

# STABLE ISOTOPE STUDY OF HUNTER-GATHERER-FISHER DIET, MOBILITY, AND INTENSIFICATION ON THE TEXAS GULF COASTAL PLAIN

Robert J. Hard and M. Anne Katzenberg

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*The Gulf Coastal Plain of Texas was populated by hunter-gatherers from the Early Archaic (ca. 7000 B.P.) through to the Late Prehistoric period (ca. A.D. 700–1400). In order to characterize past dietary adaptations along the coast and further inland, stable isotopes of carbon and nitrogen were analyzed in preserved bone from 198 individuals from mortuary sites. In addition, 140 samples of faunal bone were analyzed to elucidate the stable isotope ecology for each region. The results indicate long-term stability in dietary adaptations with regional variation among coastal, riverine, and inland groups, including an early and, substantial, use of freshwater and marine resources. There is also evidence for constrained mobility and increasing use of plant resources within regions as populations increased in size and density.*

*La llanura costera del Golfo de México en Texas fue habitada por sociedades de cazadores-recolectores desde el Arcaico-Temprano (circa 5000 a.C.) hasta el período Prehistórico Tardío (circa 700-1400 d.C.). Para determinar las adaptaciones dietéticas en el pasado, a lo largo de la costa y hacia el interior, se realizaron análisis de isótopos estables de carbón y nitrógeno en material óseo preservado de 198 individuos procedentes de sitios mortuorios. Adicionalmente, 140 muestras de restos faunísticos fueron estudiadas con el fin de obtener la ecología isotópica de cada región. Los resultados sugieren estabilidad a largo plazo en las adaptaciones dietéticas con variación regional entre los grupos costeros, ribereños y del interior, incluyendo el uso temprano y sustancial de recursos marinos y dulceacuícolas. Hay también una cierta tendencia de movilidad restringida y aumento en el uso de recursos vegetales entre las regiones como resultado del incremento en los tamaños de la población.*

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On the Texas Coastal Plain, hunters and gatherers used communal cemeteries for over six millennia. While many of these locations have been known to archaeologists for decades, it has been difficult to integrate their use into a general understanding of hunter-gatherer ecology of the region. We examine human and animal isotope data from a series of prehistoric communal cemeteries on the Texas Coastal Plain in order to better appreciate their significance in the context of regional adaptations. In contrast to the ubiquitous mortuary sites of sedentary agriculturalists, hunter-gatherer cemeteries are sometimes considered anomalous. In fact, they are found around the globe and have demonstrated important implications for understanding hunter-gatherer ecology, mobility, complexity,

territoriality, resource intensification, warfare, demography, ritual, and the creation of persistent places (e.g., Arnold 1996; Littleton and Allen 2007; Mitchell 1997; Pardoe 1995; Rick et al. 2005). For example, most, but not all, archaeological examples of hunter-gatherer cemeteries are associated with marine or freshwater resource exploitation. Indeed hunter-gatherer cemeteries are known from all of North America's coasts, as well as multiple interior regions (Bell and Renouf 2003; Custer 1994; Fritz 1995; Sassaman 2004; Tuck 1971). On a global scale, other archaeological examples are found on the coasts of Ecuador, Peru, Brazil, the Cape of Africa, and northern Europe as well as the interiors of Argentina, southern Australia, the Levant, and Siberia (Gaspar et al. 2008; Lavallée 1995; Lieberman 1993;

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**Robert J. Hard** ■ Department of Anthropology, University of Texas at San Antonio, One UTSA Circle, San Antonio, Texas 78249 (robert.hard@utsa.edu)

**M. Anne Katzenberg** ■ Department of Archaeology, University of Calgary, 2500 University Dr. N.W., Calgary, Alberta T2N 1N4 (katzenbe@ucalgary.ca)

Table 1. Mortuary and Faunal Sites Used in the Study.

	Site Number	Site Name	Period	Dates	Human Valid n/ Submitted n	Sources <sup>a</sup>
Inland	41BX1	Olmos Dam	Late Archaic	400 B.C.-A.D. 260	6/6	1
Coastal	41HR80	Harris Co. Boys School	Ceramic	A.D. 400-1400	12/13	2
Coastal	41NU2	Oso Bay	Late Prehistoric	A.D. 600-1000	15/15	3
Coastal	41GV66	Mitchell Ridge	Final Late Prehistoric	A.D. 1300-1500	7/7	4
			Initial Late Prehistoric	A.D. 700-1300	5/5	
			Late Archaic	50 B.C.-A.D. 300	1/1	
				All components	13/13	
Riverine	41LK28	Loma Sandia	Late Archaic	850-550 B.C.	0/37 <sup>b</sup>	5
Riverine	41WH39	Crestmont	Late Archaic	1000 B.C.-A.D. 100	15/15	6
Riverine	41AU36	Ernest Witte	Late Prehistoric	A.D. 900-1400	8/9	7
			Late Archaic/Late Prehistoric	500 B.C.-A.D. 1500	9/9	
			Late to Transitional Archaic	500 B.C.-A.D. 700	20/20	
			Middle Archaic	2500-1500 B.C.	7/15	
				All components	44/53	
Riverine	41FB3	Bowser	late Late Archaic	800 B.C.-A.D. 200	15/15	8
			early Late Archaic	1600-1300 B.C.	4/4	
				All components	19/19	
Riverine	41VT1	Morhiss	Late Prehistoric	A.D. 1000-1200	1/1	9
			Late Archaic	900-400 B.C.	3/3	
			Middle Archaic	2900-1700 B.C.	3/3	
			Early Archaic	5300-4700 B.C.	3/3	
			Unknown		12/17	
				All components	22/27	
					146/198	
Inland	41BX5	Mission San Juan Capistrano	Spanish Colonial	A.D. 1764-1862	fauna	10
Coastal	41NU5		Archaic & Late Prehistoric	?	fauna	11
Coastal	41HR33		early Late Prehistoric	A.D. 100-A.D. 650	fauna	12
Coastal	41RF1	Mission Refugio	Spanish Colonial	A.D. 1794-1830	fauna	13
Coastal	41VT4	Fort Saint Louis	French & Spanish Colonial	A.D. 1685-1726	fauna	14
Riverine	41GD2	Mission Rosario	Spanish Colonial	A.D. 1754-1808	fauna	15
Riverine	41AU37	Leonard K	Middle Archaic-	2500 B.C.-A.D. 1400	fauna	7
			Late Prehistoric			

<sup>a</sup>Sources: 1=Lukowski 1988; 2= Aten et al. 1976; 3= Jackson et al. 2004; Martin 1930; Meissner et al. 2009; Ricklis 1997; 4=Ricklis 1994; 5=Taylor and Highley 1995; 6= Vernon 1989; 7= Hall 1981; 8=Patterson et al. 1993, 1998; 9=Campbell 1976, Dockall and Black 2006; 10=Cargill 1996, Hunziker 1997; 11=Texas Historic Sites Atlas 1967; 12=Takac et al. 2000; 13=Tennis 2002; 14=Roel 2008; 15=Nickels 2000.

<sup>b</sup>Samples were poorly preserved (Taylor 1995) and only a few yielded sufficient collagen for analysis and only one had acceptable preservation indicators. Some samples appeared to have a preservative on them. Additional bone was prepared using a method described by Chisholm and colleagues (1983). Unfortunately, this method also yielded little or no collagen. The single valid sample is excluded from further analysis.

Luna et al. 2008; Mitchell 1997; Price 1991; Stothert 1985; Weber et al. 2002). A global analysis of hunter-gatherer ethnographies is consistent with the archaeological patterns—groups that use communal mortuary locations also tend to have reduced mobility, use aquatic resources, and live under demographically packed conditions (Binford 2004). Packing results in intensification that includes the use of aquatic resources if they are available (Binford 2001).

Our analysis of hunter-gatherer subsistence patterns using stable carbon and nitrogen isotope analysis allows us to address issues related to the use of aquatic resources, patterns of resource intensification, population packing, territory formation, and hunter-gatherer resilience. In this study, subsistence is examined through the analysis of stable carbon and nitrogen isotopes for 198 individuals from nine prehistoric cemeteries (Table 1, Figure 1). In addition, 140 animal bone

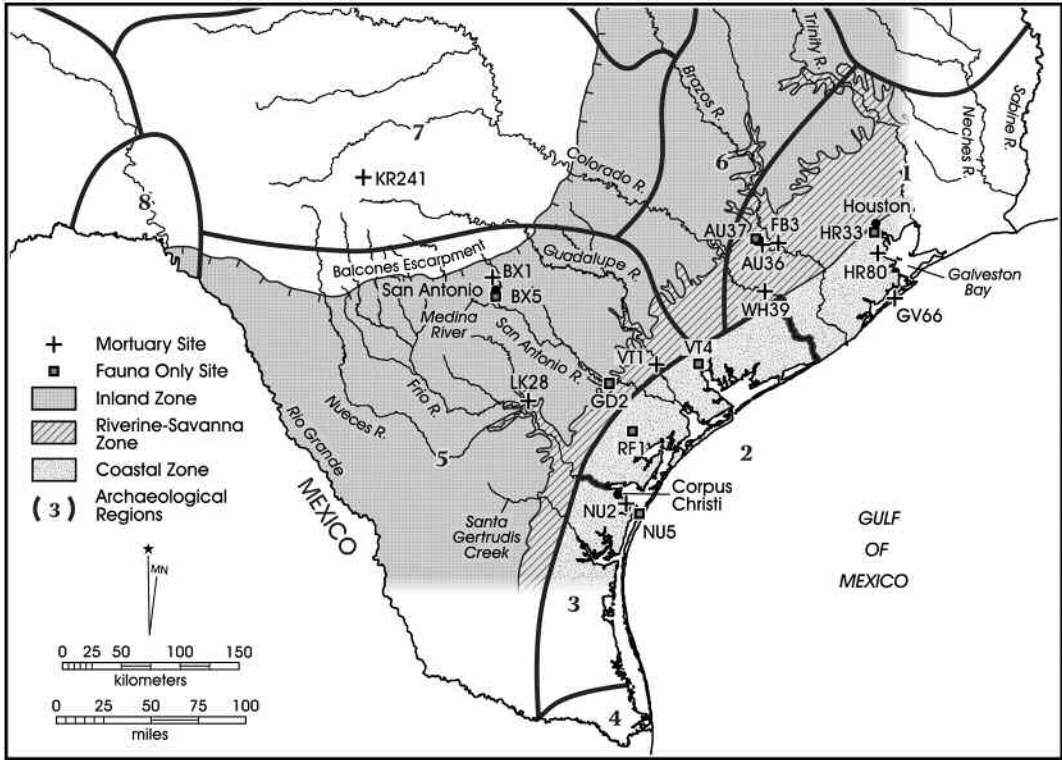


Figure 1. Map of archaeological sites, ecological zones, and archaeological regions: 1) Southeast Texas, 2) Central Coast, 3) Lower Coast, 4) Rio Grande Delta, 5) South Texas, 6) Savanna and Prairie, 7) Central Texas, 8) Lower Pecos (Perttula 2004).

samples and 44 shell samples from sites in the study area were analyzed in order to obtain baseline data for dietary reconstruction based on stable isotopes.

The study area extends from Galveston Bay near Houston southwestward to the Nueces River near Corpus Christi and reaches from the Gulf Coast inland to the Balcones Escarpment near San Antonio, and it includes the regions that contain some of the largest and longest-lived mortuary locations. The study area cross-cuts five recognized archaeological regions: Southeast Texas, the Savanna and Prairie, the Central Coast, the Lower Coast, and South Texas (Figure 1) (Perttula 2004). Texas hunter-gatherer mortuary locations also extend beyond the limits of our study area and include Central Texas, the Lower Pecos, and the Rio Grande Delta regions and involve open sites, rockshelters, and sink holes (Collins 2004; Terneny 2005; Turpin 2004). Mortuary locations apparently do not occur in the south Texas brush country away from major drainages nor in the coastal regions south of the Nueces River where

there are few rivers and the bays are highly saline (Hester 2004).

Neither constructed mounds nor other clear surface indicators mark the presence of mortuary locations. At times they occur on slightly elevated landforms, but typically their topographic settings are not distinctive. They may or may not be associated with residential sites and, as is typical for the region, architectural remains are rarely found. A recent compilation identified 186 prehistoric burial locations in south Texas (Tomka et al. 2009). Considering only the Texas Coastal Plain study area, at least 66 locations containing from 5–275 individuals are known (median = 16) (Hall 1995a; Perttula 2001; Ricklis 1994; Taylor 1995a). Seven locations held from 50–100 individuals and only four held more than 100 documented burials. These estimates are only minimums since professional archaeologists have only excavated and documented a handful of these mortuary sites.

We identified a previously unknown Early Archaic (8500–5000 B.P.) component at the Morhiss

site (41VT1) with our radiocarbon dating program. Both it and the nearby Buckeye Knoll site are located on the lower Guadalupe River and date to about 5000 cal B.C., making them among some of the oldest mortuary locations in North America. A few cemeteries dating to the Middle Archaic period (5000–3500 B.P.) are found in the lower Brazos River and Guadalupe River valleys. Cemetery use was much higher in the Late Archaic period (3500–1400 B.P.) than preceding periods in both number of internments and frequency of sites (Hall 1995a; Tomka et al. 2009). Use of mortuary locations continued into the Late Prehistoric period (1400–500 B.P.), but by the latter part of this period the use of cemeteries shifted as there appears to be a decline in the number of internments per component.

A number of investigators have linked cemetery formation to population increases and the formation of territories (Hall 1995b; Story 1985; Taylor 1995b, 1998). The economic and social foundations of cemetery formation have been related to dense resources found near bays, estuaries, and riverine floodplains (Hester 1981; Johnson and Hard 2008; Story 1985). Grant Hall (1998) proposed that pecans, fish, prickly pear cactus (*Opuntia sp.*), and related resources of the Holocene floodplains and estuarine bays were sufficiently rich, patchy, stable, and constrained to support relatively dense prehistoric hunter-gatherer populations. Mortuary locations are not necessarily clustered in the most productive resource zones but are found in multiple riverine settings with a mix of resources that favor reoccupation (Tomka et al. 2009). The largest cemeteries are found on a strip of land paralleling the coast, about 50 km inland, known as the Riverine–Savanna Zone where the floodplains of the lower reaches of the major rivers are particularly productive (Figure 1). Inland mortuary sites, although generally smaller, are found both adjacent to the Balcones Escarpment and on the Edwards Plateau, and are usually associated with more constricted floodplains.

### Study Area

Mean annual precipitation in the study area decreases from east to west with a high of 44.8 inches (113.7 cm) in Houston to 29.1 inches (73.9

cm) in San Antonio with generally hot summers and mild winters (Bomar 1983). Five parallel major rivers slash the region in a northwest-southeast direction, draining the Edwards Plateau into the Gulf of Mexico. From north to south they are the Brazos River, Colorado River, Guadalupe River, San Antonio River, and Nueces River; with their tributaries they are central to understanding hunter-gatherer cemetery use. The vegetation is a complex mixture of grasslands, shrublands, and woodlands that are characterized by a high degree of diversity. The study area is divided into three ecological zones based on the availability of key resources: the Coastal Zone, Riverine–Savanna Zone, and Inland Zone (Figure 1).

### Coastal Zone

The Coastal Zone is a strip of land about 50 km wide that extends from the shoreline inland and includes the coastline, bays, estuaries, and river mouths. The exploitation of the Coastal Zone was tied to sea-level stillstands and the formation of barrier islands since during periods of rising sea levels, coastal areas were not as productive (Ricklis 2004b; Ricklis and Weinstein 2005). Predictable and concentrated resources developed with modern sea levels after 3000 B.P. when the continuous chain of barrier islands emerged. Shallow bays formed that provided habitat for redfish and black drum that aggregate in large numbers for the fall and winter/early spring spawn (Ricklis 2004b; Ricklis and Weinstein 2005). Although Early and Middle Archaic populations certainly exploited the Coastal Zone, the scale and intensity of exploitation greatly increased after 3000 B.P. Coastal Zone cemeteries predating the Late Archaic period are quite rare.

Documents indicate that during the seventeenth century groups of Karankawa resided in this region on a strip of territory extending from about the Nueces River north to the Colorado River and perhaps as far north as Galveston Island (e.g., Newcomb Jr. 1983; Ricklis 1996). Populations were high as explorers noted multiple encampments of 400–500 individuals with a total of about 8,000 Karankawa in the region, yielding a population density of about 1 person/km<sup>2</sup> (Ricklis 1996:130, 140).

Ricklis (1996, 2004b; Ricklis and Cox 1993) combined ethnohistorical and archaeological in-

formation to explore settlement and subsistence models for the Coastal Zone. The Karankawa made substantial use of fish, particularly black drum and red drum, that concentrated in the bay shallows and inlet areas during their fall-winter spawn. Mollusks were found in similar areas but were available year round. Known as the Gulf Marshes and Prairies ecoregion, it ranges from sea level to a few feet in elevation and is commonly covered with saline water and supports edible sedges, rushes, bulrushes, reeds, and forbs such as pepper weeds and smartweed. The Coastal Zone also includes tall grass prairie and post oak savanna habitat, although today they are invaded by shrubs. Plant resources included greens, fruits (particularly prickly pear), seeds, and nuts (pecans and acorns) whose availability correlated with the warm growing season while roots were important in the fall and winter (Ricklis 1996:20–21). White-tailed deer populations were generally substantial and bison appeared during moist intervals on the adjacent prairies in both the Prehistoric and early Historic periods (Dillehay 1974; Huebner 1991; Kemp 2008; Thompson et al. 2007). The Karankawa exploited these plant and animal resources with settlement systems that included large fall-winter aggregations at bay fishing locales followed by dispersal into smaller groups during the spring and summer to utilize prairie upland and floodplain woodland camps. Reports from Cabeza de Vaca in 1528–1529 are similar in that an indigenous group exploited a barrier island trapping fish and collecting underwater roots from October to February and then canoed to the mainland and erected huts at bay locations where they collected oysters. In early spring they returned to the island and ate blackberries, roots, and small prey through the summer until they resumed a focus on fish and roots in August. Ethnohistoric evidence indicates that from 1528 until the Colonial period, the Karankawa were apparently confined by the presence of other groups to a 40 km wide strip of territory that included shores, bays, and marshes (Aten 1983; Campbell and Campbell 1981; Newcomb Jr. 1983; Ricklis 1996:96–97, 2004b; Story 1985). An array of archaeological data, including faunal, otolith, settlement pattern, and artifactual material, suggest that this pattern was ongoing during the Rockport phase (ca. 700–250 B.P.) of the Late Prehistoric period and

was likely underway by the later part of the Late Archaic period (ca. 1900 B.P.) (Hester 1981; Ricklis 2004b; Ricklis and Weinstein 2005).

Coastal Zone sites tend to be dominated by deer, turtles, snakes, fish, and shellfish (Meissner and Thompson 2009; Ricklis 1994, 2004a). By far the dominant mammal is white-tailed deer (*Odocoileus virginianus*); other mammals that typically occur include hispid cotton rat (*Sigmodon hispidus*), cottontail (*Sylvilagus* sp.), blacktail jackrabbit (*Lepus californicus*), and opossum (*Didelphis virginianus*). Bison (*Bos bison*) occur consistently in small quantities in Late Prehistoric contexts. Reptiles include box turtles (*Terrapene* sp.), softshell turtles (*Apalone* sp.), water turtles (Emydidae), and snakes (Serpentes). Fish include marine gar (*Lepisosteus* sp), sheepshead (*Archosargus probatocephalus*), seatrout (*Cynoscion* sp.), sea catfish (*Arius* sp.), black drum (*Pogonias cromis*), red drum (*Sciaenops ocellata*), and Atlantic croaker (*Micropogon undulates*). The common rangia clam (*Rangia cuneata*) was a key brackish water resource and the main constituent of many shell middens (LaSalle and de la Cruz 1985). Most of the other marine mollusks that commonly occur on the Coastal Zone sites were included in the analysis and are considered below.

#### *Riverine–Savanna Zone*

The Riverine–Savanna Zone extends from the western boundary of the Coastal Zone, which is 50 km inland, westward to about the 200 ft (61 m) amsl contour level (Figure 1). We selected this elevation as an approximate western boundary of the Riverine–Savanna Zone as it is where the rivers become more sinuous with wider floodplains, oxbow lakes, swamps and sloughs, and freshwater aquatic resources are abundant along the five major rivers and their tributaries (Hall 1998). The Riverine–Savanna Zone is about 30–70 km wide but extends an additional 30–100 km further inland to follow the 200 ft contour along the low-lying floodplains of the major rivers (Figure 1). These floodplains are filled with alluvium, decreasing the gradient and slowing the rivers following sea-level rises. With modern sea-level stabilization, the Texas rivers became more sinuous, creating aggradational settings, and meander belts became more common in the flat,

broad alluvial plains (Hall 1998). The floodplain features of the Riverine–Savanna Zone are attractive to spawning fish in the spring and form resource-rich zones that Hall (1998) describes as “natural catfish farms.” The vegetation is dominated by grasslands, including many  $C_4$  grasses, and within this zone are representatives of the Gulf Coast Prairies and Marshes, South Texas Brush Country, Texas Blackland Prairies, and Oak Woods and Prairies ecoregions (Bailey 1994; Osowski et al. 2005). Major mammal resources include deer, bison, rabbits, and hares. Plant resources include forbs, oaks, pecans, hackberries, hickory nuts, mesquite, and prickly pear.

Useful accounts of indigenous groups in the Riverine–Savanna Zone included the Mariame with whom Cabeza de Vaca lived for about 18 months in 1533–1534 (Campbell 1983; Nuñez Cabeza de Vaca 1983:79–83; Thoms 2008; Tomka 2009). The Mariame are only one of about 11 groups that occupied a 170 km strip between the lower sections of the Guadalupe River to beyond the Nueces River to Santa Gertrudis Creek, an area that roughly corresponds to the southern half of the Riverine–Savanna Zone. During the fall, winter, and spring the Mariame moved along the lower Guadalupe River Valley, just above its junction with the San Antonio River. For example, about 200 Mariame utilized approximately 40 houses in a single camp that remained as long as resources were in the area (Campbell 1983:351; Nuñez Cabeza de Vaca 1983:79–83). Cabeza de Vaca indicated that deer were a key resource; rats, mice, and snakes were consumed; and bison were sometimes in the area. The Mariame ate fish in quantity during the April–May flood season when they were taken from shallow pools following receding flood waters. Pecans were the principle food in fall and other Indian groups also came to the Guadalupe River valley for the fall harvest. Roots, some cooked in earth ovens, were a key resource during the lean winter months. During the summer, the Mariame traveled 100–200 km to harvest prickly pear fruit, a time during which they also consumed land snails (Campbell 1983; Nuñez Cabeza de Vaca 1983; Thoms 2008). Food shortages were not unusual, especially in the winter, and at times they moved every two to three days in search of food (Tomka 2009). Apparently these groups made no use of

coastal resources, despite their proximity. However, they did stage communal deer hunts in which deer were herded into a bay and drowned. In one report, 60 men took 200–300 deer and on another hunt 500 deer were killed (Tomka 2009).

Archaeological evidence indicates the inhabitants exploited a wide diversity of terrestrial and aquatic fauna (e.g., Hall 1981; Hellier et al. 1995). White-tailed deer are usually the most common mammal on sites, frequently representing over 70 percent of mammals. Other common species include blacktail jackrabbit, cottontail rabbit, raccoon (*Procyon lotor*), pocket gopher (*Geomys* sp.), ground squirrel (*Spermophilus* sp.), cotton rat (*Sigmodon hispidus*), opossum, turkeys (*Meleagris gallopavo*), and bison. The latter are more frequently present in Late Prehistoric contexts. The freshwater fish common to these sites include bowfin (*Amia calva*), freshwater catfish (*Ictalurus* sp.), freshwater drum (*Aplodinotus grunniens*), gar (*Lepisosteus* sp.), and freshwater mussels (Unionids). Marine fish and marine mollusks, as food remains, are generally rare on Riverine–Savanna Zone sites. Turtles are frequently found with box turtles (*Terrepenne* sp.) and cooters (*Pseudemys* sp.) being the most common while diamondback terrapins (*Malaclemys terrapin*), mud turtles (*Chrysemys* sp.), pond sliders (*Trachemys* sp.), softshell turtles (*Apalone* sp.), and Emydid turtles (Emydidae) are typical. Other aquatic species include frogs (*Rana* sp.), ducks (*Anas* sp.), and alligators (*Alligator mississippiensis*).

#### *Inland Zone*

The Inland Zone extends west from the Riverine–Savanna Zone to the edge of the Edwards Plateau that is formed by Balcones Escarpment (Figure 1). The flat to hilly land rises from 200 ft (61 m) amsl to about 1,000 ft (305 m) amsl in the vicinity of San Antonio. The northeastern and southwestern extent of the study area includes the watersheds of the Brazos River and Nueces River, respectively. The upstream reaches of the major rivers tend to be narrow, downcut, and with numerous tributaries. The southwestern half of the Inland Zone includes the South Texas Brush Country and the northeastern half includes portions of the Blackland Prairies and Oak Woods and Prairies ecoregions. The Inland Zone offers a

complex mosaic of resources whose productivity varies dramatically through time and space (Hall 1998; Hester 1981, 2004; Story 1985).

Campbell (1975) summarizes the limited 1688–1717 documentary evidence regarding the Payaya Indians that lived along the margins of the Edwards Plateau. They harvested pecans along the Medina River and the nuts were sufficiently abundant to store for winter and to attract other groups for the harvest. The Payaya hunted abundant bison and deer on the prairies south of San Antonio as well as between the Colorado River and Brazos River, during a period when bison density may have peaked in South Texas (Thompson et al. 2007). During early historic times the population density of the Inland Zone was apparently below that of the Coastal and Riverine–Savanna Zones.

In the fall, gallery forests in riparian habitats produce millions of kilograms of pecans but yields are cyclical, and oaks, hickories, and walnuts also produce large crops, but involve greater labor costs (Hall 1995b, 1998, 2000). White-tailed deer were particularly dense in some areas, but bison populations fluctuated dramatically, with peaks in the Late Prehistoric and Colonial periods (Black 1986; Dillehay 1974; Kemp 2008). During the summer fruiting, large concentrations of prickly pear in the southern part of the Inland Zone were a key resource. Mesquite pods were important in the late summer but remained available, sometimes for months. Root foods were particularly important. Fish and mollusks were not as abundant as in the Riverine–Savanna Zone but were certainly utilized (Campbell and Campbell 1981; Hall 1998; Thoms 2008).

The most commonly recovered fauna from Inland Zone archaeological sites are: white-tailed deer, pronghorn antelope (*Antilocapra americana*), raccoon, opossum, dog/coyote/wolf, raccoon, cottontail rabbit, blacktail jackrabbit, collared peccary, striped skunk (*Mephitis mephitis*), cotton rat, pocket gopher, bison, pond sliders, softshell turtles, Eymid turtles, land turtles, and rattlesnake (*Crotalus* sp.) (Hester 2004; Scott 1988; Steele and Hunter 1986). Other notable species include turkey, freshwater catfish, flat-head catfish (*Pylodictus olivaris*), javelina, and alligator. Freshwater mussels and snails (Gastropods) are often recovered, including *Rabdotus* snails.

## Methods

### Background

The use of stable carbon and nitrogen isotope ratios from prehistoric skeletal remains has become a widely used technique and detailed reviews of stable isotope methods and applications related to past peoples are available (e.g., Ambrose 1993; Katzenberg 2008; Katzenberg and Harrison 1997; Lee-Thorp 2008; Schoeninger and Moore 1992; Schwarcz and Schoeninger 1991). Regional reviews (Bousman and Quigg 2006; Perttula 2001) indicate researchers have used stable isotopic analyses in multiple regions across the state in both prehistoric and historic contexts (e.g., Bement 1994; Hard 2002; Hard et al. 1996; Perttula 2001; Turpin 1988). In South Texas, stable isotope studies of paleodiet were first conducted by Huebner and his colleagues (e.g., Huebner 1994; Huebner and Boutton 1992; Huebner and Comuzzie 1992). Thus far, stable isotope research from the Texas Coastal Plain has identified three principal patterns emphasizing terrestrial, riverine, and marine patterns of exploitation (Cargill and Hard 1999; Huebner and Comuzzie 1992; Ternery 2005).

Stable isotope analyses are most effective when an attempt is made to reconstruct the stable isotope ecology rather than focusing only on human remains. Stable isotope ecology involves understanding variation in stable isotope ratios and the reasons for that variation in an entire ecosystem, from the sources of carbon and nitrogen throughout the food web at every level. Largely the domain of ecologists, such thorough, bottom-up analysis is rarely possible for prehistoric remains, but it is possible to include analyses of collagen from animals found in archaeological assemblages. Since the source of carbon and nitrogen may vary, stable isotope ratios for an animal in one place cannot be used as proxies in a different region. This fact has been illustrated many times in the literature; see Keegan and DeNiro (1988) for reef ecosystems; Katzenberg and Weber (1999) for deep lakes; and Ambrose and colleagues (1997) for island ecosystems. The differences in stable carbon and nitrogen isotope ratios in marine and terrestrial resources have provided a tool to explore resource exploitation

among coastal dwelling human groups worldwide (e.g., Coltrain 2009; Keenleyside et al. 2009; Prowse et al. 2004; Richards and Hedges 1999; Sealy 2006).

The stable isotope ecology of the Texas Gulf Coastal Plain has been examined from the perspective of modern marine and freshwater ecosystems and terrestrial environmental change (Fry 2006; Fry and Parker 1979; Jepsen 1999; Jessup et al. 2003; Nordt et al. 1994; Winemiller et al. 2007). A synopsis of the principle sources of variability in stable carbon and nitrogen isotope ratios in bone collagen and carbonate provides a background for our focus on prehistoric populations and the faunal species most likely consumed.

Stable isotopes are useful tracers in food webs because the ratio of the heavier to the lighter isotope varies during the chemical reactions involved in photosynthesis in plants and metabolism in animals. It is necessary to understand the sources and flows of carbon and nitrogen in the particular environments under consideration, and to understand the processes that result in variation in isotope ratios. Stable isotope ratios of carbon and nitrogen are reported using the delta notation wherein:  $\delta^{13}\text{C}\text{‰} = [(R_{\text{sample}}/R_{\text{standard}}) - 1] * 1000$ , and R = the ratio of the heavier to the lighter isotope (i.e., the number of atoms of  $^{13}\text{C}$  divided by the number of atoms of  $^{12}\text{C}$ ).

The source carbon for terrestrial plants is atmospheric  $\text{CO}_2$ , which had a  $\delta^{13}\text{C}$  value of  $-7\text{‰}$  prior to the widespread use of fossil fuels (Boutton 1991). Burning of fossil fuels, which are predominantly composed of decayed  $\text{C}_3$  plants, has resulted in more  $^{12}\text{C}$  in the atmosphere and thus the  $\delta^{13}\text{C}$  of atmospheric  $\text{CO}_2$  is now approximately  $-8\text{‰}$ . Plants fractionate carbon isotopes differentially depending on their mode of photosynthesis.  $\text{C}_3$  plants have  $\delta^{13}\text{C}$  values ranging from  $-35\text{‰}$  to  $-20\text{‰}$  while  $\text{C}_4$  plants have  $\delta^{13}\text{C}$  values ranging from  $-14\text{‰}$  to  $-9\text{‰}$  (e.g., Deines 1980; Smith and Epstein 1971).  $\text{C}_4$  plants include a number of tropical grasses which are adapted to hot and dry or saline conditions. Those which are of economic importance to humans include maize, amaranth (*Amaranthus* sp.), and dropseed grasses (*Sporobolus* sp.) among others.  $\text{C}_4$  grasses consumed by herbivorous animals leave a  $\text{C}_4$  isotopic signature in human tissues if humans consume those animals. A third photosynthetic path-

way is referred to as CAM (Crassulacean Acid Metabolism) and is characteristic of cacti, such as prickly pear and other succulents. CAM plants have  $\delta^{13}\text{C}$  values that overlap those of  $\text{C}_3$  and  $\text{C}_4$  plants (Deines 1980).

In aquatic systems there are numerous sources of carbon, including plants growing in and around the water, decayed organic matter, dissolved carbonate from rock weathering, and atmospheric  $\text{CO}_2$  (Boutton 1991). As is true of terrestrial plants, aquatic plants vary in the enzyme used to fix carbon, and thus there is variation both in source carbon and in the amount of fractionation between the source and the plant tissues.

In the ocean, the source carbon is primarily dissolved inorganic carbon as well as dissolved  $\text{CO}_2$  and  $\text{CO}_3$  with  $\delta^{13}\text{C}$  equal to  $0\text{‰}$ . Since the source carbon is more enriched in the heavier isotope relative to the source carbon in terrestrial and freshwater environments (atmospheric  $\text{CO}_2$ ), marine organisms are similarly more enriched (Chisholm et al. 1982). Variation in the  $\delta^{13}\text{C}$  of marine plants occurs in different environments such as seagrass meadows and coral reefs, and estuarine and littoral waters typically have plankton with enriched  $\delta^{13}\text{C}$  (Boutton 1991).

In modern ecological studies,  $\delta^{13}\text{C}$  values of estuarine primary producers on the Texas coast range from  $-5$  to  $-20\text{‰}$ . Most seagrass species are  $\text{C}_4$  plants with values ranging between  $-3$  and  $-15\text{‰}$  (Fry and Sherr 1989). Algae are highly variable with  $\delta^{13}\text{C}$  values as high as  $-5$  and as low as  $-34.7\text{‰}$  (Fry and Sherr 1989).  $\text{C}_4$  seagrass meadows are limited to shallow ( $<2$  m) estuarine settings and are frequently the principal primary producer while in offshore environments  $\text{C}_3$  algae dominates the base of the food web (Fry 2006; Fry and Parker 1979). Fish from seagrass meadows in portions of some Texas shallow bays yield  $\delta^{13}\text{C}$  values from  $-8.3$  to  $-15.5\text{‰}$  for flesh (mean  $-12.1\text{‰}$ ). Offshore fish are more depleted in the heavy isotope with values from  $-14.8$  to  $-19.2\text{‰}$  (mean  $-17.5\text{‰}$ ) (Fry and Parker 1979). But seagrass meadows are not ubiquitous in Texas estuarine settings and the degree that seagrass versus algae is the primary producer in any particular Texas estuarine environment can vary. For example in a Texas estuarine saltmarsh, fish flesh (including several species economically valuable to hunters, gatherers, and fishers) yielded more de-



pleted flesh values from  $-13$  to  $-20\text{‰}$  (Winemiller et al. 2007). The lifecycle of some economic species involves movement from offshore to near-shore settings exposing them to both seagrass and algae-dominated niches. Humans feeding on near-shore fish may have elevated  $\delta^{13}\text{C}$  values, similar to those derived from consumption of  $\text{C}_4$  plants or a mix of  $\text{C}_3$  and  $\text{C}_4$  plants. Because fish flesh provides considerably more protein than plant foods, fish isotope signatures may be more strongly reflected in collagen  $\delta^{13}\text{C}$ . The addition of analysis of  $\delta^{13}\text{C}$  in bone carbonate should allow some differentiation of these situations by providing evidence for plant and animal foods.

Fractionation of nitrogen isotopes occurs in food webs with an average enrichment of approximately  $3\text{‰}$  in each step of a food web (Minagawa and Wada 1984; Schoeninger and DeNiro 1984). In terrestrial ecosystems, plants vary in their nitrogen sources. Legumes make use of atmospheric nitrogen that becomes available through the action of bacteria. Non-leguminous plants obtain nitrogen from the breakdown of organic matter in the soil and have  $\delta^{15}\text{N}$  that is approximately  $3\text{‰}$  higher than legumes. Animals feeding on plants have tissues that are approximately  $3\text{‰}$  higher than their food, and this is also true of carnivores consuming herbivores. In aquatic and marine systems, there are more steps in the food chain, thus greater enrichment of the heavier isotope and higher  $\delta^{15}\text{N}$  values at the top of the food web. Soils with significant animal inputs, and the plants they support, tend to have elevated  $\delta^{15}\text{N}$  values since the source nitrogen comes from a higher trophic level; and saline soils may also have elevated  $\delta^{15}\text{N}$  (Ambrose 1993; Schoeninger and Moore 1992).

Isotopic analysis of local faunal samples reveals the presence of such variation and assists in the interpretation of isotopic data from humans for dietary reconstructions. For example, in a study of the isotope ecology of the Brazos River, Jepsen (1999) found that  $\delta^{13}\text{C}$  for freshwater aquatic plant ranges from  $-18\text{‰}$  (macroalgae) to  $-25\text{‰}$  (periphyton), and fish flesh from several species ranges from  $-31.0\text{‰}$  to  $-24.1\text{‰}$ , with variability related to source carbon, habitat, and seasonality.  $\delta^{15}\text{N}$  variation in flesh from various fish species ranges from  $10.1\text{‰}$  to  $13.5\text{‰}$  with variability related to trophic position and the age of the fish

since diet can shift during maturation (Jepsen 1999).  $\delta^{15}\text{N}$  values from aquatic plants in a Texas saltmarsh ranged from  $.7$  to  $6.5\text{‰}$ , generally greater than the range of most terrestrial plants while marine fish have elevated  $\delta^{15}\text{N}$  values ranging between  $8\text{‰}$  and  $14\text{‰}$  (Winemiller et al. 2007). Nitrogen fixation occurs in seagrass meadows lowering their  $\delta^{15}\text{N}$  values relative to algae-based ecosystems, including salt marshes, which do not fix nitrogen.

#### *Laboratory Methods*

Collagen, the structural protein of bone, is most often used for determinations of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  since collagen may be preserved for thousands of years, depending on the burial environment. A second source of carbon from bone is the carbonate in bone mineral. With adequate controls for diagenesis, it is possible to isolate biologically deposited carbonate from hydroxyapatite, where carbonate substitutes for phosphate and hydroxyl. The carbon in collagen is drawn preferentially from dietary protein while the carbon in carbonate comes from all dietary sources, since it is derived from dissolved bicarbonate in the blood (Ambrose 1993; Ambrose and Norr 1993; Krueger and Sullivan 1984; Tieszen and Fagre 1993a).

In the current study, collagen was analyzed for stable isotopes of carbon and nitrogen, and bone carbonate was analyzed for stable isotopes of carbon. Collagen integrity was assessed from the yield of collagen relative to the total sample weight, as well as the proportions of carbon and nitrogen in the sample, expressed both as percent C and percent N, and C/N.

For shellfish, only stable carbon isotopes were analyzed. Shell protein was extracted but yields were too low to provide enough material to analyze both carbon and nitrogen stable isotopes.

#### *Sample Preparation*

*Collagen.* Bone preservation varied among the sites sampled. Initially, the method of isolating collagen described by Sealy (1986) was used. In this method, small chunks of bone are soaked in a 1 percent solution of hydrochloric acid until all mineral has been dissolved. The remaining collagen is rinsed and then soaked in a .1 molar solution of sodium hydroxide. This step should re-

move any extraneous organic materials from the burial environment, such as humic and fulvic acids. The remaining collagen is freeze-dried and then analyzed by mass spectrometry.

Collagen samples were analyzed on a Finnegan MAT Delta Plus mass spectrometer interfaced with a Carlo Erba gas analyzer in the Isotope Science Laboratory, University of Calgary. The latter produced data on the percentage of carbon and nitrogen in the samples and the C/N ratio. Only samples with C/N ratios between 2.9 and 3.6 are reported here, following the recommendations of DeNiro (1985) for mammalian bone. Three fish and two turtle collagen samples fell just outside this range (3.7 for all five samples), but were included in the analyses following empirical studies (e.g., Grupe et al. 2009) in which a case is made for allowing a slightly greater range for fish collagen. Precision for percent C and percent N, used to calculate C/N is  $\pm 5$  percent.

**Carbonate.** Bone carbonate was isolated following the procedure described by Lee-Thorp (1989). Ground bone is soaked in bleach in order to remove organic matter. Dilute acetic acid (.1 M) is used to remove any recently deposited carbonate. The sample is then freeze-dried. Samples were sent to Dr. Michael Joachimski of the Institute of Geology and Mineralogy, University of Erlangen, in Germany for analysis, where the following procedure was used: carbonate powders were reacted with 100 percent phosphoric acid (density  $>1.9$ ) (Wachter and Hayes 1985) at  $75^{\circ}\text{C}$  using a Kiel III online carbonate preparation line connected to a ThermoFinnigan 252 mass spectrometer. All values are reported in per mil relative to Vienna Pee Dee belemnite standard (V-PDB) by assigning a  $\delta^{13}\text{C}$  value of  $+1.95\text{‰}$  and a  $\delta^{18}\text{O}$  value of  $-2.20\text{‰}$  to reference NBS19 from the US National Institute of Standards and Technology. Reproducibility was checked by replicate analysis of laboratory standards and is better than  $\pm .03$ . In order to test for diagenetic alteration of the carbonate portion of bone, a subset of human bones prepared for carbonate analysis, including all three regions and multiple sites, was analyzed by Fourier transform infrared spectroscopy (FT-IR). Absorbance spectra were collected from  $2000$  to  $400\text{ cm}^{-1}$  on Nicolet Nexus 470 FTIR EPS analyzer in the Department of

Chemistry, University of Calgary. Crystallinity index was calculated after baseline correction for peaks at  $565$  and  $605\text{ cm}^{-1}$  and the valley between these peaks at  $590\text{ cm}^{-1}$  (Garvie-Lok et al. 2004; Wright and Schwarcz 1996).

**Shell Protein.** Protein from archaeologically recovered shells was extracted following a modification of the method for collagen extraction described by Longin (1971). In the original method, Longin (1971) suggests that his rapid and simple method of collagen extraction should also work for extracting conchiolin, the protein matrix of shells. The periostracum was removed with a motor-driven wire brush. Shells were sonicated, and then ground using a water-cooled micro mill. The mineral portion was removed by treatment with 1M HCl for 24–28 hours. The sample was filtered and the residue was rinsed, then solubilized in acidic hot water (pH = 3; at  $90^{\circ}\text{C}$  for 17–24 hours) following Longin (1971). Samples were freeze-dried and analyzed by mass spectrometry. There was an insufficient sample for analysis of both carbon and nitrogen so only stable carbon isotopes were analyzed. The organic matrix of shells of clams (*Mercenaria mercenaria*) and a variety of neogastropods have been studied to learn their amino acid composition (Crenshaw 1972; Meenakshi et al. 1971). Using published nutritional data, we compared the amino acid composition of acid soluble shell protein to that of the edible portions of similar species and while there are some differences, they are similar enough to suggest that the  $\delta^{13}\text{C}$  of shell protein will give an estimate of the  $\delta^{13}\text{C}$  of the edible portion of the organism. The edible portions of eastern oyster, clam, and mussel all contain approximately 15 percent glutamic acid, 10 percent aspartic acid, and 8 percent lysine as the three most abundant amino acids (Nutrient Data Laboratory 2008). Soluble protein from gastropod shells contains 12–14 percent glutamic acid, 9–12 percent aspartic acid, and 5 percent lysine, while clam shells (*Mercenaria mercenaria*) contain approximately 6 percent glutamic acid, 30 percent aspartic acid, and 4 percent lysine. Soluble shell protein contains more glycine in comparison to the edible portion (15–20 percent compared to 7 percent). Given the similarities in the composition of edible protein and shell protein, we assume that our stable carbon isotope re-

Table 2. Published Radiocarbon Dates.

Site	Acc No.	Burial No.	Period	Calibrated $^{14}\text{C}$ $2\sigma$	Component	$^{14}\text{C}$ Lab No	Sources
41AU36	2569	127*	Middle Archaic	1620–1440 B.C.	1	Tx-2127	Hall 1981
41FB3	83	14	early Late Archaic	1875–1130 B.C.	Lower	GX-24383	Patterson 1999
41FB3	87	1	early Late Archaic	1680–1130 B.C.	Lower	I-8946	"
41FB3	91	10	late Late Archaic	790–410 B.C.	Upper	GX-24500	"
41FB3	99	36	late Late Archaic	760 B.C.–A.D. 20	Upper	GX-25330	"
41FB3	85B	19	late Late Archaic	760 B.C.–A.D. 65	Upper	GX-25537	"
41FB3	98	35	late Late Archaic	480 B.C.–A.D. 130	Upper	GX-24613	"
41FB3	84	21	late Late Archaic	390 B.C.–A.D. 200	Upper	GX-24575	"
41GV66	3011	10	Late Archaic	45 B.C.–A.D. 310	1	Beta-58748	Ricklis 1994
41GV66	3013	12	Initial Late Prehistoric	A.D. 670–1000	2	Beta-58749	"
41GV66	3005	4	Initial Late Prehistoric	A.D. 785–1005	2	Beta 64565	"
41GV66	3008	7	Initial Late Prehistoric	A.D. 970–1205	2	Beta-58747	"
41GV66	71	Fea 52	Final Late Prehistoric	A.D. 1220–1395	3	Beta-53670	"
41GV66	77	Fea 84	Final Late Prehistoric	A.D. 1230–1485	3	Beta-64563	"
41GV66	3004	3	Final Late Prehistoric	A.D. 1270–1400	3	Beta 64564	"
41GV66	73	Fea 87	Final Late Prehistoric	A.D. 1280–1440	3	Beta-58746	"
41GV66	76	Fea 86	Final Late Prehistoric	A.D. 1300–1485	3	Beta-58745	"
41GV66	70	Fea 92–1a	Final Late Prehistoric	A.D. 1400–1630	3	Beta-53668	"

\*Same sample as SR-6160, Table 3.

sults for acid soluble shell protein provide a reasonable estimate of the stable isotope composition of the edible protein. Finally, comparisons between published  $\delta^{13}\text{C}$  values of modern oyster tissue and ancient shell are consistent with expectations (see below). While there may be minor variation in  $\delta^{13}\text{C}$  values, for our purposes, such data will indicate whether shellfish consumption contributes to enrichment in the heavier isotope of carbon.

*Sample quality.* Human collagen data are presented with C/N ratios and yields. Low yields (below 1 percent) merit caution but were included if the C/N ratios were within the acceptable range (2.9–3.6). These samples are indicated on Table 7. Fifty-two of 198 human samples were excluded from further discussion due to poor preservation and most of these were from the Loma Sandia site (Table 1). Nineteen of 140 faunal samples were also excluded due to poor preservation.

### Samples

The original research design, based on the assumption that cemetery use was underway by the Middle Archaic period in the Riverine–Savanna Zone, called for a minimum of 15 samples of adult individuals from each of the three prehistoric time periods in each of the three ecological zones (Table 1). While we were able to exceed the 135

samples, they are not so evenly distributed as the original design specified. For example, it appears that substantial mortuary site use was not underway in the Coastal Zone until quite late in the sequence. In other cases cemetery use was known to occur, but samples were not available.

Selection of samples within burials was directed toward preserving the research integrity of collections, so rib fragments were sampled whenever possible. Samples from 198 individuals from nine archaeological sites were included in the study and 146 from eight sites yielded usable results (Table 1). The study focused on adults as young children may have elevated  $\delta^{15}\text{N}$  due to the effects of nursing (e.g., Katzenberg et al. 1993). Infants are excluded, and only four children are represented in the data. Published radiocarbon date details are listed in Table 2 and a deliberate attempt was made to include previously dated individuals in the isotope study. In cases where site or sample age was in question 22 additional radiocarbon dates on human bone were processed and details are listed in Table 3. Permission to sample the materials was obtained from the Texas Historical Commission and the appropriate curatorial facilities (University of Texas at San Antonio, Center for Archaeological Research and the University of Texas at Austin, Texas Archeological Research Laboratory) following all compli-

Table 3. Radiocarbon Dates from This Study.

Site	Acc No.	Burial No.	Period	Calibrated $^{14}\text{C}$ $2\sigma$	Component	$^{14}\text{C}$ Lab No	$^{14}\text{C}$ , 5,568-year half-life	$\delta^{13}\text{C}\%$	$\delta^{15}\text{N}\%$
41AU36	2569	127	Middle Archaic	2130–1820 B.C.	1	SR-6160 <sup>a</sup>	3610 ± 35	-19.0	9.5
41AU36	2539	178	Late to Transitional Archaic	385–185 B.C.	2	SR-6162	2220 ± 35	-19.2	10.8
41AU36	2506A	33	Late to Transitional Archaic	A.D. 560-770	2	SR-6157	1390 ± 40	-16.7	11.1
41AU36	3341	154	Late Archaic/Late Prehistoric	160 B.C.–A.D. 60	3 <sup>b</sup>	SR-6161	2030 ± 35	-18.3	11.4
41AU36	2558	2	Late Archaic/Late Prehistoric	A.D. 1470–1655	3 <sup>b</sup>	SR-6156	320 ± 45	-14.4	13.3
41AU36	2627	57	Late Prehistoric	A.D. 1270–1400	4	SR-6159	675 ± 40	-17.8	9.3
41HR80	2404A	29	Ceramic	A.D. 430–640		SR-6165	1510 ± 35	-13.1	11.3
41HR80	2397A	15	Ceramic	A.D. 1270–1400		SR-6164	670 ± 35	-16.5	11.1
41NU2	85	M15	Late Prehistoric	A.D. 660–870		SR-6166	1270 ± 35	-10.7	11.7
41NU2	22	M4	Late Prehistoric	A.D. 720-980		SR-6168	1180 ± 35	-7.3	12.3
41VT1	273B	96	Early Archaic	5340–5080 B.C.		SR-6171	6280 ± 35	-16.2	10.4
41VT1	230	6	Early Archaic	5000–4795 B.C.		SR-6376	6020 ± 35	-17.2	10.4
41VT1	252	AA-10	Early Archaic	4850–4710 B.C.		SR-6177	5910 ± 30	-16.8	12.2
41VT1	269B	AA-1	Middle Archaic	2910–2760 B.C.		Beta-231615	4250 ± 40	-19.1	9.6
41VT1	209	52	Middle Archaic	2040–1770 B.C.		SR-6170	3580 ± 35	-17.5	9.2
41VT1	217	70A	Middle Archaic	1880–1680 B.C.		SR-6175	3460 ± 35	-16.6	9.2
41VT1	255	155	Late Archaic	905–800 B.C.		SR-6377	2695 ± 35	-17.6	10.2
41VT1	214	113	Late Archaic	780–415 B.C.		SR-6172	2485 ± 40	-8.4	11.9
41VT1	203	45	Late Archaic	510–380 B.C.		Beta-231614 <sup>c</sup>	2350 ± 40	-18.4	
41VT1	204	82	Late Prehistoric	A.D. 1010–1170		Beta-231616	960 ± 40	-17.0	11.7
41WH39	3037	FEA 42	Late Archaic	360–50 B.C.		SR-6179	2145 ± 40	-18.4	
41WH39	3052	FEA 3	Late Archaic	360–50 B.C.		SR-6178	2145 ± 35	-18.7	11.7

All samples are human bone collagen and were processed by Stafford Research Laboratories, Inc. and Beta Analytic, Inc. All are corrected for isotope fractionation.

<sup>a</sup>Same sample as Tx-2127, Table 2

<sup>b</sup>Component 3 is probably mixed.

<sup>c</sup>Beta Analytic reran this sample with a result of 2270±40 (B-231614 QA-1414), statistically indistinguishable from the original date.

ance procedures. At the time of the study, all of the remains were classified as unaffiliated according to Native American Graves Protection and Repatriation Act (NAGPRA).

Human bone samples from three prehistoric Coastal Zone cemeteries are included in the study, Oso Bay (41NU2), Mitchell Ridge Site (41GV66), and Harris County Boys' School Cemetery (41HR80); all are largely Late Prehistoric period in age (see Table 1 and Figure 1). The five prehistoric mortuary sites from the Riverine–Savanna Zone are: the Loma Sandia site (41LK28), the Morhiss site (41VT1), the Ernst Witte site (41AU36), the Bowser site (41FB3), and the Crestmont site (41WH39). Mortuary locations in the Riverine–Savanna Zone were used during the Archaic and Late Prehistoric periods, are more numerous, and tend to be larger; in fact, the first three listed above each contained at least 200–250 individuals. The 1930s Civilian Conservation Corps excavations of the Morhiss site did not identify discrete components and therefore the roughly 250 excavated burials remain chronologically unsorted (Campbell 1976; Dockall and Black 2006). However, the radiocarbon dating of 10 individuals (Table 3) identified four components. This small sample is particularly significant as it recognized a previously unknown Early Archaic (7300–6700 cal. B.P.) component; coeval with the Buckeye Knoll site cemetery located a short distance away (Ricklis and Weinstein 2005<sup>1</sup>). Although quite a number of Inland Zone mortuary sites are known from the study area, most were eliminated from consideration as the collections were not available or inappropriate for this study. Therefore, the only Inland Zone site in the study is the Olmos Dam site (41BX1). However, the isotope results from Bering Sinkhole (41KR241), located on the Balcones Escarpment, are considered below as representative of an Inland Zone sample (Bement 1994).

Isotopic analysis of faunal samples yields insight into local food webs. Archaeological, rather than modern samples, were chosen to eliminate the problem of modern contaminants. The goal to sample three individuals of each commonly recovered species from each of the three zones was at times constrained by the availability of usable samples. Commonly recovered taxa are listed with the ecological zone descriptions above but all of these

taxa were not available for study. At times fauna from nearby sites, including historic sites, were included if the needed faunal samples were not available from the sites that yielded the human bone and those sites are also listed in Table 1. Table 4a lists the 121 valid collagen results from 21 taxa from two prehistoric and five historic sites out of 140 samples submitted. Summary data are provided in table 4b. In many cases, archaeological faunal remains are identified only to the level of genus or sometimes family. However, because they were recovered from archaeological contexts, they are appropriate either as environmental indicators or potential foods. Only collagen was analyzed from the faunal bone. In studies of mammalian tissues, collagen is slightly enriched in <sup>13</sup>C relative to muscle, and more so relative to fatty tissue (Vogel 1978), so animal tissue consumed by humans would have  $\delta^{13}\text{C}$  values approximately 2‰ less than the  $\delta^{13}\text{C}$  of collagen from that animal. Table 5 lists the  $\delta^{13}\text{C}$  results of the shell protein analysis of 44 shell samples from 15 taxa from six prehistoric sites. The variability in aquatic and terrestrial resources makes this a complex region from the perspective of stable isotope ecology, but it is possible to suggest dietary variation, and indeed to test for variation versus homogeneity, among the human groups who exploited these resources by establishing baseline faunal isotope values.

Identifying potential edible plant species in the study region encounters some difficulty as ethnobotanical records are largely limited to eighteenth-century reports and archaeobotanical remains are not abundant. Plant recovery in open sites is notoriously meager due to generally poor preservation and recovery related to the impermanent nature of hunter-gatherer camps, the scarcity of architecture, and other features that enhance recovery. Nonetheless, Table 6 lists charred plant remains recovered from archaeological sites in the region (Tomka et al. 1997: Table D5) and their photosynthetic pathway (Jornada Basin Long Term Ecological Research 2007; Sage et al. 1999; Smith and Winter 1996). Most of the economically important wild plants, including pecans, hickory nuts, walnuts, sotol, and the lily family geophytes (roots and tubers) use the C<sub>3</sub> mode of photosynthesis.

What was the potential role of C<sub>4</sub> and CAM plants in the diet? Prehistorically, maize agricul-

Table 4a. Faunal Bone Stable Isotope Values.

Taxon (Common name)	Site -Sample	$\delta^{13}\text{C}_{\text{col}}$	$\delta^{15}\text{N}$	C/N	Site-Sample	$\delta^{13}\text{C}_{\text{col}}$	$\delta^{15}\text{N}$	C/N
<b>Fish</b>								
<i>Amia calva</i> (bowfin)	AU37-0154F	-19.0	8.9	3.3				
<i>Ictalurus sp.</i> (catfish)	AU37-0149F	-20.9	9.6	3.4	AU37-0156F	-21.7	7.6	3.3
<i>Ictalurus sp.</i> (catfish)	AU37-0157F	-21.3	8.6	3.3	BX5-0074F	-14.3	10.7	3.3
<i>Ictalurus sp.</i> (catfish)	BX5-0073F	-15.0	7.4	3.2	BX5-0069F	-19.7	10.7	3.4
<i>Ictalurus sp.</i> (catfish)	GD2-0093F	-17.0	9.4	3.6	GD2-0097F	-15.7	11.9	3.3
<i>Ictalurus sp.</i> (catfish)	GD2-0098F	-17.7	11.5	3.5	GD2-0113F	-20.3	8.8	3.5
<i>Ictalurus sp.</i> (catfish)	GD2-0119F	-18.6	9.5	3.7	GD2-0121F	-17.3	11.3	3.3
<i>Ictalurus sp.</i> (catfish)	GD2-0127F	-15.1	10.6	3.4	GD2-0131F	-18.8	13.4	3.3
<i>Ictalurus sp.</i> (catfish)	GD2-0138F	-18.2	9.7	3.5	GD2-0134F	-20.0	11.0	3.6
<i>Ictalurus sp.</i> (catfish)	GD2-0132F	-16.8	11.4	3.7	RF1-0050F	-16.6	10.6	3.5
<i>Ictalurus sp.</i> (catfish)	RF1-0048F	-16.8	10.6	3.2	RF1-0055F	-15.6	10.9	3.5
<i>Ictalurus sp.</i> (catfish)	RF1-0054F	-14.7	11.7	3.3				
<i>Lepisosteus sp.</i> (gar) Group 1	AU37-0145F	-23.0	8.3	3.3	AU37-0147F	-20.6	8.2	3.2
<i>Lepisosteus sp.</i> (gar) Group 1	AU37-0150F	-21.0	9.5	3.2	GD2-0133F	-18.3	11.8	3.1
<i>Lepisosteus sp.</i> (gar) Group 1	GD2-0125F	-18.5	10.7	3.5	GD2-0114F	-22.0	11.8	3.2
<i>Lepisosteus sp.</i> (gar) Group 1	GD2-0123F	-17.0	9.9	3.2	GD2-0116F	-21.6	9.9	3.2
<i>Lepisosteus sp.</i> (gar) Group 1	GD2-0128F	-22.6	9.0	3.2	RF1-0056F	-18.0	11.8	3.4
<i>Lepisosteus sp.</i> (gar) Group 1	RF1-0057F	-21.2	10.6	3.3				
<i>Lepisosteus sp.</i> (gar) Group 2	GD2-0120F	-14.6	11.2	3.5	GV66-0182F	-9.4	10.1	3.5
<i>Lepisosteus sp.</i> (gar) Group 2	GV66-0179F	-11.8	10.2	3.7	GV66-0172F	-9.5	10.1	3.4
<i>Lepisosteus sp.</i> (gar) Group 2	GD2-0124F	-13.4	9.9	3.2	RF1-0043F	-11.4	11.3	3.2
<i>Lepisosteus sp.</i> (gar) Group 2	RF1-0041F	-9.8	12.9	3.4				
<i>Pylodictis olivaris</i> (flathead catfish)	BX5-0070F	-20.1	12.7	3.5	GD2-0129F	-19.0	13.2	3.4
<i>Pylodictis olivaris</i> (flathead catfish)	GD2-0111F	-18.5	9.3	3.4	GD2-0117F	-20.6	10.7	3.4
Sciaenidae (drum, croaker, seatrout, etc.)	VT4-0059F	-9.7	5.4	3.4	VT4-0060F	-15.3	10.0	3.3
Sciaenidae (drum, croaker, seatrout, etc.)	VT4-0061F	-10.7	7.8	3.2	VT4-0063F	-5.4	7.7	3.2
Sciaenidae (drum, croaker, seatrout, etc.)	GD2-0086F	-9.2	9.2	3.5	GD2-0112F	-6.8	6.3	3.3
Sciaenidae (drum, croaker, seatrout, etc.)	GD2-0118F	-8.4	5.3	3.4	GD2-0136F	-8.1	8.6	3.5
Sciaenidae (drum, croaker, seatrout, etc.)	GD2-0139F	-7.4	8.3	3.5				
<b>Amphibians</b>								
<i>Rana sp.</i> (frog)	AU37-0148F	-22.5	6.1	3.5	AU37-0155F	-21.2	6.5	3.3
<i>Rana sp.</i> (frog)	AU37-0159F	-22.6	5.9	3.4	AU37-0160F	-20.6	7.8	3.6
<i>Rana sp.</i> (frog)	AU37-0163F	-20.8	7.6	3.4				
<b>Reptiles</b>								
<i>Alligator mississippiensis</i> (alligator)	VT4-0015F	-18.7	7.7	3.2	VT4-0018F	-16.9	8.1	3.2
	VT4-0020F	-15.4	9.1	3.2				
<i>Emydidae</i> (pond/water turtle)	BX1-0079F	-21.7	6.3	3.5	BX1-0108F	-20.5	6.9	3.3
<i>Emydidae</i> (pond/water turtle)	BX1-0080F	-25.9	7.4	3.4	GD2-0092F	-20.8	7.5	3.7
<i>Emydidae</i> (pond/water turtle)	GD2-0089F	-12.0	6.1	3.5	GD2-0135F	-15.6	10.5	3.7
<i>Emydidae</i> (pond/water turtle)	GD2-0099F	-20.8	8.1	3.3				
<i>Malaclemys terrepin</i> (diamondback terrapin)	VT4-0017F	-19.5	5.5	3.2	VT4-0016F	-20.1	6.8	3.2
<i>Malaclemys terrepin</i> (diamondback terrapin)	VT4-0019F	-20.3	8.7	3.2				
<i>Pseudomys sp.</i> (cooter turtle)	AU37-0141F	-20.5	8.2	3.3	AU37-0153F	-20.7	8.4	3.3
<i>Pseudomys sp.</i> (cooter turtle)	AU37-0158F	-13.6	5.8	3.3				
<i>Terrepene sp.</i> (box turtle)	AU37-0142F	-22.3	6.7	3.6	AU37-0152F	-14.6	7.3	3.2

Table 4a (continued). Faunal Bone Stable Isotope Values.

Taxon (Common name)	Site -Sample	$\delta^{13}\text{C}_{\text{col}}$	$\delta^{15}\text{N}$	C/N	Site-Sample	$\delta^{13}\text{C}_{\text{col}}$	$\delta^{15}\text{N}$	C/N
Apalone sp. (soft shelled turtle)	GD2-0090F	-17.5	9.8	3.4	GD2-0094F	-16.9	10.8	3.4
Apalone sp. (soft shelled turtle)	GD2-0096F	-18.9	9.5	3.0	RF1-0026F	-14.2	10.3	3.4
Apalone sp. (soft shelled turtle)	RF1-0040F	-14.8	10.7	3.4	RF1-0042F	-14.0	10.8	3.4
<b>Birds</b>								
Anatidae (waterfowl)	RF1-0037F	-19.5	9.0	3.3	RF1-0049F	-11.3	9.8	3.5
Anserinae (geese/swans)	RF1-0053F	-21.2	5.8	3.2	RF1-0047F	-18.8	9.5	3.4
Anserinae (geese/swans)	RF1-0052F	-21.2	6.2	3.4				
Meleagris gallopavo (wild turkey)	BX5-0067F	-18.2	7.5	3.5	BX5-0065F	-18.4	7.1	3.4
Meleagris gallopavo (wild turkey)	BX5-0071F	-17.4	7.6	3.4	GD2-0083F	-16.9	6.5	3.4
Meleagris gallopavo (wild turkey)	GD2-0103F	-17.0	6.5	3.5	RF1-0024F	-10.3	6.4	3.3
Meleagris gallapavo (wild turkey)	RF1-0030F	-12.7	7.7	3.4				
<b>Mammals</b>								
Didelphis virginiana (opossum)	AU37-0162F	-18.7	6.8	3.4	AU37-0165F	-19.2	7.5	3.3
Didelphis virginiana (opossum)	AU37-0166F	-19.8	8.0	3.3	AU37-0168F	-18.5	8.5	3.3
Sylvilagus sp. (cottontail rabbit)	AU37-0161F	-18.8	3.5	3.3	AU37-0164F	-20.8	5.2	3.3
Sylvilagus sp. (cottontail rabbit)	AU37-0167F	-18.9	4.5	3.3	BX5-0105F	-16.5	12.0	3.3
Sylvilagus sp. (cottontail rabbit)	BX5-0106F	-15.8	8.3	3.2	BX5-0107F	-18.9	5.3	3.2
Sigmodon hispidus (hispid cotton rat)	GV66-0174F	-15.2	1.7	3.4				
Procyon lotor (raccoon)	BX1-0081F	-16.7	5.9	3.3				
Odocoileus virginianus (white-tailed deer)	AU37-0144F	-20.6	4.5	3.2	AU37-0143F	-20.9	5.0	3.2
Odocoileus virginianus (white-tailed deer)	AU37-0146F	-20.9	3.6	3.2	BX1-0009F	-20.3	6.2	3.2
Odocoileus virginianus (white-tailed deer)	BX1-0008F	-20.1	6.3	3.3	BX1-0007F	-19.8	6.2	3.2
Odocoileus virginianus (white-tailed deer)	RF1-0021F	-21.3	5.2	3.2	RF1-0023F	-19.4	7.3	3.4
Odocoileus virginianus (white-tailed deer)	RF1-0028F	-19.8	6.9	3.2				
Bison bison (bison)	BX1-0011F	-8.8	6.1	3.2	BX1-0110F	-17.6	7.3	3.5
Bison bison (bison)	BX1-0010F	-8.1	6.5	3.2	RF1-0039F	-12.1	7.9	3.3
Bison bison (bison)	RF1-0046F	-8.3	8.0	3.4	RF1-0034F	-9.3	6.2	3.5

ture was all but nonexistent in the region (Hester 2004; Johnson and Hard 2008). A list of 208 plant species useful for food and drink in the Gulf Prairies and Marshes, Post-Oak Savanna, Blackland Prairie, and South Texas Plains vegetation zones (Mauldin 2005) contain about 20 that are  $C_4$  or CAM plants.  $C_4$  plants are from the Amaranthus and the grass genera (Digitaria, Distichlis, Echinochloa, Eragrostis, Panicum, Sporobolus, and Tridens), as well as *Portulaca olacera*. CAM genera include agave and cacti (Agave, Opuntia, and Ferocactus) (Jornada Basin Long Term Ecological Research 2007; Sage et al. 1999; Smith and Winter 1996). Of the  $C_4$  and CAM plants, prickly pear (*Opuntia* sp.) is the most visible in

both the ethnohistoric and archaeological records and was likely utilized as a staple. Based only on these limited data and the variable ground stone record, amaranth and grass seed processing may have been less important than prickly pear.

The  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of most edible species are unavailable for this region. The mean  $\delta^{13}\text{C}$  values of  $C_3$  and  $C_4$  plants are  $-27.1\text{‰}$  ( $s = 2\text{‰}$ ) and  $-13.1\text{‰}$  ( $s = 1.2\text{‰}$ ) respectively (O'Leary 1988). However, mean  $\delta^{15}\text{N}$  values are more difficult to obtain as they can vary locally based on soils and climate (Schwarcz and Schoeninger 1991).

A  $\delta^{13}\text{C}$  mean value for prickly pear (*Opuntia lindheimeri*) from South Texas is  $-15.4\text{‰}$  (stan-

Table 4b. Summary Stable Isotope Data for Faunal Samples.

Taxon (Common name)	n	$\delta^{13}\text{C}_{\text{col}}$ Mean	$\delta^{13}\text{C}_{\text{col}}$ Std Dev	$\delta^{15}\text{N}$ Mean	$\delta^{15}\text{N}$ Std Dev
<b>Fish</b>					
<i>Amia calva</i> (bowfin)	1	-19.0		8.9	
<i>Ictalurus</i> sp. (catfish)	21	-17.7	2.3	10.3	1.5
<i>Lepisosteus</i> sp. (gar) Group 1	11	-20.3	2.1	10.2	1.3
<i>Lepisosteus</i> sp. (gar) Group 2	7	-11.4	2.0	10.8	1.1
<i>Pylodictis olivaris</i> (flathead catfish)	4	-19.6	1.0	11.5	1.8
Sciaenidae (drum, croaker, seatrout, etc.)	9	-9.0	2.9	7.6	1.6
<b>Amphibians</b>					
<i>Rana</i> sp. (frog)	5	-21.6	1.0	6.8	.9
<b>Reptiles</b>					
Alligator mississippiensis (alligator)	3	-17.0	1.7	8.3	.8
Emydidae (pond/water turtle)	7	-19.6	4.5	7.5	1.5
<i>Malaclemys terrepin</i> (diamondback terrapin)	3	-20.0	.4	7.0	1.6
<i>Pseudomys</i> sp. (cooter turtle)	3	-18.2	4.0	7.5	1.5
<i>Terrepena</i> sp. (box turtle)	2	-18.4	5.4	7.0	.4
<i>Apalone</i> sp. (soft shelled turtle)	6	-16.0	2.0	10.3	.5
<b>Birds</b>					
Anatidae (waterfowl)	2	-15.4	5.8	9.4	.6
Anserinae (geese/swans)	3	-20.4	1.4	7.2	2.0
<i>Meleagris gallapavo</i> (wild turkey)	7	-15.8	3.1	7.0	.6
<b>Mammals</b>					
<i>Didelphis virginiana</i> (opossum)	4	-19.0	.6	7.7	.7
<i>Sylvilagus</i> sp. (cottontail rabbit)	6	-18.3	1.8	6.5	3.2
<i>Sigmodon hispidus</i> (hispid cotton rat)	1	-15.2	.	1.7	
<i>Procyon lotor</i> (raccoon)	1	-16.7		5.9	
<i>Odocoileus virginianus</i> (white-tailed deer)	9	-20.3	.6	5.7	1.2
<i>Bison bison</i> (bison)	6	-10.7	3.7	7.0	.8

Table 5. Shellfish Stable Isotope Values.

Taxon (Common name)	Site -Sample	$\delta^{13}\text{C}$	Site -Sample	$\delta^{13}\text{C}$	Site -Sample	$\delta^{13}\text{C}$
<i>Amblema plicata</i> (shell)	BX1-0013F	-22.8				
<i>Argopecten irradians</i> (bay scallop)	NU2-0194F	-21.0	NU2-0197F	-17.8		
<i>Busycon perversum</i> (lightning whelk)	NU2-0190F	-23.3	NU2-0198F	-20.3	NU2-0201F	-20.4
<i>Crassostrea virginica</i> (eastern oyster)	NU2-0191F	-18.5	NU2-0208F	-9.9	NU2-0216F	-19.8
<i>Cyrtoneias tampicoensis</i> (shell)	LK28-0076F	-18.7	LK28-0077F	-24.9	LK28-0078F	-25.7
<i>Cyrtoneias tampicoensis</i> (shell)	BX1-0012F	-14.5				
<i>Fasciolaria lilium</i> (tulip shell)	NU2-0214F	-11.3	NU2-0196F	-20.9	NU2-0213F	-20.2
<i>Laevicardium robustum</i> (egg cockle)	NU2-0215F	-7.4	NU2-0195F	-17.6		
<i>Lampsilis teres</i> (shell)	BX1-0014F	-21.9				
<i>Littorina irroata</i> (periwinkle)	GV66-0176F	-21.0	GV66-0180F	-21.0	GV66-0185F	-22.1
<i>Macrocallista nimbosa</i> (sunray venus)	NU5-0205F	-17.7	NU5-0211F	-15.1	NU5-0204F	-22.0
<i>Mercenaris</i> sp. (hard clam)	NU2-0200F	-14.7	NU2-0210F	-19.6		
<i>Noetia ponderosa</i> (ponderous ark)	NU2-0209F	-16.8	NU5-0207F	-14.4		
<i>Pleuroplaca gigantes</i> (horse conch)	NU2-0199F	-22.7	NU2-0202F	-18.7	NU2-0192F	-19.2
<i>Polinices duplicatus</i> (shark eye snail)	GV66-0177F	-26.1	GV66-0186F	-22.8	GV66-0188F	-22.4
<i>Polinices duplicatus</i> (shark eye snail)	NU2-0193F	-17.3	NU2-0212F	-22.1	NU5-0203F	-17.2
<i>Rangia</i> sp (clam)	GV66-0173F	-21.4	GV66-0178F	-23.4	GV66-0181F	-23.2
<i>Rangia</i> sp (clam)	HR33-0170F	-25.1	HR33-0171F	-23.8	HR33-0169F	-25.0



Table 6. Plant Taxa and Photosynthetic Pathways.

Family	Arch. Recovered Taxa	Common Name	Recovered Zones	Growth Zones	Photosyn. pathway
Agavaceae	<i>Yucca</i> sp.	Yucca	I	C, R, I	C <sub>3</sub> , CAM
Anacardiaceae	<i>Rhus</i> sp.	Sumac	I	C, R, I	C <sub>3</sub>
Anacardiaceae	<i>Rhus trilobata</i>	Fragrant sumac	I	C, R, I	C <sub>3</sub>
Asteraceae	Asteraceae	Sunflower family	I	C, R, I	C <sub>3</sub> , C <sub>4</sub> , CAM
Asteraceae	<i>Helianthus</i> sp.	Sunflowers	I	C, R, I	C <sub>3</sub>
Berberidaceae	<i>Berberis trifoliolata</i>	Agarita	I	C, R, I	C <sub>3</sub>
Cactaceae	<i>Opuntia</i> sp.	Prickly pear	I	C, R, I	CAM
Caryophyllaceae	<i>Silene</i> sp.	Catchfly	I	I	?
Chenopodiaceae	<i>Chenopodium berlandieri</i>	Pigweed	I	C, R, I	C <sub>3</sub>
Chenopodiaceae	<i>Chenopodium</i> sp.	Goosefoot	I	C, R, I	C <sub>3</sub>
Cupressaceae	<i>Juniperus</i> sp.	Juniper	I	C, R, I	C <sub>3</sub>
Ebenaceae	<i>Diospyros</i> sp.	Persimmons	I, R	C, R, I	C <sub>3</sub>
Ebenaceae	<i>Diospyros texana</i>	Tx. persimmon	I	C, R, I	C <sub>3</sub>
Fagaceae	<i>Quercus fusiformis</i>	Plateau live oak	I	C, R, I	C <sub>3</sub>
Fagaceae	<i>Quercus</i> sp.	Oaks	I	C, R, I	C <sub>3</sub>
Fagaceae	<i>Quercus virginiana</i>	Live oak	I	C, R, I	C <sub>3</sub>
Juglandaceae	<i>Carya</i> sp.	Pecan, Hickory	I, R	C, R, I	C <sub>3</sub>
Juglandaceae	<i>Juglans microcarpa</i>	Little walnut	I	I	C <sub>3</sub>
Juglandaceae	<i>Juglans</i> sp.	Walnuts	I	C, R, I	C <sub>3</sub>
Leguminosae	<i>Acacia</i> sp.	Acacia	I, R	C, R, I	C <sub>3</sub>
Leguminosae	<i>Prosopis glandulosa</i>	Honey mesquite	I, R	C, R, I	C <sub>3</sub>
Leguminosae	<i>Prosopis</i> sp.	Mesquites	I, R	C, R, I	C <sub>3</sub>
Liliaceae	<i>Allium</i> sp. / <i>Camassia</i> sp., etc	Onions, garlic, camas bulb	I	C, R, I	C <sub>3</sub>
Malvaceae	Malvaceae	Mallow family	I	C, R, I	C <sub>3</sub>
Papaveraceae	<i>Argemone</i> sp.	Prickly poppy	I	I	C <sub>3</sub>
Pedaliaceae	<i>Proboscidea</i> sp.	Unicorn plants	I	C, R, I	C <sub>3</sub>
Phytolaccaceae	Phytolaccaceae	Pokeberry	I	C, R, I	?
Poaceae	Poaceae	Grass	I	C, R, I	C <sub>3</sub> , C <sub>4</sub>
Poaceae	<i>Setaria</i> sp.	Millet	I	C, R, I	C <sub>4</sub>
Rosaceae	Rosaceae	Rose	I	R, I	C <sub>3</sub>
Ulmaceae	<i>Celtis</i> sp.	Hackberry	I, R	C, R, I	C <sub>3</sub>
Ulmaceae	Ulmaceae	Elm	I	C, R, I	C <sub>3</sub>

C = Coastal Zone, R = Riverine Zone, I = Inland Zone

dard error =  $\pm 0.7\%$ ) and  $\delta^{15}\text{N}$  is  $6.5\%$  ( $n = 5$ , standard error =  $\pm 1.0\%$ ) (Boutton et al. 1999 Table 1; Boutton personal communication 2006). Thus, if prickly pear made up a significant portion of the diet, as is suggested for the ethnohistoric period (Campbell 1983; Campbell and Campbell 1981), it should be reflected in  $\delta^{13}\text{C}$  of human bone carbonate, and to a lesser degree in bone collagen. Human carbonate values are influenced by whole diet and collagen primarily by dietary protein. The primary nutrient in prickly pear, after water, is carbohydrate (9.6 grams/100 grams), while the protein content is very low (.73 grams/100 grams) (Nutrient Data Laboratory 2008).

## Results

### Fauna

Stable isotope data from faunal samples, arranged taxonomically in Tables 4a, 4b, and 5, provide a baseline for interpreting the stable isotope ratios from humans. The variability among taxa reflects their trophic levels and the carbon sources of particular aquatic and terrestrial habitats. Figure 2 is a plot of all individual vertebrate specimens and illustrates the wide range of variation among major taxa. Figure 3 plots the mean values (plus or minus one standard deviation) for faunal groups that are most highly represented in the archaeological record. Fish and turtles have higher  $\delta^{15}\text{N}$  than all terrestrial mammals, and terrestrial mam-

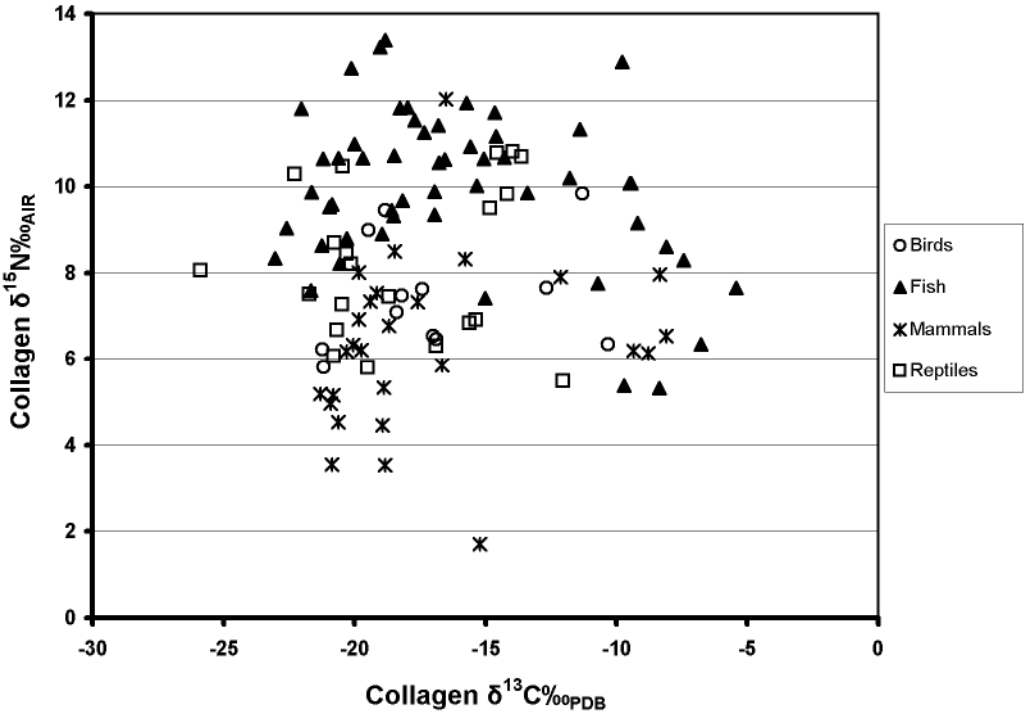


Figure 2. Individual faunal samples,  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  from collagen.

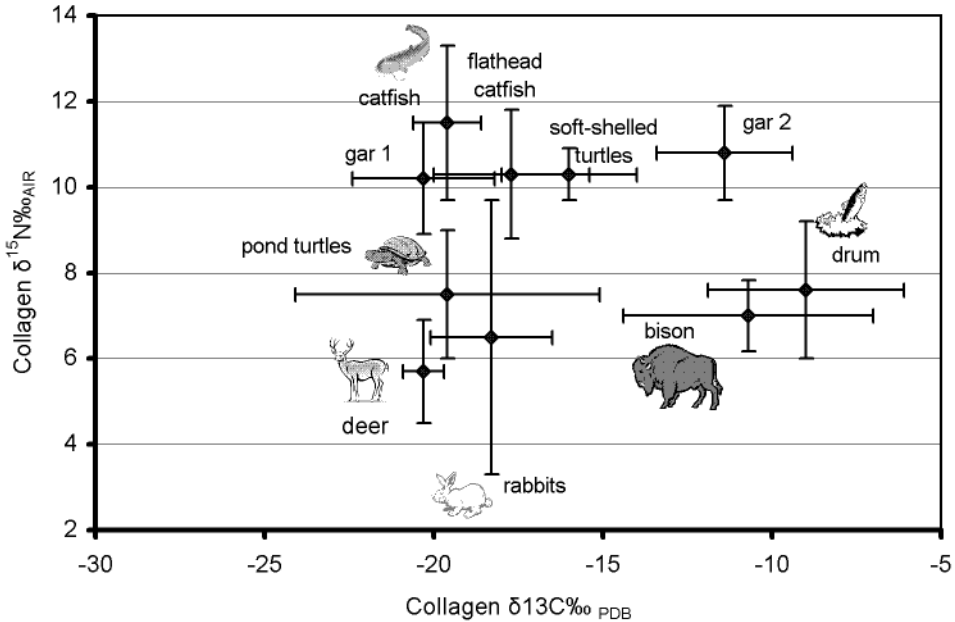


Figure 3. Mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  plus or minus one standard deviation for fauna most frequently represented in the archaeological record.

mals are quite distinctive with respect to  $\delta^{13}\text{C}$  depending on whether they feed primarily on  $\text{C}_3$  or  $\text{C}_4$  plants (e.g., white-tailed deer and bison, respectively).

We determined  $\delta^{13}\text{C}$  on shell protein from archaeological sites from a variety of habitats (Table 5). For example, eastern oysters (*Crassostrea virginica*) have  $\delta^{13}\text{C}$  values from  $-19.8$  to  $-9.9\text{‰}$  and inhabit shallow saltwater bays, as well as estuaries and lagoons. These values are consistent with those from the edible portion of modern oysters from a Texas saltmarsh that have a  $\delta^{13}\text{C}$  mean value of  $-22.8\text{‰}$  ( $n = 4$ ,  $s = .3\text{‰}$ ) and a  $\delta^{15}\text{N}$  of  $10.2$  ( $n = 4$ ,  $s = 1.3\text{‰}$ ) (Winemiller et al. 2007). Rangia clams (*Rangia* sp.) inhabit low salinity, brackish waters (LaSalle and de la Cruz 1985), and have  $\delta^{13}\text{C}$  from  $-21.4\text{‰}$  to  $-25.0\text{‰}$ .

Fish are quite variable in both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , as expected (Figure 3). Nitrogen isotope variation may be, in part, due to habitat differences. Seagrass fixes nitrogen and uses  $\text{C}_4$  photosynthesis; therefore, seagrass meadows should contain species with lower  $\delta^{15}\text{N}$  and higher  $\delta^{13}\text{C}$  relative to algal-based systems (Fry 2006; Winemiller et al. 2007). This may explain why there are not clear trophic level  $\delta^{15}\text{N}$  distinctions among species. In addition, fish habitats and diets change over their lifespan. Catfish (*Ictalurus* sp.) and flathead catfish (*Pylodictus olivaris*) are more depleted in the heavy isotope of carbon (more negative  $\delta^{13}\text{C}$  values) and more enriched in the heavy isotope of nitrogen, reflecting their freshwater habitat and omnivorous diet with larger individuals being efficient piscivores (Boschung and Mayden 2004:336, 349). The *Lepisoteus* sp. (gar) specimens likely include *Atractosteus spatula* (alligator gar) as taxonomists split them from *Lepisoteus* sp. (Ross and Brenneman 2001). The gar  $\delta^{15}\text{N}$  values are elevated (mean  $10.4\text{‰}$ ,  $n = 18$ ,  $s = 1.3\text{‰}$ ) due to their preference for fish. Gar  $\delta^{13}\text{C}$  values have a bimodal distribution, as Coastal Zone specimens tended to have higher values than those from the Riverine Zone, a pattern consistent with this freshwater fish's tolerance for brackish, even saline waters, particularly the alligator gar (Boschung and Mayden 2004:114–120). The clear bimodal distribution and gar sample size was sufficiently large so that subdivision into its two modes was appropriate using  $\delta^{13}\text{C} -15.0$  as the break point. Those with depleted values are

labeled "Group 1" and those with elevated values are labeled "Group 2" (Tables 4a and b, Figure 3). Similarly flexible, catfish (*Ictalurus* sp.) specimens from the Coastal Zone also have higher  $\delta^{13}\text{C}$  values than those from the Riverine Zone, although the sample was not bimodal. A further consideration of the taxonomic identification of the five Sciaenidae specimens from 41GD2 indicates that some of them share the characteristics of *Sciaenops ocellatus* (red drum) though the identification is not certain (Hendrickson 2009, personal communication). The Sciaenidae (seatrout, red drum, and black drum) have elevated  $\delta^{13}\text{C}$  values (mean =  $-9.2\text{‰}$ ,  $n = 10$ ,  $s = 2.7\text{‰}$ ) and somewhat elevated  $\delta^{15}\text{N}$  values (mean =  $7.7\text{‰}$ ,  $n = 10$ ,  $s = 1.6\text{‰}$ ) indicating their marine habitat, omnivorous diet, and adult tendency to feed on fishes as well as shrimp and crab (Boschung and Mayden 2004:611). The Sciaenidae also include freshwater drum that thrive in freshwater to estuarine habitats and were a food source (Hoese and Moore 1977:274). This almost continuous variation highlights some of the limitations in applying stable isotope analysis to paleodiet reconstruction in complex environments, since there are often several possible solutions to a particular set of data. However, gar and catfish (including both genera) tend to have among the highest  $\delta^{15}\text{N}$  of all fauna (mean =  $10.4\text{‰}$ ,  $n = 46$ ,  $s = 1.6\text{‰}$ ) and their consumption should be clearly visible in human diets, depending on the frequency of exploitation of these species by humans.

Of the reptile species analyzed (Figures 2 and 3), turtles are the most frequently represented in the archaeological record. Turtles include aquatic as well as terrestrial species. Among the family Emydidae,  $\delta^{13}\text{C}$  values are widely distributed, with the low of  $-25.9\text{‰}$  from the Inland Zone and the high of  $-12.0\text{‰}$  from Riverine Zone. The  $\delta^{13}\text{C}$  values of *Apalone* sp. (softshell turtles) also have a wide distribution; not surprisingly, those from the Riverine Zone have a low of  $-18.9\text{‰}$  while those from the Coastal Zone have a high of  $-14.0\text{‰}$ , consistent with their tolerance for brackish waters. The small sample size of both Emydidae and softshell turtles does not warrant subdividing either taxa into two modes as was done with the gar sample. The two terrestrial box turtle (*Terrepene* sp.) samples are almost  $8\text{‰}$  apart

for  $\delta^{13}\text{C}$ , but both are from a single Riverine Zone site. Some turtles, particularly softshell turtles, from the Coastal Zone have elevated  $\delta^{15}\text{N}$  (greater than 10‰), trending slightly higher than those from the Riverine Zone. Alligators are usually found around freshwater, including marshes, but they can tolerate brackish water. Their isotope values reflect this, with  $\delta^{13}\text{C}$  from  $-18.7$  to  $-15.4$ ‰, while  $\delta^{15}\text{N}$  reflects their carnivorous diet (7.7 to 9.1‰).

Birds are also quite variable in their stable carbon isotope ratios, although less so for stable nitrogen isotope ratios (Figure 2). Waterfowl migrate long distances and many species spend some time in both freshwater and estuarine environments and may feed on both  $\text{C}_3$  and  $\text{C}_4$  grasses. Turkeys appear to be mixed feeders, including both  $\text{C}_3$  and  $\text{C}_4$  based plants and insects in their diets. The single turkey with both elevated  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values is one of several from Colonial period mission sites where maize was being grown. These are thought to have been wild birds, but they may have been cared for.

The terrestrial mammals (Figures 2 and 3) that were exploited by prehistoric inhabitants are primarily feeding on  $\text{C}_3$  plants, with the exception of bison. White-tailed deer are  $\text{C}_3$  plant consumers with relatively depleted  $\delta^{15}\text{N}$ . The single rat sample has the most depleted  $\delta^{15}\text{N}$ .

To summarize, isotopic variation among prehistoric human groups in our study area will be primarily due to differential exploitation of terrestrial versus marine resources, the latter having higher  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ . Exploitation of freshwater fish will be reflected in elevated  $\delta^{15}\text{N}$  and lower  $\delta^{13}\text{C}$  relative to both marine and terrestrial resources. Further inland, reliance on terrestrial animals feeding on  $\text{C}_3$  plants will be distinctive from those individuals exploiting bison.

### Humans

*$\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  Collagen.* Stable isotope data for human samples from the eight prehistoric sites are reported in Table 7 and Figures 4 to 10. One of the four children in the dataset (Table 7) has a slightly elevated  $\delta^{15}\text{N}$  of 12.2‰ (41AU36, Acc 2534), possibly due to the weaning effect (e.g., Katzenberg et al. 1993), but this single value does not affect the overall patterns.

Figure 4 plots the individual  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$

collagen values while Figure 5 plots the mean and standard deviation for each site (Table 8). The results clearly sort by zone. Coastal Zone  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  collagen values form a linear correlation as a result of diets that emphasize estuarine resources, particularly fish from seagrass meadows. In contrast, riverine sites have variable  $\delta^{15}\text{N}$  values as a likely function of the role of freshwater fish in the diet, while the  $\delta^{13}\text{C}$  values are lower, consistent with the  $\text{C}_3$  values of plants and most terrestrial and freshwater prey. The Inland Zone sample forms a clear cluster with both lower  $\delta^{13}\text{C}$  and lower  $\delta^{15}\text{N}$  consistent with a diet based primarily on terrestrial  $\text{C}_3$  plants and their consumers.

Assuming spacing values of approximately +3‰ from animals to humans for  $\delta^{15}\text{N}$ , and approximately +2‰ from animal flesh to human bone collagen for  $\delta^{13}\text{C}$  (Tieszen and Fagre 1993b), it is possible to estimate the most likely diets of individuals from the three biotic zones. For  $\delta^{15}\text{N}$ , both riverine and coastal groups fall between 10‰ and 12‰. A diet of exclusively high trophic level fish (catfish and gar) would result in human collagen  $\delta^{15}\text{N}$  values of around 14‰ (Figure 6). Therefore, the data indicate that other protein sources with lower  $\delta^{15}\text{N}$  were also included. The archaeological faunal evidence suggests that white-tailed deer were a significant source of protein. Since deer meat has a  $\delta^{15}\text{N}$  around 5‰ to 7‰, this is a likely candidate. Other food sources, including plants and other species not well represented in the faunal record, would also dampen the  $\delta^{15}\text{N}$  from some fish species in both coastal and riverine settings. The inland site has the lowest  $\delta^{15}\text{N}$  and this suggests greater reliance on terrestrial animals in comparison to the riverine and coastal sites. Further details of the coastal, riverine, and inland samples provide further insight into the isotope ecology of the inhabitants.

Human remains from prehistoric people recovered from the three coastal sites are consistently enriched in the heavier isotope of carbon with  $\delta^{13}\text{C}$  collagen values ranging from  $-17.1$  to  $-7.2$ ‰; median =  $-12.3$ ‰, interquartile range = 5.0‰, and  $n = 40$ . As a result of the isotopic variability in marine resources as well as variable combinations of available resources, the  $\delta^{13}\text{C}$  from each coastal site forms a distinct mode. Several groups of data aggregated by zone are not

Table 7a. Human Data.

Zone <sup>a</sup>	Site	Acc No.	Burial No.	$\delta^{13}\text{C} \text{‰}$ collagen	$\delta^{13}\text{C} \text{‰}$ apatite	Spacing	$\delta^{15}\text{N} \text{‰}$	C/N	Period <sup>b</sup>	Site Compon	See Table	Calibrated $^{14}\text{C} 2\sigma$	Sex <sup>c</sup>	Age <sup>d</sup>	Yield < 1%	
<b>Mitchell Ridge</b>																
Coas	GV66	3004	3	-12.7	-8.9	3.8	10.2	3.4	FLPh	3	2	A.D. 1270-1400	F	10-15		
Coas	GV66	71	Fea 52	-11.9	-5.7	6.2	11.5	3.3	FLPh	3	2	A.D. 1220-1395	M	50+		
Coas	GV66	77	Fea 84	-12.5	-7.4	5.1	10.9	3.4	FLPh	3	2	A.D. 1230-1485	M	35-45		
Coas	GV66	76	Fea 86	-13.9	-8.4	5.5	11.1	3.3	FLPh	3	2	A.D. 1300-1485	M	35-39		
Coas	GV66	73	Fea 87	-12.7	-9.0	3.7	11.3	3.3	FLPh	3	2	A.D. 1280-1440	M	30-50		
Coas	GV66	70	Fea 92-1a	-13.0	-6.3	6.7	11.6	3.4	FLPh	3	2	A.D. 1400-1630	M	40-50		
Coas	GV66	72	Fea 92-2	-15.7	-10.4	5.3	10.4	3.2	FLPh	3	2	A.D. 1530-1955	F	50+	*	
Coas	GV66	3003	2	-12.1	-8.5	3.6	11.3	3.5	ILPh	2	2	A.D. 785-1005	M	25-45		
Coas	GV66	3005	4	-13.2	-8.7	4.5	11.3	3.5	ILPh	2	2	A.D. 970-1205	F	20-50+		
Coas	GV66	3006	5	-12.5	-8.0	4.5	10.9	3.5	ILPh	2	2	A.D. 670-1000	M	35-50		
Coas	GV66	3008	7	-10.7	-7.4	3.3	11.6	3.4	ILPh	2	2	A.D. 670-1000	F	10-20		
Coas	GV66	3013	12	-10.6	-7.3	3.3	11.6	3.4	ILPh	2	2	45 B.C.-A.D. 310	M	20-25		
Coas	GV66	3011	10	-11.5	-6.9	4.6	11.6	3.3	LA	1	2					
<b>Harris County Boys School</b>																
Coas	HR80	2397A	15	- <sup>e</sup>					Cer		3	A.D. 1270-1400				
Coas	HR80	2404A	29	- <sup>e</sup>					Cer		3	A.D. 430-640				
Coas	HR80	2403A	1	-16.7	-10.3	6.4	10.2	3.3	Cer				M	30-40		
Coas	HR80	2391	4	-16.7	-9.7	7.0	9.8	3.4	Cer				F	30-40		
Coas	HR80	2407	5	-15.9	-9.3	6.6	10.2	3.3	Cer				M	30-40		
Coas	HR80	2410	6	-14.6	-8.4	6.2	10.4	3.5	Cer				M?	AD		
Coas	HR80	2392A	9	-16.9	-9.8	7.1	10.1	3.3	Cer				F	20-30		
Coas	HR80	2395	13	-13.8	-9.1	4.7	10.8	3.3	Cer				M	30-40		
Coas	HR80	2396	14	-15.7	-9.5	6.2	10.1	3.3	Cer				M	30-35		
Coas	HR80	2398A	16	-16.7	-9.8	6.9	10.6	3.3	Cer				M	30-40		
Coas	HR80	2402A	17	-17.1	-10.1	7.0	9.9	3.3	Cer				F?	18-22		
Coas	HR80	2399	20	-15.1	-8.9	6.2	10.4	3.2	Cer				F	30-40		
Coas	HR80	2411A	31	-12.4	-8.2	4.2	10.6	3.2	Cer				M	20-25		
Coas	HR80	2393	9A	-16.4	-9.5	6.9	10.1	3.3	Cer				F	20-30		

Table 7b. Human Data.

Zone <sup>a</sup>	Site	Acc No.	Burial No.	$\delta^{13}\text{C} \text{‰}$ collagen	$\delta^{13}\text{C} \text{‰}$ apatite	Spacing	$\delta^{15}\text{N} \text{‰}$	C/N	Period <sup>b</sup>	Site Compon	See Table	Calibrated $^{14}\text{C} \ 2\sigma$	Sex <sup>c</sup>	Age <sup>d</sup>	Yield < 1%	
<b>Cayo del Oso</b>																
Coas	NU2	4	M1	-9.7	-4.1	5.6	13.9	3.3	LPh				M	AD	*	
Coas	NU2	22	M4	-7.2	-3.7	3.5	10.7	3.2	LPh		3	A.D. 720-980	M	AD	*	
Coas	NU2	30	M5	-10.0	-5.9	4.1	11.6	3.3	LPh				M	20-35		
Coas	NU2	35	M8	-9.5	-6.1	3.4	11.1	3.2	LPh				M	AD		
Coas	NU2	36	M8	-8.8	-5.6	3.2	11.6	3.3	LPh				F	AD		
Coas	NU2	46	M9	-10.0	-6.3	3.7	11.4	3.2	LPh				F	AD		
Coas	NU2	47	M10	-11.5	-7.3	4.2	11.0	3.2	LPh				F	AD		
Coas	NU2	56	M12	-10.7	-6.7	4.0	11.0	3.2	LPh				F	AD		
Coas	NU2	69	M13	-9.8	-5.9	3.9	11.2	3.3	LPh				F	AD	*	
Coas	NU2	85	M15	-10.4	-6.1	4.3	11.1	3.2	LPh		3	A.D. 660-870	F	AD		
Coas	NU2	96	M20	-8.9	-6.1	2.8	11.4	3.3	LPh				F	50+		
Coas	NU2	101	M35	-9.3	-6.2	3.1	11.8	3.2	LPh				M	20-35		
Coas	NU2	103	M19	-9.3	-6.3	3.0	11.5	3.3	LPh				F	35-50		
Coas	NU2	111	M38	-11.1	-6.4	4.7	11.2	3.2	LPh				F	35-50		
Coas	NU2	113	M37	-9.4	-5.4	4.0	11.3	3.2	LPh				F	35-50		
<b>Olmos Dam</b>																
Inld	BX1	16	2	-17.3	-9.6	7.7	8.8	3.2	LA				M	17-25		
Inld	BX1	17	3	-19.0	-10.2	8.8	8.7	3.2	LA				F	17-25		
Inld	BX1	18	4	-19.3	-9.8	9.5	9.0	3.2	LA				F	14-18		
Inld	BX1	19	5	-17.7	-9.9	7.8	9.3	3.2	LA				M	25-35		
Inld	BX1	21	10	-19.3	-9.3	10.0	8.7	3.2	LA				F	16-19		
Inld	BX1	20	5A	-17.9	-9.6	8.3	8.8	3.2	LA				M	17-25		
<b>Ernest Witte</b>																
Rver	AU36	2560	46	-19.5	-8.4	11.1	11.8	3.4	LPh	4			M	MA		
Rver	AU36	2561	47	-19.4	-6.9	12.5	8.7	3.4	LPh	4			F	YA	*	
Rver	AU36	2600	48	-18.9	-7.2	11.7	10.8	3.3	LPh	4			F	OA	*	
Rver	AU36	3228	51	-19.2	-10.8	8.4	11.0	3.4	LPh	4			M	AD	*	
Rver	AU36	2594	56	-18.5	-6.4	12.1	11.2	3.3	LPh	4			M	AD	*	
Rver	AU36	2627	57	-18.8	-7.3	11.5	10.2	3.5	LPh	4	3	A.D. 1270-1400	F?	AD	*	
Rver	AU36	2608	58	-19.2	-6.7	12.5	10.4	3.5	LPh	4			F?	Adol	*	
Rver	AU36	2609	59	-19.5	-6.6	12.9	10.4	3.4	LPh	4			F	OA		
Rver	AU36	3107	1	-18.8	-11.7	7.1	10.6	3.3	LA/LPh	3			M	YA		
Rver	AU36	2558	2	-16.1	-10.1	6.0	13.9	3.2	LA/LPh	3	3	A.D. 1470-1655	M	OA		
Rver	AU36	3234	73	-18.2	-10.8	7.4	11.1	3.3	LA/LPh	3			M	OA		

Rver	AU36	2529	84	-19.5	-7.3	12.2	10.5	3.2	LA/LPh	3		F	OA	*
Rver	AU36	2542	109	-19.1	-11.8	7.3	10.4	3.3	LA/LPh	3		M	YA	
Rver	AU36	3341	154	-19.1	-9.2	9.9	11.0	3.3	LA/LPh	3	3	M	Adol	
Rver	AU36	3351	167	-19.2	-11.3	7.9	11.2	3.2	LA/LPh	3		M	MA	
Rver	AU36	2602	194	-19.0	-8.9	10.1	11.9	3.3	LA/LPh	3		M	YA	
Rver	AU36	2548	224	-19.2	-6.4	12.8	10.6	3.3	LA/LPh	3		F	YA	
Rver	AU36	2506A	33	-16.0	-9.6	6.4	10.8	3.5	LA-TA	2	3	M	YA	
Rver	AU36	2605	34	-18.8	-11.2	7.6	11.1	3.3	LA-TA	2		M	YA	
Rver	AU36	2543	40	-19.7	-8.5	11.2	11.0	3.3	LA-TA	2		M	OA	
Rver	AU36	2574	61	-19.5	-9.8	9.7	10.7	3.3	LA-TA	2		F	MA	
Rver	AU36	2586	78	-20.0	-10.8	9.2	11.0	3.3	LA-TA	2		F	YA	*
Rver	AU36	2604	104	-19.2	-6.4	12.9	11.2	3.3	LA-TA	2		F	AD	
Rver	AU36	2554	105	-18.5	-8.5	10.0	10.1	3.2	LA-TA	2		F	OA	
Rver	AU36	2564	112	-19.1	-11.0	8.1	11.9	3.2	LA-TA	2		F	AD	
Rver	AU36	2534	165	-19.1	-9.2	9.9	12.2	3.2	LA-TA	2		M	C	*
Rver	AU36	2553	170	-19.5	-10.4	9.1	10.8	3.3	LA-TA	2		F?	MA	
Rver	AU36	2647	173	-19.3	-8.1	11.2	11.7	3.3	LA-TA	2		M	MA	
Rver	AU36	2539	178	-19.6	-11.2	8.4	10.8	3.2	LA-TA	2	3	M	MA	
Rver	AU36	2541	186	-19.4	-10.1	9.3	11.0	3.3	LA-TA	2		M	MA	
Rver	AU36	2527	190	-19.5	-10.1	9.4	11.2	3.2	LA-TA	2		F?	MA	
Rver	AU36	2566	202	-19.2	-11.0	8.2	10.4	3.3	LA-TA	2		M?	C	
Rver	AU36	2573	208	-19.1	-8.4	10.7	11.1	3.3	LA-TA	2		M	YA	
Rver	AU36	2575	217	-19.5	-9.2	10.3	12.1	3.3	LA-TA	2		F	AD	
Rver	AU36	2576	226	-19.0	-8.0	11.0	9.6	3.2	LA-TA	2		F	YA	*
Rver	AU36	2536	16B	-19.1	-11.5	7.6	11.0	3.2	LA-TA	2		F	AD	
Rver	AU36	2556A	171A	-19.1	-8.5	10.6	11.7	3.3	LA-TA	2		M	C	
Rver	AU36	2569	127	- <sup>e</sup>					MA	1	2		MA	
Rver	AU36	2569	127	- <sup>e</sup>					MA	1	3		MA	
Rver	AU36	2584	141	-18.5	-8.2	10.3	12.1	3.3	MA	1			AD	*
Rver	AU36	2537	147	-18.8	-7.9	10.9	10.7	3.2	MA	1		F?	Adol	*
Rver	AU36	2538	148	-19.7	-11.1	8.6	11.3	3.3	MA	1		F	OA	
Rver	AU36	2618	206	-18.4	-8.7	9.7	11.8	3.2	MA	1		M	MA	*
Rver	AU36	2526	210	-19.6	-7.8	11.8	13.5	3.3	MA	1		M	YA	*
Rver	AU36	2599	211	-20.4	-9.0	11.4	10.6	3.2	MA	1		M	AD	*
Rver	AU36	2552	212	-17.9	-9.0	8.9	11.6	3.3	MA	1		F	MA	*

Table 7c. Human Data.

Zone <sup>a</sup>	Site	Acc No.	Burial No.	$\delta^{13}\text{C} \text{‰}$ collagen	$\delta^{13}\text{C} \text{‰}$ apatite	Spacing	$\delta^{15}\text{N} \text{‰}$	C/N	Period <sup>b</sup>	Site Compon	See Table	Calibrated $^{14}\text{C} \text{ } 2\sigma$	Sex <sup>c</sup>	Age <sup>d</sup>	Yield < 1%	
<b>Bowser</b>																
Rver	FB3	88	5	-18.9	-10.9	8.0	10.1	3.3	LLA	Upper			F	AD		
Rver	FB3	95	7	-19.2	-11.3	7.9	11.8	3.2	LLA	Upper			M	AD		
Rver	FB3	90	9	-19.4	-11.2	8.2	11.6	3.3	LLA	Upper			M	AD		
Rver	FB3	91	10	-18.8	-9.5	9.3	10.5	3.2	LLA	Upper	2	790-410 B.C.	M	25-35		
Rver	FB3	86	11	-19.3	-11.5	7.8	10.4	3.3	LLA	Upper			M	45+		
Rver	FB3	96B	16	-19.7	-11.8	7.9	11.3	3.2	LLA	Upper			M	45+		
Rver	FB3	85B	19	-19.1	-8.0	11.1	10.8	3.3	LLA	Upper	2	760 B.C.-A.D. 65	M	25-35		
Rver	FB3	84	21	-19.4	-10.0	9.4	9.7	3.2	LLA	Upper	2	390 B.C.-A.D. 200	F	YA		
Rver	FB3	89	23	-19.0	-12.2	6.8	10.7	3.3	LLA	Upper			M	AD		
Rver	FB3	92	24	-19.1	-9.8	9.3	10.3	3.3	LLA	Upper			F	AD		
Rver	FB3	93	26	-19.0	-10.6	8.4	11.5	3.3	LLA	Upper			M	45+	*	
Rver	FB3	97	33	-18.5	-8.9	9.6	11.6	3.3	LLA	Upper			M	45+		
Rver	FB3	98	35	-19.1	-8.3	10.8	10.0	3.2	LLA	Upper	2	480 B.C.-A.D. 130	M	35-45		
Rver	FB3	100	36	-19.0	-7.8	11.2	11.0	3.4	LLA	Upper	2	760 B.C.-A.D. 20	M	35-45		
Rver	FB3	87	1	-19.2	-9.1	10.1	12.4	3.2	ELA	Lower	2	1680-1130 B.C.	M	25-35		
Rver	FB3	83	14	-19.4	-9.9	9.5	11.2	3.2	ELA	Lower	2	1875-1130 B.C.	F	25-35		
Rver	FB3	94	27	-19.0	-8.0	11.0	11.0	3.3	ELA	Lower			F		*	
Rver	FB3	101B	37	-18.6	-10.5	8.1	13.3	3.2	ELA	Lower			M	25-35		
<b>Morhiss</b>																
Rver	VT1	230	6	-16.5	-8.3	8.2	12.4	3.3	EA		3	5000-4795 B.C.		AD	*	
Rver	VT1	273B	96	-16.9	-7.9	9.0	10.3	3.3	EA		3	5340-5080 B.C.		AD		
Rver	VT1	252	AA-10	-17.1	-8.6	8.5	11.2	3.3	EA		3	4850-4710 B.C.		AD	*	
Rver	VT1	209	52	-17.9	-9.8	8.1	10.1	3.2	MA		3	2040-1770 B.C.		9-13		
Rver	VT1	217	70A	-16.2	-7.4	8.8	11.1	3.3	MA		3	1880-1680 B.C.	M	40+		
Rver	VT1	269B	AA-1	-18.3	-9.6	8.7	9.1	3.3	MA		3	2910-2760 B.C.		AD	*	
Rver	VT1	203	45	-17.1	-8.9	8.2	10.3	3.2	LA		3	510-380 B.C.	M	25-35		
Rver	VT1	255	155	-17.7	-10.5	7.2	9.6	3.2	LA		3	905-800 B.C.	F	15-20		
Rver	VT1	214	113	-8.01	-7.12	0.9	11.7	3.2	LA		3	780-415 B.C.	M	AD		
Rver	VT1	204	82	-18.2	-11.8	6.4	9.6	3.3	LPh		3	A.D. 1010-1170	M	13-17		
Rver	VT1	205	50	-17.5	-9.6	7.9	9.3	3.3	Uk				M	20-30		
Rver	VT1	291	112	-18.1	-9.0	9.1	9.8	3.2	Uk				F			
Rver	VT1	207	114	-19.0	-10.2	8.8	10.8	3.3	Uk				F	30-40		



Rver	VT1	258	141	-17.3	-7.0	10.3	9.8	3.3	Uk	AD
Rver	VT1	245	144	-18.4	-10.5	7.9	9.6	3.3	Uk	15-20
Rver	VT1	271	145	-18.4	-9.6	8.8	11.8	3.3	Uk	12-18
Rver	VT1	237	147	-14.5	-8.8	5.7	12.6	3.3	Uk	*
Rver	VT1	243	154	-18.3	-7.6	10.7	9.7	3.3	Uk	*
Rver	VT1	241	159	-17.5	-10.7	6.8	10.0	3.3	Uk	20-30
Rver	VT1	277	160	-18.4	-11.6	6.8	10.3	3.3	Uk	35+
Rver	VT1	244	177	-18.4	-10.3	8.1	9.6	3.2	Uk	2-4
Rver	VT1	266	AA3	-15.7	-8.2	7.5	9.1	3.3	Uk	AD
<b>Crestmont</b>										
Rver	WH39	3051	FEA 18	-18.7	-9.2	9.5	11.4	3.3	LA	OA
Rver	WH39	3034	FEA 20	-19.0	-11.1	7.9	10.2	3.2	LA	MA
Rver	WH39	3027	FEA 25	-18.8	-11.9	6.9	10.9	3.2	LA	MA
Rver	WH39	3052	FEA 3	-18.9	-7.9	11.0	10.9	3.2	LA	MA
Rver	WH39	3048	FEA 31	-19.1	-6.2	12.9	10.1	3.2	LA	3 360-50 B.C.
Rver	WH39	3049	FEA 36	-19.1	-5.3	13.8	10.1	3.2	LA	SA
Rver	WH39	3046	FEA 39	-19.0	-6.1	12.9	11.1	3.2	LA	SA
Rver	WH39	3036	FEA 4	-18.5	-6.5	12.0	10.7	3.2	LA	SA
Rver	WH39	3047	FEA 41	-19.1	-9.6	9.5	10.2	3.3	LA	YA
Rver	WH39	3037	FEA 42	-18.8	-4.2	14.6	11.2	3.2	LA	YA
Rver	WH39	3044	FEA 47	-19.4	-5.5	13.9	10.3	3.3	LA	3 360-50 B.C.
Rver	WH39	3043	FEA 49	-18.9	-6.1	12.8	10.9	3.3	LA	MA
Rver	WH39	3041	FEA 6	-19.2	-5.8	13.4	10.2	3.3	LA	MA
Rver	WH39	3035	FEA 9	-18.5	-6.5	12.0	10.7	3.3	LA	F? AD
Rver	WH39	3024	FEA B	-18.5	-9.7	8.8	10.6	3.3	LA	MA

<sup>a</sup>Coas = Coastal, Inld = Inland, Rver = Riverine-Savanna.

<sup>b</sup>Cer = Ceramic, EA = Early Archaic, EH = Early Historic, ELA = Early Late Archaic, FLPh = final Late Prehistoric, ILPh = Initial Late Prehistoric, LA = Late Archaic, LA/LPh = Late Archaic/Late Prehistoric, LA-TA = Late to Transitional Archaic, LLA = late Late Archaic, LPh = Late Prehistoric, MA = Middle Archaic, PH = Protohistoric, PH/EH = Protohistoric/Early Historic, Uk = Unknown.

<sup>c</sup>Age and sex identifications are from: Ernest Witt site (Hall 1981), Morhiss site (Jackson 1985); Crestmont site (Vernon 1989); Loma Sandia (Taylor 1995b); Mitchell Ridge (Ricklis 1994); Harris County Boys' School (Aten et al. 1976; Powell 1989); Oso Bay (Jackson et al. 2004; Munoz 2004); Olmos Dam (Lukowski 1988), and the Bowser site (Marianne Marek, personal communication 2008).

<sup>d</sup>OA = Old Adult, MA = Middle Adult, YA = Young Adult, AD = Adult, Adol = Adolescent, SA = Sub-Adult, C = Child.

<sup>e</sup>Samples were radiocarbon dated but were not included in isotope analysis.

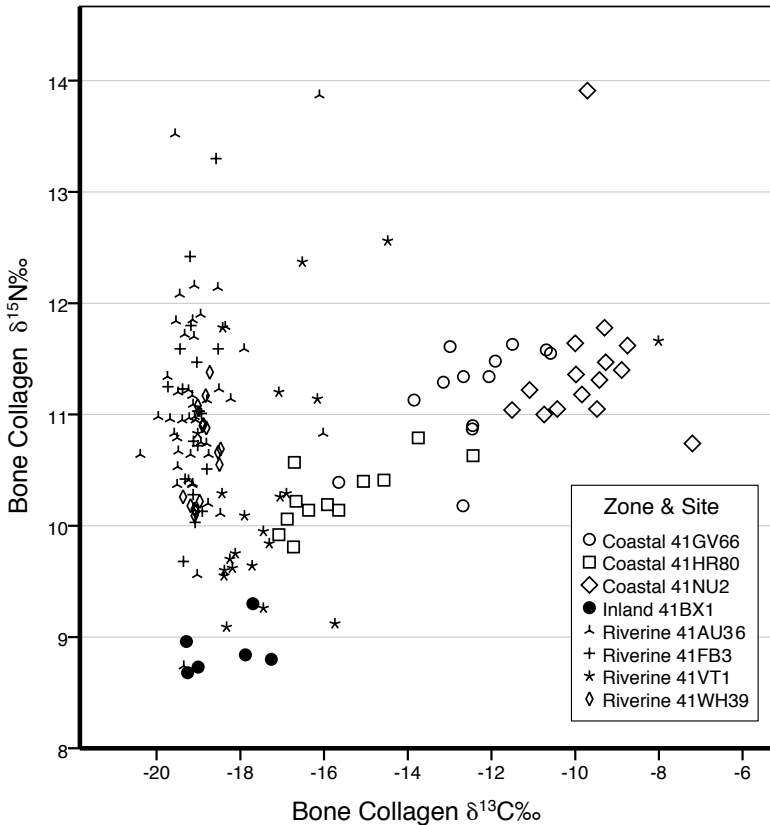


Figure 4.  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  from collagen for all human bone samples by zone and site. See Figure 5 for site names.

normally distributed therefore; medians and interquartile ranges are reported for all zonal batches. In contrast, data grouped at the site level tend to be normally distributed so means and standard deviations are appropriate. For all coastal data,  $\delta^{15}\text{N}$  is less variable than  $\delta^{13}\text{C}$ , the median = 11.1‰ and interquartile range = 1.1‰. The isotope data for all coastal individuals, with both elevated collagen  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , provide evidence of reliance on marine and estuary resources.

Figure 5 indicates that the Harris County Boys' School site (41HR80), situated on the western side of Galveston Bay, has the most depleted  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  of all coastal sites (mean  $\delta^{13}\text{C}$  = -15.7,  $s$  = 1.4‰,  $n$  = 12, and mean  $\delta^{15}\text{N}$  = 10.3‰,  $s$  = .3‰). Even so, there is clear evidence of marine resources in the diet. These lower  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values may best be accounted for by lower contributions of marine fish and greater contributions of marine shellfish; as shellfish have inter-

mediate to low  $\delta^{13}\text{C}$  values (Table 5) and intermediate to high  $\delta^{15}\text{N}$  values (Winemiller et al. 2007). This is made increasingly likely since the Harris County Boys' School site contains large quantities of shell. However, given the variation in marine resources and potential overlap with other resources, it is not possible to make firm statements from the isotope data alone. The Mitchell Ridge site (41GV66), on Galveston Island has  $\delta^{13}\text{C}$  values that are between those of Harris County Boys' School and the Oso Bay site (41NU2) but the  $\delta^{15}\text{N}$  values trend as high as any other riverine or coastal site (mean  $\delta^{13}\text{C}$  = -12.5‰,  $s$  = 1.3‰,  $n$  = 13, and the mean  $\delta^{15}\text{N}$  = 11.2‰,  $s$  = .5‰). A diet that includes marine fish from both seagrass and algal-based habitats, yielding variable isotope values, combined with terrestrial resources, may account for this pattern. Faunal remains—white-tailed deer, cotton rat, gar, sea catfish, black drum, red drum, sea

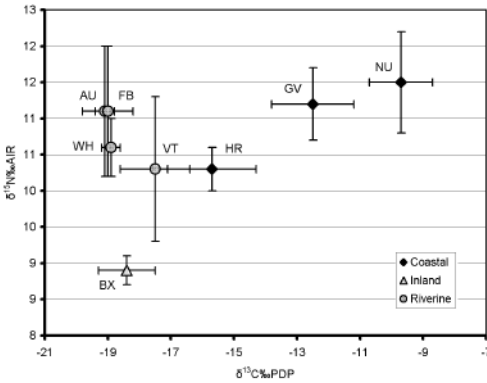


Figure 5. Mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  plus or minus one standard deviation for human samples by site. AU = Ernst Witte (41AU36), BX = Olmos Dam (41BX1), FB = Bowser (41FB3), GV = Mitchell Ridge (41GV66), HR = Harris County Boys' School (41HR80), NU = Oso Bay (41NU2), VT = Morhiss (41VT1), and WH = Crestmont (41WH39).

trout, sheepshead, turtles, and mollusks—are consistent with this pattern (Ricklis 1994).

However, the highest values were from the Oso Bay site (41NU2), located on Corpus Christi Bay. These enriched values (mean  $\delta^{13}\text{C} = -9.7\text{‰}$ ,  $s = 1.0\text{‰}$ ; mean  $\delta^{15}\text{N} = 11.5\text{‰}$ ,  $s = .7\text{‰}$ ) suggest these individuals had little in the way of freshwater resources in their diet. Remarkably, the site is only 25 km from the mouth of the Nueces River.

In contrast to the coastal sites, the inland Olmos Dam site (41BX1), is depleted in the heavier isotope of carbon with a mean  $\delta^{13}\text{C}$  of  $-18.4\text{‰}$  and  $s = .9\text{‰}$ . The mean  $\delta^{15}\text{N}$  is  $8.9\text{‰}$  and  $s = .2\text{‰}$ . Together, the stable carbon and nitrogen isotope data support the archaeological evidence for primary reliance on  $\text{C}_3$  plants and herbivores consuming a mix of  $\text{C}_3$  and  $\text{C}_4$  plants. Approximately 40 percent of the number of identified specimens (NISP) in the faunal record from Olmos Dam is from white-tailed deer. Turtle bones from the family Emydidae made up 10 percent of the NISP and 7 percent are from bison (Lukowski 1988; Scott 1988). Thus, the isotope data fit very well with the faunal data for this site, although some freshwater resource use may also have contributed to the intermediate  $\delta^{15}\text{N}$  values.

The riverine sites are the most depleted in  $^{13}\text{C}$  with a median  $\delta^{13}\text{C} = -19.0\text{‰}$ , interquartile range

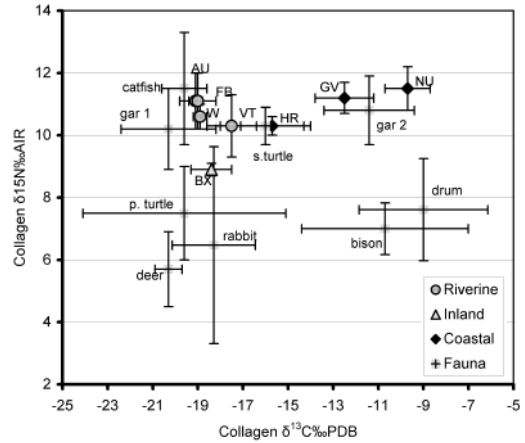


Figure 6. Mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  (plus or minus one standard deviation) of collagen from humans and economically important fauna. Trophic level differences of approximately  $+3\text{‰}$  for  $\delta^{15}\text{N}$  and approximately  $+1\text{‰}$  for  $\delta^{13}\text{C}$  have not been included since these values may vary slightly depending on dietary constituents. See Figure 5 for abbreviations.

$= .8\text{‰}$ , and  $n = 100$ . The riverine sites have an elevated median  $\delta^{15}\text{N} = 10.8\text{‰}$  with an interquartile range  $= 1.0\text{‰}$ , similar to the coastal sites. These values indicate people in the Riverine–Savanna Zone are exploiting fish and other freshwater taxa as well as terrestrial plants and animals. The riverine  $\delta^{13}\text{C}$  values, compared with the coastal values, are notably less variable, but have similar  $\delta^{15}\text{N}$  variability. This is somewhat surprising given the variability in the faunal isotope values for freshwater fish and turtles (Figures 2 and 3) and suggests that dietary isotope values were strongly influenced by the taxa with the more negative  $\delta^{13}\text{C}$  and elevated  $\delta^{15}\text{N}$  values, such as catfish, some gar, some turtles, and waterfowl. It is also notable that, despite their location near  $\text{C}_4$  savanna grasslands, herbivores such as bison enriched in the heavy isotope  $^{13}\text{C}$  are not reflected in the human isotope values at the riverine sites. Means and standard deviations for the large number of riverine components are provided in Table 8.

It is clear that both Riverine–Savanna and Coastal Zone inhabitants were exploiting fish, and that the coastal inhabitants made substantial use of estuarine resources while riverine inhabitants were exploiting freshwater fish. The riverine inhabitants of the Ernst Witte (41AU36), Bowser (41FB3), and Crestmont (41WH39) sites, other

Table 8. Mean Isotope Values by Component and Site.

Zone	Site	Period	Dates	Midpoint BP	Sample size	$\delta^{13}\text{C}\text{‰}$ Collagen			$\delta^{15}\text{N}\text{‰}$ Collagen			$\delta^{13}\text{C}\text{‰}$ Apatite		
						Mean	Std	Dev	Mean	Std	Dev	Mean	Std	Dev
Coastal	41GV66	Late Archaic	50 B.C.-A.D. 300	1825	1	-11.5			11.6			-6.9		
	41GV66	Initial Late Prehistoric	A.D. 700-1300	950	5	-11.8	1.1	1.1	11.3	3	3	-8.0		.6
	41GV66	Final Late Prehistoric	A.D. 1300-1500	550	7	-12.2	1.2	1.2	11.0	.5	.5	-8.0		1.6
	41GV66	All components			13	-12.5	1.3	1.3	11.2	.5	.5	-7.9		1.3
Coastal	41HR80	Ceramic Period	A.D. 400-1400	1050	12	-15.7	1.4	1.4	10.3	3	3	-9.4		.6
	41NU2	Late Prehistoric	A.D. 600-1000	1150	15	-9.7	1.0	1.0	11.5	.7	.7	-5.9		.9
Inland	41BX1	Late Archaic	400 B.C.-A.D. 260	2020	6	-18.4	9	9	8.9	2	2	-9.7		.3
	KR241 <sup>a</sup>	Early Archaic	5500-3100 B.C.	6400	5	-14.7	.7	.7	8.7	.8	.8	-7.2		.9
Inland	KR241	Middle Archaic	3100-2000 B.C.	4550	4	-16.0	.6	.6	7.5	.6	.6	-8.8		1.1
	KR241	Late Archaic	2000-800 B.C.	3350	4	-16.1	.3	.3	7.5	.3	.3	-9.2		1.0
	KR241	Late Archaic	800 B.C.-A.D. 1	2350	3	-16.9	.5	.5	8.7	.9	.9	-9.9		.7
	KR241	All components			16	-15.8	1.0	1.0	8.1	.9	.9	-8.6		1.4
	41AU36	Middle Archaic	2500-1500 B.C.	3950	7	-19.0	9	9	11.7	1.0	1.0	-8.8		1.1
	41AU36	Late/ Transitional Archaic	500 B.C.-A.D. 700	1850	20	-19.1	.8	.8	11.1	.6	.6	-9.6		1.4
Riverine	41AU36	Late Archaic/Late Prehistoric	500 B.C.-A.D. 1500	1450	9	-18.7	1.0	1.0	11.3	1.1	1.1	-9.7		1.9
	41AU36	Late Prehistoric	A.D. 900-1400	800	8	-19.1	4	4	10.6	.9	.9	-7.5		1.5
	41AU36	All components			44	-19.0	.8	.8	11.1	.9	.9	-9.1		1.6
	41FB3	early Late Archaic	1600-1300 B.C.	3300	4	-19.0	3	3	12.0	1.1	1.1	-9.4		1.1
	41FB3	late Late Archaic	800 B.C.-A.D. 200	2250	15	-19.1	.3	.3	10.8	.6	.6	-10.1		1.4
	41FB3	All components			19	-19.1	3	3	11.1	.9	.9	-10.0		1.4
Riverine	41VT1	Early Archaic	5300-4700 B.C.	6950	3	-16.8	3	3	11.3	1.0	1.0	-8.3		.3
	41VT1	Middle Archaic	2900-1700 B.C.	4300	3	-17.5	1.1	1.1	10.1	1.0	1.0	-8.9		1.3
	41VT1	Late Archaic	900-400 B.C.	2600	2 <sup>b</sup>	-17.4	.5	.5	10.0	.4	.4	-9.7		1.1
	41VT1	Late Prehistoric	A.D. 1000-1200	900	1	-18.2			9.6			-11.8		
Riverine	41VT1	Unknown			12	-17.6	1.3	1.3	10.2	1.0	1.0	-9.4		1.4
	41VT1	All components			21 <sup>b</sup>	-17.5	1.1	1.1	10.3	1.0	1.0	-9.3		1.3
	41WH39	Late Archaic	1000 B.C. - A.D. 100	2400	15	-18.9	.3	.3	10.6	.4	.4	-7.4		2.3

<sup>a</sup>All KR241 values from Bement (1994).<sup>b</sup>Single outlier (Acc. 214) is not included.

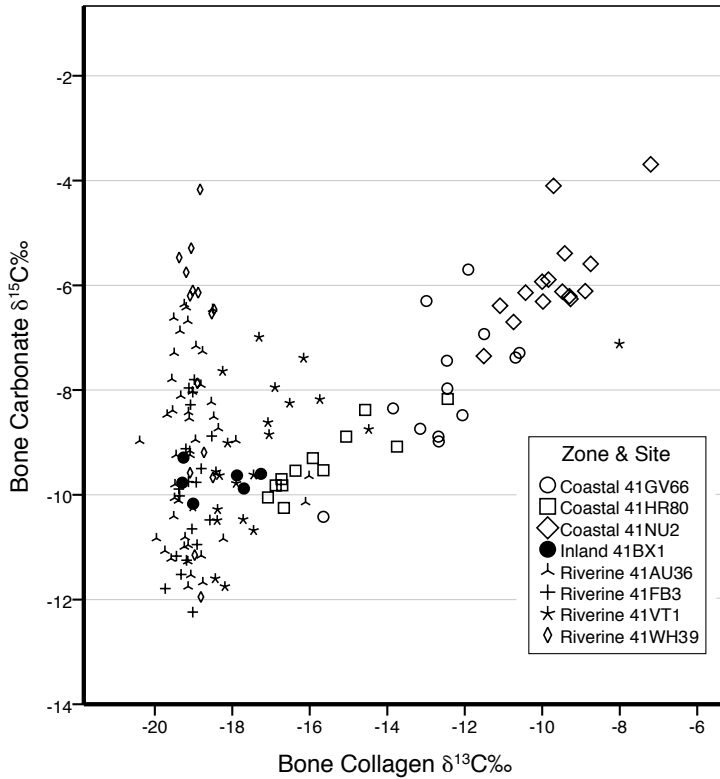


Figure 7.  $\delta^{13}\text{C}$  from collagen and bone carbonate for all human samples, by site and zone.

than a few outliers, tightly cluster around  $-19\text{‰}$  for  $\delta^{13}\text{C}$  and show little or no evidence for including marine resources in their diets. Their elevated  $\delta^{15}\text{N}$  values are most likely from exploitation of freshwater fish. The Morhiss site (41VT1), however, has isotope values intermediate between those of the Coastal and Riverine–Savanna Zones. Figure 1 illustrates that this variation is related to site location. While the first three riverine sites are 75 to 100 km from coastal bays, the Morhiss site, close to the boundary of the Coastal and Riverine–Savanna Zones, is only about 35 km from San Antonio Bay, apparently allowing access to both zones, particularly since these zones grade into one another.

**$\delta^{13}\text{C}$  Bone carbonate.** Crystallinity index (CI) values range from 3.21 to 5.00 with a mean of 3.93. There is no correlation between CI and bone carbonate  $\delta^{13}\text{C}$  (Pearson's  $r = .033$ ) indicating that bone carbonate data are not significantly affected by diagenesis. The carbon in the amino acids that comprise collagen is largely derived

from dietary protein and the carbon in bone carbonate  $\delta^{13}\text{C}$  is derived from all dietary components; that is, carbohydrates, fats, and the protein not used in protein synthesis (Ambrose and Norr 1993; Krueger and Sullivan 1984; Tieszen and Fagre 1993b). Plants, which provide both protein and energy, will be reflected in carbonate values, but less so in the collagen values when animal protein sources are plentiful. Animal lipids, also a source of energy, will be more evident in the carbonate values. Since collagen is made up of both essential (22 percent) and non-essential (78 percent) amino acids, dietary energy may also provide carbon to collagen, but as Schwarcz (2001) points out, it is less likely that the body will manufacture the non-essential amino acids if they are already present in the diet. Figure 7 plots  $\delta^{13}\text{C}$  collagen versus  $\delta^{13}\text{C}$  carbonate for all sites. Coastal sites form a linear correlation since marine protein is contributing to the collagen values and oils from the same sources are contributing to the carbonate values. Riverine–Savanna Zone sites form

a vertical array due to the variability in the level of CAM/C<sub>4</sub> plants in diets which effect carbonate  $\delta^{13}\text{C}$  values. The Inland Zone site forms a cluster, since the intake of CAM/C<sub>4</sub> protein and energy are independent of one another and occurred at low levels. The relationships between  $\delta^{13}\text{C}$  collagen and carbonate can be further analyzed by considering (a) the difference or spacing between carbonate and collagen values; (b) the correlation between the values; and (c) the distribution of carbonate and collagen relative to three modeled regression lines Kellner and Schoeninger (2007) derived from a meta-analysis of controlled feeding studies. A brief discussion of each analytical tool will be useful prior to further reviewing the archaeological data.

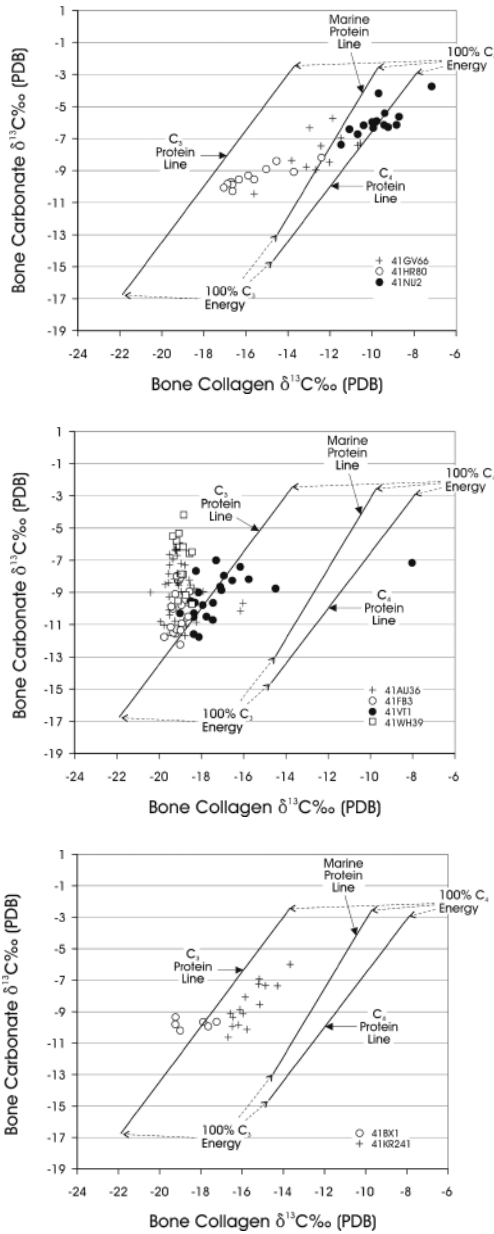
The spacing between  $\delta^{13}\text{C}$  for collagen and carbonate is related to sources of protein and energy in the diet (Ambrose et al. 1997; Ambrose and Norr 1993). Bone carbonate is considerably more enriched in the heavier isotope  $^{13}\text{C}$  in comparison to bone collagen, so while the spacing between the  $\delta^{13}\text{C}$  of the diet and that of collagen is usually around +5‰, the spacing between diet and bone carbonate is approximately +9.4‰ based on controlled feeding studies of rats (Ambrose and Norr 1993; DeNiro and Epstein 1978). The spacing between  $\delta^{13}\text{C}$  for collagen and carbonate is modeled as the difference between the diet-carbonate spacing and the diet-collagen spacing (9.4‰ - 5‰ = 4.4‰). When the dietary energy source is more enriched in the heavy isotope  $^{13}\text{C}$  in comparison to the protein source, the spacing between  $\delta^{13}\text{C}$  for collagen and carbonate should be greater (Ambrose et al. 1997). When the energy source is less enriched in the heavy isotope relative to the protein source, the spacing between  $\delta^{13}\text{C}$  for collagen and carbonate should be lower.

Carbonate and collagen  $\delta^{13}\text{C}$  data from a population of humans should be correlated to the degree that the consumption of protein and energy sources is a function of one another. If a single dietary source like fish yields protein and energy that provide carbon to both collagen and carbonate formation, then  $\delta^{13}\text{C}$  carbon and collagen values should be closely correlated. However, humans rarely consume one food. In addition, the degree that molecules from energy sources are routed to collagen production should also en-

hance the correlation between collagen and carbonate values.

The Kellner and Schoeninger (2007) models consist of three highly correlated sets of  $\delta^{13}\text{C}$  collagen and carbonate points derived from controlled feeding studies (Figures 8a-8c). The strong correlations exist since protein and energy sources were consumed simultaneously in the laboratory animal chow. Each line represents experiments which held the type of protein (either C<sub>3</sub>, C<sub>4</sub>, or marine) constant while type of energy (C<sub>3</sub> to C<sub>4</sub>) varied. Therefore, the lower end of each line represents a diet consisting of 100 percent C<sub>3</sub> energy and the upper ends represent 100 percent dietary C<sub>4</sub> energy. Each regression line has a slope of about 1.7; that is, for each 1‰ increase in  $\delta^{13}\text{C}$  collagen,  $\delta^{13}\text{C}$  carbonate increases by about 1.7‰. The authors suggest that greater slopes are related to the increasing degree that the energy component of the diet is being routed to collagen production. Graphic comparisons between the archaeological human data, the three models, the spacing, and correlations allow inferences about the relative influence of C<sub>3</sub> and C<sub>4</sub> protein and energy in the diets of these ancient populations.

For coastal sites the spacing between  $\delta^{13}\text{C}$  of collagen and carbonate has a median = 4.4‰ similar to the modeled 4.4‰ spacing value (minimum = 2.8, maximum = 7.1‰, interquartile range = 2.5‰, and  $n = 40$ , Table 7). There is also a close correlation ( $r = .913$ ,  $p = .000$ ,  $n = 40$ ) between the  $\delta^{13}\text{C}$  of collagen and carbonate for all individuals from coastal sites (Figure 8a). The correlation and spacing indicate that both protein and energy are from sources with similar  $\delta^{13}\text{C}$  (Ambrose and Norr 1993). These sources are most likely the protein and energy from the flesh and lipids of marine and estuary fish and shellfish. Consumption of C<sub>3</sub> plants would explain the less-than-perfect correlation between the two dietary indicators. Figure 8a shows important variability among the three coastal sites. Oso Bay ( $r = .730$ ,  $p = .002$ ,  $n = 15$ ) and Harris County Boys' School ( $r = .893$ ,  $p = .000$ ,  $n = 12$ ) have high, statistically significant correlation coefficients. Mitchell Ridge ( $r = .643$ ,  $p = .018$ ,  $n = 13$ ) has the lowest correlation coefficient but the relationship remains statistically significant. The sites also form three distinct clusters along the fit line, in declining order they are Oso Bay, Mitchell Ridge, and Harris



**Figure 8.** Kellner and Schoeninger’s (2007) three linear models based on controlled feeding studies are plotted against the Coastal, Riverine-Savanna, and Inland Zone data in Figures 8a-8c respectively.

County Boys’ School following the relative decline in C<sub>4</sub> resources in the diet. These data are consistent with the δ<sup>15</sup>N collagen data discussed above and indicate the Oso Bay population was consuming substantial quantities of fish with elevated δ<sup>13</sup>C values that provided both dietary pro-

tein and lipids. The Harris County Boys’ School δ<sup>13</sup>C collagen and carbonate data support a greater emphasis on shellfish which tend to have lower and more variable δ<sup>13</sup>C values but yet would also provide both protein and lipids yielding the strong and statistically significant correlation coefficient. The Mitchell Ridge collagen and carbonate values have a significant but somewhat lower correlation coefficient, suggesting that the diet was more mixed including shellfish, marine fish, as well as terrestrial plants and animals, yet marine resources were still a key aspect of those individuals’ protein and energy demands.

The Coastal Zone data cross-cuts and has a lower slope (about one) than Kellner and Schoeninger’s (2007) modeled marine and C<sub>4</sub> protein lines, with most of our points falling between their C<sub>3</sub> and C<sub>4</sub> protein lines. Their marine protein line is based on tuna fish flesh with a δ<sup>13</sup>C of -17.2 (Jim et al. 2004) while the bulk of the marine and estuarine fish in our study would have lower δ<sup>13</sup>C flesh values and thus be more similar to C<sub>4</sub> resources. In our data marine resources are contributing both protein and energy, yet C<sub>3</sub> terrestrial mammals and plants are contributing to the diet as well and are most likely accounting for the lower slope of our coastal data.

Our riverine collagen and carbonate data are not correlated and do not fit Kellner and Schoeninger’s (2007) modeled C<sub>3</sub> terrestrial protein line since all but one of the riverine sites form a vertical distribution (Figure 8b, *r* = .118, *p* = .242, *n* = 100). The vertical array also indicates there is considerably greater variation in δ<sup>13</sup>C from carbonate relative to variability in collagen values, indicating protein sources are C<sub>3</sub> and energy sources are variable and include C<sub>4</sub>/CAM plants. Spacing between collagen and carbonate is higher for all riverine sites (median = 9.3‰, minimum = .9‰, maximum = 14.7‰, interquartile range = 3.0‰), in contrast to coastal sites (median = 4.4‰). This is consistent with predictions from controlled feeding experiments (Ambrose and Norr 1993) regarding protein and energy sources with different δ<sup>13</sup>C values. The consumption of an energy source that is enriched in the heavier isotope <sup>13</sup>C and a protein source that is depleted results in the greater spacing seen in the riverine individuals. Such a scenario fits well with the ethnographic evidence for exploitation of the

CAM plant prickly pear, with a  $\delta^{13}\text{C}$  value of  $-15.4\text{‰}$ , and reliance on white-tailed deer and freshwater fish. The prickly pear has less than 1 percent protein but provides 41 calories per 100 grams (Nutrient Data Laboratory 2008). Fish and deer provide primarily protein, but also lipids. Thus, variable consumption of CAM or  $\text{C}_4$  plant energy and relatively consistent levels of  $\text{C}_3$  protein would result in the vertical array seen in Figure 8b and account for the variable spacing in  $\delta^{13}\text{C}$  between the carbonate and collagen values. For example, the individuals from the Crestmont site (41WH39) reflect the highest level of CAM/ $\text{C}_4$  energy intake and have the highest collagen carbonate spacing (median = 12.0, interquartile range = 3.9,  $n = 15$ ). In contrast, the Morhiss site shows a low, but statistically significant correlation between  $\delta^{13}\text{C}$  carbonate and collagen ( $r = .537$ ,  $p = .010$ ,  $n = 22$ ) and the collagen carbonate spacing is above 4.5 (median = 8.2, interquartile range 1.7,  $n = 22$ ), yet is the lowest of the riverine sites. These data indicate that energy and protein sources are somewhat related, likely due to the consumption of some marine food, but overall energy is more enriched relative to protein, consistent with protein from freshwater fish and deer, and carbohydrates from prickly pear or other CAM/ $\text{C}_4$  plants. Given that the Morhiss data are graphically arrayed between the other riverine sites and the coastal sites and that the site is geographically near the boundary of the Riverine–Savanna and Coastal Zones indicates a mixed diet of terrestrial, freshwater, and marine flesh as well as  $\text{C}_3$  and CAM/ $\text{C}_4$  plants, an interpretation that is consistent with data discussed earlier (Figure 4).

For the inland Olmos Dam site there is no correlation between collagen and carbonate  $\delta^{13}\text{C}$  in this small sample suggesting some independence between protein and energy sources (Figure 8c). In order to further evaluate inland isotope ecology we use published data from 41KR241, the Bering Sinkhole (Bement 1994). Bering Sinkhole is on the Edwards Plateau (Figure 1), and outside of our original Inland Zone study area but the isotope ecology of this area is somewhat similar to that of the originally defined Inland Zone. The site yielded isotope data on 16 individuals representing Early, Middle, and Late Archaic period individuals (Bement 1994). For the Bering Sinkhole  $\delta^{13}\text{C}$  carbonate and collagen are highly correlated

( $r = .859$ ,  $p = .000$ ,  $n = 16$ ), suggesting both protein and energy intake are closely related. These data are close to and parallel to Kellner and Schoeninger's  $\text{C}_3$  protein line while the Olmos Dam data cluster on either side of that line indicating that  $\text{C}_3$  protein was the dominant source of protein. These inland individuals trend toward the upper end of the line where the experimental energy sources include a mix of  $\text{C}_3$  and  $\text{C}_4$  inputs as well as 100 percent  $\text{C}_4$  energy suggesting that among our inland population CAM/ $\text{C}_4$  resources were playing a notable role. This is consistent with the combined collagen carbonate spacing of both inland sites (median = 7.6, interquartile range = 1.2,  $n = 22$ ) indicating that energy sources are more enriched than protein sources. However, this correlation is strongly influenced by the enriched Early Archaic data points, suggesting there is dietary shift through time, a topic that will be explored in the next section.

#### *Diachronic analysis*

Multicomponent sites most useful for examining long term change include the Ernst Witte and Morhiss sites for the Riverine–Savanna Zone, Mitchell Ridge for the Coastal Zone, and in the absence of a multicomponent Inland Zone site, we use the Bering Sinkhole data (Bement 1994). Figures 9, 10, and 11 plot the means and standard deviations for collagen  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ , and carbonate  $\delta^{13}\text{C}$  against time. The x axis is the approximate temporal midpoint (calibrated B.P.) for each component (Table 8).

Riverine populations grew rapidly and appear to peak in the Late Archaic period as cemeteries in the Riverine–Savanna Zone increase in frequency and size (Hall 1995b, 1998; Taylor 1995a). These populations had access to freshwater fish, turtles, and other riverine resources but they also extensively exploited white-tailed deer, nut resources, other plants, and had varying access to prickly pear or  $\text{C}_4$  plants. Resources from both the terrestrial and riverine biomes provided system stability without use of marine resources, despite being located only about 100 km from a bay.

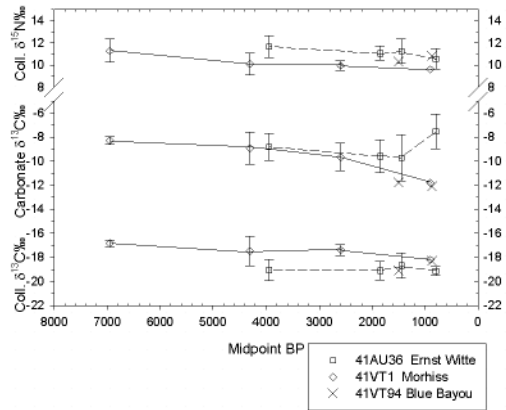
Bands of hunter-gatherer-fishers returned to Ernst Witte site for 3,200 years to bury their dead. This Riverine–Savanna Zone site has four dated components spanning the Middle Archaic to the Late Prehistoric period (4500 B.P. to 500 B.P.), al-



though the third component appears to be a mixed Late Archaic to Late Prehistoric component based on two radiocarbon dates (Table 3, SR 6156 and 6161).

Stability in collagen  $\delta^{13}\text{C}$  values show little change in total  $\text{C}_3$  protein sources, including fish and deer (Figure 9). The absence of evidence for use of  $\text{C}_4$  protein sources, despite being located within a  $\text{C}_4$  savanna habitat, is striking and indicates that grazers, such as bison and lagomorphs were, at best, inconspicuous in the diet. The view that bison exploitation increased during the Late Prehistoric period, especially after A.D. 1250, is not supported by these data. Against an overall picture of system stability there were adjustments in the dietary intake of Ernst Witte individuals.  $\delta^{15}\text{N}$  values decreased from 11.7‰ in the Middle Archaic period to 10.6‰ in the Late Prehistoric period, suggesting that the use of high trophic level fish may have declined slightly. A decrease in total aquatic resources with a compensating increase in deer is also a possibility, but not the reverse. A decrease in the use of deer, which have lower  $\delta^{15}\text{N}$  values, would not have brought about such a decline within the upper range of the  $\delta^{15}\text{N}$  scale. Carbonate  $\delta^{13}\text{C}$  also decreases at the Ernst Witted site from the Middle Archaic period to the Late Archaic period, which may be related to a slight decrease in the role of prickly pear or other CAM/ $\text{C}_4$  plants. However, during the Late Prehistoric period there is a notable increase in carbonate  $\delta^{13}\text{C}$  indicating a greater role of prickly pear or  $\text{C}_4$  plants than in the Middle Archaic period. Since collagen  $\delta^{13}\text{C}$  values are stable, it is unlikely that shifts in protein intake could account for these changes in carbonate  $\delta^{13}\text{C}$  values.

The long-term changes at the Morhiss site complement the isotopic patterns at Ernst Witte, but at the Morhiss site 6,000 years are represented. Three Early Archaic period individuals, dating to 7300–6700 cal. B.P., have an elevated mean collagen of  $\delta^{13}\text{C}$  of  $-16.8$ , carbonate  $\delta^{13}\text{C}$  of  $-8.3$ , and  $\delta^{15}\text{N}$  of 11.3 reflecting use of freshwater fish, terrestrial resources, and marine resources (Table 8). This is the only riverine site that shows evidence of the use of both marine and freshwater resources. All three measures show a slow declining trend, with one upturn, during the 300 generations of site use (Figure 9). These correlated declines suggest that the marine portion of



**Figure 9.** Means and standard deviations for  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  from collagen and  $\delta^{13}\text{C}$  from carbonate through time for Riverine–Savanna Zone sites. Blue Bayou points (Huebner and Comuzzie 1992) do not include standard deviations to minimize overwriting symbols (see text).

the diet was decreasing and was being replaced by  $\text{C}_3$  plant resources. Note that a Morhiss site, Late Archaic period individual (Acc. 214, Table 7), for which all three isotopic values were quite positive, was excluded from the mean calculations and these values suggest that this adult male was from the Coastal Zone, rather than from the local region (see point in far right of Figure 7). The Late Prehistoric period is represented by a single individual but suggests estuarine resources were no longer being used given the decline in carbonate values. Huebner and Comuzzie (1992) report stable isotope values from the Blue Bayou site (41VT94), located only five km from the Morhiss site. Blue Bayou was utilized from the late Late Archaic period to the early Late Prehistoric period (2200–700 B.P.). The Blue Bayou site late Late Archaic period mean values for five individuals are:  $\delta^{13}\text{C}$  collagen =  $-19.1$ ‰ ( $s = .9$ ‰),  $\delta^{13}\text{C}$  carbonate =  $-11.8$ ‰ ( $s = 2.0$ ‰), and  $\delta^{15}\text{N} = 10.3$ ‰ ( $s = 1.4$ ‰). Late Prehistoric mean values for six individuals are:  $\delta^{13}\text{C}$  collagen =  $-18.3$ ‰ ( $s = .7$ ‰), carbonate =  $-12.1$ ‰ ( $s = 1.5$ ‰), and  $\delta^{15}\text{N} = 10.8$ ‰ ( $s = .7$ ‰,  $n = 4$ ) (Huebner and Comuzzie 1992:199). Both the late Late Archaic period and Late Prehistoric period Blue Bayou values are similar to the single Late Prehistoric Morhiss value (Figure 9). Considering both sites, following 2000 B.P., use of estuarine resources largely ceased and was replaced by  $\text{C}_3$  plants as

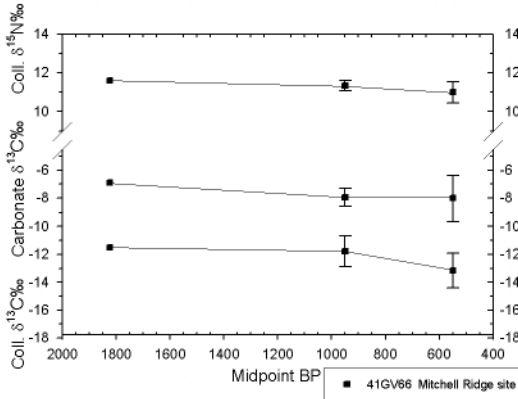


Figure 10.  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  from collagen and  $\delta^{13}\text{C}$  from carbonate through time for a Coastal Zone site.

indicated by the more negative  $\delta^{13}\text{C}$  carbonate values. In contrast, the sharp upturn in the Ernst Witte, Late Prehistoric  $\delta^{13}\text{C}$  carbonate values, indicate that prickly pear or other CAM/ $\text{C}_4$  plant use increased rather than  $\text{C}_3$  plant use. There is no isotopic evidence of bison exploitation during the Late Prehistoric period at Ernst Witte, Morhiss or the Blue Bayou site despite their savanna location.

Mitchell Ridge (41GV66) is the only multi-component coastal site and contains three separate periods of prehistoric occupation from the Late Archaic to the Final Late Prehistoric period (2000–450 B.P.) (Figure 10). However, its use as a burial location began with only a single Late Archaic period individual. Through time, carbonate  $\delta^{13}\text{C}$  shows a slight decline and collagen  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  are static from the Late Archaic to the Initial Late Prehistoric period (ca. 1000 cal. B.P.). From the Initial Late Prehistoric to the Final Late Prehistoric (600 cal. B.P.) period,  $\delta^{13}\text{C}$  collagen declines while the other two values remain unchanged. Such a change could occur if the mix of marine resources shifted so that dietary protein  $\delta^{13}\text{C}$  declined while both energy  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  remained constant.

Figure 11 plots the Inland Zone sites and the Late Archaic Olmos Dam and Bering Sinkhole components. As in the Riverine–Savanna Zone, these data suggest an overall pattern of long term continuity in hunter-gatherer adaptations. The Bering Sinkhole, Early Archaic period (ca. 6400 cal B.P.) values for collagen  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ , and carbonate  $\delta^{13}\text{C}$ , are all elevated, indicating that

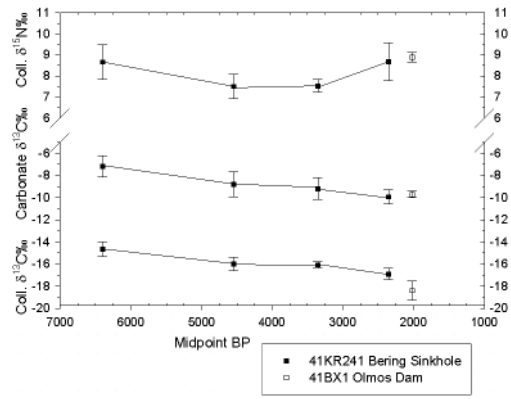


Figure 11.  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  from collagen and  $\delta^{13}\text{C}$  from carbonate through time for Bering Sinkhole (Bement 1994) and Olmos Dam sites that represent the Inland Zone.

both energy and protein are coming from some resources enriched in heavy isotopes combined with  $\text{C}_3$  resources. Limited bison exploitation may have influenced these Early Archaic values as bison were present in Central Texas at this time (Collins 2004:120; Dillehay 1974), whereas the use of coastal resources, over 340 km distant, would seem unlikely. By the Middle Archaic period (ca. 4500 cal. B.P.), all three values had declined, related to increased use of  $\text{C}_3$  resources that may include a decline in bison use. Values remained stable until about 3200 B.P. and by 2300 cal B.P. (Late Archaic period) both collagen and carbonate  $\delta^{13}\text{C}$  declined slightly while  $\delta^{15}\text{N}$  increased, shifts that could be related to increased use of freshwater aquatic species including turtles and fish. The Late Archaic Olmos Dam values are similar to the latest Bering Sinkhole data, although the  $\delta^{13}\text{C}$  collagen Olmos Dam value is lower. In summary, the Bering Sinkhole data show that following the Early Archaic period there was a long-term increase in use of  $\text{C}_3$  plants (Bement 1994); these data may reflect some bison exploitation in the Early Archaic period and limited use of aquatic resources in the Late Archaic period, although far less than that seen at the Riverine Zone sites.

## Discussion

Three global generalizations regarding hunter-gatherer packing and use of cemeteries provide

frameworks for consideration of the archaeological record of hunters and gatherers on the Texas Coastal Plain. First, hunters and gatherers use mobility to offset short and long-term resource fluctuations and unconstrained mobility allows resilience in the face of environmental fluctuations. Use of multiple biomes whose resources fluctuate independently of one another also enhances system resilience (Binford 2001); for example, a drought that reduces both plant and animal resources in the terrestrial biome has little effect on coastal resources. Second, in the face of population packing (greater than 9 individuals per 100 sq km) that constrains mobility, hunter-gatherers should intensify their use of aquatic resources if they are available and, if not, they should intensify use of available plant resources (Binford 2001). Third, a global cross-cultural analysis of hunters and gatherers indicates that groups that use mortuary locations tend to live under packed conditions and use aquatic resources. Eighty-one of 263 hunter-gatherer groups Binford (2004) considered used burial locations for social units larger than the family; of these, 79 percent lived under packed conditions, 77 percent moved less than 150 km per year, and 63 percent focused on aquatic resources (Binford 2004; Johnson and Hard 2008). Are the Texas Coastal Plain isotopic and archaeological data consistent with these generalizations? Were these groups living under packed conditions with limited mobility and a focus on aquatic resources as the ethnological correlations suggest? Is there evidence of intensification on aquatic resources or plants?

Reuse of the same mortuary locations for millennia while exploiting a relatively stable mix of resources indicates prehistoric hunter-gatherer-fisher populations showed remarkable long-term resilience and stability. In the Inland Zone, Bering Sinkhole was used for 5,500 years (Bement 1994), and in the Riverine-Savanna Zone the Ernst Witte site was used for at least three millennia. Our discovery of the 7000 cal. B.P. Early Archaic component at the Morhiss site, as well as Ricklis and Weinstein's (2005) work at the contemporaneous Buckeye Knoll site, indicate these highly stable systems were in place for as long as six millennia in some portions of the Texas Coastal Plain. Use of multiple biomes is certainly contributing to long-term stability and resilience.

The individuals from the mortuary sites in the Riverine-Savanna and Coastal Zones used the terrestrial biome and their respective aquatic biome. Only the individuals from Morhiss site were clearly using all three biomes as were individuals from Buckeye Knoll (Ricklis and Weinstein 2005). However, individuals at Bering Sinkhole exploited the terrestrial biome for 5,500 years biome with only minor use of aquatic resources.

Since the individuals in the Riverine-Savanna and Coastal Zones were using aquatic resources and communal mortuary locations, were these populations packed with constrained mobility analogous to the pattern in global hunter-gather samples? The number and scale of mortuary sites in the Riverine-Savanna and Coastal Zones suggest packed conditions were ongoing; if so, theory suggests intensification should have first occurred with aquatic resources and then plant resources.

In the Riverine-Savanna Zone, by the Early and Middle Archaic period intensive use of riverine resources was underway. However, aquatic resource use did not increase through time, as expected; in fact, it was at its maximum in the Early and Middle Archaic periods but intensification may have included use of lower trophic level aquatic species at the Ernst Witte site. The Morhiss data indicate a declining trend in the use of marine species and an increase in the use of freshwater species. Evidence for plant intensification includes increased use of  $C_3$  plants at the Morhiss site and  $C_4$ /CAM plants at the Ernst Witte site particularly following the Late Archaic period. If intensification did not involve increases in the dietary proportion of aquatic resources, was it because the exploitation of additional aquatic resources was already limited, perhaps by seasonal availability in the spring or competition, leaving exploiting lower trophic level species and plants as the best alternative?

Individuals from three of the four Riverine-Savanna Zone sites; the Ernest Witte, Crestmont, and Bowser sites, have lower  $\delta^{13}C$  collagen and carbonate values relative to the coastal sites, suggesting that little or no marine foods were in the diet and estuarine resources available only 75 to 100 km away were ignored. In contrast, data from the Morhiss site (41VT1), now located only 35

km from a bay, indicate that populations on the boundary of the Riverine–Savanna and Coastal Zones were exploiting both marine and freshwater resources beginning as early as the Early Archaic period (ca. 7000 cal. B.P.). Eight km to the south of Morhiss is the Buckeye Knoll site (41VT98), a cemetery where 73 Early Archaic period individuals were interred who had a similar mixed adaptation (Ricklis and Weinstein 2005:176). Both of these Early Archaic period occupations occurred during a 7500–6800 B.P. sea-level stillstand, which allowed increases in the productivity of estuarine resources (Ricklis 2004b:176; Ricklis and Blum 1997). Estuarine productivity diminished during periods of rising sea levels but with stillstands productivity increased again. During the Middle and Late Archaic periods, populations at Morhiss continued to exploit all three zones although sea levels fluctuated and estuarine resources varied in their availability (Ricklis 2004b). After 3000 B.P., sea levels reached modern levels and barrier islands were in place, and estuarine resources returned to high levels of productivity. This shift, perhaps for the first time, allowed the Coastal Zone to be occupied continuously (Ricklis 2004b; Ricklis and Blum 1997).

The isotope values of the single Late Prehistoric period individual from the Morhiss site and the late Late Archaic and Late Prehistoric period occupations from the nearby Blue Bayou site (Huebner and Comuzzie 1992) indicate that estuarine resources stopped being utilized between 2500 and 2000 B.P., despite their distance of only 30–35 km and increased productivity brought by stable, modern sea levels. Perhaps the new residents of the Coastal Zone defended their territories so that populations from the Riverine–Savanna Zone could no longer acquire coastal resources and vice-versa; Coastal Zone populations were no longer able to access the Riverine–Savanna Zone. With the loss of access to coastal resources, the Morhiss site riverine inhabitants increased their use of  $C_3$  plant resources. This choice suggests that mobility was limited, bison were not available, and the use of freshwater fish had reached a point of diminishing returns.

However, non-edible material from the coast, including stingray spines and sharks teeth, occur in Riverine-Savanna Zone sites, suggesting that

these items came by way of trade networks rather than from direct access to the coast (Hall 1981; Patterson et al. 1998). Trade items from the coast were also present at the Bering Sinkhole (Bement 1994).

The loss of coastal resources at Morhiss, coincident with the rise of residential occupation of the coast, and the related evidence from the Oso Bay site described below, are strong, independent lines of evidence that population packing in the Riverine–Savanna and Coastal Zones occurred in accord with theoretical predictions. Intensification responses, however, apparently did not include increasing levels of aquatic resources, but may have included using lower trophic level species and increasing uses of  $C_3$  and  $C_4$ /CAM plants. Considering both the Blue Bayou and Morhiss data, intensification of the use of  $C_3$  plant resources occurred by 2200 cal. B.P., at the same time that access to marine resources was eliminated. Evidence of  $C_4$ /CAM plants includes high  $\delta^{13}C$  carbonate values at the Late Archaic period, riverine Crestmont site (mean =  $-7.4\text{‰}$ ,  $s = 2.3\text{‰}$ , Table 8), suggesting notable use of these resources at this location. By the Late Prehistoric period, at the Ernst Witte site, there was an increase in  $C_4$ /CAM plant use.

It is surprising that the isotopic record of use of  $C_4$ /CAM plants and their consumers is not greater, given that the Riverine–Savanna Zone is dominated by  $C_4$  grasslands. Archaeologists have long suspected that bison played a key role in Late Prehistoric adaptations, but evidence of bison use was not clearly visible in the Late Prehistoric isotopic data from any zone, although Early Archaic bison use may be reflected in the Early Archaic Bering Sinkhole data.

Coastal Zone mortuary locations were not used until the terminal Late Archaic period, but aquatic resource use apparently did not increase beyond initial levels but adjustments in species exploited is a possibility. The Coastal Zone Oso Bay site is located only 110 km southwest of the Morhiss site and dates to the early Late Prehistoric period. Oso Bay isotope values indicate that individuals relied on high trophic level marine fish and terrestrial resources without the input of freshwater foods, despite the mouth of the Nueces River being only 25 km distant, suggesting that mobility further inland to exploit Riverine-Savanna Zone

resources was also constrained. The Mitchell Ridge and the Harris County Boys' School sites have a marine-based diet but with lower inputs of the enriched isotope than Oso Bay. The high correlation between carbonate and collagen at Harris County Boys' School suggests that protein and carbohydrate sources were closely linked and isotopically variable marine resources, such as mollusks, were likely playing an important role. A similar situation may exist for Mitchell Ridge, but the lower correlation between carbonate and collagen suggests more  $C_3$  resources are in the diet, and these could include terrestrial plants and animals as well as freshwater fish. These data indicate there was variability in Coastal Zone subsistence and the degree that mobility was constrained. In the Inland Zone the Bering Sinkhole data suggests long-term increases in the use of  $C_3$  plants and an increase in the use of freshwater aquatic resources may have occurred in the Late Archaic period.

The evidence we present indicates packing was underway by 2500–2000 B.P. By that time enhanced marine productivity brought about by sea-level stillstand allowed more intensive exploitation of the coast. However, territoriality prevented some Coastal Zone occupants, such as those at Oso Bay, from moving inland to obtain freshwater resources, and some groups in the Riverine Savanna Zone could no longer access coastal resources. Intensified use of both  $C_3$  and  $C_4$ /CAM plants occurred in both the Riverine–Savanna and Inland Zones at about the same time.

However, what accounts for use of communal cemeteries during the prior five millennia? Was mobility constrained by other populations? Few investigators would suspect population packing during the Early Archaic period. Is it possible that hunter-gatherer-fishers in some parts of the Texas Coastal Plain limited their mobility without the presence of packing? We lack other independent data to evaluate these possibilities.

Nevertheless, the existence for millennia of highly stable, yet flexible, hunter-gatherer-fisher systems on the Texas Coastal Plain adds a rich body of information to our knowledge but raises a number of important areas for future research. For example, there are many organizational aspects of the use mortuary sites that are critical topics for future consideration (Bement 1994). Pro-

cessing additional isotope samples, particularly from sites with long-term use, are critical to further research. With regard to plants, enhanced recovery of ethnobotanical samples may allow better resolution among the likely  $C_4$ /CAM species that were utilized. Further advances in isotope ecology are needed, for example a better understanding of aquatic species should allow us to enhance our ability to detect shifts to lower trophic levels species, particularly the exploitation of shellfish. Advances in understanding the routing of dietary  $\delta^{13}C$  in carbonate versus collagen would allow better interpretive models of isotopic data. Finally this research identifies a number of long-term changes in hunter-gatherer-fisher adaptations on the Texas Coastal Plain that need to be independently evaluated with other archaeological data.

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### Note

1. See Ricklis's (2011) detailed discussion of the Buckeye Knoll site, published shortly before press time.

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