archaeological evidence suggests that southern Belize was occupied by small inland farming and coastal fishing communities until the end of the Late Preclassic, when larger centers established inland (Prufer et al. 2011) and coastal trade developed (McKillop 2005b). As a basic dietary necessity, the need for salt associated with expanding regional populations created a demand beyond the level of household production, providing the impetus for the establishment of the Paynes Creek salt works. Archaeological research in the lagoon system has identified salt works occupied throughout the Classic Period (300–900 C.E.; McKillop 2002, 2005a, 2007), mirroring the regional population dynamics.

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, including wooden posts (Robinson and McKillop 2013). The abandonment of the inland urban centers resulted in a decline in demand for salt, leading to the cessation of salt production in the Terminal Classic period (850–900 C.E.). Chan B'i, a salt production workshop radiocarbon dated to the Early Classic (440–490 C.E., 520–640 C.E., 2σ), is located in the eastern arm of Punta Ycacos lagoon in Paynes Creek National Park (Fig. 1).

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). 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 heating 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). Adshead (1992) documents an energy

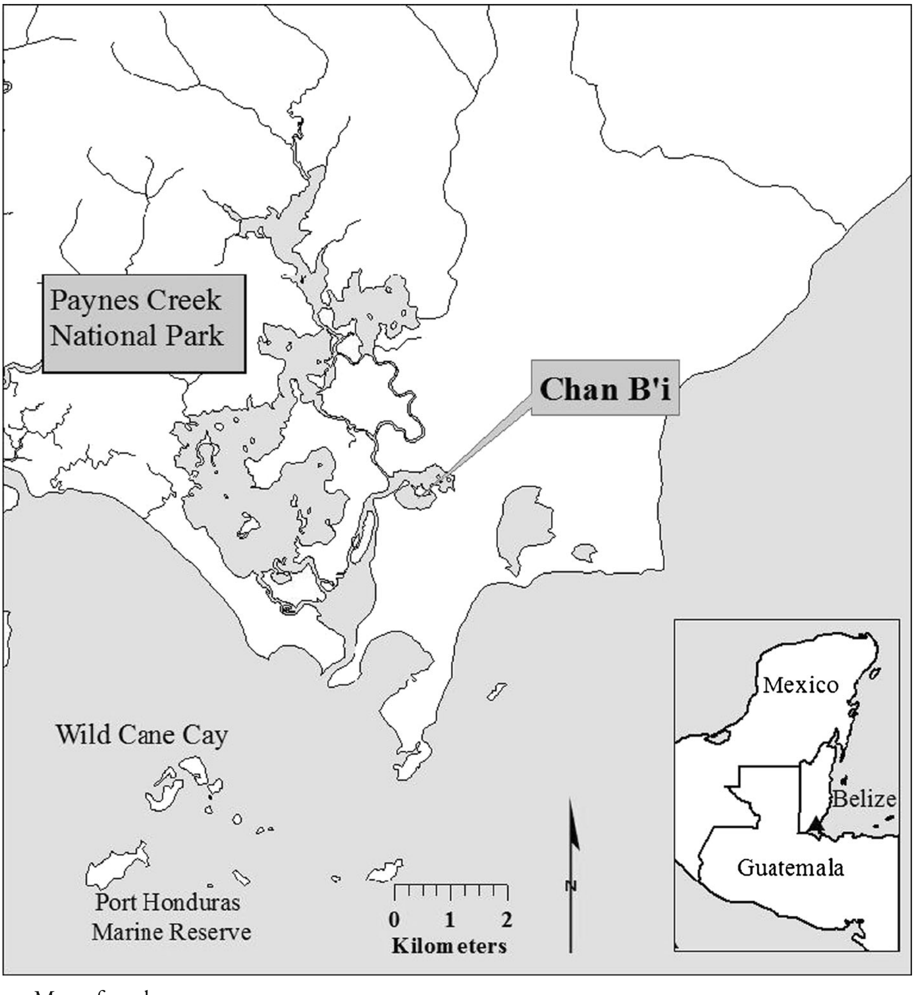

Fig. 1. Map of study area.

crisis in sixteenth-century China 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. Thus there is a lack of information on specific woods utilized, forest management, and ecological adaptations in fuel procurement.

Methods

Charcoal was recovered from underwater excavations at Chan B'i associated with briquetage.

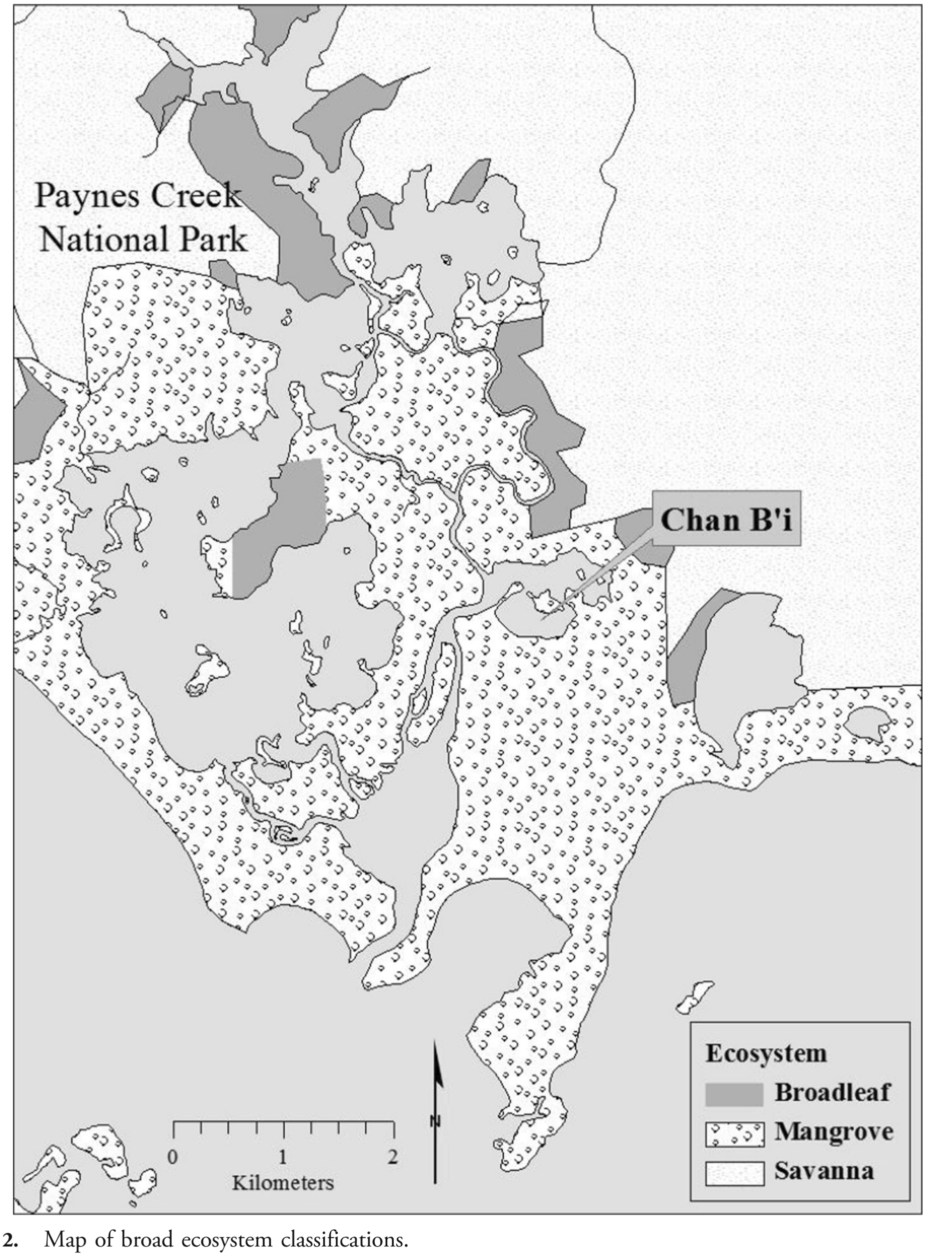

Fig. 2. Map of broad ecosystem classifications.

All encountered charcoal was collected from two trench excavations across the site, representing multiple contexts. The inundated nature of the site did not allow separation of individual contexts. Charcoal samples were identified using standard methods (Figueiral and Mosbrugger 2000). 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 2004; Barajas-Morales et al. 1997; Detienne and Jacquet 1983; Kribs 1968). 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 physical characteristics of the wood were an important factor in wood selection. SG is a measure of the structural material allocated to support and strength (Williamson and Wiemann 2010), calculated as green weight/oven dry weight divided by fresh volume (Muller-Landau 2004; Williamson and Wiemann 2010). Although oversimplified, high wood density is a desirable trait in fuel woods (Goel and Behl 1996), typically correlating with thermal conductivity (Ragland et al. 1991). Denser woods, however, often come at a higher cost in terms of energy expenditure in felling and processing.

Results

Taxonomic identification was attempted on all charcoal fragments >1 mm collected during excavation. A total of 310 charcoal fragments, weighing 120.85 g, were recovered from the excavations at Chan B'i. One hundred ninety-one fragments, representing 21 taxa, were identified (Fig. 3; Table 1). Taxonomic counts represent Number of Identified Specimens Present (NISP). An additional indeterminate category represents samples that could not be identified (n = 119, 22.12 g weight). A directly proportional relationship exists between fragment count and weight for the identified taxa (Fig. 4; R^2 = 0.7169). Researchers have demonstrated that there is little difference in fragmentation and mass reduction among species (Asouti and Austin 2005). Thus 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 10.42 g provides an anomalous result; however, the pine fragment is large and not fully combusted and may not have been used as fuel. Certain types of wood function may be underrepresented, such as wood used as kindling, which is unlikely to leave any remains due to complete combustion. Other wood species used in low frequency may also be missing from the record due to complete combustion or lack of preserved structure. Future analysis of botanical remains from other contexts in Paynes Creek will create a more complete understanding of wood resource use. The 119 indeterminate samples are mostly <2 mm in size and either too small to identify or too degraded to analyze wood structure.

Exploited Ecosystems

Table 1 and Fig. 5 show the proportion of taxa by habitat of growth, divided amongst mangrove, broadleaf, and savanna habitats. 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 and isolated pockets containing a mixture of species (Farruggia et al. 2008). For this discussion, species are assigned to an ecosystem of growth based on local growth habits, field observations, documented voucher specimens, and the closest supporting habitat. 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 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.

Exploited Taxa

Four taxa stand out in the assemblage for both counts and weights: *L. racemosa* (n = 16, 8.99 g; Fig. 6e,f), *Hieronyma* sp. (n = 21, 15 g), *R. mangle* (n = 28, 18.55 g; Fig. 6c,d), and the dominant Chrysobalanaceae (n = 85, 31.13 g; Fig. 6a,b). Fourteen of the identified taxa have three instances or less. *Alchornea latifolia* Sw. and *Casearia* sp.

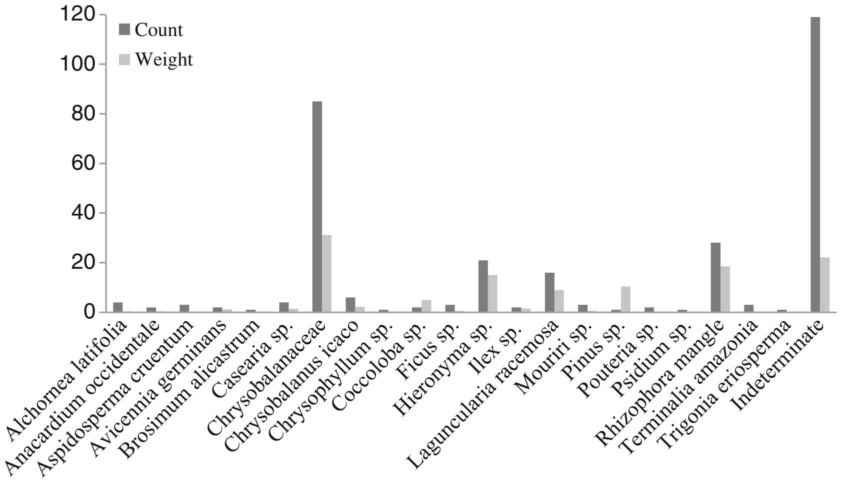

Fig. 3. Charcoal identifications from Chan B'i.

appear four times, whereas *Chrysobalanus icaco* L. has six occurrences.

The New World mangrove species *R. mangle, L. racemosa,* and *A. germinans* (n = 1) are 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 in architecture.

Table 1. Charcoal identifications from Chan B'i. (Specific gravity [SG] 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* L.	black mangrove	2	1.28	0.90
Chrysobalanaceae	*Chrysobalanus icaco* L.	coco plum	6	2.18	0.80
Combretaceae	*Laguncularia racemosa* (L.) C.F. Gaertn.	white mangrove	16	8.99	0.60
Polygonaceae	*Coccoloba* sp.	sea grape	2	4.90	0.80
Rhizophoraceae	*Rhizophora mangle* L.	red mangrove	28	18.55	0.84
Broadleaf Habitat					
Euphorbiaceae	*Alchornea latifolia* Sw.	fiddlewood	4	0.37	0.40
Anacardiaceae	*Anacardium occidentale* L.	cashew	2	0.41	0.50
Apocynaceae	*Aspidosperma cruentum* Woodson	mylady	3	0.28	0.75
Moraceae	*Brosimum alicastrum* Sw.	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* (J.F. Gmel.) Exell	nargusta	3	0.33	0.68
Trigoniaceae	*Trigonia eriosperma* (Lam.) Fromm & E.Santos	—	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	

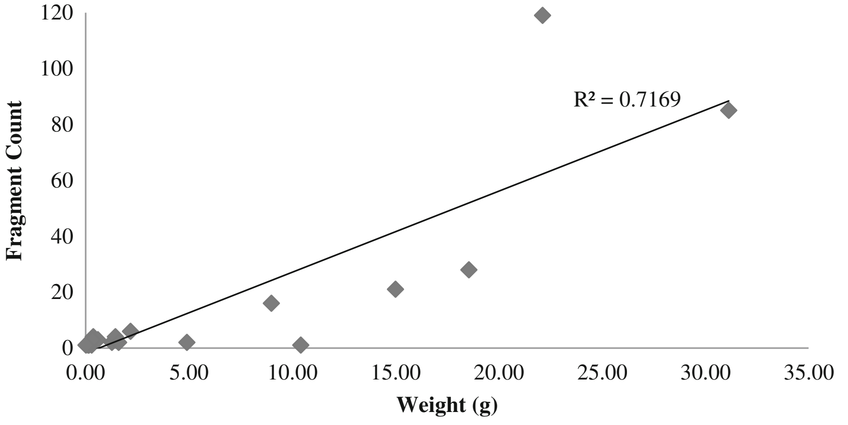

Fig. 4. Relationship between charcoal weight and fragment count.

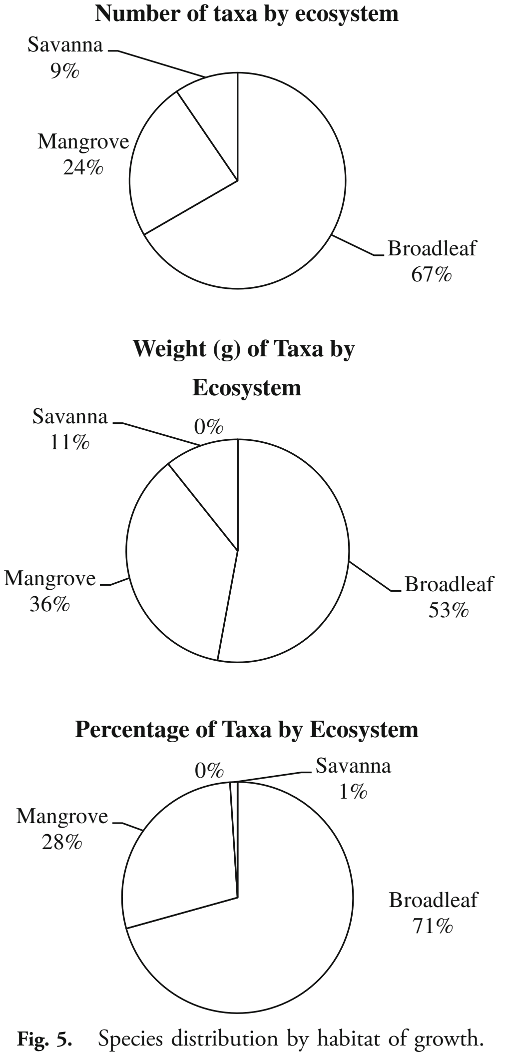

Fig. 5. Species distribution by habitat of growth.

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).

The samples identified as Chrysobalanaceae (Fig. 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 in modern Belize (Balick et al. 2000), suggesting they are not clearly separated in folk classification systems. *Chrysobalanus icaco* L. (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* Allem. and *Hieronyma oblonga* (Tul.) Mull. Arg. 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 (50–100 μm), suggests the samples may be predominately *H. oblonga*. Overlap in anatomical variability between

Table 2. Species distribution by habitat of growth.

Habitat	Number of Taxa	Count	Weight (g)
Broadleaf	14	135	52.24
Mangrove	5	54	35.90
Savanna	2	2	10.59
Indeterminate	-	119	22.12

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* Sw. is a common tree growing to 15 m with a hard, heavy wood. The three fragments of *T. 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 (SG) 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.

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

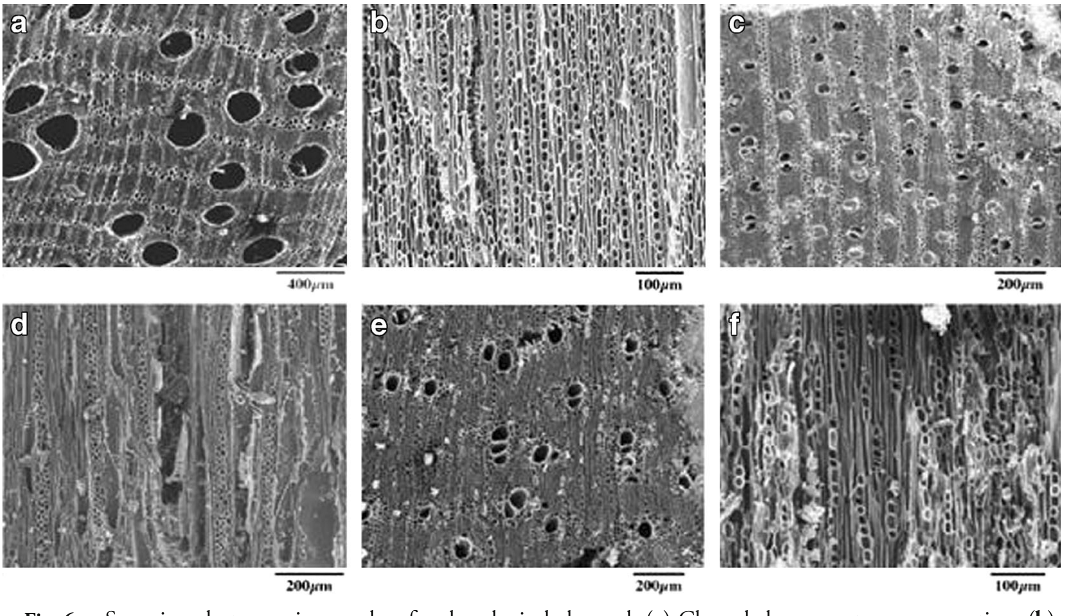

Fig. 6. Scanning electron micrographs of archaeological charcoal: (**a**) Chrysobalanaceae, transverse section; (**b**) Chrysobalanaceae, tangential section; (**c**) *Rhizophora mangle*, transverse section; (**d**) *R. mangle*, tangential section; (**e**) *Laguncularia racemosa*, transverse section; (f) *L. racemosa*, tangential section.

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, it includes a number of woody species, among them oak 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 (Lentz et al. 2005; Morehart and Helmke 2008; Morehart et al. 2005; Prufer and Dunham 2009; Wyatt 2008) 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). However, 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, just as 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). The control of the pine resources for prestige and ceremonial contexts can also not be ruled out.

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; MacArthur and Pianka 1966; Stephens and Krebs 1986). The greater distance to the savanna compared to mangrove or broadleaf patches 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, which encompass an abundance of viable forest resources for construction and fuel, become available. 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 wood left over 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 *T. amazonia* distinctive of primary forest. Three principal factors could explain the high frequency 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 classificatory 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 be more suitable as fuel for the salt production industry, typically producing a higher, more constant heat over a longer period than less dense woods (Goel and Behl 1996; Ragland et al. 1991). Furthermore, the preference for the higher density wood outweighed any extra costs incurred in felling and processing the wood.

During production, the high demand for fuel would have required a planned fuel procurement strategy. Whether fuel resources were obtained by specialized groups as an autonomous industry, or if the salt producers were self-sufficient in fuel procurement (perhaps during the wet season when lower lagoon salinity and high rainfall reduced productivity in salt production), cannot be determined at present. However, the presence of mangrove species and the low frequency of many species in the record strongly suggests the salt production community did not import fuel, but were self-sufficient (perhaps incorporating a division in labor) in obtaining fuel.

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*. Broadleaf taxa make up the bulk of identified species, with samples identified to Chrysobalanaceae accounting for 46% of the assemblage. 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.

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 reserving the large primary species for alternative functions. 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.

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