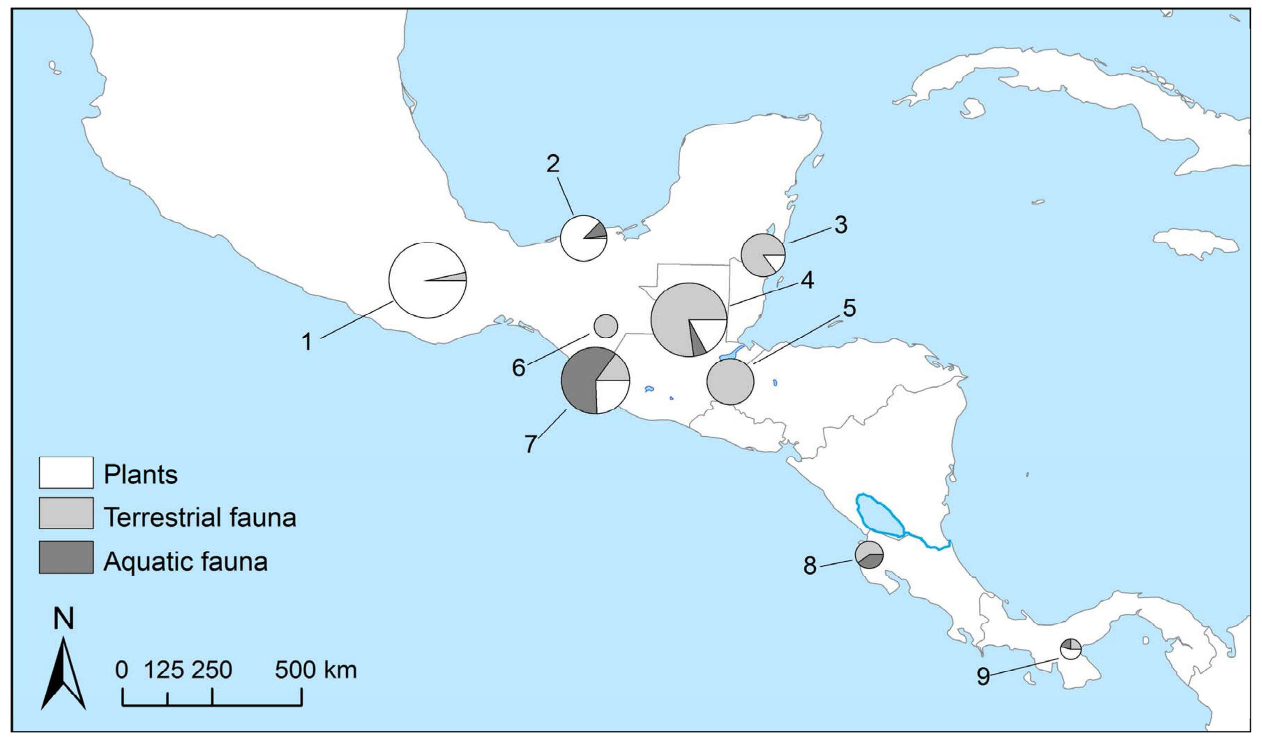

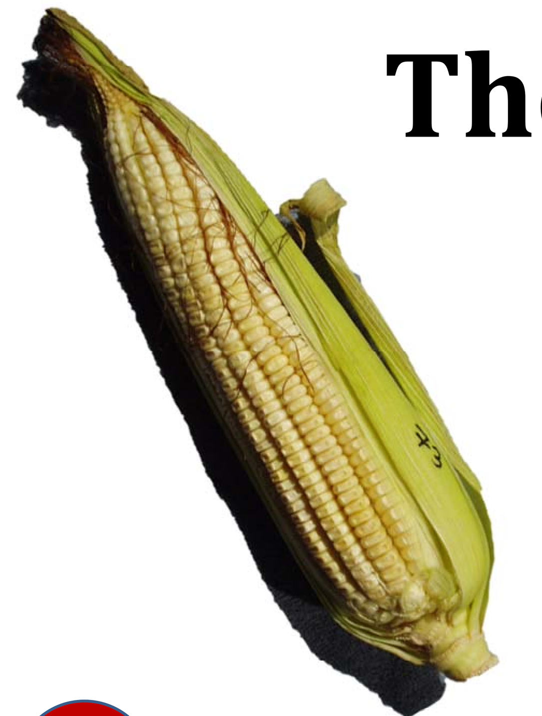

The isotopic diversity of the Middle American dietome: implications for paleodiet reconstruction

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1 ABSTRACT

Stable isotope-based paleodiet reconstructions in Middle America have relied on idealized models of plant isotopic diversity drawn from global isotopic averages of particular plant types. As archaeologists increasingly employ isotopic evidence in high-resolution paleodietary studies, a more detailed understanding of the underlying local food web is required. In this study, we obtained carbon and nitrogen isotopic data for more than 350 plants collected from traditional markets in highland and lowland Mesoamerica, herbarium collections, and a field transect in the Valley of Oaxaca. Combined with a meta-analysis of previously published regional isotopic flora and fauna data, we demonstrate a much more diverse and complicated isotopic landscape than has been previously assumed for Middle America. In addition, our data contradict several generalizations that have been made in paleodietary modeling, and suggest that previous analyses may need to be reconsidered in light of a broader understanding of the underlying food base.

2 MATERIALS & METHODS

This study is a meta-analysis of new and previously published regional isotopic data from Middle America. Isotopic data for Middle American flora and fauna have been published from seven principal locations (see map): northern Belize (3), the Petén (4), Copan/Quirigua (5), Lagartero (6), coastal Soconusco (7), Costa Rica (8), and Panama (9). For this study, we selected the Valley of Oaxaca (1) and coastal Tabasco (2) as additional regions of isotopic interest and collected 200 native foodstuffs in these regions.

Map	Site	Plants[a] $\delta^{13}C$	Plants[a] $\delta^{15}N$	Terrestrial Fauna[b] $\delta^{13}C$	Terrestrial Fauna[b] $\delta^{15}N$	Aquatic Fauna[b] $\delta^{13}C$	Aquatic Fauna[b] $\delta^{15}N$	References[c]
Central Mexico								
-	Unknown[d,e]	9[e]	-	-	-	-	-	5
Oaxaca								
1	Valley of Oaxaca	146	143	5	5	-	-	This study
Gulf Coast								
2	Villahermosa	47	46	2	2	5	5	This study
Southern Maya Lowlands								
3	Northern Belize	9	-	48[e]	38[e]	-	-	6, 7
4	Peten	31	10	130	63	11	11	2, 3, 8, 9, 10
5	Copan/Quirigua	-	-	58	56	-	-	3, 8
Maya Highlands								
6	Lagartero	-	-	14	14	-	-	8
Pacific Coast								
7	Soconusco	32	24	19	19	67	61	1
Lower Central America								
8	Costa Rica	-	-	14	14	8	8	4
9	Panama	12	7	2	2	4	4	4
	Total	**286**	**230**	**292**	**213**	**95**	**89**	

Notes:
[a]Only modern plants native to prehistoric Middle America are included. Does not include herbarium samples.
[b]Includes both modern and ancient samples. Ancient samples included only if reported C/N is 2.8-3.6 (DeNiro1985).
[c]1=Chisholm and Blake 2006; 2=Emery et al. 2000; 3=Gerry 1993; 4=Norr 1991; 5=Tieszen and Fagre 1993; 6=van der Merwe et al. 2000; 7=White et al. 2001; 8=White et al. 2004; 9=Wright 1994; 10=Wright 2006
[d]Maize grown on CIMMYT experimental farms at undisclosed locations in Central Mexico.
[e]Excludes samples that are reported in averaged summary form only.

Additionally, in order to assess isotopic diversity in wild vegetation and to examine temporal isotopic change, we conducted an elevational plant transect in the Valley of Oaxaca and analyzed 52 Middle American plants obtained from historic herbarium collections dating 1850-1950. All Oaxacan, Gulf Coast, and herbarium samples were analyzed for $\delta^{13}C$ and $\delta^{15}N$ at the Harvard University Biogeochemistry Laboratory.

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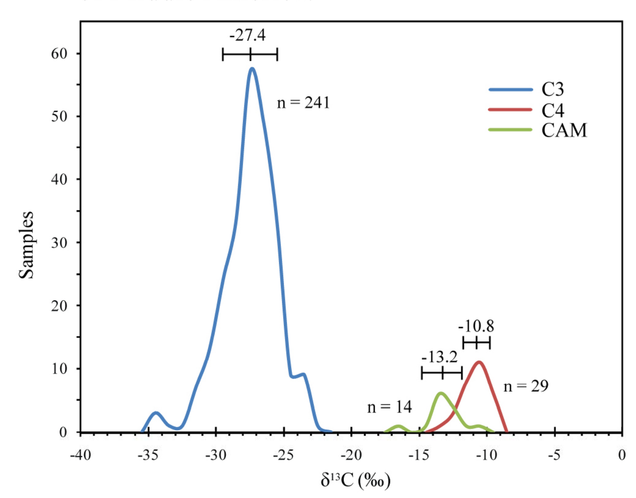
3 RESULTS

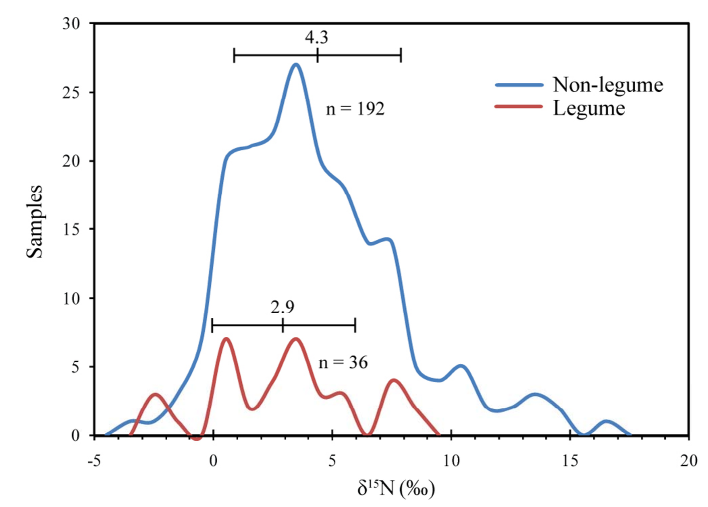
Isotopic characterization of modern food webs

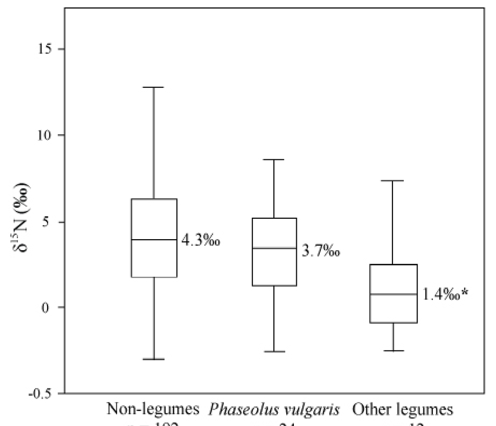
Based on their characteristic carbon and nitrogen isotopic signatures, plants may be classified into five basic categories: $\delta^{13}C$: C4, CAM, C3; $\delta^{15}N$: legume and non-legume. Dietary reconstruction models rely on accurate isotopic estimates for each category in order to determine the relative proportion of each food type in the total diet. Little isotopic work has been conducted on Middle American plants, and as a result most paleodietary studies base their analyses on estimates derived from global empirical studies. However, there is little agreement in either the empirical or paleodietary literature about which estimates are most appropriate, which has resulted in serious interpretive inconsistencies. To overcome this problem, we determined the average, range, and standard deviation of isotopic values for each plant category among native cultivated plants of Middle America.

	Location[a]	$\delta^{13}C$ C4	$\delta^{13}C$ C3	$\delta^{15}N$ Legume	$\delta^{15}N$ Non-legume	Ref.[b]
Empirically determined isotopic averages	CA, TX	-14.4	-28.0	-	-	9
	SA	-12.5	-26.5	-	-	11
	GB	-14.0	-28.0	-	-	6
	CA	-	-	0.8	3.5	2
	CA	-	-	0.2	1.3	3
	JA	-	-	0.0	1.9	12
	CA	-	-	~1	~3	10
	SD	-	-	2.0-6.3	3.0-13.0	8
	SA	-	-	-2 to 8	-4 to 19	5
Isotopic estimates employed in dietary reconstructions	CM	-9.0	-25.0	0.0	6.2	4
	SML	-12.5	-27.0	1.0	9.0	7
	SML	-12.5	-27.0	1.0	9.0	15
	SML	-9.0	-26.5	1.0	2.0-4.0	1
	SML	-11.0	-25.0	0.0	2.0-6.0	14
	SML	-11.0	-25.0	0.0	2.0-6.0	13
	LCA	-12.0	-26.0	0.0	4.0	8

Notes
[a]CA=California; CM=Central Mexico; GB=Global; JA=Japan; LCA=lower Central America; SA=South Africa; SD=Sonoran Desert; SML=Southern Maya Lowlands; TX=Texas.
[b]1=Coyston et al. 1999; 2=Delwiche and Steyn 1970; 3=Delwiche et al 1979; 4=Farnsworth et al. 1985; 5=Heaton 1987; 6=O'Leary 1988; 7=Reed 1994; 8=Shearer et al 1983; 9=Smith and Epstein 1971; 10=Virginia and Delwiche 1982; 11=Vogel et al. 1978; 12=Wada et al. 1975; 13=White 2005; 14=White et al. 2001; 15=Whittington and Reed 1997.







As expected, C3 and C4 plants demonstrated good isotopic discrimination with respect to $\delta^{13}C$, although carbon isotopic values differed slightly from previous estimates.

By contrast, the range of $\delta^{15}N$ in non-legumes and legumes overlap completely. Although the means of non-legumes and legumes are significantly different, there is no significant isotopic difference between non-legumes and the bean *Phaseolus vulgaris*, the most commonly consumed legume in Middle America.

Intra-taxa isotopic variation is nearly as great as that observed for entire plant types. We measured 61 chile peppers (*Capsicum spp.*) and found a total range of -24.8 to -33.2‰ in $\delta^{13}C$ and 9.9 to -3.1‰ in $\delta^{15}N$.

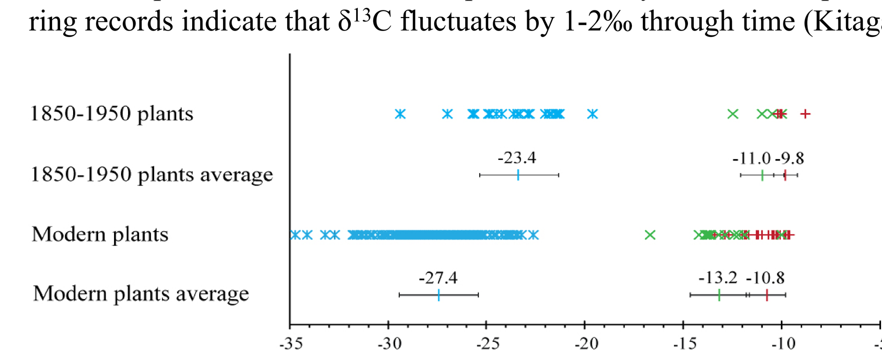
4 RESULTS

Reconstructing ancient food webs

Ideally, dietary isotopic modeling would involve the direct measurement of plant and animal taxa comprising a foodweb. Although this is possible in some ecological studies, it is not feasible in studies of the past. Ancient macrobotanical finds are rare, and, if present, may be taphonomically altered (DeNiro and Hastorf 1985), and archaeological faunal remains, although abundantly attested by skeletal material, rarely include animal products that were consumed by humans, such as meat, organs, or fat stores. As a result, ancient foodwebs must be reconstructed by proxy from modern specimens and ancient skeletal remains. Two isotopic adjustments are generally applied to modern data in order to approximate ancient values: a +1.5‰ carbon offset applied to all samples to account for industrial pollution, and a -2‰ carbon offset applied to faunal collagen to approximate meat values. Using historically collected herbarium plants and bone collagen/meat sample pairs, we evaluated the utility of both adjustments.

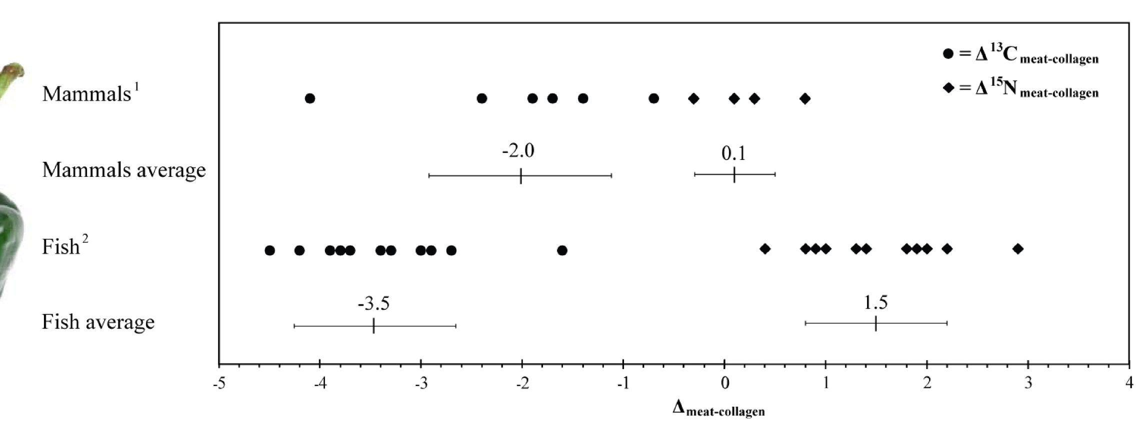
The impact of industrial carbon inputs

The average $\delta^{13}C$ of native C3, CAM, and C4 plants collected in Middle America from 1850-1950 and in 2006 are displayed in Figure 4. Rather than a simple 1.5‰ offset, C3 plants differ by 4‰ from past values, while CAM plants differ by 2‰ and C4 plants by 1‰. Additionally, tree ring records indicate that $\delta^{13}C$ fluctuates by 1-2‰ through time (Kitagawa and Matsumoto 1995; (McCarroll and Loader 2004; Padur et al. 2007). As a result, different plant types may require different offsets, and these offsets may need to be calibrated through time. Additional research in this area is necessary.



Estimating isotopic offsets between meat and bone collagen

Carbon and nitrogen isotopic data from paired bone collagen and meat samples are available for a variety of mammal and fish taxa. We found a wide spread of $\Delta_{coll\text{-}meat}$ offsets in both mammals and fish. Mean $\Delta^{13}C_{coll\text{-}meat}$ and $\Delta^{15}N_{coll\text{-}meat}$ in mammals closely matches the -2‰ and 0‰ offsets currently applied in paleodietary reconstructions. We found that fish meat, however, is more depleted in carbon and enriched in nitrogen relative to bone collagen. The relative degree of carbon depletion in meat may be related to lipid content, but more research is necessary.

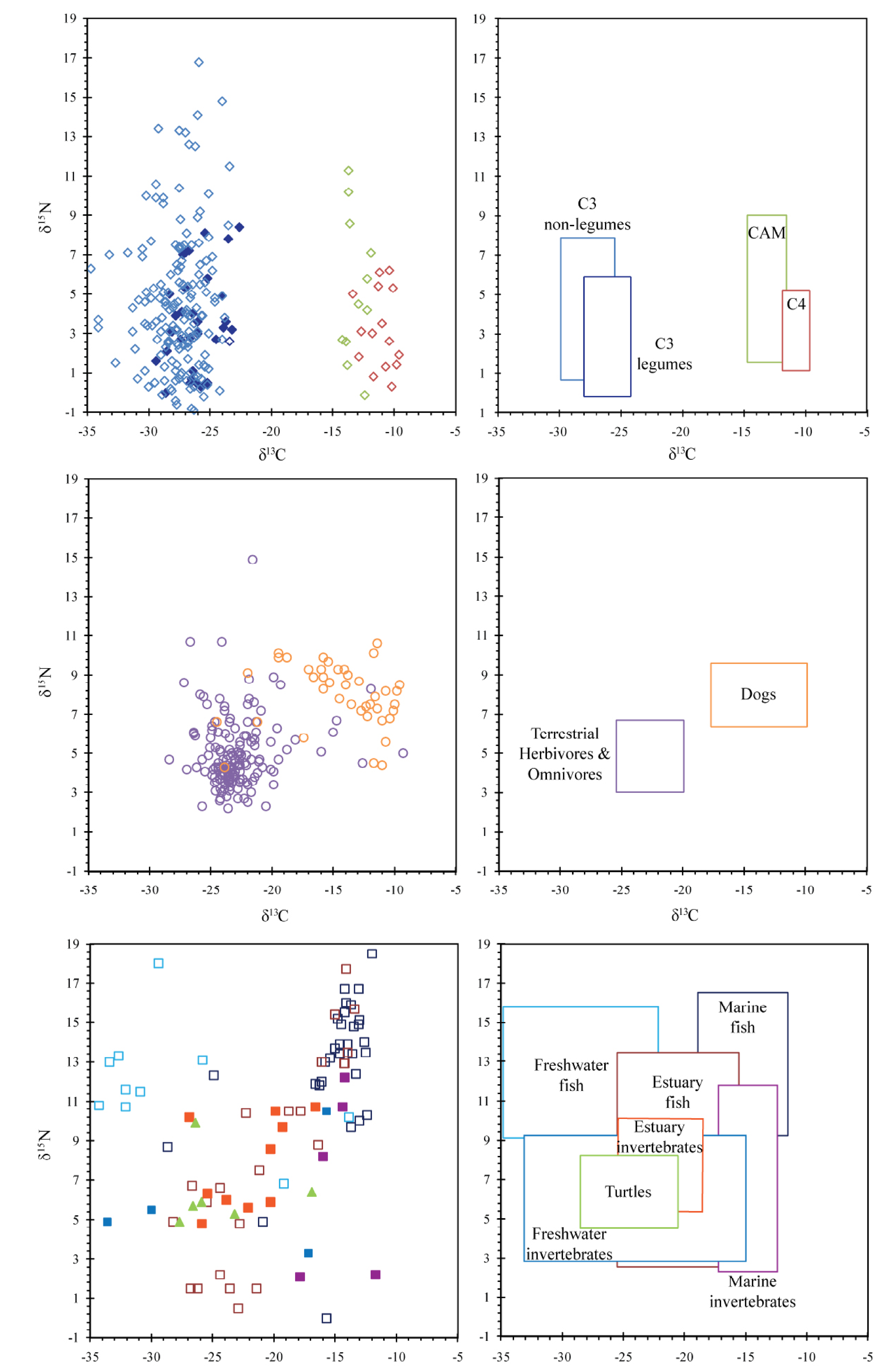


[1]DeNiro and Epstein 1978; DeNiro and Epstein 1981; Sealy et al. 1987; Tieszen and Fagre 1993b; Vogel 1978; Wariner and Tuross 2009
[2]Keegan and DeNiro 1988; Wright 1994

5 RESULTS

Reconstructed isotopic distribution of ancient Middle American foods

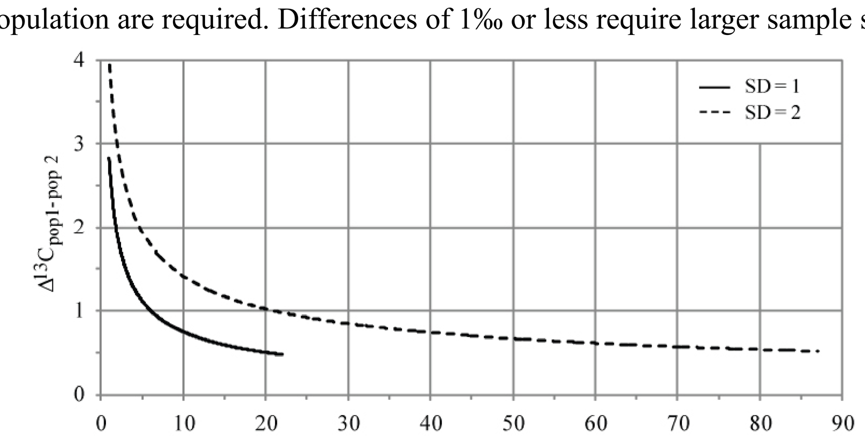
Middle American foodstuff isotopic data collected from modern plants and ancient and modern terrestrial and aquatic fauna are presented below in isotopic distribution plots. Left side plots depict raw data, while right side plots contain bounded regions representing the mean and 1SD for each food type. Given the uncertainty associated with estimating changes in plant $\delta^{13}C$ through time, carbon isotopic values were not adjusted for industrial carbon inputs. Collagen carbon and nitrogen isotopic data were adjusted to estimated meat values using the empirically derived offsets determined in this study. In general, the isotopic variation within and between food types is greater than previously estimated.



6 CONCLUSIONS

Dietary difference detection limits

Given uncertainties in food web $\delta^{13}C$ due to taxonomic isotopic variation, climatic and temporal fluctuation, and variable meat-collagen offsets, any reconstruction of average dietary $\delta^{13}C$ will carry a certain level of uncertainty. Using a conservative estimate of uncertainty of ±1-2‰, we can use a power test to calculate the population size and magnitude of isotopic difference required to demonstrate that two populations are isotopically distinct. In cases where the two populations differ by more than 2‰, fewer than 10 individuals in each population are required. Differences of 1‰ or less require larger sample sizes.

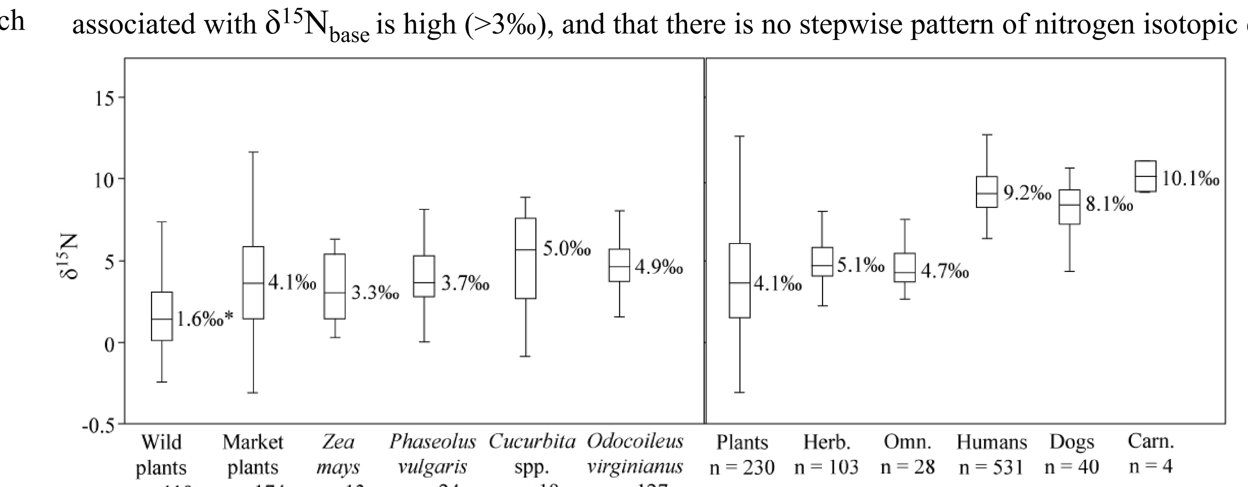


Trophic level estimation

Determination of dietary trophic level is important in both ecological and archaeological studies, and it is calculated using the formula at right (Post 2002).

$$\lambda_{consumer} = 1 + \frac{\delta^{15}N_{consumer} - \delta^{15}N_{base}}{\Delta^{15}N}$$

This formula contains two major assumptions that must be met in order to accurately reconstruct trophic level: 1) the $\delta^{15}N$ at the base of the food web (i.e., plants) must be known and constant; and 2) there must be a stepwise pattern of isotopic enrichment up the food chain (i.e., plants to herbivores to omnivores to carnivores). The magnitude of isotopic enrichment is generally assumed to be 3‰ (Minagawa and Wada 1984). Using our Middle American data, we found that the uncertainty associated with $\delta^{15}N_{base}$ is high (>3‰), and that there is no stepwise pattern of nitrogen isotopic enrichment in traditional human food webs. For example, although deer are significantly more enriched than wild plants, they are not different from cultivated plants. Overall, rather than a stepwise pattern of enrichment, plants, herbivores, and omnivores form a single isotopic cluster, while humans, dogs, and carnivores form another.



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