Stable Isotopes and the Human-Animal Interface in Maya Biosocial and Environmental Systems

CHRISTINE D. WHITE

Department of Anthropology. The University of Western Ontario

ABSTRACT: Stable isotope analysis of human skeletons has been used succesfully for years to determine the quatity and kind of animals consumed as food, even in the humid tropics where skeletal material may not be diagnostically useful for many other things. This paper discusses the largely unrealized potential, and the pros and cons, of using stable isotopic analysis of animals to answer questions and humans. Animals share the same ecosystem with humans and are often incorporated into social and ideological systems. The paper examines the use of intentionally fed animals as proxies for humans where human material is politically or archaeologically unavailable; it also reviews other aspects of ancient life, including the role of animals in the exercise of ideological practice, human-animal relationships involved in hunting, synathropy, domestication, and husbanding, and the use of animals as barometers of human-induced and natural environmental change. The examples in the paper are taken from isotopic analyses at various Maya sites.

KEYWORDS: ISOTOPES, MAYA, ENVIRONMENT, HUMAN-ANIMAL INTERACTIONS

RESUMEN: El análisis de isótopos estables en esqueletos humanos ha sido durante años utilizado con éxito para determinar las cantidades y tipos de animales consumidos incluso en las zonas tropicales húmedas donde los restos óseos pueden no ser útiles para muchas otras investigaciones. Este artículo discute el potencial generalmente insospechado así como los pros y los contras del uso de los análisis de isótopos estables en restos animales para averiguar cuestiones relativas a la biología de los seres humanos. Los animales comparten similares ecosistemas con los humanos y se encuentran a menudo incorporados en los sistemas sociales e ideológicos de éstos. Este trabajo examina la utilidad de animales que han sido alimentados intencionalmente como sustitutos de los humanos en aquellos casos en donde los restos óseos humanos no se encuentran disponibles por razones políticas o arqueológicas. Al mismo tiempo se repasan aspectos alternativos que incluyen el papel de los animales en el ejercicio de las prácticas ideológicas así como las interacciones hombre animal en acutaciones tales como la caza, la sinantropía, la domesticación y las prácticas pecuarias. Por último, se explora el uso de animales como indicadores de cambios ambientales de origen natural o inducidos por el hombre. Todos los ejemplos seleccionados proceden de análisis isotópicos de varios yacimientos mayas.

PALABRAS CLAVE: ISÓTOPOS, MAYAS, MEDIO AMBIENTE, INTERACCIONES DE ANIMALES Y HUMANOS

INTRODUCTION

Most research methods using archaeological skeletal material rely on gross examination. Only under conditions of good preservation, however, are such methods possible. The Maya region of Mesoamerica, consisting of a wide variety of regional and microenvironments, is generally considered to be tropical, thus subject to extremely hot and seasonally wet conditions. Skeletal

analyses of any kind (whether human or animal) have always been hindered by preservation in this area. The climate promotes the growth of microorganisms, which accelerate processes of decay; heavy rainfalls leach out the organic fraction of bone; alkaline soils dissolve its mineral fraction; insects and animals feed on remains and carry them away; and the powerful actions of plant and tree roots are physically destructive. Consequently, if preserved at all, skeletal remains are often differentially preserved. Small bones and bones of young individuals are the most common elements to disintegrate. The burial context also plays an important role in preservation, depending on how well protected the skeleton is. Its protection may or may not depend on human agency. Even when humans have gone to extreme lengths to protect bodies, placing them in tombs, for example, the skeletons deteriorate badly. It follows that animals may not have been as well treated. Teeth are commonly the only skeletal elements that are preserved well enough to be diagnostically useful.

This was the backdrop out of which dietary chemical (isotopic) analysis emerged in Mesoamerica (White & Schwarcz, 1989). Such analysis allowed the reconstruction of food consumption without relying on the preservation of individuals who were so nutritionally diseased that their bones had been affected. Furthermore, one could move from the "menus" provided by faunal and floral remains to the meals that had actually been eaten. Although preservation does put limitations on chemical analyses, particularly elemental studies, stable isotope analyses of human skeletal material have been used successfully for about two decades to reconstruct Maya diets (White, 1999). These techniques can measure relative quantities of the following: maize (the agricultural staple), protein sources, the use of terrestrial versus aquatic or marine foodwebs, and the degree of herbivory versus carnivory.

Isotopic analyses have dominantly been used as an alternative to traditional faunal studies that reconstruct the animal portion of the human menu. As such, they were a cross-check on whether or not what was in the midden went into the mouth. Unlike faunal studies, however, they cannot provide detail on the particular species consumed. Nonetheless, they are invaluable when fauna are not available or preserved. Even more important, however, and the focus of this chapter, is the potential of stable isotopic analyses of animals in reconstructing behavior of humans and the environments in which they live.

CARBON-ISOTOPE ANALYSIS

Stable isotope ratios are all measures of our interactions with different aspects of our environments and are expressed in per mil ($^0/_{00}$) as _-values using the formula:

$$\Delta = [(R_{sample}/R_{standard}) - 1] \times 1000, \text{ where } R = {}^{13}C/{}^{12}C,$$
${}^{15}N/{}^{14}N$, or ${}^{18}O/{}^{16}O$.

Stable carbon-isotope ratios are used to reconstruct diet on the basis of natural variation in the food web. Plants form the bottom of the food chain and fall into three categories of isotopic differentiation. The most common plant types are called C_3. During photosynthesis these plants discriminate most against atmospheric ${}^{13}C$ and therefore have the most negative $\delta^{13}C$ values (modern average of -26.5 $^0/_{00}$, Smith & Epstein, 1971; O' Leary, 1988) In the Maya area, most wild plants, trees, fruits, nuts, and vegetables fall into this category. Plants that incorporate more atmospheric ${}^{13}C$ during photosynthesis have the least negative $\delta^{13}C$ values (modern average of -12.5 $^0/_{00}$, O'Leary, 1988) and are called C_4 plants. In the Maya area the staple grain, maize, falls into this category. Although amaranth (*Amaranthus* spp.) and epazote (*Chenopodium ambrosoides)* are also C_4 plants and may have made some contribution to the C_4 component of the diet, the evidence from ethnohistorical documents (Landa, 1566, in Tozzer 1941), paleobotany (Mikisicek *et al.*, 1981; Rue, 1987; Pohl *et al.*, 1996), and stable carbon isotope analysis of humans (White & Schwarcz, 1989; Reed, 1994; Wright, 1994, 1997; Tykot *et al.*, 1996; Gerry & Krueger, 1997) demonstrates maize dependency throughout the Maya world. There is no overlap in $\delta^{13}C$ values between C_3 and C_4 plants, although the CAM (Crassulacean Acid Metabolism) plant category does have a range that overlaps (-27 to -12 $^0/_{00}$). CAM plants are succulents and cacti (e.g., nopal cactus [*Opuntis*] and piñuela [*Bromelia karatas*]) and may have been consumed more by animals than humans, and thus may confound dietary measures. The $\delta^{13}C$ values of all modern plants are about 1.5 $^0/_{00}$ lower than pre-industrial ones because the burning of fossil

fuels has lowered the $\delta^{13}C$ value of atmospheric carbon (Friedli *et al*., 1986; Marino & McElroy,1991).

Bones and teeth have both organic and mineral components. The organic component, collagen, normally reflects the protein portion of the diet (Krueger & Sullivan, 1984; Lee-Thorp *et al*., 1989; Ambrose & Norr, 1993; Tieszen & Fagre, 1993) because it is derived from both plants and animals. However, the mineral component, apatite, reflects the whole diet – that is, all the macronutrients: protein, carbohydrates, and lipids (Ambrose & Norr, 1993; Tieszen & Fagre, 1993), although models theorizing on the fate of macronutrient carbon in apatite vary (e.g., Krueger & Sullivan, 1984; Ambrose & Norr, 1993; Schwarcz, 2000). The difference between carbon-isotope ratios in collagen ($\delta^{13}C_{col}$) and apatite ($\delta^{13}C_{ap}$) - that is, $\Delta^{13}C_{col-ap}$ - is used as an index of meat consumption (Krueger & Sullivan, 1984; Lee-Thorp *et al*., 1989) or trophic level (Ambrose, 1993) because the amount of ^{13}C varies by macronutrient. For example, lipids, which are consumed more by carnivores, are lower in ^{13}C. In general, herbivores have $\Delta^{13}C_{col-ap}$ values averaging 7 $^0/_{00}$, omnivores 5 $^0/_{00}$, and carnivores 3 to 4 $^0/_{00}$. The consumption of marine resources produces the appearance of extreme carnivory ($\Delta^{13}C_{col-ap} = 1$ to 2) (Ericson *et al*., 1989; Lee-Thorp *et al*., 1989; White *et al*., 2001).

NITROGEN-ISOTOPE ANALYSIS

Although $\delta^{13}C$ analyses of both collagen and apatite provide a means of determining the relative amounts of protein consumed and the main plant source at the base of the food chain, they cannot identify the kind of protein consumed. For this, nitrogen-isotope ratios of collagen ($\delta^{15}N_{col}$) are useful because they are good indicators of trophic level. Nitrogen-isotope ratios do not vary among plants, with the exception of legumes (e.g., beans *Phaseolus vulgaris*), which were consumed by the Maya, and blue-green algae, which is part of the food web in the Caribbean barrier reef. Legumes and algae have $\delta^{15}N$ values close to 0 $^0/_{00}$, compared with most other plants, which range from 2 to 6 $^0/_{00}$. An enrichment of 3 to 4 $^0/_{00}$ in ^{15}N occurs as nitrogen passes from one level of the food chain to the next. Because there are more trophic levels in marine food webs, marine fish and mammals often have the highest $_{15}N$ values. Reef fish have higher values than reef shellfish. These resources overlap with their terrestrial counterparts, but can be differentiated on the basis of ^{13}C values.

OXYGEN-ISOTOPE ANALYSIS

Environmental variables such as temperature, humidity, distance from the ocean, and altitude affect $\delta^{18}O$ values of water as ^{16}O is lost through increasing evaporation (Yurtsever & Gat, 1981; Ayliffe & Chivas, 1990). The isotopic composition of water is incorporated into the phosphate and carbonate components of the skeleton via their equilibration with body water. Liquid water is the main source of oxygen in body water (Luz *et al*., 1984; Luz & Kolodny, 1985). Other minor sources include water in food, and atmospheric oxygen in breathing. The oxygen-isotope composition of body water is determined by the oxygen consumed and lost (through breath, sweat, urine, and feces) (Bryant & Froelich, 1995; Kohn, 1996; Kohn *et al*., 1996). There is also a trophic level effect (higher $\delta^{18}O$ values) in breastfeeding infants (Wright & Schwarcz, 1998; White *et al*., 2000, 2003). Not surprisingly, seasonality in climate and/or water sources can produce significant variability in their $\delta^{18}O$ values (Luz *et al*., 1990; Stuart-Williams & Schwarcz, 1997).

Until recently, oxygen-isotope analysis was used mainly on animal tissues and shells to reconstruct paleoenvironmental change over both long-term and short-term (season) periods (Koch *et al*., 1989; Fricke & O'Neil, 1996; Stuart-Williams & Schwarcz, 1997; Fricke *et al*., 1998; Weideman *et al*., 1999; Gadbury *et al*, 2000; Bocherens *et al*., 2001), to understand the relationship between animal physiology, diet, and the environment (e.g., Bocherens *et al*., 1996; Kohn *et al*., 1996; Sponheimer & Lee-Thorp, 1999), and to reconstruct migratory patterns in fish and animals (Killingly & Lutcavage, 1983; Nelson *et al*., 1989; Meyer-Rochow *et al*., 1992; Hobson, 1999). Because species size, physiology, and dietary behavior affect the oxygen-isotope composition of animals (Bryant & Froelich, 1995: Kohn *et al*., 1996), $\delta^{18}O$ values are not necessarily comparable among species. Therefore, studies involving environmental reconstruction are best done using only single species, whereas studies developing models of biological, behavioral, and

environmental interaction are more likely to use species comparisons.

In human populations in other parts of the world, oxygen-isotope analysis has been used for migration studies and to identify foreigners (Schwarcz et al., 1991; Fricke et al., 1995; Dupras et al., 2001; Blyth, 2003). In Mesoamerica, these applications have extended to testing the following: invasion hypotheses and models of political control (White et al., 2000, 2001a, 2002; Buikstra et al., 2003); the maintenance of ethnicity in powerful state contexts (White et al., 1998; in press a, submitted); the structure of the Teotihuacan military (White et al., 2002); and models of economic organization (White et al., in press b; in press c).

ISSUES OF CHEMICAL INTEGRITY

The validity of data retrieved using biogeochemical techniques rests on both preservation and the ability to recover original biogenic signals (Koch et al., 1990; Price et al., 1992; Stuart-Williams et al., 1996). Because preservation can be very poor in the humid tropics, this is a particularly serious issue for stable isotope studies in many areas of the Maya region. Needless to say, collagen (being organic) is the first component of skeletal tissue to disappear. The heat, humidity, and microbial activity contribute to its degradation, but more seriously, for material that is not buried deeply, regular and heavy rainfalls can flush away this water-soluble substance from its skeletal matrix. Sample preparation must include removing as many inorganics as possible as well as removing non-biogenic organics (such as humic acids in soils). Collagen yields are typically low, that is, below 5%, and often made up of insoluble collagen. It is not uncommon for collagen samples to fail tests of diagenesis (e.g., C/N ratios), and $\delta^{13}C$ values are usually affected by samples with yields below 1.5%.

The original biogenic signal of the carbon-bearing mineral component of skeletal tissue (apatite) is variably preserved. Wright & Schwarcz (1996) have cautioned that preservation in the Maya area may be adversely affected by the addition of post-depositional carbonates to skeletal matrices. In spite of its ability to add important depth to dietary reconstruction, the use of apatite has been quite limited in the Maya region (Wright, 1994; Coyston, 1995; Coyston et al., 1999; Gerry & Krueger,

1997; Wright & Schwarcz, 1998; White et al., 2001c). Nonetheless, careful cleaning treatment involving infrared spectroscopy, calcium/phosphorus ratios, weight percent of carbon, and crystallinity indices can produce samples that pass tests of diagenesis (White et al., 2001c).

Oxygen-isotope ratios can be measured in both phosphate and carbonate, but phosphate appears to be less subject to post-mortem chemical alteration (Shemesh, 1990) and may be more appropriate for use in the humid tropics. Certainly, phosphate oxygen-isotope data do not often fail tests of diagenesis (e.g., crystallinity indices, correlations with phosphate yields). The disadvantage to using phosphate is that its preparation procedure is much more complex, labour intensive, and dangerous than that for extracting carbonate.

APPLICATIONS

Isotopic analyses are based on the assumptions that all animals (including humans) are a chemical reflection of their environment - that is, they are what they eat and what they drink. Animals and humans are part of the same ecosystems, which means that large portions of available food and liquid "menus" are shared. Because of this relationship, the isotopic ratios of animals have acted as controls for valid interpretation of human ratios. The most common use of isotopic analyses of animals by far is the reconstruction of food webs as a context for understanding human diets. Anthropologists have often drawn on the isotopic work of environmental ecologists to provide such background. However, it is often not recognized that ecological databases developed by anthropologists from archaeological and local modern fauna are useful to environmental ecologists; the databases then become hidden in the anthropological literature. The works of Keegan & DeNiro (1988), Emery et al. (2000) and Williams (2000) provide good examples of data that can integrate these fields.

Although most studies using animals are based on the analysis of skeletal tissues, isotopic ratios can be measured in any tissue (such as hair and fur, hide, nails, hooves, or antlers) or product (feces or coprolites, or human-modified artifacts). Similarly marine and aquatic tissues (such as shell, chitin, scales, or otoliths) can be used. Different tissues are often formed at different ontogenetic stages in the lifetime of the animal. These differences can

be used to advantage, particularly if the investigator is interested in detecting a shifting diet or a change in residence. For example, bone has a slow turnover rate and represents long-term diet or exposure to an environment. If there has been a change in diet or location, the isotopic composition of whole bone will represent the stage of equilibration to a new environment. Tissues that are formed incrementally (such as dental tissues, hair, nails, antlers, shell, or otoliths) can provide much finer detail on the life history of the animal.

1) *The Wild-to-Domesticated Continuum in Human/Animal Interaction*

The domestication of animals may have begun as the animals became scavengers, were taken as pets or used as hunting companions (Downs, 1960; Zeuner, 1963; Tennessen & Hudson, 1981), or were needed for labour, ritual, medicine, or trade (Cranstone, 1969; Isaac, 1970; Crabtree & Campana, 1989). Regardless of the human motivation to control animals, some degree of animal dependency on humans and a restriction of their natural freedom were usually involved. Purposeful feeding was often involved, which is possible to detect isotopically, particularly if the animal's new diet was different from that in the wild (if, for example, the isotopic plant types were different or if the protein in carnivore or omnivore diets came from a different source). Here it would be useful to combine analyses of organic and inorganic portions of bone. Because the staple in the Maya area is a C_4 plant (maize) and wild plants are in a different isotopic category (C_3), isotopic analysis provides a good opportunity for investigating the nature of human/animal relationships.

Theoretically, it is possible to track the origins of domestication if both human and animal remains are preserved over very early sequences. A convergence of animal and human dietary signals over time could indicate the occurrence of such a process. Most of the samples now available in Mesoamerica, however, post-date the actual process of domestication. Dogs were probably among the earliest domesticates in Mesoamerica (Flannery, 1967; Andrews & Hammond, 1990; Clutton-Brock & Hammond, 1994). Used in hunting, for eating (Landa, 1566, in Tozzer, 1941; López de Cogolludo, 1688, cited in Tozzer & Allen, 1910; Roys, 1943), and no doubt as companions, dogs are found in art (e.g., Pendergast,

1984; Danien, 1997) and often in faunal remains (Pohl, 1990; Clutton-Brock & Hammond, 1994). Domesticated dogs are assumed to have had diets similar to those of humans. Their use as faunal controls for human $\delta^{13}C$ values supports this assumption in the Maya area (White & Schwarcz, 1989; White *et al.*, 1993; Reed, 1994; Tykot *et al.*, 1996; Gerry & Krueger, 1997).

Dogs consuming "wild" C_3 diets have been identified, however, suggesting that feral dogs were still part of the ecosystem. For example, one of the six dogs analyzed at Lagartero has a predominantly C_3 signature, which would indicate that it is probably wild (White *et al.*, in press a; Figure 1a).

When forced into the same ecosystem with humans, some animals, such as deer and peccary, will exploit human agricultural products. Animals that are attracted to environments modified by humans are referred to as "synathropist." Such animals feed on young plants at the edge of maize fields, where they can easily be hunted (Reina, 1967; Pohl, 1977). The isotopic compositions of animals that regularly practice this feeding habit will be intermediate between those that are wild and those consuming human diets. Synathropist deer have been found at Lagartero, Copán, and Pacbitun (Figures 1a, b, c), but there is a continuum in the degree of maize consumption. This is illustrated by data from Copán. Most deer found in archaeological deposits do occasionally come to feed on maize, but a few clearly use the fields as a major source of food.

Species differences in feeding patterns are also evident. White-tailed deer (*Odocoileus virginianus*) prefer to feed in disturbed forest and occur most commonly in archaeological deposits. This is the species most likely to be captured at the interface between field and forest, and at all sites where they have both been analyzed (Pacbitun [White *et al.*, 1993]; Cuello [Tykot *et al.*, 1996]; Tikal [White *et al.*, 1997]) is, not surprisingly, more enriched in $\delta^{13}C$ values (~1 $^0/_{00}$) than the smaller brocket deer (*Mazama* sp.), which prefer undisturbed areas.

The hunting of deer is often mentioned both in ethnohistoric records (Landa, 1566, in Tozzer, 1941) and in art (Helmuth, 1966; Pohl, 1981). Because of their behavior, today deer are most easily hunted near the edges of milpa fields (Reina, 1967; Pohl, 1977). It is quite likely that this location was used for hunting in ancient times as well.
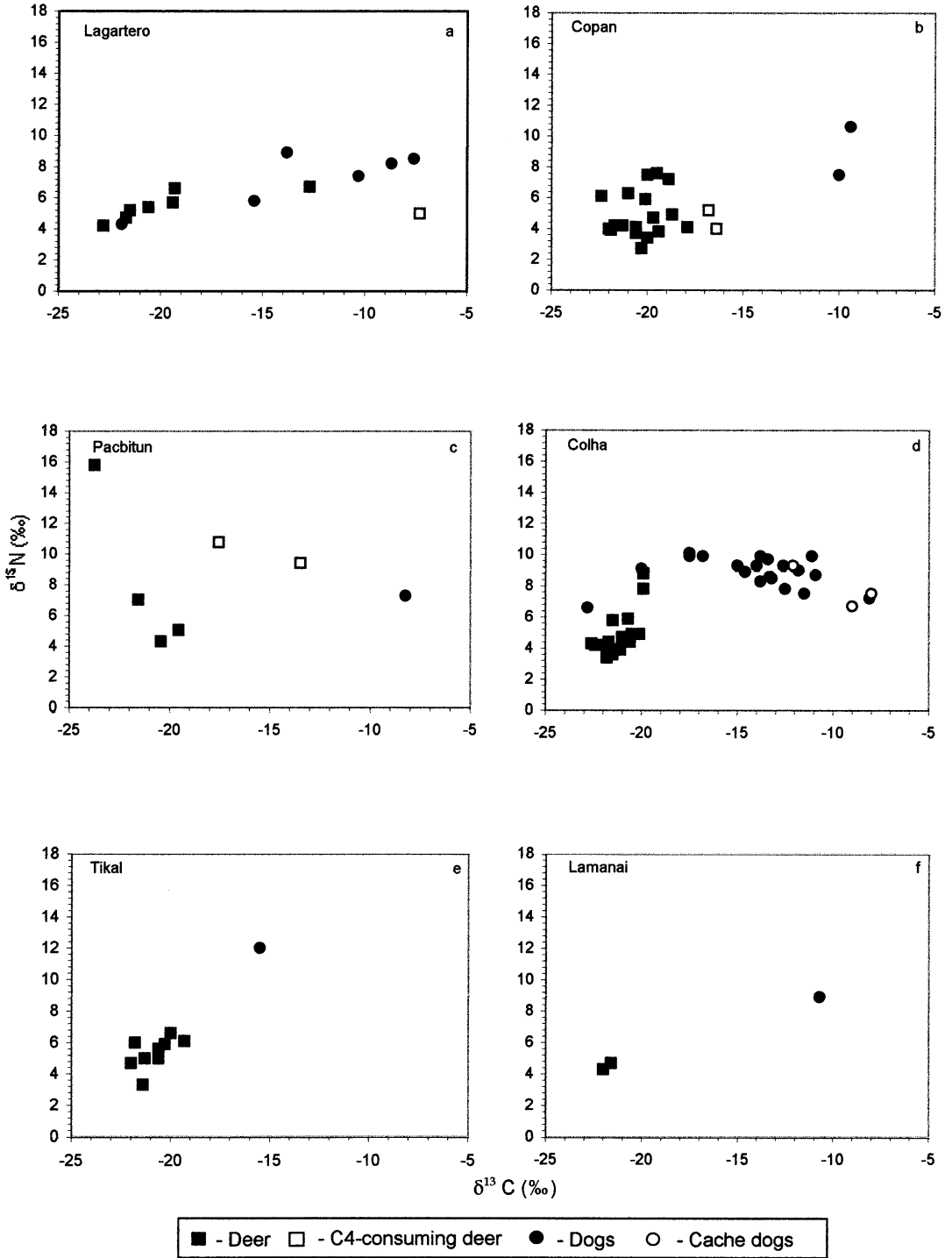
FIGURE 1

Isotopic values (δ^{13}C. δ^{15}N) for deer and dogs from: (a) Lagartero, (b) Copán, (c) Pacbitun, (d) Colha, (e) Tikal, (f) Lamanai (data from White *et al*., 1989, 1997, 2001, in press).

The modern Maya are also known to raise deer (usually fawns) captured on hunting trips (Reina, 1967).

Ethnohistoric references are also made to the ancient Maya's nursing, and then husbanding deer: "deer suck their breast, by which means they raise them and make them so tame that they will never go into the woods, although they take them and carry them through the woods and raise them there" (Landa, 1566, cited in Tozzer, 1941: 127). In addition, the phrase *ah may as nenadillo pequeño criado en casa* found in the Motul Dictionary (Martínez Hernández, 1929) is translated as "a little deer raised in a house" (Pohl & Feldman, 1982). Modern deer herd management using pens is found in Guatemala (Lewis, 1970), but whether it was practiced in ancient times is not known, nor is the kind of diet that penned deer would have consumed. One possible pen structure has been found in association with antlers at Terminal Classic Seibal (Pohl, 1990). Forest husbandry with large pens should produce deer with low variation in their isotopic compositions because their access to a wide variety of foods would have been limited. This is hinted at in data from Colha (White *et al*., 2001b) during the Terminal Late Preclassic period, but population expansion could also have reduced deer feeding territories, with similar results. Although both wild and forest-husbanded deer should have C_3 diets, the wild deer would be expected to exhibit greater variability within the C_3 range. It is also possible that deer were penned close to habitations, where they would likely have been fed agricultural produce, and thus have had predominantly C_4 diets, again with low variation in isotopic composition.

Thus we would expect to find a continuum in the $\delta^{13}C$ values of deer, from wild C_3 to essentially domesticated C_4 diets. Most of the deer analyzed at ancient Maya sites have signatures indicating that they were wild and therefore probably hunted in the forest. Those with a significant C_4 component in their diets may have been hunted at the edge of milpa fields, and those with predominantly C_4 diets would not have been hunted at all. Feeding from maize fields has been found in deer at Cuello (Tykot *et al*., 1996), Pacbitun (White *et al*., 1997), Petexbatun (Emery *et al*., 2000), Colha, and Copán (White *et al*., in press a). Further research on ancient Maya deer populations is needed to clarify our understanding of the regional and temporal patterning in relationships between deer and humans.

2) *Ideology*

Animals all over the world have great ideological significance and were used in ritual, medicine, and trade in many ways. Maya dogs are buried in graves (Kidder *et al*., 1946; Pollock & Ray, 1957; Hamblin, 1984; Tourtellot, 1990) and also on their own in ceremonial contexts (Wing, 1978; White *et al*., 2001b). Both dogs and deer were placed in ideologically significant locations such as caves and cenotes (Pollock & Ray, 1957; Pendergast, 1969, 1974). Their ritual use is further implied by buried concentrations of specific body parts (such as teeth for dogs, head, foot, and ankle for deer) (Hamblin, 1984). In the Maya belief system, both dogs and deer are associated with yearly renewal ceremonies and political rituals, such as ceremonies marking the investiture of authority (Pohl, 1981,1983; Danien, 1997). Deer were thought to embody the essential life forces of the sun and rain, and dogs were associated with death and the journey to the underworld as well as being protectors of the hearth (Trik, 1963; Coe, 1982; Schele & Miller, 1986; Friedel *et al*., 1993; Grube & Nahm, 1994). According the *Popul Vuh*, a Quiche Maya creation text, traditional Maya beliefs involving dogs include the following: (1) the survival of humans on earth was dependent on their feeding and treating dogs well, (2) the sacrifice of a dog allowed humans a place on earth, and (3) sacrificed dogs could be brought back to life and were, therefore, symbols of regeneration. This ideology is embodied in the isotopic compositions of dogs found in caches at Colha. Compared with dogs found in middens at the same site, the cache dogs had diets that indicated exclusive C_4 consumption throughout their lifespan (Figure 1d). Although $\delta^{13}C_{col-ap}$ values are not available to demonstrate conclusively that the C_4 content of their diet came predominantly from plants rather than from C_4-fed animals, these dogs do have low $\delta^{15}N$ values, which suggests that they did not get much meat and that the C_4 source in their diet was maize. For the diets of these dogs to have been so tightly restricted, they must have been physically restrained, that is, penned or leashed, so that they could not scavenge. Such behavior goes well beyond the normal boundaries of canine domestication. Because the *Popul Vuh* also states that humans were created from maize, it is possible that the Maya were using these dogs to create replacements for themselves in sacrificial rites. One might also expect to find tightly controlled

maize feeding in dogs from other ritually significant contexts, such as caves and cenotes.

There is an analogous example of purposeful feeding of deer from a Late Classic refuse pit at Lagartero, where ceremonial artifacts and animal bones were deposited (White *et al*., in press a). Two of the deer analyzed from this context consumed significant amounts of maize. One must have been fed maize exclusively from its infancy, and therefore penned, because its diet was almost pure C_4, and bone represents long-term dietary consumption. Although there is hot debate over the time it takes for the isotopic composition of bone to equilibrate to that of the diet (i.e., bone turnover) (Stenhouse & Baxter, 1979; Parfitt, 1983; Tieszen *et al*., 1983), it is probably minimally 4 years (up to 30 years), and this deer does not appear to have been old. The other deer had consumed some C_3 foods, so was either penned for a shorter period of time, or had regular access to a maize field. We hypothesize that either these deer were "tamed" or raised for the re-enactment of mythology related to weaving (which would be consistent with artifactual evidence from the dump), or they were sacrificed in a New Year's renewal ceremony. This is the first dietary evidence of purposeful feeding of deer for ceremonial reasons. It is quite possible that isotopic analysis of deer found in ritual contexts would reveal a more widespread practice of this behavior.

3) *Trade*

Just as stable isotope ratios have been used to identify the origin of illegally exported elephant ivory (van der Merwe *et al*., 1990; Vogel *et al*., 1990), the presence of "foreigners" in archaeological populations, and geographic movements of humans across the Mesoamerican landscape (e.g., White *et al*., 2000, 2001, 2002; Spence *et al*., in press), they can also be used to identify fauna that have been traded to foreign locations. Exotic fauna, or fauna that are rare and imported, were valued trade or ritual commodities for high status individuals and are often found in ceremonial or elite contexts. For species that are not found in restricted geographic areas, oxygen-isotopic analysis would be a useful source of information about economic or political interactions between sites. Marcus (2003) has recently advocated more chemical studies to source artifacts in

the Maya area. The combination of oxygen- and strontium-isotope analyses (e.g., Price *et al*., 2000), which is based on geological rather than climatic environments, would be an even more powerful means of sourcing animals or artifacts made from them. Strontium-isotope analysis is based on the premise that plants that form the base of the food chain reflect the age and type of rock that formed the soil in which they are grown. Through food consumption, the isotopic signature of the plants moves into the skeleton, where it is substituted for calcium.

Isotopic baselines for regions already used in the analysis of humans should be able to provide geographic controls for strontium-isotope studies, but species size and physiological differences could confound oxygen-isotope studies. For example, a mouse and a deer from the same location could not be expected to yield exactly the same $\delta^{18}O$ values. Oxygen-isotope analyses, in particular, would need to be controlled by comparing similar-sized species of local fauna with foreign archaeological fauna from sites of suspected origin, just as studies using humans do. A caveat for both types of studies is the avoidance of wide-ranging species. For example, animals that eat and drink in isotopically distinct environments during seasonal movement would be constantly equilibrating to changing environments. They would, therefore, have bone $\delta^{18}O$ values that average the signatures of the environments to which they are exposed. To control for geographic movement within individuals, a fine definition of ranging could be determined by analyzing the growth increments in dental tissues (enamel and dentine). Such studies would have the added benefit of contributing to ecological reconstructions.

4) *Animals as proxies for humans*

Because dogs share our food, it has been assumed that their isotopic values can be used to provide circumstantial evidence for shifts in diet or subsistence in populations where human material was unavailable (e.g., Burleigh & Brothwell, 1978; Noe-Nygaard, 1988; Clutton-Brock & Noe-Nygaard, 1990; Cannon *et al*., 1999). This assumption must be carefully considered in isotopic interpretations because of the scavenging habits of most domestic dogs and because of ideological factors (such as those above) that result in
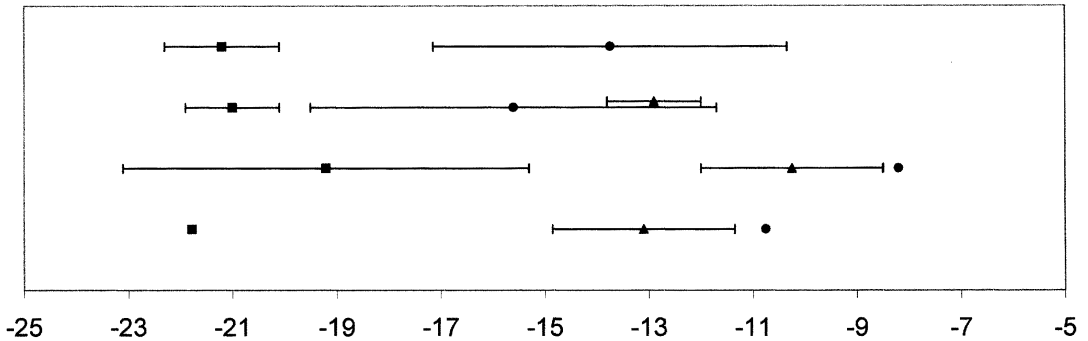
FIGURE 2

Comparison of isotopic values between humans, dogs, and deer from selected sites (after White *et al*., 2001).

tightly controlled feeding. At all the Maya sites from which both dogs and humans have been analyzed, some dogs had more maize in their diets than did the humans (White & Schwarcz, 1989; White *et al*., 1993; Tykot *et al*., 1996; Figure 2). Careful attention must be paid to the depositional context of dogs when using them as proxies for human diets. When controlled for context, such as the household midden, dogs at Colha do appear to work well as human representatives for dietary change during a period for which there is little human material available, the Preclassic (White *et al*., 2001b). Over the Preclassic sequence at Colha, dogs show increasing maize consumption and decreasing trophic levels - that is, the dogs are becoming more herbivorous (Figure 3). This pattern is consistent with the reduction of dietary variability expected during human population growth in Late Preclassic period and the consequent development of intensive agriculture. Theoretically, dogs may be used as proxies for humans in the investigation of social structure as well. For example, just as social status is reflected in human diets, it should also be reflected in the dogs owned by humans from different levels of society, unless dogs are a communal resource, which is an interesting question on its own.

This study, as most other isotopic analyses of dogs, has been limited to collagen. Expanding analyses to include apatite would provide a better definition of dog diets and allow us to understand more clearly the relationships between dogs and humans. Correlating the diets of dogs and the pathology observed in their skeletons would further extend our understanding of the effect of culture on our domesticates.

5) *Environmental Change*

Because isotopic studies are always fundamentally grounded in environmental or ecological relationships, isotopic analysis of fauna can be used to explore the serious issues of human-induced environmental degradation and long-term climatic change that affected the course of Maya civilization. Emery *et al*. (2000) pioneered the use of isotopic data from fauna to address these issues. They used $\delta^{13}C$ values of deer collagen from a number of Peten sites to test the model of Late Classic period environmental degradation, with the assumption that it would affect the diets of deer. They found that both carbon-isotope values and species fidelity demonstrated biotic stability, a finding that calls into question the ecological model of the Classic period collapse. By contrast, they found an increase in the maize content of deer diets during the Preclassic, which was likely associated with increased maize production and their browsing behavior at the edge of the fields. Similar studies to see if this pattern shows up in other areas would be useful.

In terms of paleoclimatology, fauna in the Maya area have been largely underused in favor of palynological and pedological data from lake sediments (Wiseman, 1978; Dahlin, 1983; Vaughan *et al*., 1985; Bradbury *et al*., 1990; Leyden *et al*., 1993, 1996; Hodell *et al*., 1995; Curtis *et al*., 1996; Haug *et al*., 2003). Drought and severe cold have been invoked to explain the demographic events of the Preclassic abandonment (AD 150-200), the Hiatus (AD 535-590), the Classic collapse (AD 800-900) and the Postclassic abandonment (AD
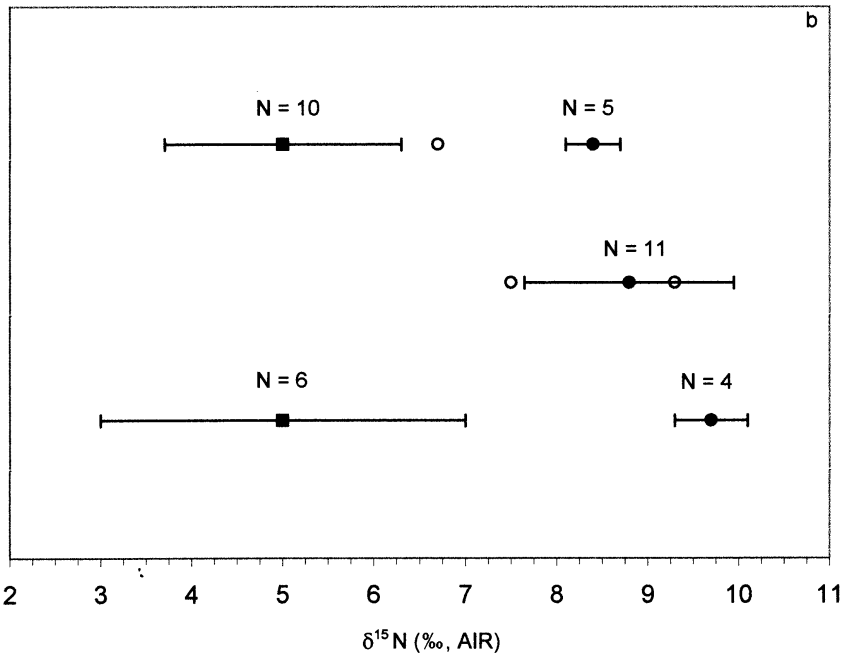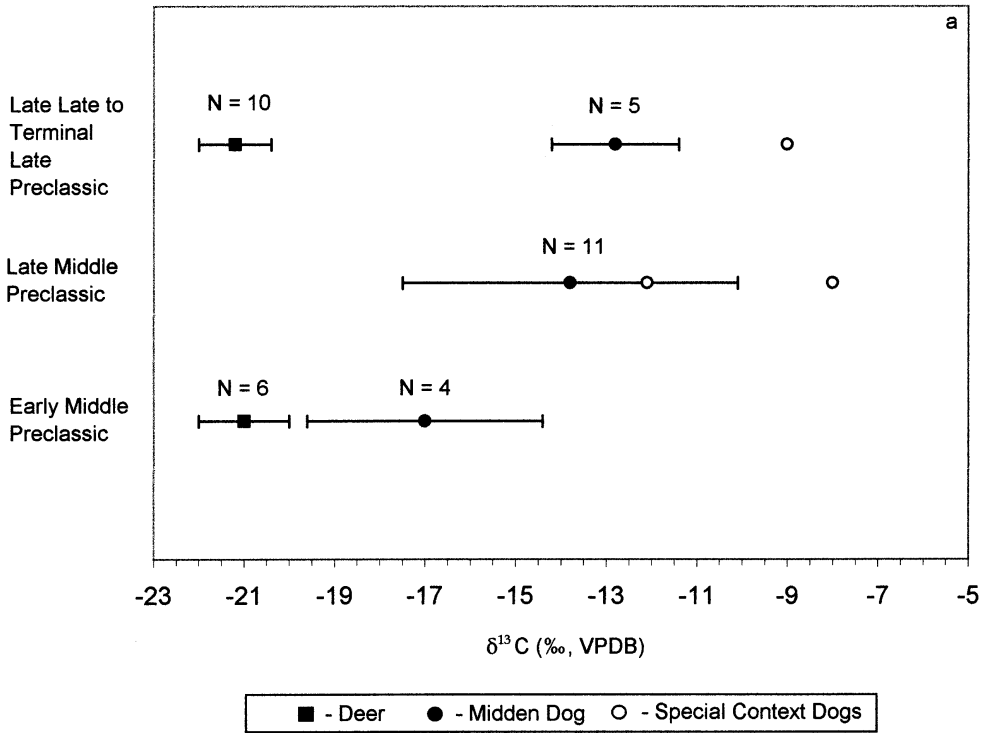
FIGURE 3

Temporal trends in isotopic values of dogs from the Preclassic period at Colha (after White *et al.*, 2001).

1450) (for a review see Gill, 2000), but the majority of these studies pertain to the southern lowlands (Peten Lakes).

Oxygen-isotope ratios are particularly sensitive to temperature, precipitation, and humidity and have been used to document long-term climate change in many other parts of the world (e.g., Reinhard *et al*., 1996; Fricke *et al*., 1998a, 1998b; Iacumin *et al*., 2000). Snails have been used for this purpose in Mesoamerica (Covich & Stuiver, 1974) and to detect seasonal use of wetlands (Kennett & Voorhies, 1996). Archaeological snails are commonly found and could be used to extend the geographic boundaries and temporal frames of climatic research. Turtles, which are also common in faunal remains and hold ideological significance, would be particularly useful for climatic reconstruction because they are not affected by humidity or species-specific metabolic effects (Barrick *et al*., 1999). In conjunction with fish remains, turtles can be used to calculate water and lake temperatures, which correlate with air temperature. Provided one controls for species, any mammal found in each temporal unit of an assemblage should be able to contribute to a climatic data base. However, mammals that are dietarily dependent on leaves will reflect the relative humidity and precipitation of their environment (Ayliffe *et al*., 1990). Thus deer, which are very common in faunal assemblages, would be particularly sensitive indicators of long-term climatic change (Luz *et al*., 1990).

Reconstruction of seasonality in climate change using oxygen-isotope ratios (and in some cases carbon-isotope ratios) in teeth has been done for a variety of animals (e.g., Koch *et al*., 1989; Bryant *et al*., 1996; Cerling & Sharp, 1996; Fricke & O'Neil, 1996; Fricke *et al*., 1996; Stuart-Williams & Schwarcz, 1997; Weiderman *et al*., 1999; Gadbury *et al*., 2000). Isotopic analysis of animal teeth in the Maya area is a ripe area of study (recall also that teeth are most often better preserved than bone). Because enamel is laid down incrementally and does not remodel as bone does, it creates a permanent record of short-term environmental change over the period of tooth formation. To date, seasonality has not been reconstructed using any tissue that grows incrementally (such as enamel, antlers, shells, otoliths) for Mesoamerican fauna, but seasonality studies have tremendous potential to contribute to our understanding of both environment and culture. For example, reconstructing the season of death from antlers could indicate either ritual behavior or environmental stress,

depending on the archaeological context of the remains. Furthermore, a more detailed picture of climatic seasonal changes over time would more precisely elucidate the processes involved in climatic change - for example, how long droughts lasted in the annual climatic cycle, and how they progressed over time. From such information the response of plants and animals in the ecosytem (including humans) could be modeled.

CONCLUSION

The potential for stable isotope analysis of animal remains in the Maya area is sadly unexploited by anthropologists and ecologists alike. Even though the poor preservation in this region is not conducive to more traditional analyses involving gross morphology, it still allows us generally to obtain reliable isotopic data, particularly from materials commonly found in archaeological contexts - for example, teeth, cortical bone, antlers, and shell. We can use stable isotope ratios to learn not only about social behavior, such as trade, the practice of ideological beliefs, and social organization, but also about the ways in which the Maya interacted with their animals, from hunting to full domestication. Because we all share the same ecosystem, we can use animal studies to reconstruct changes in the natural environment, both short and long-term, human-induced and natural. It is imperative, for these reasons, that we build a database of isotopic values for animals that goes beyond the routine use for controlling data on human diets. Such a database will also obviate any future problems of accessibility to human archaeological remains.

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