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ASSESSING THE EARLY HOLOCENE ENVIRONMENT OF NORTHWESTERN GUYANA: AN ISOTOPIC ANALYSIS OF HUMAN AND FAUNAL REMAINS

Louisa Daggers, Mark G. Plew, Alex Edwards, Samantha Evans, and Robin B. Trayler

This study uses stable carbon $\delta^{13}C$ and oxygen $\delta^{18}O$ isotope compositions data to assess the extent to which diet breadths of northwestern Guyana changed during the Holocene. We analyzed human bone and enamel remains from seven shell mound sites dating between 7500 and 2600 BP. Our analyses demonstrate some constancy in C_3 plant availability during the past several thousand years, though we note increasing reliance on such plants beginning in the Early Holocene. We also document warming intervals during the Early Holocene (Early Archaic) that appear to correlate with dry periods known elsewhere in the central Amazon during this period.

Esta investigación utiliza datos de isótopos estables de carbono $\delta^{13}C$ y oxígeno $\delta^{18}O$ para evaluar en qué medida cambió la amplitud de la dieta del noroeste de Guyana durante el Holoceno. Analizamos restos óseos humanos y esmalte de siete concheros fechados entre 7500 y 2600 años aP. Nuestros análisis muestran cierto grado de constancia en la disponibilidad de plantas C_3 durante los últimos miles de años, aunque se observa una creciente dependencia en tales plantas a comienzos del Holoceno temprano. También documentamos intervalos más cálidos durante el Holoceno temprano (Arcaico Temprano) que parecen correlacionarse con los periodos secos conocidos en otras partes del Amazonas central durante este lapso.

Little is known of the prehistoric environment of northwestern Guyana as it relates to the unique shell mound culture of the area. Although we presume a degree of constancy in Holocene contexts, few area studies address environmental change (Van der Hammen 1982; Van der Hammen and Wijmstra 1964). Williams (2003) argues that environmental conditions of the Late Pleistocene/Early Holocene resulted in instability, leading to diet breadth shifts. To date, no studies have attempted to assess the diet breadth shifts of hunter-gatherers using the shellfish resources of the Guyana littoral. This study uses the results of isotopic analyses of human and other faunal remains from shell mounds to assess environmental changes in northwestern Guyana during the Archaic period. Owing to highly degraded samples that failed to produce sufficient levels of collagen for nitrogen analysis, we used stable carbon $\delta^{13}C$ and oxygen $\delta^{18}O$ isotope compositions data to assess the degree of dietary constancy during the past several thousand years as a proxy for determining the likelihood of there being any significant changes in the Archaic/Holocene environment that would have influenced the use of shellfish resources in the northwest.

Archaic Shell Middens

The coastal plain of northwestern Guyana is characterized by Early to Middle Holocene-age shell mounds (Figure 1). The mounds, which are accumulations of shell refuse, served as living areas

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1, Barabina; 2, Piraka; 3, Kabakaburi; 4, Siriki; 5, Wyva Creek; 6, Waramuri; 7, Little Kaniballi

Figure 1. Map showing general location shell mound sites mentioned in text: 1- Barabina, 2- Piraka, 3- Kabakaburi, 4- Siriki, 5- Wyva Creek, 6- Waramuri, 7- Little Kaniballi. (Color online)

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and as places for burials. The landscape is covered by primary, secondary, and marsh forests. Archaeological discoveries of mounds within this area have reported assemblages of chipped and groundstone artifacts that form the basis of Evans and Meggers' (1960) description of the so-called Alaka phase, which they originally dated between 1950 and 1450 BP. Radiocarbon dates of a number of shell midden deposits nevertheless indicate pre-ceramic occupations as early as ca. 7500 BP (Plew and Daggers 2016). Some mounds, including Barabina (Williams 1981) and Kabakaburi (Plew et al. 2007), contain early ceramic remains—the former being the focus of a debate regarding the earliest presence of pottery in northwestern Guyana (Roosevelt 1997; Williams 1996). Although shell mounds are not found in adjacent Suriname and French Guiana, they are common in the south Caribbean, where beginning around 6000 BP the Banwari Trace and El Conchero shell midden occupations represent a regional Archaic pattern similar to that of Alaka phase sites but different in assemblage variation (Boomert 2000:54–56). In general, Banwary Trace assemblages contain many more specialized tools. To the east, at Taperinha and Pedra Pintada, Mina phase pottery has been dated at 7090 BP and 7580 BP, respectively. Early and Middle Holocene Age non-ceramic-bearing shell mounds have recently been identified in lowland Bolivia (Lombardo et al. 2013).

The Holocene shell deposits examined in this study are located on the coastal plain within the Northwestern district of Guyana. The area is believed to have been occupied by the prehistoric Warrau people, who exploited marine resources and left behind an extensive shell midden complex with ages ranging between 7500 BP and 260 BP. The coastal littoral is characterized by vast rivers, creeks and tributaries, swamps and marsh forests. Coastal pollen data analysis shows that the vegetation of the period consisted predominantly of mangroves, palms, and open grass vegetation (Van der Hammen 1982). Williams (2003) argues that fluctuating environmental conditions of the Late Pleistocene-Early Holocene resulted in periods of instability and shifting resource emphases. Different species associated with marine and brackish waters were exploited with sea level rises that occurred between 7200 and 6000 BP. Additional diet breadth shifts were associated with the emergence of mangrove swamps between 6000 and 4000 BP. Although Early Holocene sea levels would have varied due to differences in precipitation and temperature, Van der Hammen (1963) suggests that Late Alleröd interstadial sea levels rose as much as 36 m above the modern land surface in the Demerara River Valley. Rull (1999) nonetheless suggests that post-glacial/Holocene sea levels vary greatly from one location to another. It appears that sea level oscillations during the past 6,000 years may have varied little more than 3 m in many locations (Fairbridge 1976). In this regard, Early Holocene sea levels along the Guyana coast most probably varied according to local terrain features, which in turn would have influenced settlement and resource availability. Acknowledging these fluctuations and their influence upon local patterns, Plew (2010:35) argues that periods of environmental change should not be seen as reflecting instability but rather as events resulting in an ever-increasing range of potential adaptive responses.

The stratigraphy of shell mounds demonstrates alternating layers of shell refuse from different species of mollusks, including the small striped snail, clams, and oysters; and crab and fish remains, intermixed with clayey lateritic soil. The remains of peccary, agouti, turtle, large birds, and cayman have also been reported (Plew 2016; Plew and Daggers 2016; Williams 2003). Subsistence appears to have relied heavily upon mollusk exploitation associated with relatively brackish environs (Jansma 1981; Williams 1981:16, 30–32). Williams's (1981, 2003) excavations have produced evidence of features including hearths, postmolds, and several storage pits measuring 30–40 cm in diameter and extending to 40–50 cm in depth. Similar features have also been noted at Kabakaburi (Plew et al. 2007) and Siriki (Plew and Daggers 2016; Plew et al. 2012).

Radiocarbon dates have been obtained for nine shell mounds. The dates establish a general temporal range of between 7500 BP and 2600 BP—the more recent dates from the upper levels of Hosororo Creek (2660 ± 45 BP, SI-6636, Williams 2003) and the earliest from Piraka,

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(7545 BP, Beta-449110) together with the earliest ones occurring at Barabina, where a radiocarbon date of 6885 ± 85 BP has been reported. An additional early date was obtained from carbon collected from the Wyva Creek shell mound near the Barima River. Wyva Creek returned a conventional radiocarbon age of 6340 ± 50 BP (Beta-264970, Plew and Willson 2009). A recently obtained date for Little Kaniballi dates its occupation to 6340 ± 30 BP (7320-7245 cal BP; Beta-449111; Daggers and Plew 2017). Other Middle Holocene dates in the range of 5965 ± 50 BP (Barabina) to 5710 ± 80 BP (Koriabo) are not common, suggesting that there may be a more limited shell mound occupation in this time frame, although the sample size is too small to provide a level of confidence. In contrast, some mounds were occupied between c. 4000 and c. 2600 BP. The most recent dates are from Hobodiah at 139 ± 60 (Beta-109244) and Siriki at 270 ± 30 BP.

Isotope Analyses as a Source of Assessing Dietary and Environmental Change

Bone and tooth enamel are composed of hydroxyapatite ($Ca_5(PO_4)_3OH$) with a carbonate (CO_3) substitution in either the PO_4 and OH sites (Elliot 2002). In this study, we analyzed the (CO_3) component in human bone and tooth enamel samples for $\delta^{13}C$ and $\delta^{18}O$ values. The carbon isotopic compositions of $\delta^{13}C$ of mammalian bones and teeth record dietary $\delta^{13}C$ values, with a fixed fractionation factor of ~13‰ in primates (Cerling et al. 2004; Sandberg et al. 2012). In enamel, there is limited fractionation in $\delta^{13}C$ composition with increasing trophic level (i.e., through carnivores and omnivores higher in the food chain, see Lee-Thorp and Sponheimer [2006]). Therefore, the $\delta^{13}C$ of animal tissue preserves the $\delta^{13}C$ value of the vegetation at the base of the food chain (Janssen et al. 2016). The majority of global vegetation (>90%) uses the C_3 photosynthetic pathway, whereas the remainder is split between the C_4 and CAM (Crassulacean acid metabolism) pathways—both adaptations to hot, arid environments through increased water use efficiency and reduced photorespiration (Ehleringer and Monson 1993; Ehleringer et al. 1992; Kohn 2010). C_3 plants have a mean $\delta^{13}C$ value of -27‰ (range -22‰ to -35‰; Kohn 2010), whereas C_4 plants have a mean $\delta^{13}C$ value of -13‰ (range -9‰ to -19‰). CAM plants have a range of value but typically fall closer to the C_4 range; nevertheless, CAM plants (e.g., succulents, orchids) rarely contribute to human diets and therefore are not considered as a food source in this study. The $\delta^{13}C$ values of C_3 plants can be further influenced by environmental factors; water stress results in higher $\delta^{13}C$ values, and a closed canopy environment shifts $\delta^{13}C$ to very low values (Janssen et al. 2016; Kohn 2010; Van der Merwe and Medina 1991). More positive $\delta^{13}C$ values in vegetation and animal tissues may indicate a habitat with more open vegetation. Thus, differences in the $\delta^{13}C$ value recorded in animal bone and tooth enamel allow detection of changing vegetation patterns (C_3 vs C_4 plants; closed vs. open canopy structure) that can be interpreted as paleodietary and paleoenvironmental proxies in archeological specimens. Furthermore, paleoclimate inferences can be made by applying a mean annual precipitation model to $\delta^{13}C$ values (Kohn 2010); nevertheless, these calculations have mainly been done on herbivore tooth specimens—omnivory and any component of artificial irrigation incorporated into the dietary $\delta^{13}C$ would potentially undermine model output. It remains important to note that fossil fuel combustion since the late 19th century has decreased the $\delta^{13}C$ value of atmospheric CO_2 by ~ 1.5‰ (Indermühle et al. 1999).

The oxygen isotope composition of mammalian tooth enamel and bone hydroxyapatite carbonate is directly linked to the $\delta^{18}O$ values of body water, reflecting food and drinking water, which are in turn a complex function of habitat, climate, and diet (Clementz and Koch 2001; Janssen et al. 2016; Kohn et al. 1996; Lüdecke et al. 2016). The $\delta^{18}O$ value of rainwater decreases with increasing distance from moisture source, increasing altitude, decreasing temperature, and intensity of precipitation (Dansgaard 1964). In arid environments, surface waters and leaf water $\delta^{18}O$ values increase with evaporation (Gonfiantini et al. 1965), and under similar conditions, C_4 plants have higher $\delta^{18}O$ values than C_3 vegetation (Helliker and Ehleringer 2000; Sternberg 1989). Fossil tooth enamel and bone

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$\delta^{18}O$ values represent the interplay of environmental parameters and diet composition influence on body water composition. For mammals, there is a constant offset (~26‰) between the $\delta^{18}O$ of body water and the CO_3 component of bioapatite (Bryant et al. 1996; Kohn and Cerling 2002; Lüdecke et al. 2016).

Methods

Geographical and dietary baseline data for this project used both animal proxies and contemporary plant materials. Oxygen and carbon stable isotope compositions were collected from tooth enamel and bone samples from seven sites. Baseline data were collected for Barabina, Kabakaburi, Piraka, and Waramuri mounds from the excavations of Denis Williams during the 1980s, and from more recent samples from the excavations of Little Kaniballi (Daggers 2017), Siriki (Plew et al. 2012) and Wyva Creek (Plew and Wilson 2009). All collections were stored at the Walter Roth Museum of Anthropology.

Surficial material was removed manually from specimens with a carbide burr followed by an ethanol rinse prior to sampling. Bioapatite samples were then hand-milled using a Dremel® rotary tool equipped with a 0.5-mm carbide dental drill bit. Approximately 8 mg of enamel or bone powder were pretreated using the approach of Koch et al. (1997). Residual organics were oxidized overnight using 30% hydrogen peroxide. Twelve hours later, the hydrogen peroxide was decanted, and powders were rinsed twice with deionized water. Powders were then treated with a 1.0 M Ca-acetate/acetic acid buffer overnight to remove labile carbonates. Following this pretreatment procedure, samples were rinsed three times with deionized water and dried in a vacuum oven at 40 °C.

The CO_3 component of powdered enamel and bone samples was analyzed by digestion in phosphoric acid using a Thermo Delta V Plus continuous-flow isotope ratio mass spectrometer coupled with a Thermo GasBench II. All carbonate isotopic compositions were standardized to Pee Dee Belemnite (PDB), using NBS-18 and NBS-19 calcite standards; oxygen isotopic compositions were then normalized to Vienna Standard Mean Ocean Water (VSMOW). Analytical reproducibility for the dataset was ± 0.20‰ and ± 0.25‰ for $\delta^{13}C$ and $\delta^{18}O$ respectively, based on NBS 18 and 19 (n = 14). All isotope data are reported in standard delta (δ) notation. Statistical analyses were completed using R - v. 3.3.2. One-way ANOVA was used to compare pooled bone and tooth data between localities. Post hoc students' T-tests corrected for multiple comparisons isolated significant differences at the $p < 0.05$ level.

Sample Selection

Differences in the quantity and condition of bone from the mound sites served to define sample size. During the selection process, bones displaying evidence of pathologies were avoided (Olsen et al. 2014). Eighty-one samples of human bone and teeth were analyzed in this study, although four lacked exact stratigraphic provenance (Table 1). Owing to considerable differences in past recovery processes, many collections are incomplete. Given this, we used remains that were available from early excavations. In the case of Barabina, we used rib fragments that had been retained in the collection. In other assemblages, long bone fragments were sampled. A significant percent of the collections analyzed was degraded, which resulted in poor collagen preservation. As a result, we were not able to conduct nitrogen analysis. Only a few samples were taken from stratigraphic units that had been radiocarbon dated. In this regard, we were cognizant of the problem of sampling elements from the same individuals. Although we cannot say with certainty that all samples come from separate individuals, we believe that most are. For better control of this problem, we relied on detailed descriptions of stratigraphic positioning of skeletal remains (Williams 1981) and distinct locations of burials within mounds (Plew et al. 2012). The samples document an age range from infants to 30 years of age (Figure 2).

In addition to bone and teeth samples from the midden sites, contemporary samples (C_3, C_4 and cam, n = 27) were collected for $\delta^{13}C$ analysis. Carbon isotope compositions were used as a primary proxy of diet and of the Archaic shell mound populations, whereas oxygen

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Table 1. Frequency Distribution of Sample by Site and Human Remains, Associated Stratigraphic Levels, Radiocarbon Dates and $\delta^{13}C$ and $\delta^{18}O$ Results.

Code	Location	Human Remains	Level record (cm)	Radiocarbon Dates Conventional (BP)	$\delta^{13}C$ (PDB)	$\delta^{18}O$ (VSMOW)
B-17	Barabina	Rib fragment	0-15		−13.15	25.07
B-17	Barabina	Enamel	0-15		−13.65	27.02
B-62.	Barabina	Rib fragment	18		−12.14	26.35
B-62	Barabina	Enamel	18		−11.76	26.20
B-76	Barabina	Enamel	20-40		−13.02	27.20
B-12	Barabina	Enamel	24-40		−14.15	27.70
B-25	Barabina	Enamel	26-35		−13.83	27.97
B-25	Barabina	Rib fragment	26-35		−12.16	26.83
B-76	Barabina	Rib fragment	32		−11.92	26.17
B-71	Barabina	Enamel	38		−12.31	26.09
B-71	Barabina	Rib fragment	38		−13.25	26.98
B-29	Barabina	Enamel	40		−12.98	27.51
B-29	Barabina	Rib fragment	40		−13.09	23.60
B-24	Barabina	Enamel	42		−13.37	27.54
B-24	Barabina	Rib fragment	42		−12.36	26.31
B-33	Barabina	Enamel	45	4470 ± 30 Beta-449112	−13.49	26.92
B-33	Barabina	Rib fragment	45		−12.10	26.85
B-22	Barabina	Rib fragment	50		−12.09	26.05
B-22	Barabina	Enamel	50		−13.41	27.52
B-5	Barabina	Rib fragment	57		−13.37	26.41
B-5	Barabina	Enamel	57		−13.49	27.19
B-12	Barabina	Rib fragment	60		−12.50	23.90
B-13	Barabina	Rib fragment	68		−13.20	24.31
B-13	Barabina	Enamel	68		−13.46	26.82
B-69	Barabina	Enamel	71		−12.59	26.28
B-69	Barabina	Enamel	71		−13.74	26.63
B-1	Barabina	Enamel	100		−14.54	27.26
B-3	Barabina	Enamel	135		−14.16	28.06
B-49	Barabina	Rib fragment	148		−11.03	26.59
B-49	Barabina	Enamel	148	4420 ± 30 Beta-449-113	−12.66	27.27
B-3	Barabina	Phalanx	238		−11.88	26.60
B-30	Barabina	Enamel	unknown		−13.20	26.61
B-30	Barabina	Rib fragment	unknown		−11.60	25.23
BLK	Little Kaniballi	Lesser trochanter	0-20		−14.75	26.87
BLK	Little Kaniballi	Proximal humerous	20-30		−15.14	26.01
BLK	Little Kaniballi	Greater trochanter	30-40		−15.02	26.79
BLK	Little Kaniballi	Proximal ulna fragment	40-50	6340 ± 30 Beta-449111	−14.80	26.67
BLK	Little Kaniballi	Bone fragment	50-60		−13.62	26.81
BP 16a	Piraka	Enamel	20-40		−13.54	26.06
BP 16b	Piraka	Enamel	20-40		−13.85	26.98
BP 11	Piraka	femur fragment	20-40		−15.09	25.96
BP 14	Piraka	Subadult femur	40-60		−13.12	24.43
BP 16	Piraka	Patella	45		−14.57	22.94
BP 2a	Piraka	Enamel	50-60		−13.89	26.39
BP 2b	Piraka	Enamel	50-60		−13.38	27.02
BP 2	Piraka	femur fragment	60	6940 ± 30 Beta-449114	−14.47	26.62
BP 6a	Piraka	Enamel	60-80		−13.70	26.48
BP 6b	Piraka	Enamel	60-80		−14.50	25.76
BP 6	Piraka	femur fragment	60-80		−14.23	26.54
BP 13a	Piraka	Enamel	80-100		−13.53	26.28
BP 13b	Piraka	Enamel	80-100		−13.92	25.97
BP 8a	Piraka	Enamel	80-100		−14.02	26.99
BP 8b	Piraka	Enamel	80-100		−13.51	27.02

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Table 1. Continued

Code	Location	Human Remains	Level record (cm)	Radiocarbon Dates Conventional (BP)	δ^{13}C (PDB)	δ^{18}O (VSMOW)
BP 13	Piraka	Femur fragment	80-100		−14.77	25.49
BP 8	Piraka	Tibia, sub adult	80-100		−14.60	26.18
BP 5a	Piraka	Enamel	120	6920 ± 30 Beta-449115	−13.03	27.03
BP 5b	Piraka	Enamel	120		−13.46	26.92
BP 5	Piraka	R. zygomatic	120		−14.80	26.32
BP 4	Piraka	Cranial fragment	120-140		−14.38	26.11
BP 4	Piraka	Possible pelvis fragment	120-140		−13.00	24.50
BP 4	Piraka	Enamel	unknown		−13.97	26.04
BS	Siriki	Cranial fragment	0-20	270 ± 30 Beta-307549	−13.28	26.26
BS	Siriki	Bone fragment	0-20		−15.45	25.10
BS	Siriki	Enamel	0-20		−13.79	26.55
BS	Siriki	Bone fragment	60-80		−14.89	23.96
BS	Siriki	Tibia, sub adult	80-100		−14.51	26.67
BS	Siriki	Rib fragment	80-100		−15.80	24.69
BW	Waramuri	Bone fragment	0-20		−12.61	26.66
BW	Waramuri	Bone fragment	0-20		−12.90	25.71
BW	Waramuri	Bone fragment	80-100		−12.17	27.51
BW	Waramuri	Bone fragment	unknown		−12.76	25.56
BW	Waramuri	Enamel	unknown		−14.30	26.30
BW	Wyva Creek	Enamel	surface		−13.41	25.73
BW	Wyva Creek	Enamel	70	6430 ± 30 Beta-264970	−13.96	26.62
BW	Wyva Creek	Bone	180		−13.23	24.86
BK	Kabakaburi	Rib fragment	unknown		−11.12	26.73

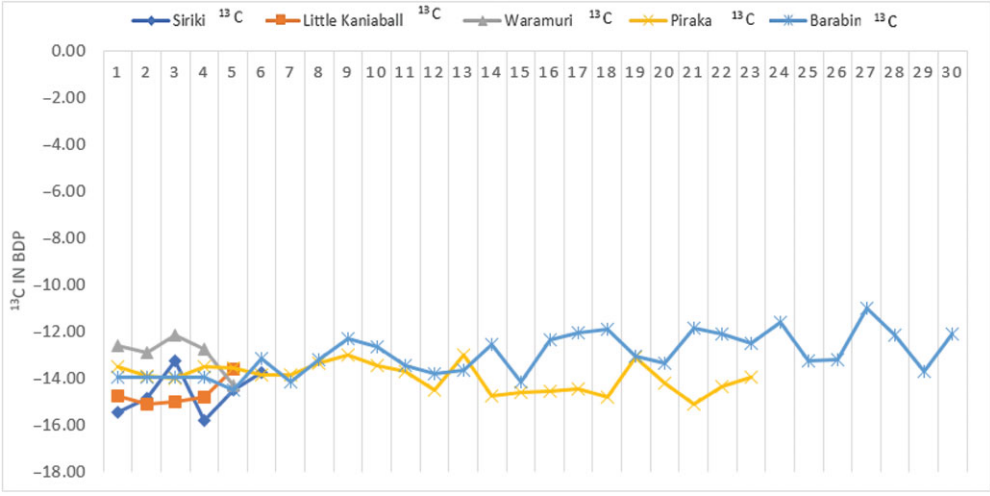

Figure 2. δ^{13}C values (range) for each locality showing age variations from youngest to oldest. (Color online)

isotope compositions provided a basis for assessing environmental changes.

Results

We analyzed 81 samples from seven sites—Barabina, Little Kaniballi, Kabakaburi, Piraka, Siriki, Waramuri, and Wyva Creek (Table 1). Although some studies have shown offsets between bone and tooth enamel isotopic compositions within individuals (Warinner and Tuross 2009; Webb et al. 2014), our analysis showed no difference between bone and tooth enamel datasets. Oxygen isotope values range from 25.7‰ to 26.7‰ and show no significant differences between localities (ANOVA,

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Table 2. Descriptive Statistics for Enamel and Bone Stable Isotope Compositions.

Locality	n	Mean $\delta^{13}C$	SD $\delta^{13}C$	Mean $\delta^{18}O$	SD $\delta^{18}O$
Barabina	33	−12.9	0.8	26.5	1.1
Little Kaniballi	5	−14.7	0.6	26.6	0.4
Piraka	23	−14.0	0.6	26.0	1.0
Siriki	6	−14.6	1.0	25.5	1.1
Waramuri	5	−13.0	0.8	26.3	0.8
Wyva Creek	3	−13.5	0.4	25.7	0.9
Kabakaburi in Wyva	1	−11.1	-	26.7	-

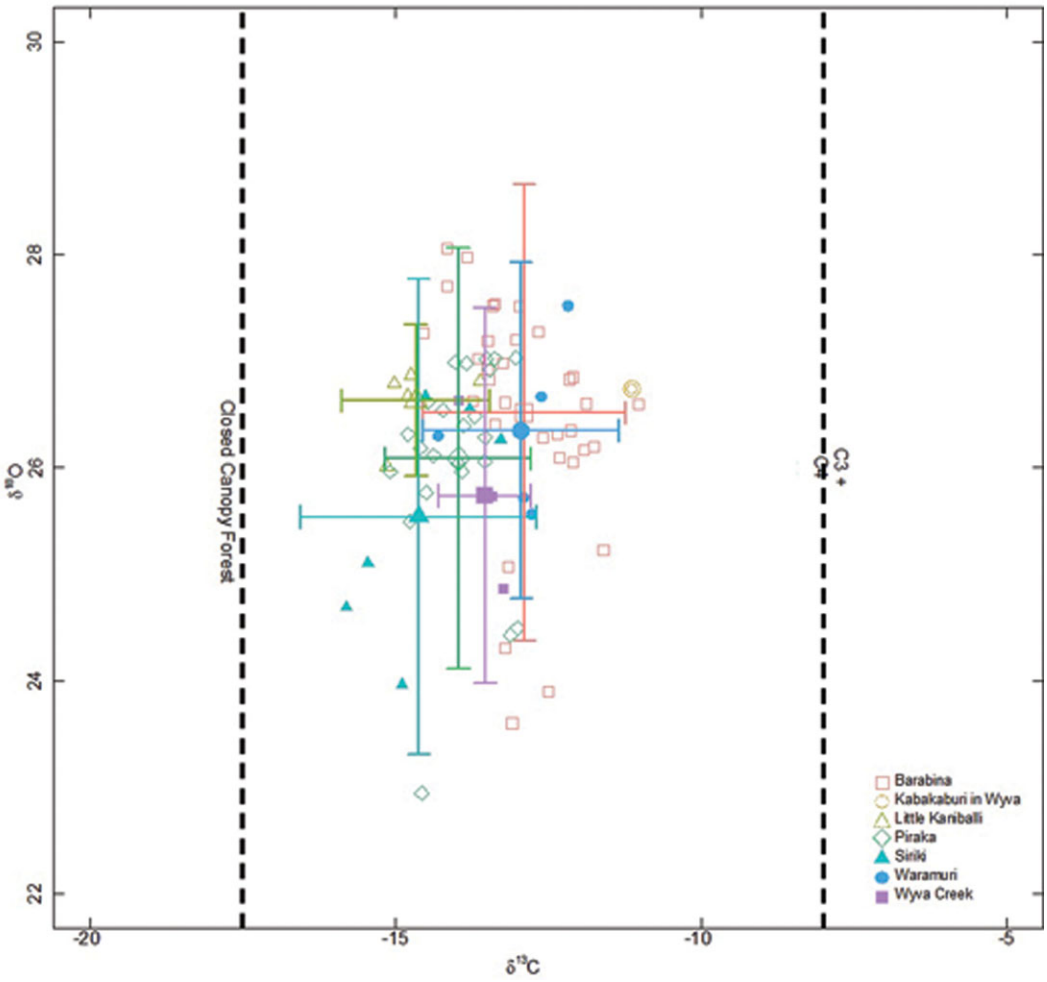

Figure 3. Values of $\delta^{13}C$ and $\delta^{18}O$ for each locality. Larger circles represent site mean values with two error bars. Vertical dashed lines indicate cutoff for closed canopy forests resources (Kohn 2010) and mixed C3-C4 resources. (Color online)

$p = 0.2274$). Carbon isotope values range from -14.7‰ to -11.1‰ and show significant differences between localities (ANOVA, $p = 0.001$). Pairwise comparisons (t-test, Bonferroni correction) are reported in Table 2.

The $\delta^{13}C$ values from all samples fall within the range indicative of C_3 plant resource use in an open canopy environment (Kohn 2010). This conclusion is supported by carbon isotopic analyses of modern examples of local plants,

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Table 3. Statistical Comparisons of $\delta^{13}C$ Values. Bold p-Values Indicate Significant Differences. For Localities Where $n = 1$, Minus Signs (−) Indicate the Data Fell Beyond 2σ of the Mean for Modern Samples

	Barabina	Little Kaniballi	Piraka	Siriki	Waramuri	Wyva Creek
Little Kaniballi	**0.00008**					
Piraka	**0.00002**	0.97				
Siriki	**0.00003**	1.0	0.9574			
Waramuri	1.0000	**0.0084**	0.1096	**0.0069**		
Wyva Creek	1.0000	0.6386	1.0000	0.6667	1.0000	
Kabakaburi in Wyva	-	-	-	-	-	-

dominantly C_3 photosynthesizing (Table 3). Plant $\delta^{13}C$ values measured here are consistent with the findings of Guehl and colleagues (1998) for regional vegetation in Guyana (Figure 3). A diet correction, incorporating the fractionation from diet to bioapatite, and an offset to account for modern decreases in atmospheric $\delta^{13}C$ (13‰ + 1.5‰), were applied to the plant $\delta^{13}C$ compositions (Table 3). Diet-corrected $\delta^{13}C$ values based on the local plant isotopic compositions are consistent with the bone and tooth enamel sample compositions shown, supporting the conclusion that the diet of the populations sampled was dominated by C_3 vegetation (Guehl et al. 1998; Supplemental Table 1).

Locations with ^{14}C dates are shown by age in Figure 4. The uniformity over time and between locations in bone and tooth enamel $\delta^{18}O$ compositions suggests that isotopically similar drinking water sources were accessed at all sites, and that other variables known to influence oxygen isotopic compositions in surface water (precipitation sources, temperature, evaporative enrichment) were similar across all sites through time. The time span represented by the majority of the dated material from these locations falls within a period referred to as the Holocene climatic optimum (HCO), which is characterized by a climatic warming spanning 8000–5000 years BP. Temperature increases of up to 4˚C at the poles and decreases to 1˚C at the equator have been inferred from ice-core datasets and global climate models (Dahl-Jensen et al. 1998; Gagan et al. 1998; Koshkarova and Koshkarov 2004; Mayle et al. 2004). This warm period may have influenced the carbon isotopic values recorded in bone and tooth enamel.

Mayle and others (2004) extend the period of warming in Amazonia to 8000–3600 years BP, spanning the full chronology potentially represented by the present study. Areas of the northern Amazon may have had reduced precipitation during this time period, leading to shifts toward more drought-tolerant dry forest taxa and savannahs in ecotonal areas (Mayle et al. 2004). The Barabina site is the recent dated location falling at the end of the HCO. It had significantly higher $\delta^{13}C$ compositions in comparison with the older Little Kaniballi, Siriki, and Piraka sites. The 1–2‰ increase in $\delta^{13}C$ values at Barabina does not seem significant enough to represent a shift toward C_4 diet inputs; it may be the result of a drier environment under water stress after prolonged warming.

In this regard, $\delta^{18}O$ fails to identify climate change unless all factors are known, but it is useful in reflecting the state of climate and surface temperature. Pooled bone and teeth data shown in Figure 5 show no statistical differences (ANOVA, $p = 0.2274$). Fricke and others (1995) posit that the $\delta^{18}O$ composition of the body water is a reflection of the water consumed, as a result of which climate and surface water temperature can be deduced. The $\delta^{18}O$ samples from Barabina suggest variations in temperatures that may indicate intense rainfall and warming during this period. A warmer trend is evident in samples for the early Holocene, including Little Kaniballi, Wyva, Piraka, and Siriki (Figure 5).

Diet Breadth

The apatite-collagen model suggests that populations in the Northwest became increasingly reliant on C3-based resources and C3-fed fauna. In this regard, Williams (2003) has argued that the later Holocene sees increasing use of multiple

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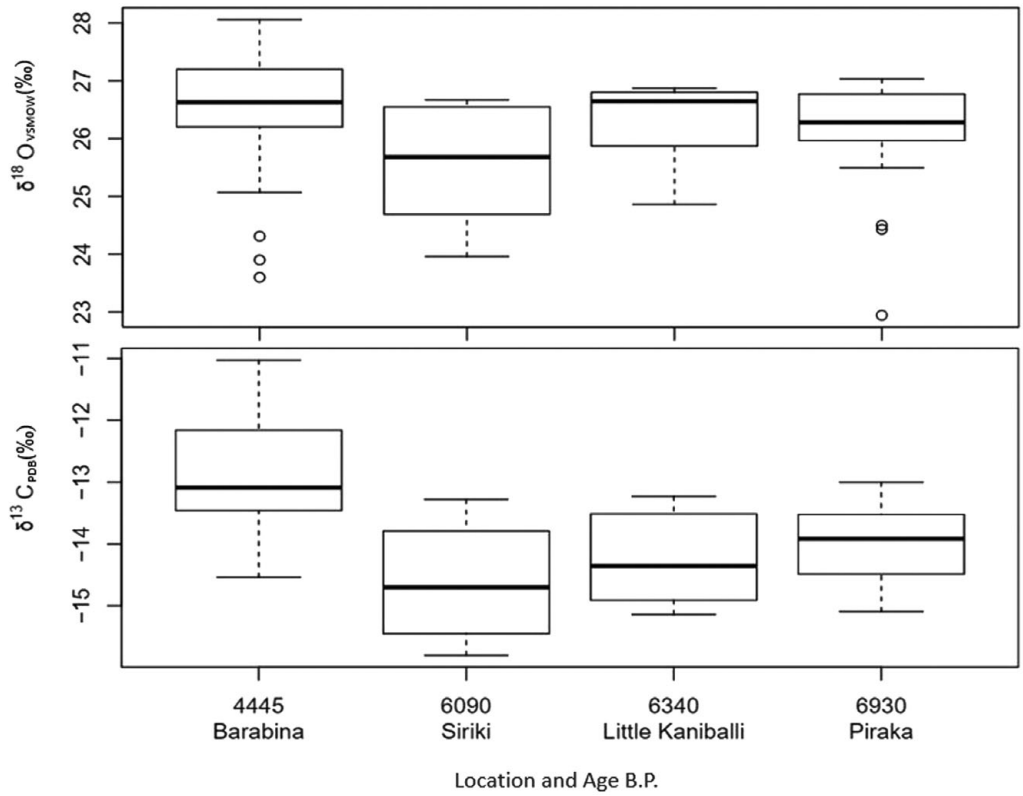

Figure 4. Values of $\delta^{18}O$ and $\delta^{13}C$ in tooth enamel and bone from four localities in coastal Guyana.

resources, including those of niche resources, specifically starchy plants (Plew et al. 2012). This is further supported by the appearance of mangrove fringes and forest along the coast during the Holocene, which provided favorable habitat for both marine resources and terrestrial fauna (Van der Hammen and Wijmstra 1964). The $\delta^{13}C$ values are consistent with an open landscape such as palm forest in the Amazon region. The population who are believed to be small, highly mobile groups would have adopted a coastal hunter-gatherer strategy, in which residential base camps were established with the seasonal use of shell midden sites, which to an extent supports William's (2003) arguments regarding shifting resource use.

The $\delta^{13}C$ values of the sediments transported and accumulated on four sites—Wyva, Siriki, Piraka, and Barabina— show varying levels of depletion and enrichment by depth and age. These values, which range between −24.3 and 27.3 ‰ (Figure 6), suggest that sediments moved to these locations were taken from an environment dominated by C_3 plants. This indicates the depletion of $\delta^{13}C$ approaching the Mid-Holocene; within our data set this is evident at Siriki 5490 ± 30 BP and at the Barabina site 4470 ± 30 BP. This is further supported by Hammond and colleagues' (2006) study of soil charcoal in the wet tropical forest of Guyana, where data indicates a series of forest fires during the Holocene with $\delta^{13}C$ values ranging between -29.4 and -25.4 ‰; this suggests charcoal formation from C_3 plants, typifying modern tropical forest habitat.

The $\delta^{13}C$ range of the human samples, while implying the consumption of C_3 plants, also indicates that these populations used resources from an open canopy environment. This is supported by Van der Hammen (1982), who reports a series of dry periods in the central Amazon basin and South America during the early and Mid-Holocene. In this regard, Ledru (1993) suggests vegetation changes and forest retreat associated

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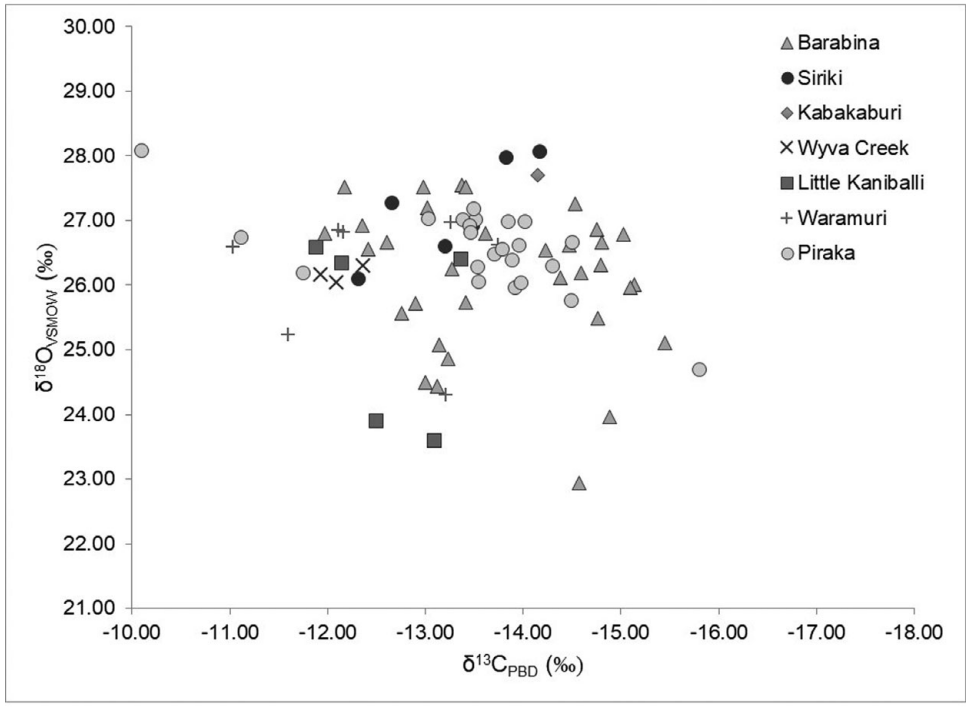

Figure 5. δ^{18}O and δ^{13}C variations across sample populations.

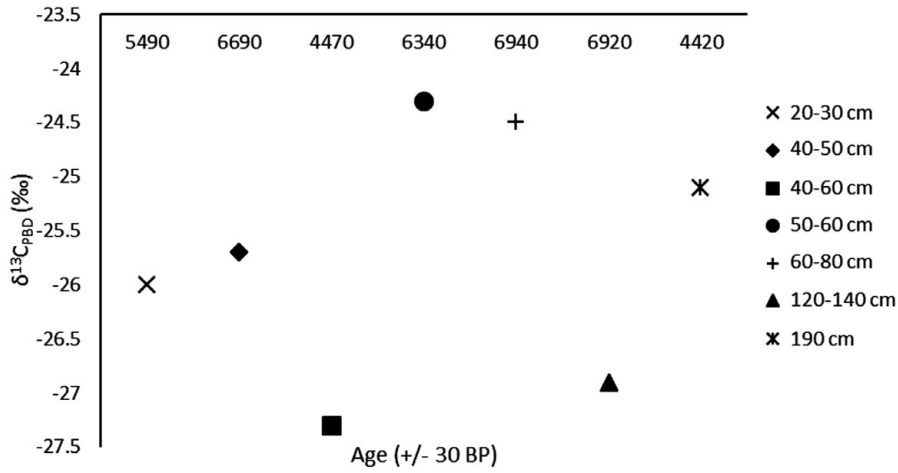

Figure 6. δ^{13}C values compared against radiocarbon dates (^{14}C) of different levels of sediment by depth from four localities.

with dry climatic conditions between 11,000 and 4500 BP, resulting in forest fires (Pessenda et al. 1996), and possibly anthropogenic fires to some degree, which would have influenced the vegetation cover, as suggested by Tardy (1998) in French Guiana. The influence of prehistoric populations on fires is arguable but possible because human ignition of combustible dry forest may have been one means of controlling forest resources during the Holocene (Hammond et al. 2006; Mayle and Power 2008; Tardy 1998). Nevertheless, in the absence of

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charcoal samples from the study area, conclusions regarding anthropogenic fires are not possible. Notably, Iriarte and others (2012) suggest fire-free land use in pre-1492 Amazonian savannas. Regardless, the fluctuating climatic conditions of the Amazon and Guyana are further supported by the $\delta^{18}O$ data. The data suggest a period of greater warming in the early Holocene, reflected in the $\delta^{18}O$ values from Piraka range of 28–26 ‰, the Wyva sample range between 26–27 ‰, and the Siriki sample range 26–28 ‰, though $\delta^{18}O$ is observed at Little Kanaballi, and a steady depletion in $\delta^{18}O$ as seen at Barabina in the Mid- Holocene. This may indicate climate fluctuation and possible stabilization resulting in more favorable temperatures.

Conclusion

This study has used the results of isotopic analyses of human and other faunal remains to assess environmental changes in northwestern Guyana during the Early to Late Archaic period. Using $\delta^{13}C$ and $\delta^{18}O$ data, we have demonstrated some degree of constancy in the availability of C_3 plants during the past several thousand years, though we note an increasing reliance on such plants beginning in the Early Holocene. We also document warming intervals during the Early Holocene (Early Archaic), which appear to correlate with dry periods known elsewhere in the central Amazon during this period. Although our data support long-term perpetuation of what may be thought of as relatively modern forest conditions, we conclude that in at least the Early Holocene there may have been more open canopy—a condition that may well have seen prehistoric peoples moving to a range of seasonally available resources. In sum, we believe that over time, what we know as the modern environment may have remained relatively unchanged, with the minor exception of drying conditions of the Early Holocene, which may have seen increased residential mobility.

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Data Availability Statement. Data and materials used and or generated in this study are available through the Amerindian Research Unit, University of Guyana, the Walter Roth Museum of Anthropology, and the Department of Geosciences, Boise State University.

Supplemental Materials. For supplementary material accompanying this paper, visit https://doi.org/10.1017/laq.2017.87.

Supplemental Table 1. Isotopic Analyses of Modern Plant Taxa with a Diet Correction to Illustrate Potential Values in Associated Bone and Tooth Enamel.

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