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Applying new approaches to modeling diet and status: isotopic evidence for commoner resiliency and elite variability in the Classic Maya lowlands

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ABSTRACT

Classic Maya states were characterized by a high degree of socioeconomic stratification. This paper investigates the degree to which status, as defined by grave goods and tomb construction, influenced dietary patterns of elites and commoners throughout the Classic Period (200–900/1000 AD) of the southern lowlands. We compile a database ($N = 102$) of previously-published stable isotope ratios (δ^{13}C collagen, δ^{13}C apatite, and δ^{15}N collagen) from Maya bone mineral and collagen, and interrogate these data through two new isotopic modeling techniques: a simple carbon isotope model (Kellner and Schoeninger, 2007; Froehle et al., 2010) and a multivariate isotope model (Froehle et al., 2012). We find that Maya elite diet varied significantly through time in terms of maize consumption and trophic level, while commoner diet remained remarkably stable. These findings provide new information relevant to studies of ancient Maya class structure and to studies of subsistence strategies of the pre-Columbian Americas.

1. Introduction

A key component in the study of complex societies concerns the degree to which they are characterized by social and economic stratification. Social distinctions between ‘elites’ and ‘commoners’ are well-established characteristics of archaic statehood, and are used by archaeologists working throughout the world (Marcus and Feinman, 1998: 6–7). Generally, such divisions are made through the study of how goods and resources were acquired and divided across a community. This is often done through the analysis of burial patterns, under the assumption that elites had greater access to high-value objects, were buried closer to ceremonial/political centers, and had more time invested in construction of their tombs (Chase and Chase, 1992b; Smith, 1987; Tainter, 1975). A complementary approach is to directly examine ancient peoples themselves through the study of osteology, paleopathology, and stable isotope analysis, to investigate differences in health, dietary practices, or cultural modifications to the body (Buikstra and Beck, 2006; Whittington and Reed, 1997a). In this paper we conduct an isotopic meta-analysis of ancient Maya diet and status in order to build a diachronic understanding of the relationship between dietary patterns and status affiliation during the ancient Maya Classic Period (250–900/1000 AD).

Patterns in dietary choices are recognized as having a close relationship to the identity of a consumer or social group (Mintz and Du Bois, 2002). Especially relevant is the link between diet and class (Goody, 1982; Gumerman, 1997). Due to socially-learned and status-linked dietary behaviors and attitudes, elites and commoners often differ in consumptive practices (Bourdieu, 1984). Food items themselves can play a key role in the negotiation of status and power. Socially desirable foods may be conspicuously consumed as part of elaborate feasts, either through elite-sponsored patron-role feasts designed to reinforce social indebtedness of individuals with lesser means (Dietler, 2001: 82–85; Mauss, 1990), or through diacritical feasts that serve to elevate and legitimize stratified class distinctions (Dietler, 2001: 85–88). Additionally, elites and commoners often have access to different food types, which may correspond to differences in quality or social desirability of the foodstuff. Elites may enjoy greater access to particular items simply due to the privilege associated with their socioeconomic standing, including their greater access to non-local

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food markets (Gumerman, 1997). Studies of differential consumption thus provide information on structured relations of ancient societies.

Research in Mesoamerica, the geographic region stretching from Northwest Mexico to portions of Panama, has long focused on the relationship between diet and status (e.g., Emery, 2003; Schoeninger, 1979; Turkon, 2004). Isotopic studies of bone tissue and tooth enamel, now routinely utilized in archaeological investigations, operate under the understanding that foods consumed in life leave characteristic signatures in preserved tissue (Schwarcz et al., 2011). Over the past several decades, isotopic analyses of human bone have made great strides in reconstructing dietary practices of the ancient Maya of Southern Mexico, Belize, and Honduras (e.g., White, 1999; Whittington and Reed, 1997c; Wright, 2006). Indeed, in terms of isotopic paleodiet studies, the ancient Maya are the most extensively investigated ancient civilization, and thus provide an excellent opportunity to explore issues of diet and status at a regional level. Previously-published regional isotopic assessments have explored gendered food behavior among the Maya (White, 2005), geographic patterning of diet (Gerry and Krueger, 1997), patterns of diet during the Maya Collapse (White, 1997; Wright, 1997; Wright, 2006; Wright and White, 1996), and the relationship between diet and status (Gerry, 1997). To date, however, no regional study has explicitly addressed the relationship between diet and status through time.

In this paper, we proceed with two goals: (1) to apply two new isotopic modeling techniques to a large archaeological database, and (2) to explore the dynamics of Maya hierarchy through time, taking into account both material correlates of wealth and patterns of food consumption. We compile a database of previously published Maya isotopic values ($\delta^{13}C_{collagen,}$ $\delta^{13}C_{apatite,}$ and $\delta^{15}N_{collagen)}$ from the Early Classic (AD 250–600), Late Classic (AD 600–800), and Terminal Classic (AD 800–900/1000) periods, focusing on settlements within the southern lowlands. We interrogate these data by use of a simple carbon isotope model (Froehle et al., 2010; Kellner and Schoeninger, 2007), and a multivariate isotope model (Froehle et al., 2012). Applying these new methods permits a more complete picture of dietary patterns across time, and compiling data from multiple settlements allows a region-wide assessment of Maya social differentiation. The results of this study demonstrate that elite diet varied considerably across time, while commoner diet remained remarkably resilient.

2. Maya background

2.1. Status differences and food availability

The ancient Maya were a highly stratified society with strong divisions between social classes. While some researchers envision a stark two-class divide between Maya elites and commoners (Adams, 1981; Adams and Smith, 1981; Marcus, 1983; Thompson, 1954; Willey, 1980), others argue that Maya society was multi-tiered and highly variable, possibly containing a large "middle class" (Becker, 1973; Chase, 1992; Haviland, 1974; Sabloff and Rathje, 1975). Recently, dynamic models for social organization have become popular, emphasizing that Maya society varied considerably through both time and space (Iannone, 2002; Marcus, 1993,, 1998). Regardless of exactly how status differences were organized, the material culture of the ancient Maya provides a clear testimony to the differences that existed between the two extremes of the social spectrum. Maya nobility lived in large and well-constructed stone buildings that dwarfed the small wooden homes built by commoners. Such status divisions are also seen in burials: elite individuals were often treated to well-constructed tombs and crypts, whereas less affluent individuals were buried in simple graves and cysts (Haviland and Moholy-Nagy, 1992). Additionally, grave goods served as status markers for the dead, elites being interred with elaborate polychrome pottery, jade jewelry, and obsidian tools, and commoners buried with little in the way of non-perishable items.

Status differences among the Maya also resulted in differential dietary practices. Studies of animal remains from some Maya sites demonstrate that elites consumed more large mammals than commoners (Emery, 2003: 499; Masson, 1999; Pohl, 1985). Elite Maya may have had access to items acquired through tribute and long-distance exchange, whereas commoners may have lacked this ability. Evidence of tribute can be seen in Maya murals, such as at Bonampak, where stacks of cacao beans are shown being presented to a local ruler. Patterns of food production and dispersal might also create dietary differences between affluent inhabitants of urban centers and more rural populations. Periodic markets sponsored in site centers, for example, may have been more accessible to urban dwellers than to individuals living in peripheral settlements. Architectural and iconographic evidence for such markets can be found at the site of Calakmul, which sponsored a large market where food items such as maize gruel and tamales were exchanged (Carrasco et al., 2009). Although, in theory, ancient markets served to economically integrate class segments within a society and distribute prestige goods across differing socioeconomic levels (Hirth, 1998; Masson and Freidel, 2012), it remains likely that elites, due to material benefits associated with their rank, were able to obtain a greater variety of imported foods than were commoners. Finally, if elites sponsored or directed the construction and maintenance of intensive agricultural systems, including raised fields and hillside terraces (Flannery, 1982), it would follow that they might have had preferential access to the products of these investments, especially during times of resource stress.

Maya commoners, on the other hand, lacked many of these means of resource acquisition. Compared to elites, commoners had less political power and likely had fewer means by which to acquire imported goods (e.g., Lohse and Valdez, 2004). Botanical studies at Copan, one of the most extensively investigated ancient Maya cities, suggest that commoners had access to a lesser diversity of edible plants species than did elites (Lentz, 1991); isotopic studies of human bones from Copan demonstrate that elites enjoyed greater dietary diversity than commoners (Whittington and Reed, 1997b). Rather than acquiring much of their food through tribute or market exchange, commoners were more intimately involved in the production of their foodstuffs, having direct access to managed forests, home gardens, and milpas (Ford and Nigh, 2009; Gómez-Pompa and Kaus, 1992). Abrupt changes in material culture at some peripheral sites, however, mimic the timing and pace of change at political/ceremonial cores, indicating that peripheral communities were economically and socially linked to nearby regional centers (Ashmore et al., 2004). Indeed, it should be clear that major political and environmental events such as wars, alliances, droughts, and famines would have had significant repercussions for diets across the social spectrum. Nevertheless, elite subsistence strategies could be characterized as relying more heavily on political and economic circumstances, while commoner strategies were more directly articulated with local environments through household-based food production. Given that political and environmental changes did occur during the Classic period, two pertinent questions are raised: to what extent were class-based dietary differences expressed across time, and what do such differences tell us about the evolution of ancient Maya class structure? These questions may be addressed through dietary reconstruction using stable isotope analysis.

3. Modeling ancient diet

3.1. Principles of stable isotope analysis

Isotopic analyses of carbon and nitrogen are well-established markers of dietary practices, and have been successfully applied to archaeological human populations for decades (Ambrose and Krigbaum, 2003; Schwarcz et al., 2011). The primary source of variation in carbon isotope ratios comes from differential fractionation rates associated with different photosynthetic pathways of plants. Plants that utilize the C_3 (Calvin–Benson) photosynthetic pathway have low $\delta^{13}C$ values, averaging $-26.5‰$, and include most fruits, vegetables, shrubs, and grasses from shaded or temperate environments (O'Leary, 1988; Smith and Epstein, 1971). Plants that utilize the C_4 (Hatch-Slack) photosynthetic pathway have higher $\delta^{13}C$ values, averaging $-12.5‰$ (O'Leary, 1988; Smith and Epstein, 1971). C_4 plants are primarily dry-adapted grasses such as millet, savannah grasses, and maize, the latter of which is the most commonly consumed C_4 plant in the Americas. Finally, plants using crassulacean acid metabolism (CAM; e.g. epiphytes and xerophytes) have values between C_3 and C_4, but overlap more substantially with C_4 (O'Leary, 1988; Smith and Epstein, 1971). The $\delta^{13}C$ values in bone are influenced by the proportions of these plant categories consumed in life.

Bone is composed of a mineral apatite phase (hydroxyapatite) and an organic collagen phase. Carbon isotope ratios from the apatite phase of bone provide different information on the consumer's diet than do carbon isotope ratios from the organic phase of bone (Krueger and Sullivan, 1984; Lee-Thorp et al., 1989; Schwarcz, 2000). Experimental feeding studies on mice, rats, and pigs demonstrate that $\delta^{13}C_{apatite}$ reflects the $\delta^{13}C$ of the total diet, while $\delta^{13}C_{collagen}$ is biased toward isotopic values of dietary protein sources (Ambrose and Norr, 1993; Froehle et al., 2010; Howland et al., 2003; Kellner and Schoeninger, 2007; Tieszen and Fagre, 1993). In other words, carbon atoms from all macronutrients, including protein, carbohydrates, and lipids are utilized to synthesize mineral apatite, while about 3/5 of carbon atoms in collagen are routed from dietary protein, the remainder coming from other macronutrient sources (Froehle et al., 2010; Krueger and Sullivan, 1984; Lee-Thorp et al., 1989; Schwarcz, 2000).

Nitrogen isotope values ($\delta^{15}N_{collagen}$) distinguish the trophic level of the consumer, and differentiate terrestrial and marine food contributions to an organism's diet (DeNiro and Epstein, 1981; Schoeninger et al., 1983). Nitrogen from bone collagen originates in proteins of plants and animals consumed by an individual. Leguminous plant species exhibit lower $\delta^{15}N$ values than other plant families as they acquire nitrogen by directly fixing atmospheric N_2, which by definition has a $\delta^{15}N$ value of 0‰ (Virginia and Delwiche, 1982). Most other plants obtain nitrogen from nitrates in soil, and, due to kinetic fractionations during microbial breakdown of organic material which produce soil nitrates, plants are enriched 3–7‰ relative to atmospheric $\delta^{15}N$. A stepwise increase in $\delta^{15}N$ values occurs with ascending positions in a trophic system (Hedges and Reynard, 2007; Minagawa and Wada, 1984; Schoeninger and DeNiro, 1984). Herbivores are $\delta^{15}N$ enriched by 3–5‰ relative to their diet as ^{14}N-containing amino acid bonds break more readily than those with the heavier isotope, resulting in preferential excretion of ^{14}N over ^{15}N. This leaves the consumer with a higher ratio of $^{15}N/^{14}N$ than the food it consumes. In turn, carnivores are enriched by about 3–5‰ relative to their prey (Minagawa and Wada, 1984; Schoeninger and DeNiro, 1984). Human diets with high meat consumption will therefore exhibit higher bone $\delta^{15}N$ values than diets with low meat consumption.

Marine vertebrates are typically 6–8‰ more enriched in ^{15}N than terrestrial vertebrates, and humans that consume marine resources are distinguishable by bone $\delta^{15}N$ values from those who do not (Schoeninger and DeNiro, 1984). Because nitrogen-fixing and thus ^{15}N-depleted algal colonies underlie the base of coral reef systems, however, fish from these environments are difficult to distinguish from C_4 food products (Capone and Carpenter, 1982; Larkum et al., 1988; Schoeninger and DeNiro, 1984). Like maize, reef fish exhibit high $\delta^{13}C$ values and low $\delta^{15}N$ values, presenting an interpretive problem for the Maya region, which will be discussed further below.

Here we explore ancient Maya dietary patterns using two related modeling procedures: a simple carbon isotope model, which plots archaeological $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ values against regression lines generated from experimental feeding studies, and a three-isotope model, which uses cluster analysis and discriminant function analysis to holistically investigate $\delta^{13}C_{collagen,}$ $\delta^{13}C_{apatite,}$ and $\delta^{15}N_{collagen}$ values. These modeling techniques improve on bivariate plotting of $\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen,}$ which are both biased toward dietary protein sources. Inclusion of $\delta^{13}C_{apatite}$ values controls for the protein bias of $\delta^{13}C_{collagen}$, and analyses that include both the organic and inorganic phases of bone permit more detailed paleodiet reconstructions.

3.2. A simple carbon isotope model

Neither $\delta^{13}C_{collagen}$ nor $\delta^{13}C_{apatite}$ alone fully characterize dietary energy or protein sources. Bivariate plots of $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ together, however, provide a more complete picture of dietary patterns (Froehle et al., 2010; Kellner and Schoeninger, 2007). Experimental feeding studies on rats, mice, and pigs demonstrate that $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ values reflect $\delta^{13}C$ ratios of dietary protein and the total diet, respectively (Ambrose and Norr, 1993; Hare et al., 1991; Howland et al., 2003; Jim et al., 2004; Tieszen and Fagre, 1993; Warinner and Tuross, 2009). Recently, Kellner and Schoeninger (2007) and Froehle et al. (2010) plotted experimental animal data grouped by known diets to produce two parallel regression lines characteristic of diets consisting of either C_3 protein or C_4/marine protein. Which regression line an individual animal falls closest to in the $\delta^{13}C_{collagen}$ axis indicates dietary protein source (C_3 or C_4/marine). Where animals fall along either of these two lines in the $\delta^{13}C_{apatite}$ axis is strongly influenced by the isotopic composition of total diet.

Since rats, mice, and pigs—animals of quite different body sizes—do not significantly differ in terms of the relationship between dietary isotopic values and bone isotopic values, they are thought to adequately serve as models for human biological processes (Froehle et al., 2010). Supporting this notion, Kellner and Schoeninger (2007) plotted $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ values of archaeological human populations with well-characterized diets against the regression lines generated from experimental feeding studies, and found that human isotope values fall largely where expected. Thus, plotting bone $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ values against regression-lines of the simple carbon isotope model provides information on dietary protein and whole diet, and affords a more complete measure of diet than does either variable alone. Recent bioarchaeological studies demonstrate the interpretative value of this bivariate model (e.g., Reitsema et al., 2010; Yoder, 2010).

3.3. A multivariate-isotope model

A drawback to the simple carbon isotope model is its difficulty in distinguishing C_4-consumers from marine-food consumers. A recently published multivariate isotopic model (Froehle et al., 2012), however, adds $\delta^{15}N_{collagen}$ values to the two carbon variables, and employs cluster analysis and discriminant function analysis to holistically investigate all three isotope variables.

Through *k*-means cluster analysis on archaeological populations with relatively well characterized diets, Froehle et al. (2012) generated dietary clusters, which served as the "training sample" for linear discriminant function analysis. Cluster analysis revealed five discrete dietary subgroups, which correlated to diets of (1) total diet = 100% C_3, protein source = 100% C_3; (2) total diet = 70% C_4, protein source > 50% $C_{4,}$ (3) total diet = 50% C_3, protein source = high marine protein; (4) total diet = 70% C_3, protein source $\geq$ 65% C_3; and (5) total diet = 70% C_4, protein source = $\geq$65% C_3. From the "training sample", discriminant function analysis generated linear equations (functions), which described how the sample varied in terms of isotopic data. Two resulting equations accounted for 98.8% of variance in the training sample:

"Carbon": $F1 = (0.322 \cdot \delta^{13}C_{apatite}) + (0.727 \cdot \delta^{13}C_{collagen}) + (0.219 \cdot \delta^{15}N) + 9.354$

"Nitrogen": $F2 = (-0.393 \cdot \delta^{13}C_{apatite}) + (0.133 \cdot \delta^{13}C_{collagen}) + (0.622 \cdot \delta^{15}N) - 8.703$

Structure coefficients indicated that Function 1 was most heavily influenced by $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$, while Function 2 was most strongly influenced by $\delta^{15}N_{collagen}$ (Froehle et al., 2012). In effect, this modeling technique "flattens" three isotopic variables into two linear functions, permitting bivariate plotting of $\delta^{13}C_{collagen}$, $\delta^{13}C_{apatite,}$ and $\delta^{15}N_{collagen}$ data. Discriminant function values for other studies, in our case the ancient Maya, may be calculated by plugging isotopic values into the above equations. Various statistical techniques (e.g. analysis of variance, or ANOVA), can then be used to test for the statistical significance of observed patterns of differences in function values between time and status groups.

4. Methods

4.1. Meta-analysis

Four criteria guided our selection of individuals for the meta-analysis: (1) We limited the study to the geographic region of the southern Maya lowlands; (2) we limited the study to the Maya Classic Period (250–900/1000 AD); (3) we selected only studies that included the three isotope variables of carbon from bone mineral apatite ($\delta^{13}C_{apatite}$), carbon from bone collagen ($\delta^{13}C_{collagen}$), and nitrogen from bone collagen ($\delta^{15}N_{collagen}$) for each individual; and (4) we included only individuals with a status designation of "elite" or "commoner", as designated by the original studies, eschewing individuals of "middle" or "intermediate" status.

4.1.1. Geographic criteria

To mitigate isotopic variability resulting from environmental differences (cf, Ambrose, 1991; Gerry and Krueger, 1997; Hartman, 2011), we focused exclusively on the southern Maya lowlands, a region which includes northern Guatemala, southern Mexico, western Honduras, and Belize (Fig. 1). The southern lowlands are characterized by heavy rainfall (~2000 mm/yr), warm temperatures (avg > 25 °C), low elevation (<250 m.a.s.l.), and are covered by tropical forests (Sharer and Traxler, 2006: 29–48). Settlements from this region with available isotopic data include Baking Pot, Barton Ramie, Holmul, Seibal (Gerry, 1993, 1997), Dos Pilas (Wright, 2006; Wright and Schwarcz, 1996), Lamanai (Coyston et al., 1999; White and Schwarcz, 1989), Pacbitun (Coyston et al., 1999; White et al., 1993), and Altun Ha (White et al., 2001). Isotopic data from Copan of western Honduras also exist (Gerry, 1993; Whittington and Reed, 1997b), but this polity lies at a higher elevation (700 m.a.s.l.) and represents a different environmental region (Gerry and Krueger, 1997). We therefore excluded Copan from the present meta-analysis.

One considerable limitation with the compiled dataset concerns differences in geographical distribution of selected elites and commoners. Gerry and Krueger (1997) found statistically significant differences in diet between environmental zones within the southern lowlands, and, although we exclude individuals from the northern lowlands and coastal Belize, a degree of environmental differences, nevertheless, remain in our sample. A substantial portion of our elite sample comes from Altun Ha and Lamanai, which are located much closer to coastal and estuary resources than selected interior sites. A lack of available data from commoner burials at Altun Ha and Lamanai means that the general elite group encompasses more environmental diversity than the commoner sample, which primarily contains individuals from inland locations. Nevertheless, we include these settlements with the understanding that *within-site* temporal differences in diet may be more meaningful than *inter-site* comparisons. Fortunately, the proportion of elite individuals from Lamanai and Altun Ha within each of our chronological sample groups is fairly consistent. This methodological issue will be considered in more detail below.

4.1.2. Temporal criteria

The meta-analysis focuses exclusively on the Maya Classic Period (250–900/1000 AD), the era in which lowland Maya population and cultural expression reached their zenith. The Classic Period is divided into three sub-periods: the Early Classic (250–600 AD), Late Classic (600–800 AD), and Terminal Classic (600–900/1000 AD). The Preclassic (2000 BC–250 AD) and Postclassic (AD 900–1520) periods were excluded in order to maintain a constrained temporal focus, and because of the paucity of available data from these eras. Although isotopic dietary data exist for the K'axob site in Belize (Henderson, 2003, 1998), temporal phases within the Classic Period at K'axob are not differentiated into Early, Late, or Terminal phases, prohibiting their inclusion in the present study.

4.1.3. Isotopic data criteria

We limited our data compilation to reports that included both collagen ($\delta^{13}C_{collagen}$ & $\delta^{15}N_{collagen}$) and apatite ($\delta^{13}C_{apatite}$) isotope values. These three variables are required for the holistic multivariate modeling utilized in this study. Other settlements with available $\delta^{13}C_{apatite,}$ $\delta^{13}C_{collagen,}$ and $\delta^{15}N_{collagen}$ data, which we include for context in the general discussion but not in the meta-analysis, are Marco Gonzalez and San Pedro from coastal Belize (Williams et al., 2005), and Chunchucmil, and Yaxuna of the Northern Lowlands (Mansell et al., 2006).

Although the included datasets are products of different laboratories and were analyzed at different times, data are considered directly comparable as all isotopic variable ratios are expressed relative to the same standards: $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ relative to the Peedee belemnite standard (PDB) and $\delta^{15}N_{collagen}$ relative to the ambient inhalable reservoir (AIR). All studies followed established methods of collagen and apatite preparation, and isotopic ratios were produced via accepted analytical techniques. In all studies, collagen preservation was assessed through measures of carbon to nitrogen ratios (C/N), and through percent of collagen yield after sample processing. Only samples with C/N ratios between 2.9 and 3.6 (DeNiro, 1985) and collagen yields above 1% (Ambrose, 1990) were included in this study. All studies treated mineral apatite with dilute acetic acid (CH_3COOH) to remove surface carbonates most prone to diagenetic contamination (Koch et al., 1997; Krueger, 1991). Mineral apatite preservation of Altun Ha and Lamanai bones was assessed by Fourier transform infrared spectroscopy (FTIR) (Coyston et al., 1999). We excluded samples displaying a crystallinity index (CI) value >3.8 (Shemesh, 1990). Bone studies of the Petén site, Dos Pilas (2006; Wright and Schwarcz, 1996; Wright personal communication 2012), also produced $\delta^{13}C_{apatite}$ values and were screened by FTIR spectroscopy. Unfortunately, only six Dos Pilas samples met the temporal and status requirements of

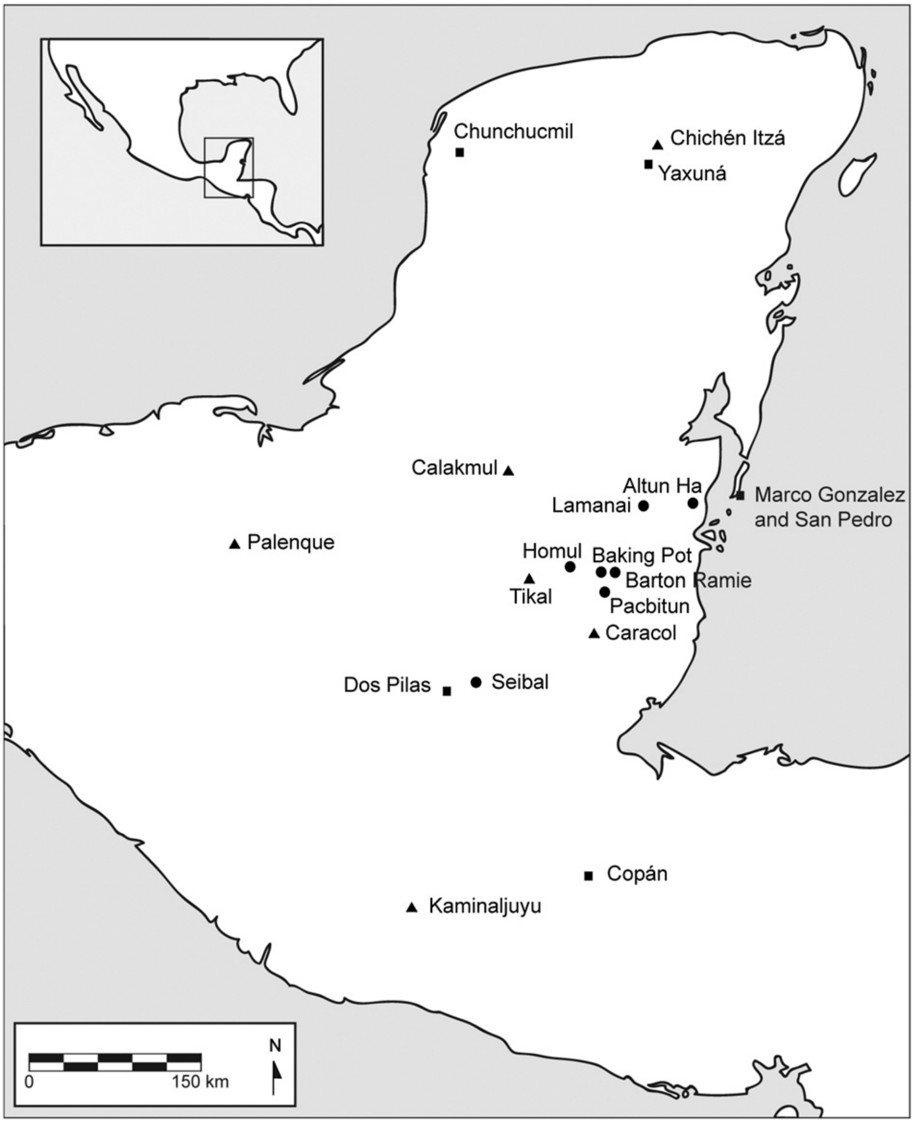

Fig. 1. Map showing the location of sites within the Maya region. Sites used in the isotopic meta-analysis are shown as circles. Sites discussed in the text but not used in the analysis are shown as squares. Important sites not discussed in the text are shown as triangles for reference.

the present meta-analysis, yet all six revealed CI values and carbonate content (C/P) values indicative of highly-degraded bone (Smith et al., 2007; Wright and Schwarcz, 1996). Bone samples from Dos Pilas, therefore, were unavailable for the present study. Since no diagenesis screening for the mineral bone phase was performed on specimens from Altun Ha, Baking Pot, Barton Ramie, Holmul, Seibal, Marco Gonzalez, San Pedro, Chunchucmil, or Yaxuna, the possibility remains that $\delta^{13}C_{apatite}$ values from these settlements are affected by post-depositional alterations to the isotopic signal. Our results, therefore, must be viewed with as much caution as given to the original reports.

4.1.4. Social status criteria

Status designations used here are based on those assigned in the original isotopic studies and archaeological reports. Exact methodologies used to assign status, however, varied between sites. Because archaeological research suggests that differences in wealth within Maya society existed along a continuum rather than in sharp bimodal contrast (Chase and Chase, 1992a; LeCount, 1999), we only sampled individuals clearly associated with the highest and lowest socioeconomic tiers of Maya society, avoiding individuals of intermediate or middle classes. General factors used to determine status in most studies included the number and quality of grave goods, burial location, and tomb construction. In effect, this meta-analysis compares dietary patterns of individuals interred with a high degree of material wealth in elaborate graves in site cores, against individuals interred with few grave goods in simple tombs located outside of ceremonial centers.

Data from, Baking Pot, Barton Ramie, Holmul, and Seibal were drawn from Gerry's (1993) dissertation, where individuals were assigned to one of four social categories on the basis of a nested cluster analysis using the variables tomb quality, tomb location, and quality of grave goods (see also Gerry, 1997). For the purposes of this study, we used only Gerry's (1993: 128) two most extreme groups, “high elite” and “commoner”, which correspond to royal individuals buried in tombs at site centers and peripheral commoners buried with little or no grave goods, respectively.

For Altun Ha, all burials come from architectural units considered to be elite residences (Pendergast, 1992: 65–66), but isotopic evidence for dietary differences between individuals from the site core and individuals from the semi-peripheral zones of H, J, and K (White et al., 2001), suggest that these outer residential units were inhabited by a less-elite or middle class. Therefore, in our effort to maintain the elite/commoner dichotomy we include only the core burials from Altun Hu and exclude individuals from "middle class" zones. No commoner graves are available from Altun Ha. All interments from Lamanai are also considered elites. Selected individuals were buried in the ceremonial core and no significant differences in grave goods were observed across the sample (Pendergast, 1981; White and Schwarcz, 1989: 455). At Pacbitun, both elites and commoners are represented. Status distinction is based primarily on burial context and grave goods (Healy, 1990; White et al., 1993). Pacbitun elite burials come from excavations within the ceremonial center and display a wealth of grave goods. A peripheral site dating to the Terminal Classic was also excavated, and burials recovered there are considered commoners due to modest grave architecture and scarcity of grave goods.

5. Results

5.1. General Maya isotopic patterns

In total, our meta-analysis of the southern lowlands includes isotopic data from 102 Maya individuals from eight archaeological settlements that span the Early Classic ($N = 26$; 250–600 AD), Late Classic ($N = 55$; 600–800 AD), and Terminal Classic ($N = 21$; 800–900/1000 AD) periods (Table 1). In terms of status, the overall sample breaks down into two equally-sized subgroups (elite: $N = 51$; commoner: $N = 51$). In the full pooled southern lowland sample, isotope values exhibit sample means of $\delta^{13}C_{apatite} = -6.5‰$ (±3.0‰; 2sd), $\delta^{13}C_{collagen} = -10.9‰$ (±4.0‰; 2sd), and $\delta^{15}N_{collagen} = 9.6‰$ (±2.0‰; 2sd; Table 2). Broadly speaking, individual diets ranged from heavy maize consumption to little C_4 inclusion, but maize was clearly the staple crop for both commoners and elites. Large variability existed in individual trophic position, suggesting differential access to meat and marine products across Maya society. Generally low bone $\delta^{15}N_{collagen}$ values indicate an absence of pelagic marine fish in diet for both elites and commoners. Fish from coral reefs, however, were potential dietary inputs throughout the Classic Period.

To contextualize the southern lowland diet in reference to other Maya regions, we compared the region to diets from the coastal Belize sites of Marco Gonzalez ($N = 23$; Williams et al., 2005) and San Pedro ($N = 24$; Williams et al., 2005), and the northern lowland sites of Cunchucmil ($N = 3$) and Yaxuna ($N = 3$)(Mansell et al., 2006). First, we plotted $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ data from all three regions against the regression lines of the simple carbon isotope model (Fig. 2a). The majority of southern lowland individuals fall closer to the "C_4/marine protein" line than to the "C_3 protein" line, and most plot slightly closer to the "100% C_4 or marine diet" end of the line than to the "100% C_3 non-protein portion of diet" end. Interestingly, most individuals from coastal Belize fall above the "C_4/marine protein" line and close to the "100% C_4 or marine diet" (Fig. 2a), which is likely a result of high quantities of coral reef fish in their diet. Individuals from the northern lowlands fall close to the "C_3 protein" line, and near the "100 C_4 non-protein portion of diet" end, suggesting a very different subsistence strategy than Maya of the southern lowlands – one which included much less C_4 or marine protein.

Second, we plotted all Maya discriminant function values, including sites from coastal Belize and the northern lowlands, against the dietary groupings created by *k*-means cluster analysis (Fig. 2b). Most southern lowland individuals fall closest to the cluster 2 centroid, which corresponds to a total diet = 70% C_4 foods; and dietary protein >50% C_4 protein. Individuals from coastal Belize sites plot outside of any known dietary cluster, likely due to frequent consumption of reef fish. Finally, northern lowland individuals fall mostly within cluster 5, which corresponds to a total diet = 70% C_4 foods; and dietary protein = ≥65% C_3 protein.

Generally, there is a high degree of correspondence between patterns observed in the simple-carbon isotope model and the multivariate isotope model. Both indicate an intermediate dietary niche for the southern lowlands, falling between dietary patterns observed in coastal Belize and the northern lowlands. All remaining discussion focuses on the distinction between commoner and elite diet within the southern lowlands.

5.2. Simple carbon isotope model

Maya commoner mean $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values from the southern lowlands for all time periods fall near the "C_4/marine protein" line (Fig. 3a) indicating that nearly all dietary protein came from amino acids in maize, maize-fed animal meat, or from marine fish traded from the coast. In respect to total diet, commoner mean carbon isotope values plot near the middle of the "C_4/marine protein" line, but fall slightly closer to the "100% C_4/marine diet" end than they do to the "100% C_3 non-protein portion of diet" end (Fig. 3a). A linear mixing model of $\delta^{13}C_{apatite}$ values (Schwarcz, 1991), which most accurately represent total diet $\delta^{13}C$ values, suggests that 54% of the total dietary carbon originated with C_4 sources.[3] The simple carbon isotope model, therefore, indicates a commoner diet heavy in C_4/marine protein and composed of a roughly even mix of C_3 and C_4/marine products for total dietary inputs. Most interestingly, bone $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values from commoners across the southern lowlands are remarkably consistent throughout the Classic Period.

Maya elite diet, in contrast, exhibits greater isotopic variation (Fig. 3b; Table 2). Early and Late Classic period elite $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ averages also fall near the "C_4 protein/marine protein" line, indicating that most dietary protein came from maize, maize-fed animals, or marine fish (Fig. 3b). The distance between these temporal averages is, however, greater than temporal averages of the corresponding commoners. According to a linear mixing model utilizing $\delta^{13}C_{apatite}$ values, 63% of carbon in Early Classic elite diets originated with C_4 or marine sources, whereas Late Classic elites obtained about 51% from C_4 or marine sources. In contrast to earlier time periods, Terminal Classic elites fall off the "C_4/marine protein" line in the direction of the "C_3 protein" line, with $\delta^{13}C_{apatite}$ values suggestive of about 52% dietary carbon from C_4 or marine foods. Thus, while Terminal Classic elite diet included less C_4/marine protein than previous periods, elites maintained a similar total diet mix of C_3 and C_4/marine resources. As mentioned above, however, the elite sample encompasses greater environmental diversity than the commoner sample and some of the observed elite variability therefore may result from these environmental differences. This issue is explored in greater detail with the multivariate-isotope model.

5.3. Multivariate-isotope model

The discriminant function analysis of southern lowland Maya $\delta^{13}C_{collagen}$, $\delta^{13}C_{apatite}$, and $\delta^{15}N_{collagen}$ values produced results generally similar to the simple carbon isotope model, but, with the addition of $\delta^{15}N_{collagen}$ values, the analysis provides greater detail

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[3] $\%C_4 = ((-25-(\delta^{13}C_{apatite} - 9.7))/-16)*100$, where 25 represents the per mil C_3 end member, $\delta^{13}C_{apatite}$ represents the observed value, 9.7 represents $\Delta\delta^{13}C_{apatite-diet}$, and −16 is the expected difference between dietary C_4 and C_3 end members, assuming a −9‰ $\delta^{13}C$ value for archaeological maize.

Table 1
Maya stable isotope database used in the present study's meta-analysis.

Status	Site	Ref	Spec #	Time	Sex	$\delta^{13}C_{ap}$	$\delta^{13}C_{col}$	$\delta^{15}N$	F1	F2
Commoner	Barton Ramie	a	br 123-34	Early	F	−7.7	−12.4	8.5	−0.28	−2.04
Commoner	Barton Ramie	a	br 123-20	Early	M	−7.9	−13.1	8.5	−0.85	−2.05
Commoner	Barton Ramie	a	br 123-32	Early	M	−6.9	−11.2	8.5	0.85	−2.19
Commoner	Barton Ramie	a	br 155-6	Late	?	−6.3	−12.8	8.1	−0.21	−2.89
Commoner	Barton Ramie	a	br 123-7	Late	?	−7	−12	8.3	0.19	−2.39
Commoner	Barton Ramie	a	br 123-36	Late	?	−6.3	−10.8	9.4	1.53	−1.82
Commoner	Barton Ramie	a	br 123-9	Late	F	−7.9	−13.3	8.8	−0.93	−1.89
Commoner	Barton Ramie	a	br 144-5	Late	F	−6.9	−12.8	8.7	−0.27	−2.28
Commoner	Barton Ramie	a	br 123-24	Late	F	−6.9	−12	8.8	0.34	−2.11
Commoner	Barton Ramie	a	br 123-16	Late	F	−6.7	−11.3	9.1	0.97	−1.91
Commoner	Barton Ramie	a	br 155-4	Late	F	−6.9	−11.7	9.2	0.64	−1.83
Commoner	Barton Ramie	a	br 123-26	Late	F	−7.7	−12.2	9.4	0.06	−1.45
Commoner	Barton Ramie	a	br 123-12	Late	F	−7.4	−12.8	8.2	−0.54	−2.40
Commoner	Barton Ramie	a	br 75-2	Late	M	−6.1	−10	8.8	2.05	−2.16
Commoner	Barton Ramie	a	br 123-4	Late	M	−6.7	−10.4	9.5	1.72	−1.54
Commoner	Barton Ramie	a	br 155-3	Late	M	−6.9	−12	9.4	0.47	−1.74
Commoner	Barton Ramie	a	br 123-6	Late	M	−6.9	−12.8	9	−0.20	−2.10
Commoner	Barton Ramie	a	br 123-8	Late	M	−7.2	−13.3	8.9	−0.68	−2.11
Commoner	Barton Ramie	a	br 123-23	Late	M	−6.5	−10.6	9.2	1.57	−1.84
Commoner	Barton Ramie	a	br 123-25	Late	M	−7.3	−11.1	8.7	0.84	−1.90
Commoner	Barton Ramie	a	br 123-17	Late	M	−7.3	−11.1	8.7	0.84	−1.90
Commoner	Barton Ramie	a	br 123-33	Late	M	−6.8	−11.2	8.7	0.93	−2.11
Commoner	Barton Ramie	a	br 123-29	Late	M	−6.3	−9.7	9.5	2.35	−1.61
Commoner	Pacbitun	b, c	Lot 301	Terminal	F	−5.92	−9.61	8.37	2.29	−2.45
Commoner	Pacbitun	b, c	Lot 415	Terminal	F	−6.09	−11.14	9.67	1.41	−1.78
Commoner	Pacbitun	b, c	Lot 472	Terminal	F	−8.08	−12.68	10.64	−0.14	−0.60
Commoner	Pacbitun	b, c	Lot 484	Terminal	F	−6.42	−10.44	9.33	1.74	−1.77
Commoner	Pacbitun	b, c	Lot 487	Terminal	F	−5.01	−10.36	9.75	2.34	−2.05
Commoner	Pacbitun	b, c	Lot 304	Terminal	M	−5.64	−9.87	8.65	2.26	−2.42
Commoner	Pacbitun	b, c	Lot 305	Terminal	M	−7.19	−9.57	8.83	2.02	−1.66
Commoner	Pacbitun	b, c	Lot 486	Terminal	M	−6.11	−10.85	9.21	1.52	−2.02
Commoner	Pacbitun	b, c	Lot 302	Terminal		−5.49	−11.48	8.4	1.08	−2.85
Commoner	Seibal	a	22	Early	F	−6	−10.9	8.9	1.45	−2.26
Commoner	Seibal	a	30	Early	M	−5.9	−9.7	10	2.59	−1.45
Commoner	Seibal	a	31	Early	M	−5.5	−8.7	9.2	3.27	−1.98
Commoner	Seibal	a	6	Late	M	−5.2	−10	10.6	2.73	−1.40
Commoner	Seibal	a	7	Late	M	−7.2	−11.6	9.6	0.70	−1.45
Commoner	Seibal	a	9	Late	F	−6.4	−9.7	7.9	1.97	−2.56
Commoner	Seibal	a	38	Late	M	−6.8	−9.3	9	2.37	−1.67
Commoner	Seibal	a	20	Late	F	−5.5	−8.2	8.9	3.57	−2.10
Commoner	Seibal	a	23	Late	M	−7.6	−8.8	9.9	2.68	−0.73
Commoner	Seibal	a	24	Late	M	−5.8	−8.3	9.8	3.60	−1.43
Commoner	Seibal	a	26	Late	M	−7.1	−9.4	9.7	2.36	−1.13
Commoner	Seibal	a	29	Late	M	−7	−8.1	10.1	3.42	−0.75
Commoner	Seibal	a	32	Late	M	−6.7	−11.2	9.9	1.22	−1.40
Commoner	Seibal	a	34	Late	M	−5.5	−9.2	8.8	2.82	−2.29
Commoner	Seibal	a	35	Late	?	−7.9	−10.1	10	1.66	−0.72
Commoner	Seibal	a	36	Late	M	−6.2	−8.4	10.1	3.46	−1.10
Commoner	Seibal	a	39	Late	M	−6.9	−10.5	9.3	1.54	−1.60
Commoner	Seibal	a	41	Late	M	−5.8	−8.5	10.5	3.61	−1.02
Commoner	Seibal	a	43	Late	M	−7	−10.3	9.4	1.67	−1.48
Elite	Altun Ha	d	A-8/4	Early		−5.7	−11.4	10.9	1.62	−1.20
Elite	Altun Ha	d	B-6/1	Early	M	−4.8	−9	10.3	3.52	−1.61
Elite	Altun Ha	d	C-18/15	Early		−6.6	−9.8	11.3	2.58	−0.38
Elite	Altun Ha	d	D-IO/1	Early	F	−7.4	−14	10.3	−0.95	−1.25
Elite	Altun Ha	d	D-IO/3	Early	M	−5.2	−8.5	11.1	3.93	−0.89
Elite	Altun Ha	d	C-IO/8	Late		−11.4	−16.3	11.9	−3.56	1.01
Elite	Altun Ha	d	C-IO/9	Late		−7.6	−10.5	12	1.90	0.35
Elite	Altun Ha	d	C-IO/18a	Late	F	−5.9	−9.5	9.2	2.56	−1.93
Elite	Altun Ha	d	C-IO/18b	Late		−9.5	−13.3	10.2	−1.14	−0.39
Elite	Altun Ha	d	C-16/20	Late	M	−8	−12.3	10.6	0.16	−0.60
Elite	Altun Ha	d	C-18/2b	Late		−9.4	−12.1	10.4	−0.19	−0.15
Elite	Altun Ha	d	C-43/6	Late	F	−7.8	−10.1	10.6	1.82	−0.39
Elite	Altun Ha	d	C-44/1	Late	M	−9.1	−11.9	9.6	−0.13	−0.74
Elite	Altun Ha	d	E-14/9	Late		−9.3	−10.5	13	1.57	1.64
Elite	Altun Ha	d	E-49/5	Late	F	−8.4	−13.2	10.1	−0.74	−0.88
Elite	Altun Ha	d	C-22/3	Terminal	F	−8.6	−13.5	9.8	−1.08	−1.02
Elite	Altun Ha	d	C-22/5	Terminal	F	−9.1	−12.7	10.3	−0.55	−0.41
Elite	Altun Ha	d	E-44/5	Terminal	F	−6.9	−10.8	10.5	1.58	−0.90
Elite	Altun Ha	d	E-44/7	Terminal	M	−7.2	−10.1	10.8	2.06	−0.50
Elite	Baking Pot	a	Burial 15	Late	?	−6.5	−9.5	10	2.54	−1.19
Elite	Holmul	a	skel 1	Early	?	−3.7	−8.7	8.7	3.74	−2.99
Elite	Holmul	a	skel 2	Early	?	−3.7	−7.8	10.2	4.73	−1.94

(*continued on next page*)

Table 1 (*continued*)

Status	Site	Ref	Spec #	Time	Sex	$\delta^{13}C_{ap}$	$\delta^{13}C_{col}$	$\delta^{15}N$	F1	F2
Elite	Holmul	a	skel 5,12	Early	F	−4.5	−9.2	9.3	3.25	−2.37
Elite	Holmul	a	skel 6	Early	?	−4	−9.3	9.3	3.34	−2.58
Elite	Holmul	a	skel 21	Early	?	−5.3	−10.8	8.6	1.68	−2.71
Elite	Holmul	a	skel 13	Early	?	−3.7	−8.2	9.1	4.19	−2.68
Elite	Holmul	a	skel 14	Early	?	−3.7	−8.3	9.7	4.25	−2.32
Elite	Holmul	a	skel 9	Early	?	−2.4	−10.9	8.5	2.52	−3.92
Elite	Holmul	a	skel 10	Early	?	−3.7	−9.4	9.4	3.39	−2.65
Elite	Holmul	a	skel 1	Early	F	−8.6	−11.3	10.9	0.76	−0.05
Elite	Holmul	a	skel 1	Early	?	−5.8	−11.6	7.6	0.72	−3.24
Elite	Holmul	a	skel 1	Late	?	−4.6	−8.9	9.3	3.44	−2.29
Elite	Holmul	a	skel 3	Late	?	−4	−9	8.8	3.45	−2.85
Elite	Lamanai	c, e	N9-53/1	Early	F	−5.71	−13.16	10	0.14	−1.99
Elite	Lamanai	c, e	N9-33/1	Early	M	−8.19	−10.62	10	1.19	−0.68
Elite	Lamanai	c, e	N9-33/2	Early	M	−7.2	−11.22	10.4	1.16	−0.90
Elite	Lamanai	c, e	N9-56/1	Early	M	−4.56	−14.11	13.2	0.52	−0.58
Elite	Lamanai	c, e	N11-5/5	Late	M	−6.45	−14.01	10.3	−0.65	−1.62
Elite	Lamanai	c, e	N9-33/6	Late	M	−6.96	−13.12	10.4	−0.15	−1.24
Elite	Lamanai	c, e	N10-66/2	Terminal	M	−7.55	−15.15	10.2	−1.86	−1.41
Elite	Lamanai	c, e	N10-66/8	Terminal	M	−5.43	−17.18	9.4	−2.83	−3.01
Elite	Lamanai	c, e	N10-68/3	Terminal	M	−8.27	−15.34	10	−2.27	−1.27
Elite	Lamanai	c, e	N10-68/4	Terminal	M	−8.35	−14.7	9.8	−1.88	−1.28
Elite	Pacbitun	b, c	BU1-1	Late	F	−4.88	−9.84	10.01	2.82	−1.87
Elite	Pacbitun	b, c	BU2-4	Late	M	−5.45	−7.28	9.14	4.31	−1.84
Elite	Pacbitun	b, c	BU4-2	Late	M	−3.89	−8.25	8.85	4.04	−2.77
Elite	Pacbitun	b, c	BU2-1	Terminal	F	−5.36	−9.27	9.59	2.99	−1.86
Elite	Pacbitun	b, c	BU1-7	Terminal	M	−4.49	−9.12	10.11	3.49	−1.86
Elite	Pacbitun	b, c	BU2-2	Terminal	M	−5.67	−7.85	9.84	3.98	−1.40
Elite	Pacbitun	b, c	BU2-5	Terminal		−6.74	−11.83	8.04	0.34	−2.63

a, Gerry (1993).
b, White et al. (1993).
c, Coyston et al. (1999).
d, White et al. (2001).
e, White and Schwarcz (1989).

with which to interpret dietary patterns over time. Generally, the commoner average function values change very little through the Classic Period, indicating stability of dietary patterns despite drastic changes in regional demographics and political organization (Table 2). Although Function 1 values suggest a slight trend of increasingly higher maize input for commoners over time (Fig. 4), one-way ANOVA showed this not to be significant [$F(2,48) = 0.22$; $P = 0.81$]. Similarly, trophic level as indicated by Function 2 values did not change significantly over time within the commoners [$F(2,48) = 1.00$; $P = 0.38$]. Multivariate analysis of variance (MANOVA) was used to detect changes in both functions simultaneously, as a measure of total dietary change, but found no significant change over time within the commoners [Wilk's Lambda = 0.95; $F(4,94) = 0.67$; $P = 0.61$].

In contrast to the commoners, elite discriminant function values exhibit more variability, displaying a trend of less maize consumption through time as evidenced by Function 1 mean values. Early Classic elites display evidence for heavy maize consumption, whereas Terminal Classic elites display the least evidence for maize consumption of any temporal or status-defined group (Fig. 4). This change over time in Function 1 values within elites was significant [one-way ANOVA: $F(2,48) = 3.94$; $P = 0.03$], but temporal change in Function 2 values within elites was not [one-way ANOVA: $F(2,48) = 2.44$; $P = 0.10$]. Evaluation of simultaneous change in both functions by MANOVA showed a significant time-dependent shift in overall elite diet [Wilks' Lambda = 0.80; $F(4,94) = 2.73$; $P = 0.03$].

We also evaluated function scores in elites and commoners simultaneously using two-way ANOVA, testing for the main effects of status and time, and for the status*time interaction. This allowed us to compare between-status differences within and across time periods. The overall ANOVA model for Function 1 was significant [$F(5,96) = 2.29$; $P = 0.05$], and the status*time interaction approached significance [$F = 2.54$; $P = 0.08$]. In terms of main effects, time was significant ($F = 2.99$; $P = 0.05$), but status was not ($F = 0.37$; $P = 0.54$). Differences in least squares means (see Table 3) showed significant change over time within elites, but not in commoners. Status-based differences in C_4 contributions to diet were generally absent, though the elite-common difference during the Terminal Classic approached significance ($P = 0.09$). For Function 2, the overall model was significant [$F(5,96) = 2.55$; $P = 0.03$], as was the main effect of status ($F = 8.20$; $P < 0.01$). Neither the main effect of

Table 2
Sample means and discriminant function values.

	N	$\delta^{13}C$ apatite		$\delta^{13}C$ collagen		$\delta^{15}N$ collagen		F1		F2	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Early classic commoners	6	−6.7	1.0	−11.0	1.6	8.9	0.6	1.172	1.6	−1.996	0.3
Early classic elites	20	−5.2	1.7	−10.4	1.9	9.9	1.2	2.313	1.6	−1.846	1.1
Late classic commoners	36	−6.7	0.7	−10.7	1.5	9.2	0.6	1.418	1.3	−1.744	0.5
Late classic elites	19	−7.1	2.1	−11.2	2.3	10.2	1.1	1.136	2.1	−1.077	1.3
Terminal classic Commoners	9	−6.2	0.9	−10.7	1.0	9.2	0.7	1.614	0.8	−1.953	0.6
Terminal classic elites	12	−7.0	1.5	−12.3	2.9	9.9	0.7	0.331	2.4	−1.462	0.8

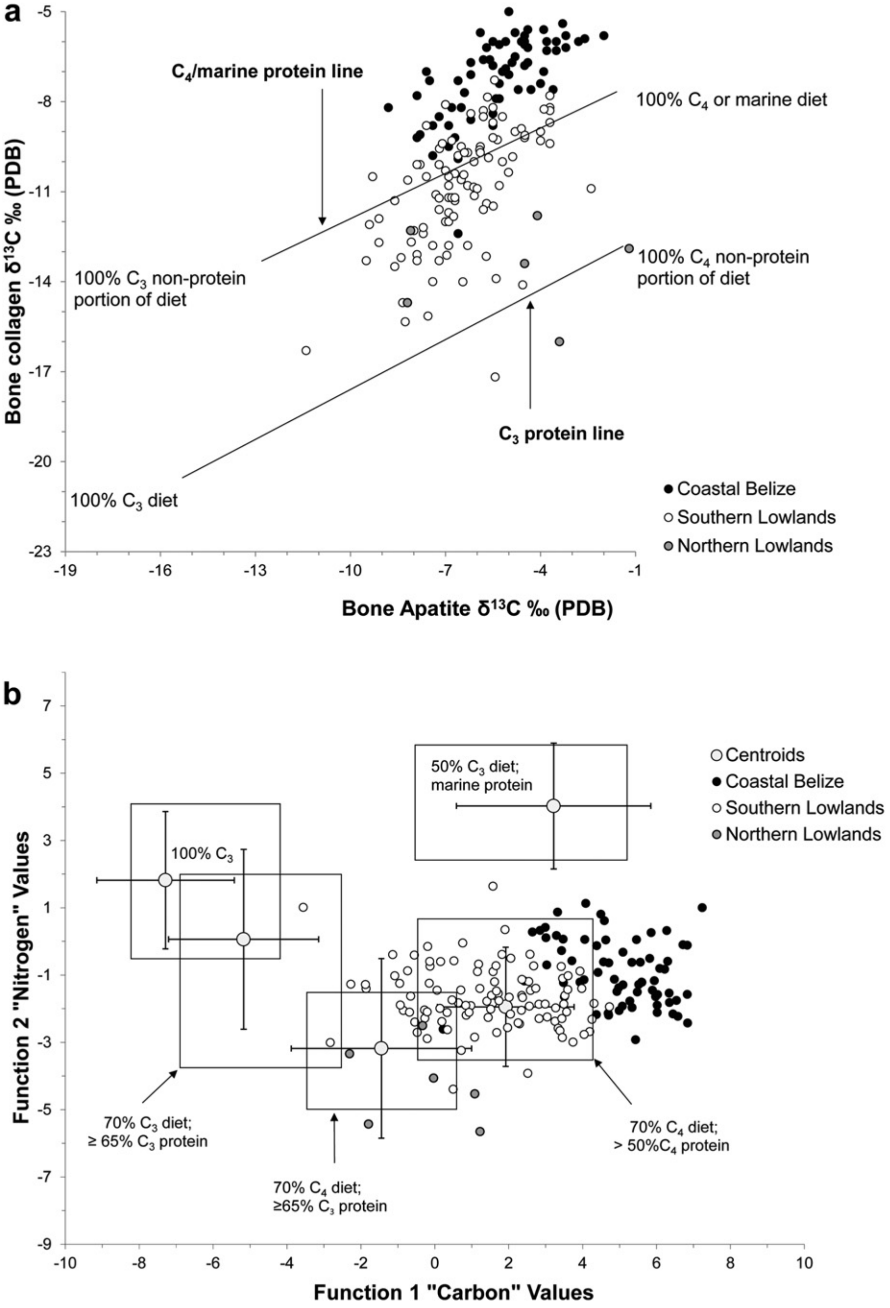

Fig. 2. (a) Carbon isotope values from across the Maya region plotted against regression lines of the simple carbon isotope model. Individuals from the southern lowlands are compared to individuals from coastal Belize and the northern lowlands, demonstrating geographic patterning of diet. Experimental animal carbon isotope data from which regression lines were produced were adjusted to reflect preindustrial atmospheric carbon levels by adding 1.5‰ (Marino and McElroy, 1991). (b) F1 and F2 discriminant function values from individuals across the Maya region plotted against previously generated dietary clusters (see Froehle et al., 2012). Individuals from the southern lowlands are compared to individuals from coastal Belize and the northern lowlands, demonstrating geographic patterning of diet. Southern lowland Maya fall largely within cluster 2. Northern lowland individuals fall closest to cluster 5. Individuals from coastal Belize fall outside of known diet clusters.

time ($F = 1.65$; $P = 0.20$) nor the status*time interaction ($F = 0.62$; $P = 0.54$) were significant. According to least squares means differences (Table 3) the status difference in Function 2 values was absent from the Early and Terminal Classic Periods, but was significant in the Late Classic Period ($P \leq 0.01$). This suggests that during the apex of Classic Maya civilization, elites enjoyed more access to meat than did commoners. The difference in Function 2 least squares means between Early and Late Classic elites was also significant ($P < 0.01$), in accordance with the gap between these time periods seen in Fig. 4.

6. Discussion

6.1. Commoner dietary patterns

Despite spanning 600 years and coming from three separate polities, Maya commoners experienced little variation in isotopic values across time and space, exhibiting a total diet roughly equal in C_3 and C_4 foods and generally high in C_4/marine protein sources such as maize, maize-fed animals, and reef fish (Fig. 3a and 5a). While it remains difficult to distinguish maize products from

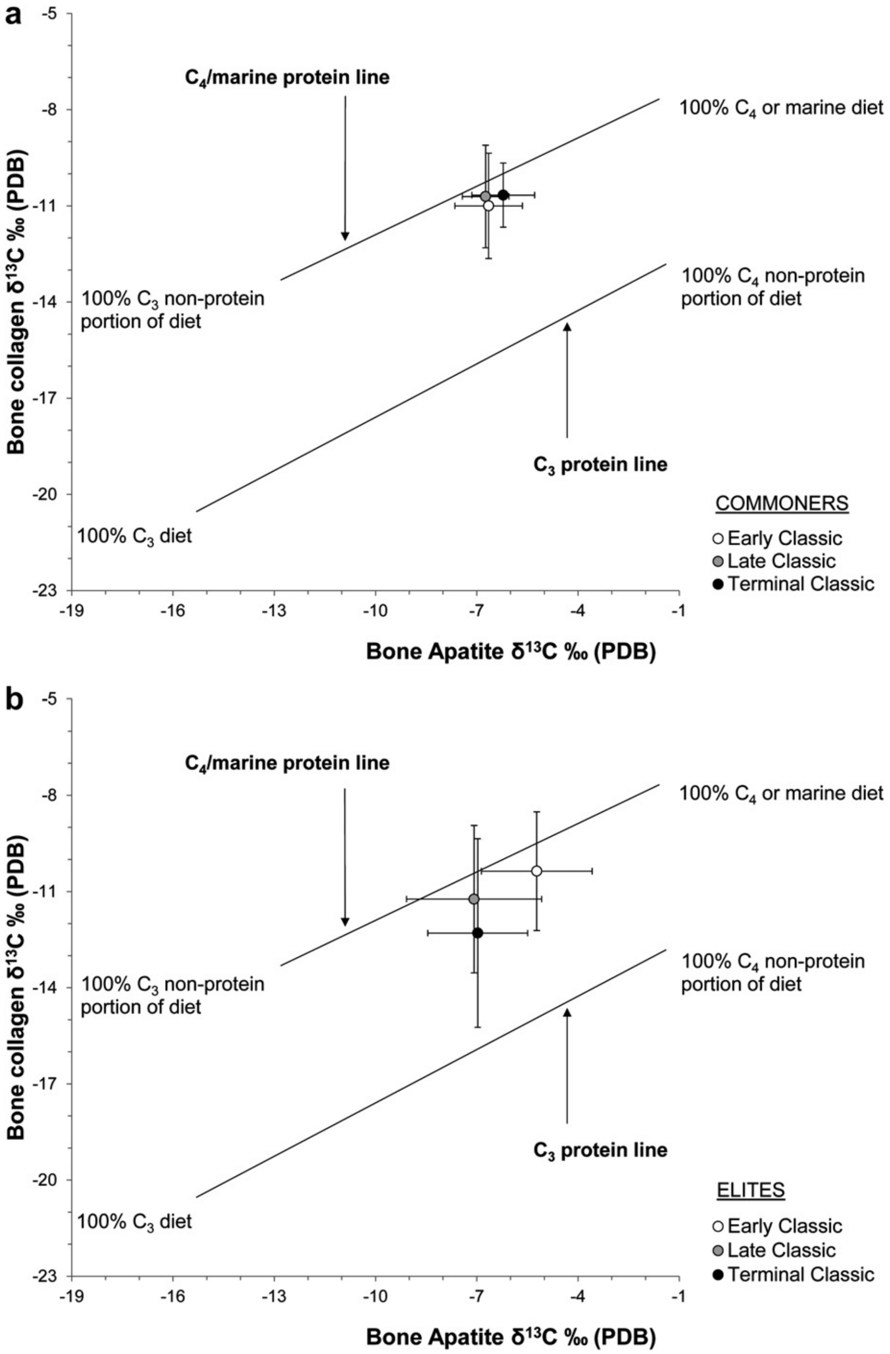

Fig. 3. (a) Scatterplot of average **commoner** $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ values from each temporal subdivision within the southern Maya lowlands. Error bars represent 1 SD. (b) Scatterplot of average **elite** $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ values from each temporal subdivision within the southern Maya lowlands. Error bars represent 1 SD.

tropical fish due to low $\delta^{15}N$ and high $\delta^{13}C$ values of coral reef systems (Schoeninger and DeNiro, 1984: 628), it is likely that maize and maize-fed animals contributed more calories to the southern lowland diet than did fish from coral reefs. Zooarchaeological analyses from non-coastal settlements, including Caracol (Teeter, 2004) and Lubaantun (Wing, 1975), demonstrate that some quantities of coral reef fish were in fact traded from the coast during the Classic Period. Still, the inland location of most sites likely precluded daily consumption of marine-based foods, particularly for less-privileged commoners.

In any case, consumption patterns of Maya commoners remained stable through periods of radical social, political, climate, and economic change, suggesting that (1) regional variation observed in previous isotopic macro studies of ancient Maya diet (Gerry and Krueger, 1997; Tykot, 2002; Wright, 2006) may be biased toward regional variations in *elite* dietary practices, and (2) that Maya commoners from across the southern lowlands may have shared more in common with one another, at least in terms of subsistence strategies, than they did with elites of nearby ceremonial centers.

Arguments that slash-and-burn/swidden agriculture served as the productive base of Maya society (e.g., Morley, 1946) largely fell out of fashion with the discovery of pre-Hispanic intensive agricultural systems in the 1970s (e.g., Hammond, 1978; Turner II,

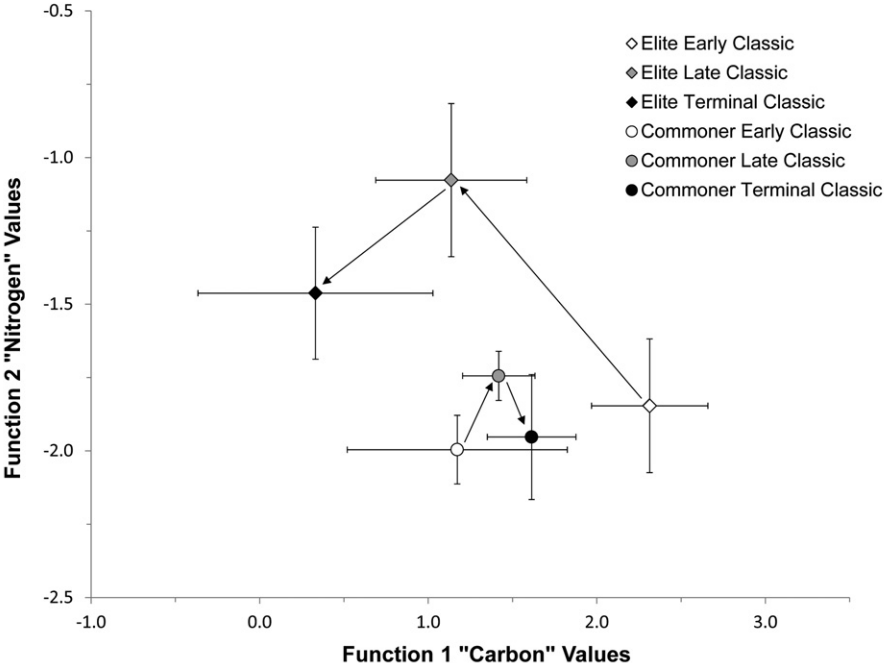

Fig. 4. Average F1 and F2 discriminant function values of southern lowland elites and commoners separated by temporal period. Error bars represent SEM.

1974). Yet some recent hypotheses return to notions of local, milpa-based agriculture as important food production loci for the ancient Maya (e.g., Ford and Nigh, 2009). Drawing from historic sources and modern ethnographic accounts, scholars identify three interrelated food-production practices that likely existed contemporaneously with intensive agricultural systems. These include managed forests, home gardens, and swidden agriculture—all of which place a large percentage of food production for the ancient Maya at the household level (Fedick et al., 2008; Gasco, 2008; Gillespie et al., 1993; Gómez-Pompa and Kaus, 1992; Nations and Nigh, 1980). The Classic Maya also clearly practiced intensive raised-field and terraced-hillside agriculture (Dunning et al., 1998; Fedick, 1997; Flannery, 1982), but the strategies listed above may have served a more important role to commoners than to individuals of higher socioeconomic standing.

Indeed, due to the 595 AD eruption of the Loma Caldera volcano in El Salvador, home gardens, milpas, and collected botanical remains from the Classic Period Maya site of El Cerén are preserved in situ, demonstrating the integration of milpa-based maize agriculture with a diversity of other plant cultivation, including squash, manioc, agave, and fruits such as avocados and cacao (Lentz et al., 1996; Sheets, 1982; Sheets and Woodward, 2002). These food-production systems were located in the immediate vicinity of the local village and demonstrate the importance of household-based permaculture for commoners during the height of the Classic Period.

We suggest that household-based agricultural practices, including forest-management, household gardens, and milpa farming, permitted the greater long-term stability of the Maya commoner diet. The simple carbon and multivariate isotope models indicate that a substantial portion of calories consumed by both commoners and elites came from maize products (Coyston et al., 1999; Gerry, 1993; White et al., 1993, 2001). Maize (C_4) was clearly the Classic-period staple, but was likely supported by a diverse array of C_3 forest and agricultural products, many of which could be utilized as fallback foods during times of drought or disease. Indeed, subsistence strategies of the modern Lacandon Maya of Chiapas (Nations and Nigh, 1980), and agricultural practices reconstructed from the above-mentioned site of El Cerén (Sheets and Woodward, 2002), demonstrate that substantial quantities of maize were produced in milpa patches. Still, significant time and space were allocated for producing other edible or economically valuable (C_3) products, thereby maintaining biodiversity and reducing risks associated with monocropping.

Table 3
P-values for differences between least squares means.

	F1	F2
Commoners		
EC vs. LC	0.74	0.50
EC vs. TC	0.62	0.92
LC vs. TC	0.76	0.51
Elites		
EC vs. LC	0.03	<0.01
EC vs. TC	<0.01	0.22
LC vs. TC	0.20	0.22
Commoners vs. elites		
ECC vs. ECE	0.15	0.70
LCC vs. LCE	0.60	<0.01
TCC vs. TCE	0.09	0.20

6.2. Elite dietary patterns

In contrast to commoner stability, Maya elite diet changed significantly through time. A limitation to our meta-analysis concerned the breadth of environmental diversity encapsulated in our elite sample in comparison to the relatively homogenous commoner sample. Nevertheless, when individual sites were considered (Fig. 5), which controlled for environmental differences, elite diets still changed more drastically through time than did commoner diets. In fact, every instance of temporal change in elite diet (for periods with ≥ 3 individuals) moved more in Euclidean distance than any temporal change seen in commoner diets (Fig. 5b). This observation raises the possibility that socioeconomic

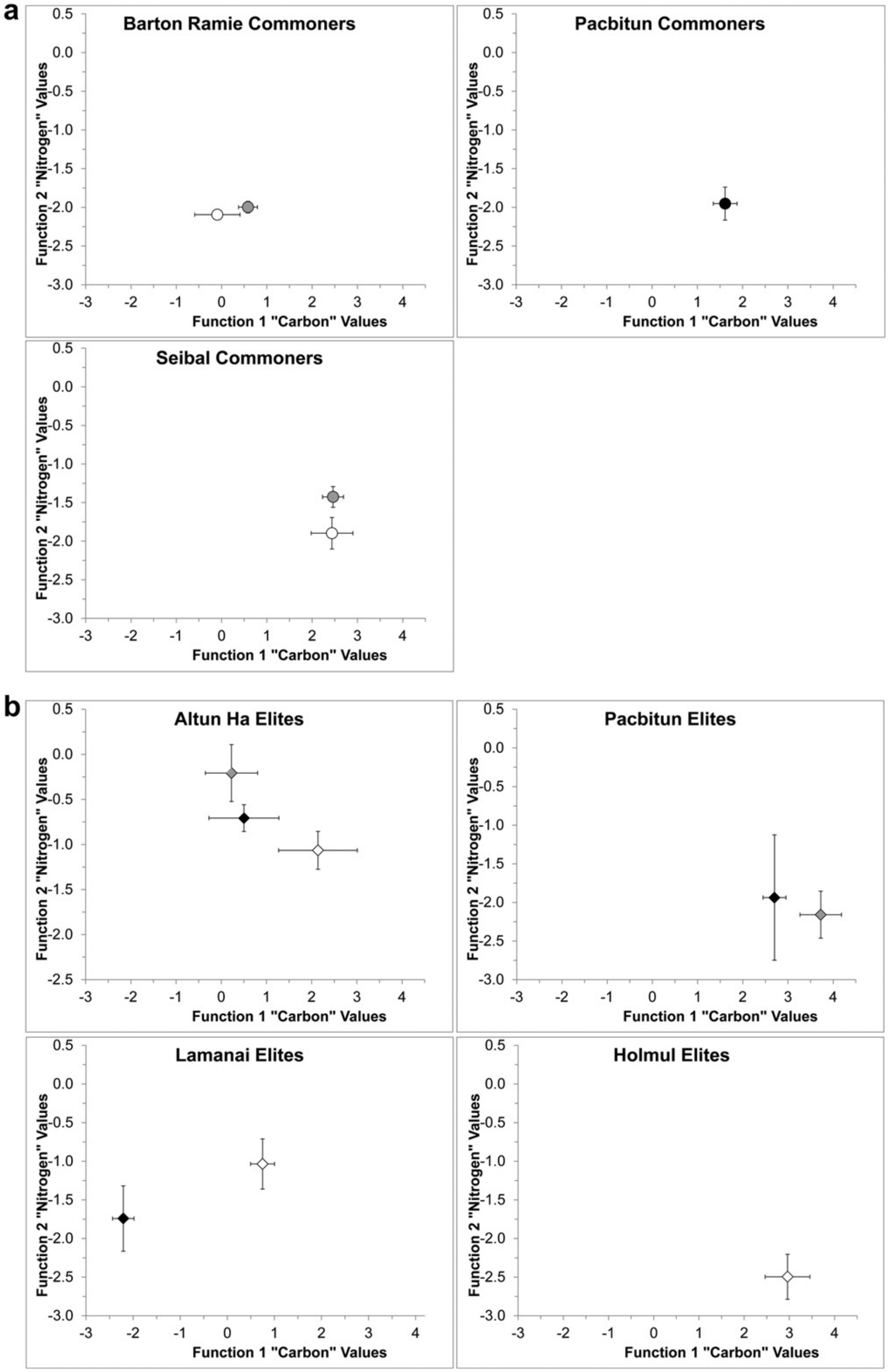

Fig. 5. (a) Scatterplot charts of Maya **commoners** separated by time and by site. Open circles represent the Early Classic; Gray circles represent the Late Classic; Black circles represent the Terminal Classic. Only averages for temporal periods with at least three individuals are presented. Error bars represent SEM. (b) Scatterplot charts of Maya **elites** separated by time and by site. Open diamonds represent the Early Classic; Gray diamonds represent the Late Classic; Black diamonds represent the Terminal Classic. Only averages for temporal periods with at least three individuals are presented. Error bars represent SEM.

differences in Maya society may have influenced dietary patterns to an extent on par with the regional influences observed by Gerry and Krueger (1997), and that previously observed regional variation in Maya diet resulted more from variation in elite cuisine rather than from dietary variability across Maya society as a whole.

When all elite values are averaged and analyzed across time, the simple carbon and multivariate isotope models both indicate a trend of less maize consumption through time for southern lowland elites. The Early Classic elite diet contained a high degree of C_4/marine products in both total diet and dietary protein (Fig. 3b and 4). In fact, averaged $\delta^{13}C_{apatite}$, $\delta^{13}C_{collage,}$ and Function 1 values suggest that Early Classic elites consumed more maize than any other status group in any time period. The Early Classic to Late Classic transition witnessed a significant decrease in C_4/marine products in elite total diet and a significant increase in the amount of meat consumed (Table 3). Rising $\delta^{15}N_{collagen,}$ and hence Function 2 values, during the Late Classic resulted in the largest gap in meat consumption between elites and commoners within the Classic Period (Tables 2 and 3; Fig. 4). Generally, this pattern accords with the notion that the Late Classic Period was a time of great social inequality.

Terminal Classic elite $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values, in contrast to Late and Early Classic values, plot below the "C_4/marine protein" line of the simple carbon isotope model, suggesting a smaller dietary contribution from maize-fed animals or marine fish (Fig. 3b; Table 2). Alternatively, maize protein, relative to animal protein, may have become less important at this time. The multivariate model suggests a drop in average trophic position and a further decline in maize consumption during the Terminal Classic (Fig. 4), but neither change reaches significance. The Terminal Classic elite Function 1 values, however, are significantly different from Early Classic values (Table 3). It is important to note that the Terminal Classic elites included in this study all come from polities of north and central Belize (Altun Ha, Lamanai, and Pacbitun). This region was among the few to survive the political, economic, and demographic upheavals of the Terminal Classic Period with a relatively high degree of sociopolitical complexity (Pendergast, 1992). An important avenue of future research will be to determine to what degree the patterns observed in this study correspond to collapse-associated changes in other regions within the Maya world.

7. Conclusion

In this paper we compiled a database of the $\delta^{13}C_{collagen,}$ $\delta^{13}C_{apatite,}$ and $\delta^{15}N_{collagen}$ values of 102 Maya commoners and elites from across the Classic Period (AD 250–900/1000) of the southern lowlands (Coyston et al., 1999; Gerry, 1993; White et al., 1993, 2001). These data were investigated through two new isotopic modeling techniques: a simple carbon isotope model (Froehle et al., 2010; Kellner and Schoeninger, 2007), and a multivariate isotope model (Froehle et al., 2012). The results demonstrate that elite Maya experienced significant temporal variations in dietary patterns at both the regional (Fig. 4) and site-specific (Fig. 5b) scales. Conversely, commoners from across time and space within the southern lowlands consumed remarkably similar cuisines. The broad trends in Maya diet mimic observations from Copan in Honduras. Botanical studies and stable isotope analyses of human bones indicate that Copan elites enjoyed greater dietary breadth than commoners (Lentz, 1991; Whittington and Reed, 1997b). Our meta-analysis suggests that this status-linked dietary pattern may have extended to the regional scale.

The variability observed in elite dietary practices could be attributed to the likelihood that elite subsistence strategies were more closely tied to political and economic circumstances than were commoner subsistence strategies. Commoners may have benefited from continuous access to nearby forests, housegardens, and milpas, which could have produced a steady and homogenous supply of food irrespective of shifting trade routes, political realignments, or disruptions in market activity. Intensive agricultural practices such as raised field systems or hillside terracing may have been under elite administration, channeling surplus food for elites and funding the artisans, merchants, and scribes of Maya urban society. Large-scale food-production systems such as these would be most susceptible to drought and disease, and may have been considered military targets during periods of heightened warfare.

Differences in diet between burial groups discussed in this paper corroborate status identifications on the basis of traditional markers such as grave goods and burial construction. The political and social disparity between Maya elites and commoners, therefore, can be seen not only in their material possessions, but also in the chemical signatures of their bones themselves. Our results highlight the utility of new isotopic modeling techniques to explore variability in ancient dietary practices. Future isotopic work will expand the available set of case studies, furthering our understanding of ancient Maya class structure and enhancing our knowledge of pre-Columbian foodways.

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